Open Cycle Liquid Desiccant Air Conditioning Systems – Theoretical and Experimental Investigations

M. Krause, W. Saman, K. Vajen*
Sustainable Energy Centre, University of South Australia
Mawson Lakes Campus, Mawson Lakes, 5095
AUSTRALIA
E-mail: michael.krause@unisa.edu.au

* Universität Kassel, Institut für Thermische Energietechnik
Kurt-Wolters-Str.3, 34109 Kassel
GERMANY

Abstract

Solar assisted air conditioning systems using liquid desiccants represent a promising option to decrease the high summer energy demand caused by electrically driven vapor compression machines. However, for these systems high efficient and reliable components need to be developed and the design has to be adjusted to each respective building design, location and user demand. The paper presents the design of a prototype for one of the main components of liquid desiccant systems and reports on its experimental performance. A numerical model has been developed for the simulation environment TRNSYS and validated using the experimental data. With this model parametric studies of the component performance have been carried out.

1. INTRODUCTION

The energy demand for air-conditioning to provide temperature and humidity control has increased continuously throughout the last decades and is still rising. This increase is found both in commercial and residential buildings and is largely caused by increased thermal loads, residents' comfort demands, and architectural trends. Since by far most of the air-conditioning systems are electrically driven vapor compression machines, the increase is responsible for a large rise in electricity demand and especially high peak loads. The substitution of these compression machines by thermally driven cooling systems using renewable energy or waste heat is a promising alternative. An overview of different technologies for thermally driven cooling systems can be found in Saman *et* al (2004). In particular, due to a high correlation between solar irradiation and cooling demand for most buildings, the application of solar energy is very attractive.
The use of liquid desiccants in an open cycle system is a promising solution for solar assisted air-conditioning in humid climates or for buildings with high humidity loads. A possible system concept for this is shown in Figure 1. The main components of these air conditioning systems are the absorber, regenerator, indirect and/or direct evaporative cooling units for the dehumidified fresh air and heat recovery stages for both, the desiccant solution and the regeneration air. In the absorber, a hygroscopic solution, e.g. LiCl or $CaCl_2$, is directly brought in contact with fresh air, which it dehumidifies. Since during the absorption process heat is released, cooling of the process is necessary. This cooling effect can be provided either using cooling water (Lävemann and Peltzer, 2003), e.g. from a cooling tower, or with indirect evaporative cooling using the waste air coming from the building (Saman and Alizadeh, 2000). Additional cooling of the fresh air can be achieved with direct/indirect evaporative cooling.
While absorbing the moisture, the concentration of the hygroscopic solution and thus, its capability to absorb water, decreases. This requires drying of the solution, which can be done in a regenerator, where solar or other low grade thermal energy is used to drive the process. Solution tanks for concentrated and weak solutions offer the option to operate the system even at times when no solar energy is available. Heat recovery from the air and desiccant is necessary for the regeneration process to achieve a high coefficient of performance.

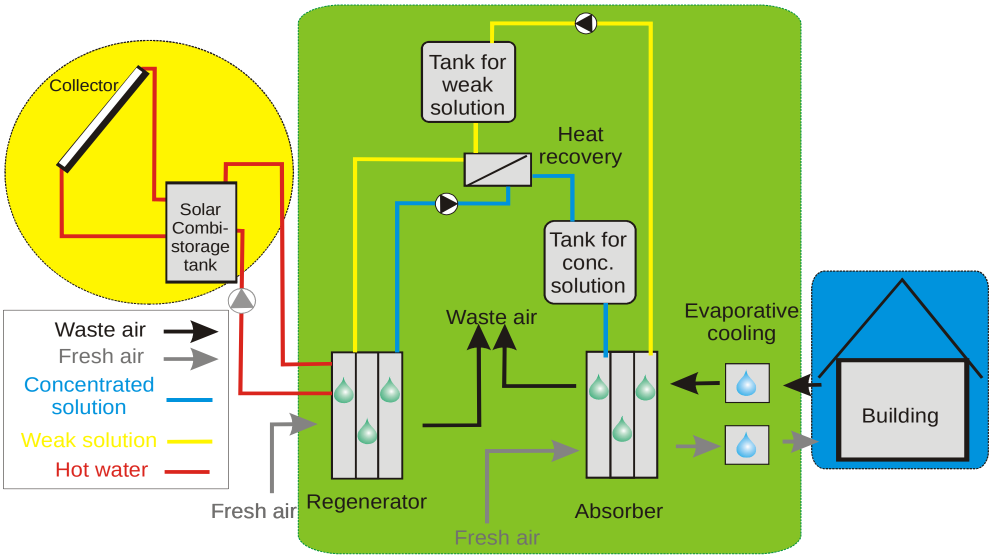

Figure 1: Design of a solar driven liquid desiccant air-conditioning system. The area marked in green represents the air-conditioning system, yellow indicates the solar thermal system and blue the building.

2. REGENERATOR DESIGN

In previous investigations at the University of South Australia, an open cycle solar air collector has been used to regenerate the desiccant solution (Alizadeh and Saman, 2000). However, most solar collectors in use are water or water/glycol based. This requires a regenerator which uses hot water for the regeneration process. At present, mainly three different water driven regenerator designs have been investigated:

- Single or multi effect boilers
- Packed bed regenerators
- Plate heat exchanger designs

All these designs have incorporated the principle of vaporising water out of the solution, which is then taken away by the regeneration air. For this, either the solution or the regeneration air has to be heated to increase the vapour pressure of the solution. From the listed designs, boilers represent the simplest concept. However, they require high heating temperatures, which cannot be efficiently delivered by common flat plate collectors. Packed bed regenerators are easy to manufacture but require high desiccant and regeneration air flow rates. Such high flow rates increase the possibility of carry over. In contrast, low flow rates can be used in plate heat exchanger designs. However, since salt solutions are highly corrosive, common metal heat exchanger designs cannot be used.

Thus, a new regenerator prototype based on a plate heat exchanger design has been developed and tested. A photograph of the regenerator prototype is shown in Figure 2 and the specifications are listed in Table 1. Similar designs have been investigated before for water-cooled absorber constructions (Lävemann and Peltzer, 2003).

Figure 2: Photograph of the regenerator prototype. Air flows from the bottom to the top in-between the plates of the regenerator, desiccant solution wets the cotton layers, introduced by an irrigation system on top of each plate and hot water flows through the channels of the twin walls from the bottom of the front manifold to the top of the rear manifold in a counter/cross flow arrangement.

Table 1: Specifications of the regenerator prototype

Requirement	Measure
Low air pressure losses	Plate heat and mass exchanger design, 23.7 m^2 surface area
No corrosion	Plastic construction
Cheap plates with good heat transfer through plates and high mechanical stability and thermal resistance	43 Polypropylene twin walls, 5 mm thickness, 6 mm distance
Good surface wetting of the plates to maximise the transfer area	Using cotton as a coating material and an irrigation system to apply the solution
No carry over	Desiccant distribution system with perforated tubes on top of each plate: 100 outlets, diameter 0.32 mm each, low desiccant flow rates
High heat and mass transfer	High air velocities, mass flow rates of about 1800 kg/h
Good performance	Internal heating and counter/cross flow arrangement
High collector efficiencies	Low driving temperature of about 70°C
High concentration lifts	Low desiccant flow rates of about 1.5-4 L/h m^2

3. REGENERATOR MODEL

As shown in Figure 3, the numerical model for the regenerator is developed as a two-dimensional model. For this, the enthalpy balances for the hot water flow, the desiccant film and one air stream are determined for each of the elements along the channels. For each element, heat and mass transfer from the desiccant to the air stream as well as heat transfer through the heat exchanger plates are determined simultaneously. The single enthalpy equations follow approaches from Khan and Sulsona, 1998. The heat transfer coefficients are determined using Reynolds and Nusselt number relationships. With these coefficients, the mass transfer coefficients follow from the Lewis analogy. The model has been integrated into the simulation environment TRNSYS.

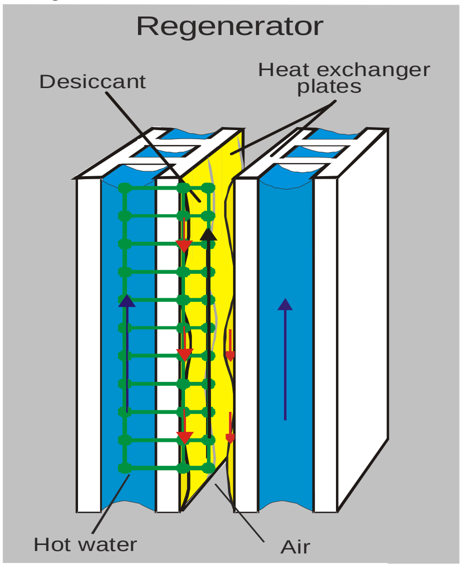

Figure 3: Schematic of the numerical models for the regenerator. As indicated by the grid, the model is implemented as a two-dimensional model. For each grid point, the enthalpy of the respective fluid is calculated for every time step during the simulation. The model offers the option of parallel flow as well as counter flow designs.

4. MODEL VALIDATION

Figure 4 shows a comparison between simulation results carried out using the TRNSYS model and experimental results of the prototype. Since the numerical model is a static model, only quasi steady state conditions can be taken into account for the comparison. From the first testing period, one data set can be used (indicated by “1” at the top of the diagram), from the second period three more sets are available. It can be seen that simulated and measured air and water temperatures show a good agreement at these points. However, the heat transfer through the heat exchanger plates is lower than expected and the parameter has been adjusted to the experimental data. One possible explanation for the low UA-value is an uneven flow distribution of air and especially water inside the regenerator. Furthermore, the comparison of the humidity shows that the mass transfer is overestimated in the simulations. The main reason for this would be again uneven flow distribution of the LiCl solution on the plate heat and mass exchanger plates. However, this has not been considered in the simulations.

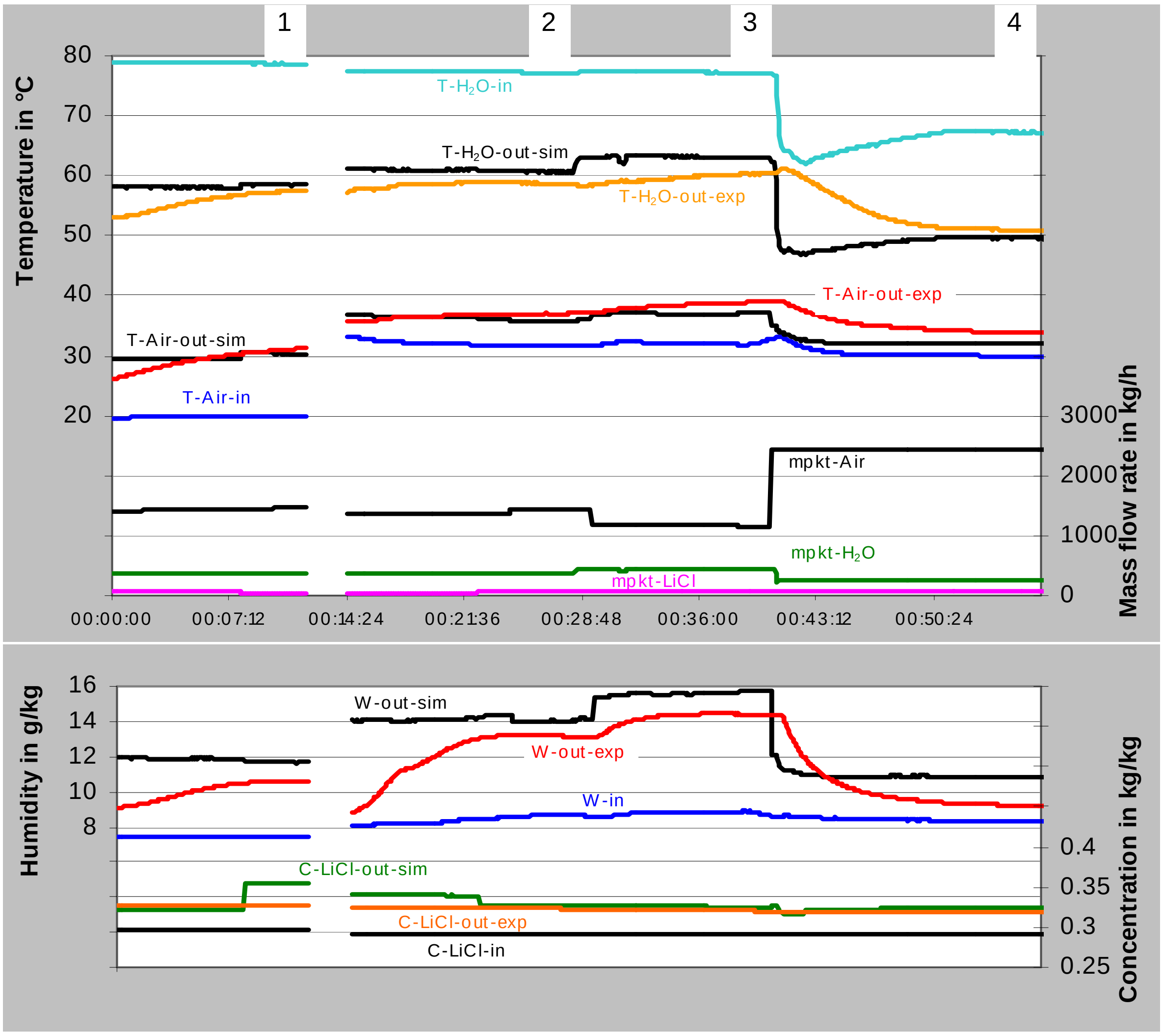

Figure 4: Comparison between simulation and experimental results of the regenerator. The top diagram shows temperatures and flow rates, the bottom diagram air humidity and solution mass concentration. The comparison consists of two testing periods, divided by the blank area in the diagram. For the comparison, only quasi steady state conditions can be considered. These times are indicated by the numbers 1 to 4 at the top of the diagram.

5. PARAMETER VARIATION

Figure 4 shows the modelled influence of the hot water temperature on the regenerator performance. In order to investigate the regenerator performance in principle, the heat and mass transfer parameters are chosen as theoretically expected and were not fitted to the experimental data, which show too small heat and mass transfer coefficients because of uneven flow distribution. It can be seen that the driving hot water temperature has a distinct influence on the moisture removal. With 85°C, a desiccant concentration of 0.38 can be achieved whereas with 60°C, only 0.33 is possible. However, the green lines demonstrate that the same desiccant concentration of about 0.38 can be achieved if both, water and air flow rates, are increased by a factor of 2.5. Thus, the flow rates through the regenerator should be adjusted during the operation on the basis of the solar collector performance.

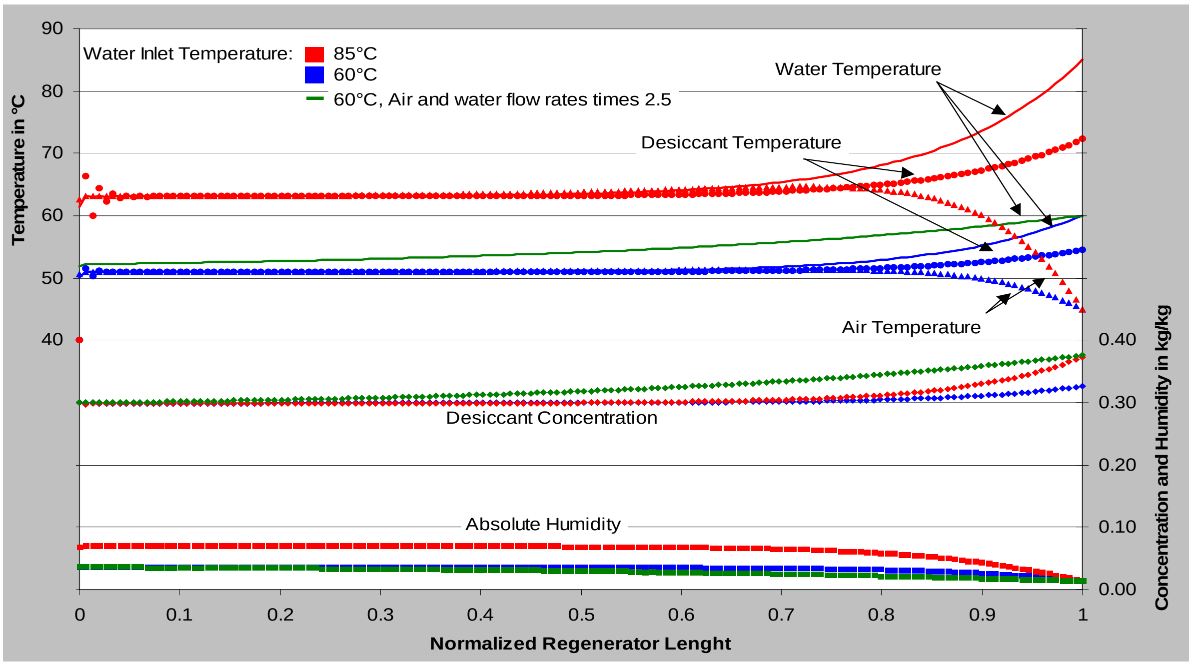

Figure 4: Influence of the hot water temperature on the performance of the regenerator. Here, water and air flows from the right hand side to the left hand side, whereas desiccant is flowing in the opposite direction. The simulation parameters are: transfer area of the regenerator: 23.7 m², mass flow rate of dry air: 1800 kg/h, water mass flow rate: 350 kg/h, desiccant mass flow rate: 50 kg/h. The additional green lines represent operating conditions where the air and water flow rates are increased by a factor of 2.5.

6. RESULTS AND OUTLOOK

Both, with the experimental and the theoretical investigations, an option for regenerating salt solutions has been demonstrated. Testing is in progress to cover a wider range of operating conditions. The first prototype showed some construction deficiencies and investigations are under way in order to design an improved prototype. Using the model developed, system simulations of a single-family house with solar domestic hot water, heating and cooling/dehumidification will be carried out in order to determine optimal component and system designs for Adelaide and Brisbane conditions.

7. ACKNOWLEDGMENTS

This research was supported by a Marie Curie International Fellowship within the 6th European Community Framework Program.

8. REFERENCES

Saman, W., Krause, M., Vajen, K. (2004), *Solar Cooling Technologies: Current Status and Recent Developments*, Proceedings of the 42nd ANZSES Conference Solar 2004, 30.11.-3.12.04, Perth

Lävemann, E., Peltzer, M. (2003): Solar Liquid Desiccant cooling System Demonstration Plant, ISES Solar World Congress, Goeteborg, 14.-19.6.2003.

Saman, W. Y., and Alizadeh, S. (2000): *An Experimental Study of a Cross-flow Type Heat Exchanger for Dehumidification/Cooling,* Proc 38th Annual Conference of the Australian and New Zealand Solar Energy Society.829-836.

Alizadeh, S., Saman, W.: *An experimental study of a forced-flow solar collector/regenerator using liquid desiccants*, Solar Energy, Vol. 73, No. 5, pp 345-362, 2003.

Khan, A., Sulsona, F.: *Modelling and parametric analysis of heat and mass transfer performance of refrigerant cooled liquid desiccant absorbers*, International Journal of Energy Research, **22**, pp 813-832, 1998.