

VALIDATION AND COMPARISON OF ABSORBER AND REGENERATOR MODELS FOR LIQUID DESICCANT AIR CONDITIONING SYSTEMS

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ABSTRACT

Solar assisted air conditioning systems using liquid desiccants represent a promising option to decrease high summer energy demand caused by electrically driven vapor compression machines. The main components of liquid desiccant systems are absorbers and regenerators. However, high efficient and validated reliable components are required and the design and operation have to be adjusted to each respective building design, location, and user demand. Simulation tools can help to optimize component and system design. The present paper presents new developed numerical models for absorbers and regenerators, as well as experimental data of a regenerator prototype. The models have been compared with a finite-difference method model as well as experimental data.

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. Since by far most of the air-conditioning systems are electrically driven vapor compression machines, high electricity demand and peak loads are resulting. However, these machines could be substituted by thermally driven cooling systems using solar thermal or waste heat. An overview on different technologies can be found in [1].

Of all the technologies, the use of liquid desiccants in an open cycle system is a promising solution. The main components of these systems are absorber and regenerator. In the absorber, a hygroscopic solution, e.g. LiCl or CaCl₂, is directly brought in contact with fresh air, which it dehumidifies. 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 thermal energy is used to drive the process.

Many investigations worldwide have been dealing with modeling and testing of absorber and regenerator designs. To provide the heat and mass transfer area, mainly packed-

bed and plate heat exchanger designs have been investigated so far. In addition to models for packed-bed absorbers and regenerators, a model for parallel plates with simultaneous heat and mass transfer using NTU relations was presented in [2]. A model with variable film thickness can be found in [3]. Prototypes for water cooled absorbers designed as plate heat and mass exchangers are for instance presented in [4] and [5]. In the present paper, absorbers and regenerators for liquid desiccant air conditioning systems are investigated experimentally and theoretically. Numerical models have been developed and two regenerator prototypes have been constructed and extensively tested. Test results of the second prototype as well as test results from literature are used to validate the numerical models.

2. PROTOTYPE DESIGN

Based on previous approaches for water-cooled absorber constructions presented in [6], two regenerator prototypes, which are designed as plate heat and mass exchangers and use hot water as the

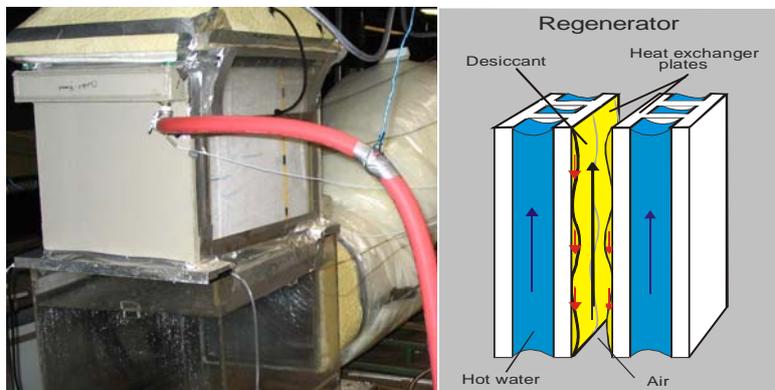


Fig. 1: Photograph of the second regenerator prototype installed in the test rig. The schematic on the right hand side shows the path of air, water and desiccant flows.

driving force have been developed and tested. Both prototypes have been extensively tested using different operating conditions. Test results for the first prototype are presented in [7]. Fig. 1 shows a photograph of the second regenerator prototype, which has an improved flow distribution. Test results are presented in Fig. 3.

3. ABSORBER/REGENERATOR MODEL

A numerical multi-element model has been developed for water cooled/heated absorber/regenerators. The models calculate for both, parallel flow and counter flow conditions, the enthalpy balances for the water flow, the desiccant film and the air stream for each element 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 [2]. The heat transfer coefficients are determined using Reynolds and Nusselt number relationships for laminar and turbulent flow. In order to model different flow directions of water, air and solution, an iterative procedure for all elements is used. For a model validation, comparisons with measured data are necessary. Since the numerical models are static models, only quasi steady state conditions are applicable.

3.1 ABSORBER MODEL

For the validation of the absorber model, test data from [6] have been used. In the tests, which consist of 14 test sequences with steady-state conditions, the performance of a single plate absorber instead of a multi-plate absorber was tested. Due to this, even distribution of all three fluids could have been assumed. Thus, a quite reliable validation of the theoretical model regarding heat and mass transfer phenomena is possible.

The main results of this comparison are presented in Fig. 2. Since the flow rate of the cooling water was chosen comparably high, and all inlet temperatures are chosen to similar values, outlet temperatures of all fluids are not varying much and are neglected in the comparison. As Fig. 2 demonstrates, modeled and experimental outlet mass concentration of the solution show very good agreement. Simulated and tested air humidity follow the same trend, however, the slight difference is caused by uncertainties in the humidity measurement during the tests.

Additionally, the performance of the model has been compared to the finite-difference model from [3]. For the same conditions used in the experiments 1 to 7 in Fig. 2, the humidity of the outlet air stream showed deviations of the models related to the overall absorbed moisture in the range of 2-3 %, cf. [8].

Fig. 3 compares the simulation results with test data of the regenerator presented in chapter 2. At points with steady-state conditions, the comparison shows good agreement between the outlet temperatures of heating water and air for most of the operating points. Additionally, the resulting air humidity shows good agreement with the experimental data, too. Due to uncertainties of the non-continuous mass concentration measurement, the desiccant mass concentration shows some discrepancy.

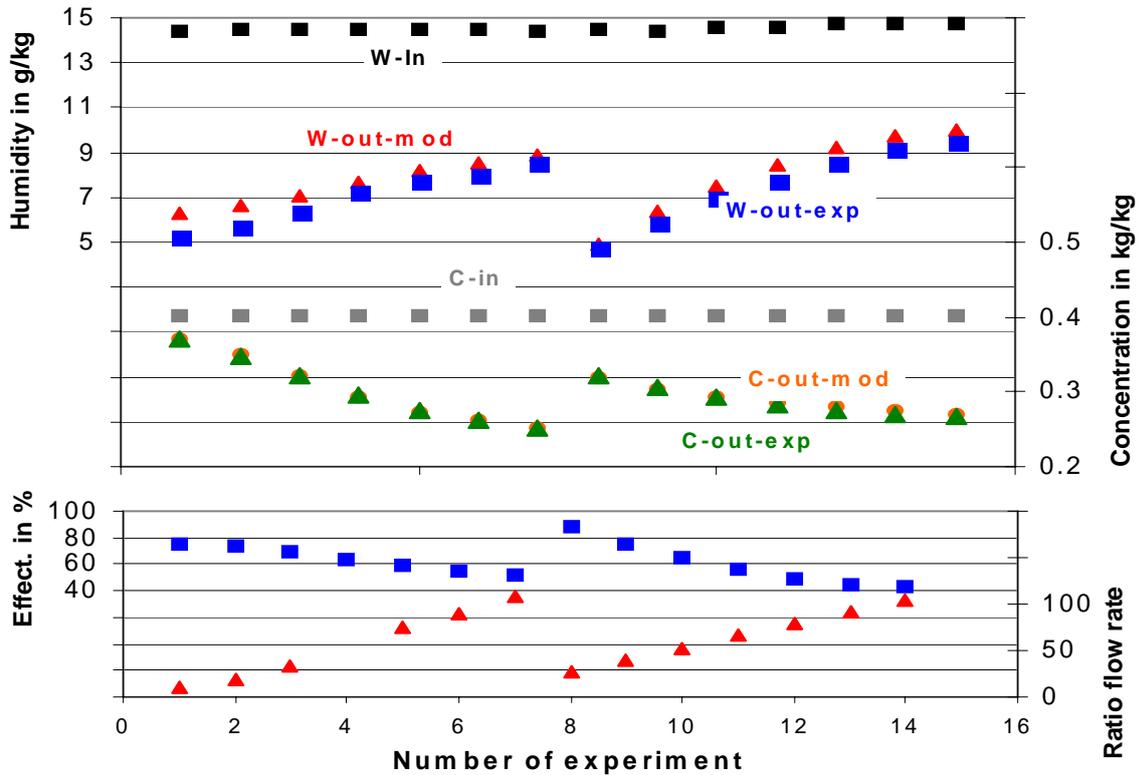


Fig. 2: Comparison of data from the absorber model and 14 sets of experiments taken from [6]. The top diagram shows air humidity and solution mass concentration (inlet, modeled outlet and experimental outlet conditions), the bottom diagram modeled effectiveness and flow rate ratio between air and solution.

3.2 REGENERATOR MODEL

In contrast to the quasi-isothermal absorber performance, significant temperature changes occur within internally heated parallel plate regenerators. Thus, all the temperature curves, solution concentration and air humidity form the basis for the comparison of model and experiments.

In the experiments, even flow of all three fluids over the plates could not be guaranteed. Especially the even distribution of the solution over the plates is very difficult to realize. Thus, since flow development on the plates is not calculated in the model, effects of non-even distribution could only be considered using additional parameters.

However, since the non-even distribution could not be measured directly, the effective heat and mass transfer area used for the simulations had been adjusted to the heat and mass transfer in the experiments. Additionally, the heat transfer value through the plastic plates was fitted to the experimental results. Considering these adjustments, experiments and model show good agreement independent on the operating conditions.

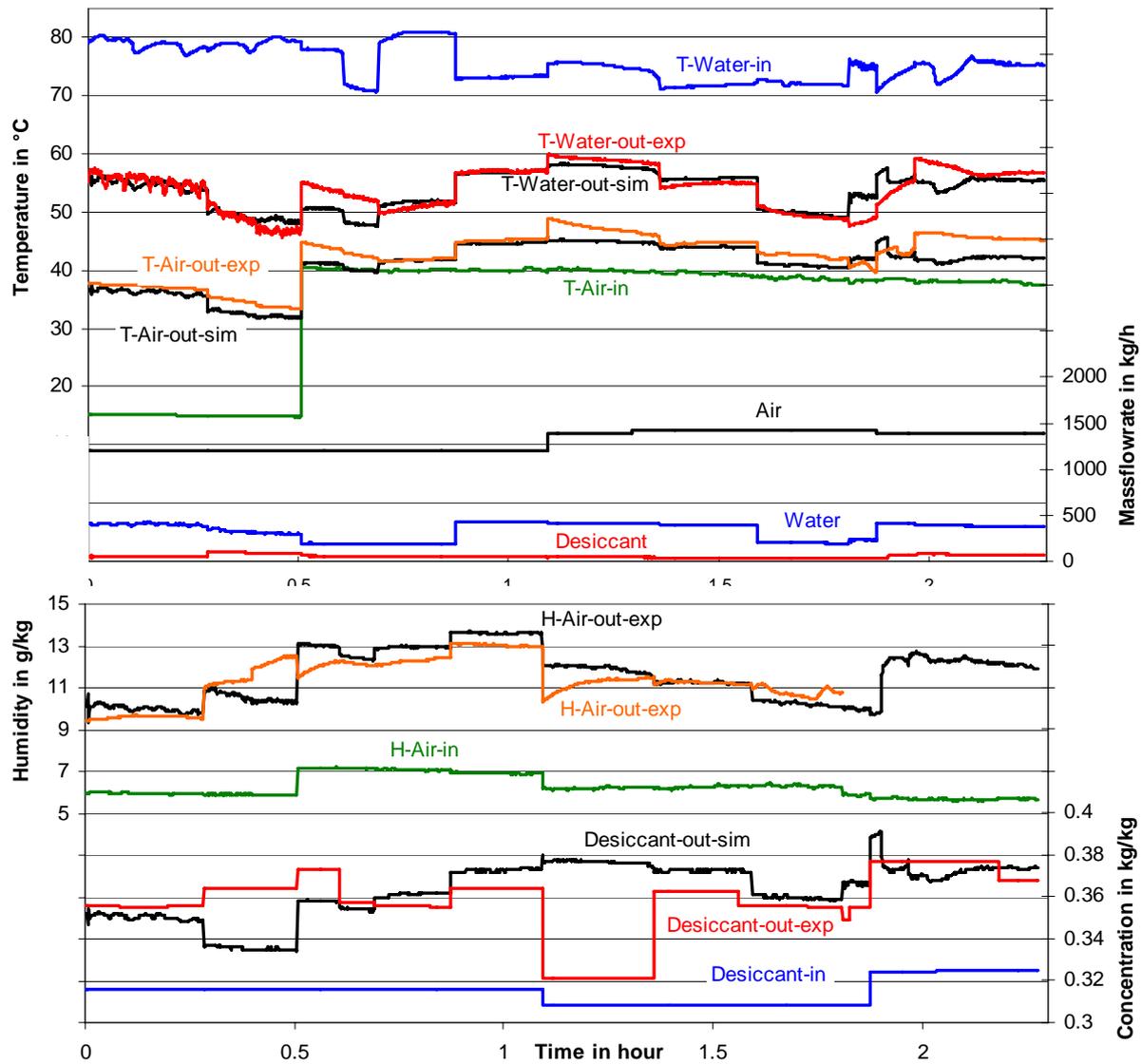


Fig. 3: Simulation and experimental results of the regenerator. The top diagram shows water and air temperatures and the three flow rates, the bottom diagram air humidity and solution mass concentration.

4. RESULTS AND OUTLOOK

Both, experimental and theoretical investigations on heat and mass exchangers for a liquid desiccant air conditioner have been carried out. Two prototypes for regenerators have been build and tested regarding their operational behavior. Additionally, models for regenerators and absorbers have been developed. The regenerator model has been compared to tests with the second regenerator prototype. The absorber model has been validated with test data from literature as well as a finite-difference model.

The investigations showed that a validation is possible within the limits of the uncertainties of the experimental tests. Both, experiments and simulations demonstrated the option of using the presented design for components of liquid desiccant systems. However, additional construction work is necessary. Additionally, in order to design solar air conditioning plants, simulation studies including the building are required.

5. ACKNOWLEDGEMENTS

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