HEAT AND MASS TRANSFER PROPERTIES OF WATER-LIBR SOLUTION IN A PLATE TYPE FALLING FILM ABSORBER

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Synopsis

Absorption chillers have a great potential for sustainable cooling, especially when the process is driven by heat from solar thermal collectors. In this study, plate heat exchangers for the use in falling-film absorption processes are investigated. Plate heat exchangers could be a cheap alternative for the nowadays usually applied shell and tube heat exchangers, especially for small scale devices. The main goal of the study is to experimentally analyze the influence of different surface structures on the fluid flow and on the absorption process. The obtained data is processed to extract heat and mass transfer coefficients, which are compared.

1 Introduction

The energy demand for air conditioning and cooling in residential and office buildings rises due to climate change, new trends in architecture and the growing desire for thermal comfort (Adnot, 2003). Thermally driven refrigeration technologies are receiving increasing interest as energy-efficient and environment-friendly alternatives to the nowadays mainly used compression chillers. Absorption technology has been used for industrial applications for nearly 150 years and is appreciated as reliable and cheap in operation. However, state of the art absorption chillers are often not competitive because of high investment costs and high space needs, resulting from complex design and the use of expensive materials, especially in the low capacity range. On the other hand, heat sources like from solar thermal applications are often found in small scales. During summer month usually more heat than needed is produced. Therefore research on small scale devices would open up a large market in the field of solar cooling applications.

To make absorption chillers affordable also in a capacity range under 10kW, new heat exchanger designs are necessary. Many researchers are currently working on design and process optimization to cut down the costs. In the field of absorption refrigeration, substantial research effort is focused on the improvement of heat and mass transfer in tubular heat exchangers, which are commonly used in absorption chillers. Due to the high share of manual work needed in the production of tubular heat exchangers, the ratio of investment costs to cooling capacity rises in the low capacity range (Siso, 2008). Therefore new heat exchanger designs are needed which are optimized for small capacities. In the field of tubular heat exchangers, the horizontal type has been popular for many years, while the vertical type has been recently applied to some absorption machines (Ogawa *et al.,* 1991; Medrano *et al.,* 2002; Jakob and Pink, 2007). Although rare, the use of helical (Kwon and Jeong, 2003; Yoon *et al.,* 2005) type falling film heat exchangers can also be found. In this study, plate type heat exchangers (PHE) will be examined. Only a few studies can be found about this type of heat exchangers (Becker, 1989; Flamensbeck *et al.,* 1998; Kim *et al.* 2008). Plate-type heat exchangers would allow a more compact and cost-effective machine. The biggest advantage of plate heat exchangers is their high area density in the order of 1000 m^2/m^3 (Kakac *et al.* 1981), allowing for a high power in a compact size. Furthermore, plate heat exchangers can be fabricated automatically, which is a very important factor for low manufacturing costs. However, PHEs have been rarely applied in absorption refrigeration machines because of their low wetting rate. Simultaneous heat and mass transfer processes in an absorption machine require large contact surfaces of liquid-solid and liquid-vapor for heat and mass transfer, respectively. It is difficult to wet the whole heat transfer surface of a PHE when used as a falling film absorber, because of the long perimeter and the contraction of the rivulets in the absorber. To enhance the wetting rate different strategies are possible. Kim and Infante Ferreira (2009a) analyzed the influence of surface structures and additives. Estiot et al. (2006) tested some compact plate-type falling film heat exchangers with macro-scale structures (in the order of millimetres) for development of absorption chillers. Furthermore, Negny et al. (2001a, 2001b) and Yeong et al. (2006) carried out fundamental studies on falling film flows flowing over some structured surfaces.

The above mentioned studies lead to the conclusion, that design optimized plate heat exchangers could be competitive for the use in low capacity absorption machines. During this paper different structured plates are examined experimentally for their ability to enhance the heat and mass transfer properties, which in future should lead to competitive manufacturing costs. Some measurements were already carried out (Hebenstreit, 2010). Based on these and further experimental data an overview of the influence of different surface structures on the fluid flow and on the absorption process is given.

2 Evaluation Method and Experimental Setup

A setup, containing a generator and an absorber using LiBr-water as a working fluid, is investigated experimentally. It is designed to analyze the absorption process in falling film flows on easily exchangeable plate heat exchangers. Fig. 1 shows schematic drawings of the experimental setup, including a plate-type absorber and a helical tube generator. The vessels are connected via a variable-speed magnetic gear pump, pumping the solution from the generator to the absorber, a solution pipe for the rich solution and a pipe for the vapor exchange. Hence the two vessels are openly connected leading to a very small pressure difference. Furthermore an electric heating rod (1.5 kW heating capacity) and a cooler (1.5 kW cooling capacity at 20°C) are installed providing water to heat the generator and cool the absorber, respectively. As secondary fluids water is used in countercurrent flow to the falling film in both cases. The setup was charged with 55 wt% of LiBr-water solution (inhibited with molibdate).

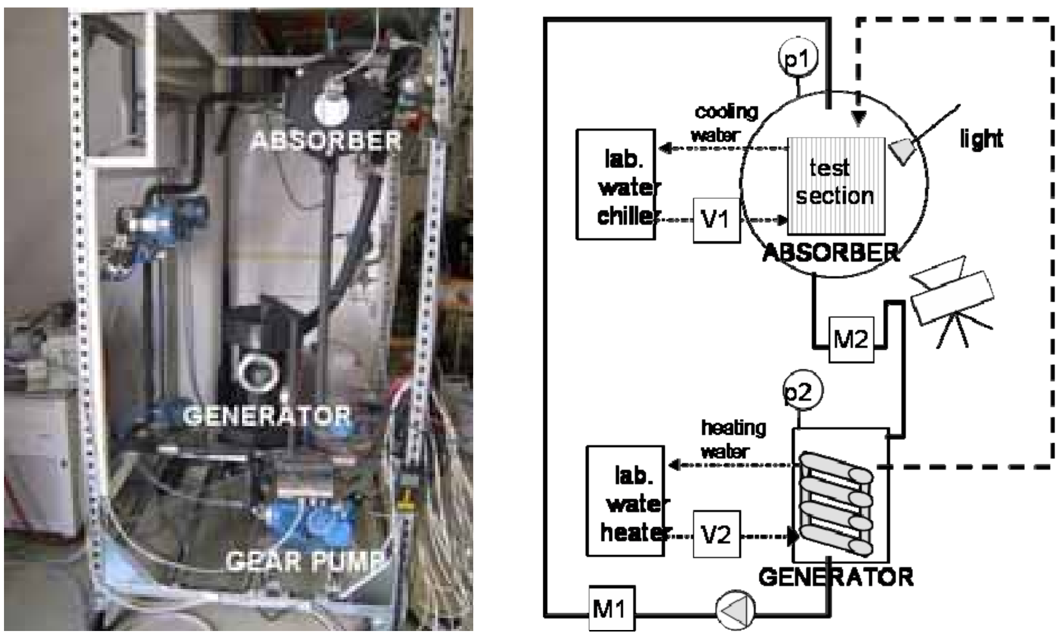

Figure 1. Experimental setup. Left: Photo of the experimental setup; Right: Schematic drawing: Lines show the fluid flows: black line – solution, dashed line – vapor, dashed-points – cooling/heating water; Measurement points: V – volume flow, M – mass flow & density, p – pressure.

Pt100 temperature sensors (max. error 0.05 K) are installed to measure in- and outlet temperatures of working fluids in each component as well as the gas temperatures in both vessels and surrounding temperature. An absolute pressure gauge (0.5~10 kPa, max error 0.17 kPa) and a differential pressure gauge (+/-10 kPa, max error 0.1 % reading) are installed to measure low- and high system pressure. Two Coriolis mass flow meters measure rich- and poor solution mass flow rates (max error 0.1 % reading) and the densities (max error 0.0005 g/cm^3). Furthermore a magnetic volume flow meter (max error 0.2 % reading) is used to measure the cooling water rate.

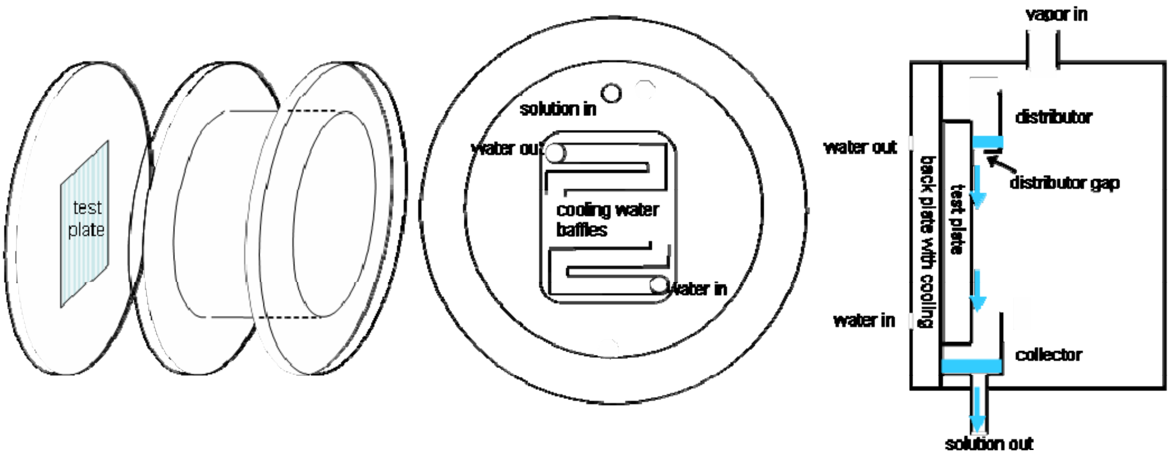

Figure 2. Sketches of the test section. Left: Vessel with mounted test plate; Middle: Back plate with sketched cooling water channels and in/outlets; Right: cut through the middle of the vessel showing solution and vapor in- and outlets, as well as the distributor gap.

Fig. 2 shows a drawing of the test section, where the test plates, containing the different structures to be evaluated, can be easily mounted. The back plate contains a milled baffle structure for the cooling water, which cools the structured surface of the test plate from behind. Screw holes to mount the distributor, collector, and test plate are also shown in the figure. The test plates have a dimension of 10x10 cm, which allows vertical and horizontal use of the plates. The solution accumulates in the distributor, before flowing through the small gap shown in the figure, which leads to the distribution of the liquid. Depending on the mass flow and the structure on the test plate, the emerging falling film shows different flow patterns. The tested configurations were below the minimum wetting rate, thus leaving dry spots on the plate. After flowing over the plate, the solution is collected in the solution collector, where it leaves the vessel through a pipe. Four different test plates are used in this study: a plain (Pl), and three structured (see figure 3). Two of the structures are half-circles (1 mm and 0.5 mm) and one is nearly sinusoidal (0.5 mm). They are named V1, V2, V3 when mounted vertically and H1, H2, H3 when mounted horizontally, respectively.

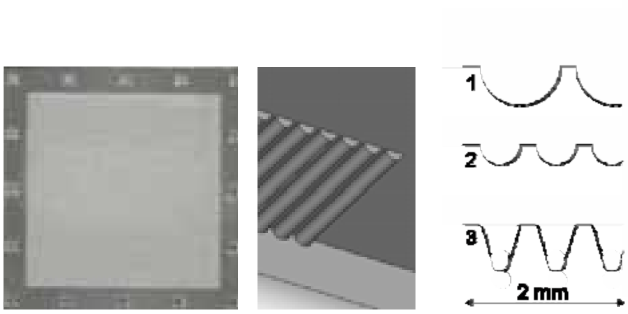

Figure 3. Structured Plates. Left: Photo of the test plate number 1 (10x10 cm total, milled structure 8x8 cm); Middle: Cut through plate number 1; Right: Detailed sketch of the milled structure of the three test plates.

All measurements were accomplished after an evacuation prozess and a pressure tighness check. During the measurements, the composition of LiBr solution and its temperature, as well as the pressure were not actively controlled and hence they were dependent variables. Only the temperatures of the secondary fluids were set to a constant value during each measurement and the flow rate of the solution was adjusted in time according to a cycle: Each measurement cycle was carried out by starting with high solution flow rates (45 % pump speed) and going down in 10 steps to zero flow rate in 5 % steps, each step of duration of at least 60 minutes for stabilization. The last 15 minutes of each step were sampled and statistically averaged. The measurements were checked for stability visually. Additionally, only measurements with statistical deviations less than 5 % were considered as valid.

Table 1. Parameter settings

Fluid	Flow rate	Temperature
Solution	4-18 kg/h ≈ Re: 20-100	not controlled
Cooling water	0.075 l/s	20°C
Heating water	0.07 l/s	45-55°C

The LiBr concentrations were not directly measured but estimated from density measurement from the mass flow meters. Since the density of LiBr solution is strongly dependent on LiBr concentration and less dependent on temperature, LiBr concentration could be calculated back from its density and temperature using a proper density-temperature concentration correlation. In this study, the correlation from Kim and Infante Ferreira (2006) is used. Afterwards the analysis of the gathered data is processed to obtain heat and mass transfer coefficients using the approach published in (Kim and Infante Ferreira, 2009b). This method uses two energy and two mass balance equations to obtain a linear differential equation from which the ratio heat to mass transfer coefficients can be deduced from the inlet and outlet temperatures, concentrations and flow rates. It is regarded to obtain better agreement with the experiments than the often used logarithmic mean differences, because it also considers the mass transfer and not only the heat transfer.

3 Results

Measurements with different flow rates and generator heating temperatures were carried out. To compare the measurements the power (figure 4) and heat and mass transfer coefficients (figure 5 & 6) are calculated and plotted versus the Reynolds number. Except for the structure V2 and partly H2 all structures lead to a higher performance.

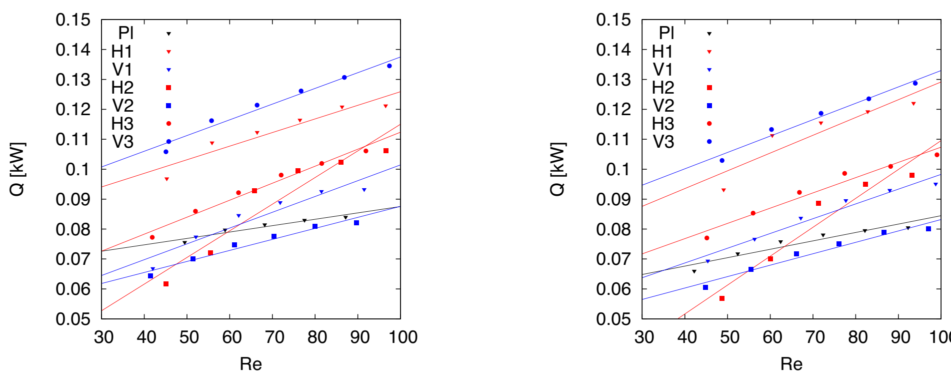

Figure 4. Power Q over Reynolds number. Measurement results for generator heating temperature of 45°C (left) and 50°C (right).

Figure 5 shows the heat transfer coefficient (U) and mass transfer coefficient (β) dependence on the Reynolds number (Re). Three different plate structure Plain, H – horizontal, V – Vertical) are used. The temperature of the generator heating water is 45°C, while the cooling water is 20°C in the structured cases and 15°C in the plain case. This could be the reason for the relatively high U compared to β from the plain plate. Furthermore figure 6 shows comparable measurements with generator heating water of 50°C and cooling water of 25°C for all plates.

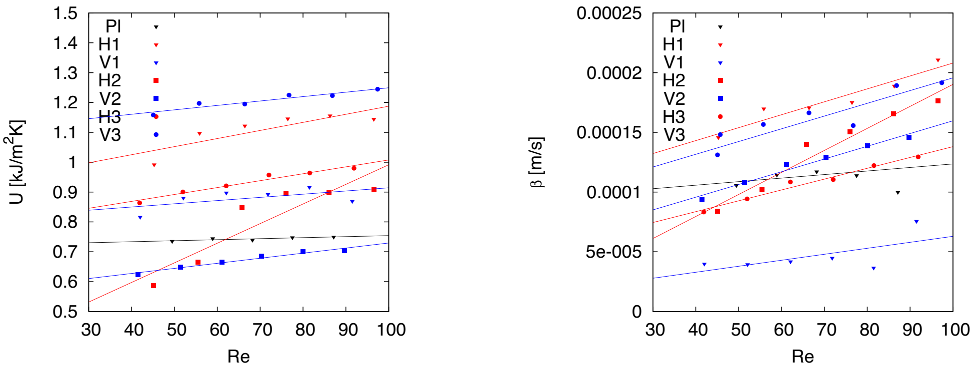

Figure 5. Heat transfer coefficient U and mass transfer coefficient β over Reynolds number. Measurement results for generator heating temperature of 45°C.

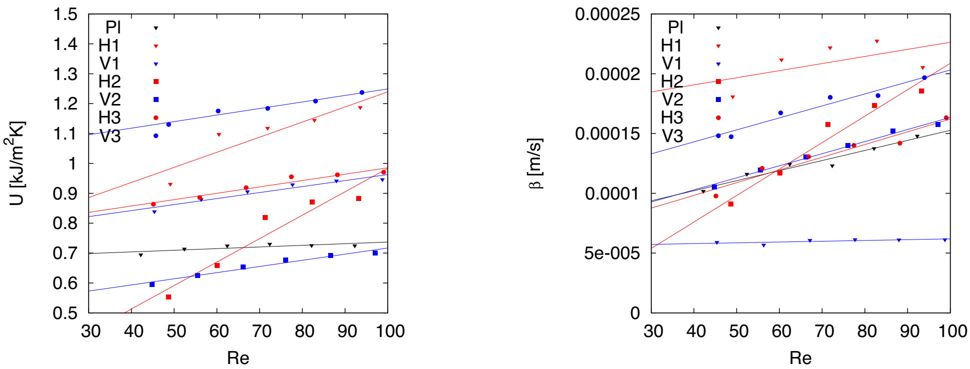

Figure 6. Heat transfer coefficient U and mass transfer coefficient β over Reynolds number. Measurement results for generator heating temperature of 50°C.

The performance enhancement is driven by two processes – wetting and mixing. Horizontal structures lead to spreading of the flow und thus to a better mixing and wetting factor, while vertical structures confine the flow to the inside of the structures and thus reduce the contraction which also leads to higher wetting rates. Mainly the horizontal structures also lead to a better mixing. This might explain the steeper linear regression curves for many of the horizontal plates (red curves) - the mixing depends strongly on the Reynolds number.

4 Conclusions & Outlook

The experiments show clearly, that structured plates can enhance the heat and mass transfer of plate heat exchangers. In the overall performance the structures H1 and V3 showed the best results. It can be noted, that a higher mass transfer coefficient does not automatically correspond to a higher heat transfer coefficient, therefore both have to be considered independently when developing a heat exchanger for absorption devices. Further investigations will be done to clearly distinguish between the wetting factor compared to other (e.g. mixing) phenomena which influence the transfer properties. A technique to identify the wetted surface and if possible the film thickness will be developed. This will lead to a better understanding of the different phenomena which influence the absorption performance.

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