EXPERIMENTAL STUDY OF WATER ABSORPTION PROCESS IN FALLING FILM HORIZONTAL TUBES WITH WATER/LIBR SOLUTION USING IONIC LIQUIDS AS ADDITIVE: PRELIMINARY RESULTS

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Abstract: *The water/LiBr pair has been widely used in absorption chillers. However, its performance is limited to a certain range of concentrations, due to the risk of salt crystallization. This prevents it from operating at high temperatures in the absorber and does not allow it to produce useful heat at suitable temperatures when functioning as heat pump. This limitation might be overcome by using Ionic liquids (ILs) as additives in the water/LiBr mixture which can improve thermophysical properties. One of the drawbacks of falling-film tubes is the non-uniform distribution of the film on the tube surface. Thermophysical properties of the new mixture as viscosity and surface tension will be of special importance for good wetting. This is a preliminary study on the influence of wettability in the absorption process of water by water/LiBr solutions in a falling film over horizontal tubes and 1,3- Dimethylimidazolium Chloride [dmim][Cl] as additive for heating and cooling purposes.*

Keywords: Falling film absorber, water/LiBr, ionic liquid, additive, heating, cooling, absorption chiller

1. INTRODUCTION

The growing population and economic growth demands air conditioning. According to an estimate, almost 2/3 of homes in the world will have air conditioning by 2050 [1]. At the other side, fossil fuels are commonly used for heating buildings. Natural refrigerants and renewable energy resources for cooling and heating systems can play a vital role to reduce the dependency on conventional refrigerants and fossil fuels which ultimately results in greenhouse emissions and global warming. The vapor compression technology is the most widely utilized technology but requires a significant electricity consumption and synthetic refrigerants. Absorption chillers are attractive as a potential solution to energy and environmental problems. These chillers are suitable when they are driven by low-grade energy resources. The environmental friendly aspect overshadows the performance of the system.

The absorption technology is more attractive using the water/LiBr as working mixture where water acts as a natural refrigerant which is non-toxic and cheap. A lot of studies reported the use of water-LiBr working pair in absorption chillers [2] [3] [4]. The use of water/LiBr mixture is limited to range of concentration because of the risk of crystallization of LiBr. This prevents the absorber to operate at higher temperature requiring cooling towers to dissipate the heat. Similarly, solubility of LiBr in water limits the heat production at desired temperature level when operates as heat pump. Ionic Liquids (ILs) which are liquids at room temperature are the focus of many researchers to address these problems. The improvement of solubility and vapor pressure by adding the Ionic Liquids (ILs) as additives in water-LiBr mixture is reported in literature [5] [6]. This can allow the absorption system to operate at higher concentration resulting in better system performance.

Among all the components of absorption heat pumps, the absorber plays a critical role in the overall performance, physical size, and capital cost. Both heat and mass transfers take place simultaneously in this component. The falling-film configuration, which is utilized in this work, is the most commonly used in the absorption heat pumps [7] [8]. The downside of this is the misdistribution of film on the surface of the tubes, affecting flow uniformity at lower Reynolds number. The non-wetted areas do not participate in the absorption process, thus, decreasing the useful area of the tubes, which results in decreasing of absorption rate. A good surface wetting depends on the thermophysical properties of the solution i.e. surface tension, viscosity. For this reason, the new working mixture will be of special importance. This is a preliminary work to study the wettability and absorption process using water/LiBr mixture in a horizontal tube falling-film absorber which intends to utilize 1,3-Dimethylimidazolium Chloride [dmim][Cl] as additive for heating and cooling purposes. To provide heat above 40 ˚C is limited by the solubility of LiBr in water, so the new mixture is intended to provide the required heating.

2. METHODOLOGY

2.1. Experimental setup

To study the absorption process, the experimental schematic is shown in Figure 2 to operate the system in a continuous mode at steady state conditions. The component of the system includes absorber, generator, cooling water circuit, solution circuit, tanks, vapor line, data acquisition system, temperature sensors, pressure sensors, flow meters and thermal baths. All the instrumentations are calibrated in the relevant range. The main system is made of stainless-steel material to avoid the possible corrosion.

The falling film absorber is made of 6 horizontal stainless tubes placed in a cylindrical chamber as shown in Figure 1. The tubes are connected in series and are perfectly aligned. There is a solution distributor placed above the horizontal tubes for evenly distribution of the flow. The cooling water inside the tubes flow in counter current direction to the solution. The falling film solution flows co currently with the vapours. The absorber is designed in such a way to visualize the falling film and wetting of the tubes via two circular windows placed at the circumference of the cylindrical chamber. The main parameter of absorber is given in the Table *1*. The solution utilized in this study is LiBr/water at 55 % and 60 % of mass fraction.

Table 1. Absorber parameters

Parameter	Value
Number of tubes	6
Outside diameter of the tubes	16 mm
Thickness of the tubes	1 mm
Tube spacing	30 mm
Wetted length of the tubes	400 mm

Figure 1. Falling film absorber for water/LiBr mixture

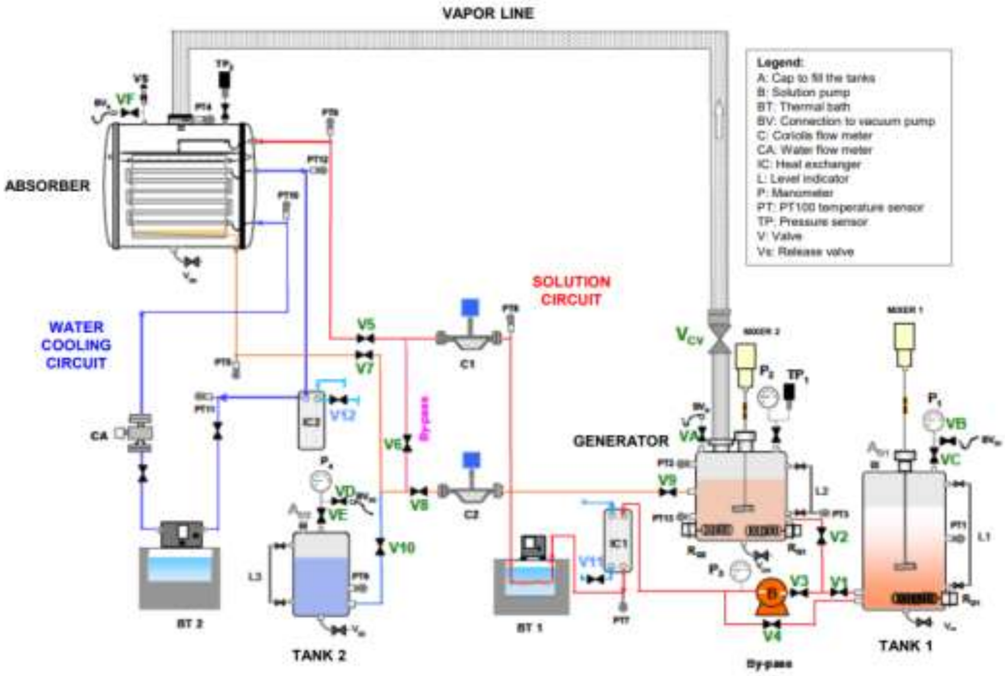

Figure 2. Schematic of test bench (adapted from ref [*[9]*])

2.2. EXPERIMENTAL CONDITIONS

The system operates in a way to provide the conditions for absorber operating as single effect absorption cycle using LiBr/water mixture. The inlet variables are controlled separately in the test facility allowing to perform the study at the absorber conditions. The vacuum pressure inside the absorber is kept as low as possible. The operating range for this study is listed in Table 2.

Table 2. Operation range

	Current study	Yoon et al. [4]	Kyung et al. [8]
LiBr concentration	55 to 60 %	61 %	57 to 60 %
Solution inlettemperature	35 °C to 50 °C	47°C	37 °C to 52 °C
Cooling water flowrate	85 to 275 L/h (0.5 to 1.3 m/s)	0.8 to 1.6 m/s	1.262*10^{-4} m^3 /s

	Current study	Yoon et al. [4]	Kyung et al. [8]
Solution flow rate	0.0187 to 0.083 (kg/s·m)	0.0142 to 0.0303 (kg/s·m)	0.01 to 0.045 (kg/s)
Cooling water inlet temperature	28 ºC to 34 ºC	32 ºC	30 ºC
Absorber pressure	1.5 kPa	0.93 kPa	1.23 kPa, 1.09 kPa

These conditions are especially applicable for cooling applications. For heating applications, LiBr concentration needs to be higher than 65 %. However, at these values of LiBr concentrations there is risk of crystallization.

2.3. Data calculations

The vapor absorbed can be calculated by using the mass balance equation

$$\dot{m}_{s,i} + \dot{m}_v = \dot{m}_{s,o} \tag{1}$$

$$\dot{m}_{s,i} \,. X_i = X_o \,. (\dot{m}_{s,i} + \dot{m}_v) \tag{2}$$

Absorber heat duty can be calculated using eq. (3)

$$\dot{Q}_{abs} = \dot{m}_w \times c_{p,w}(T_{w,o} - T_{w,i}) \tag{3}$$

Overall heat transfer coefficient is calculated from eq. (4)

$$U = \frac{\dot{Q}_{abs}}{A_y \times \Delta T_{lm}} \tag{4}$$

where ΔT_{lm} is calculated from eq. (5)

$$\Delta T_{lm} = \frac{\left(T_{s,i} - T_{w,o}\right) - \left(T_{s,o} - T_{w,i}\right)}{\ln \left(\frac{\left(T_{s,i} - T_{w,o}\right)}{\left(T_{s,o} - T_{w,i}\right)}\right.} \tag{5}$$

The mass flow rate of solution per unit length is calculated from eq. (6)

$$\Gamma_s = \frac{\dot{m}_s}{2 * L} \tag{6}$$

3. RESULTS

In Figure 3, the minimum solution flow rate required for wettability of horizontal tubes is examined as a function of solution inlet temperature. It is found that by increasing solution inlet temperature and concentration, there is a slight increase in solution flow rate to wet completely the tubes. The minimum flow rate observed is near to the values reported in previous studies utilizing LiBr/water mixture. The reason of the difference in the flow rates is due to the different tube materials used in absorber. Yoon et al. [4] and Kyung et al. [8] used copper tubes while the tubes used in current study are of stainless steel. The minimum mass flow rate observed for 50 %, 55 % and 60 % mass fraction are 0.0173kg/s.m, 0.0180 kg/s.m and 0.0187 kg/s.m, respectively. One of the problems in falling film absorber is the non-uniform film distribution on the surface of the tube. Thus, the non-wetted area does not participate in absorption resulting in decrease of absorption rate. For this reason, the new working mixture composed of LiBr/water + [Dimm][Cl] will be of special importance in forthcoming study as the thermophysical properties like surface tension and viscosity will be changed.

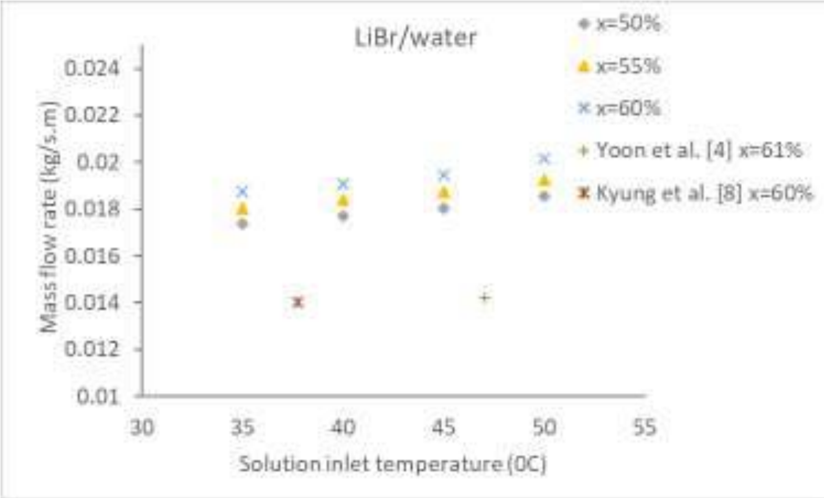

Figure 3. Wettability of solution

Absorber heat duty is shown in Figure 4 with varying cooling water flow rate for different LiBr/water solution concentration. The results shows that absorber heat duty increases by increasing cooling water flow rate and the concentration of LiBr/water from 55 % to 60 %. For instance, absorber heat duty is found 1.173 kW and 1.399 kW for 55 % and 60 % mass fraction, respectively at 197 L/h of cooling water flow rate. Higher heat transfer at mass fraction represents the better performance of absorber. This depicts that adding the ILs as additives in the LiBr/water mixture will be beneficial because of the possibility to work at higher concentration of LiBr/water mixture.

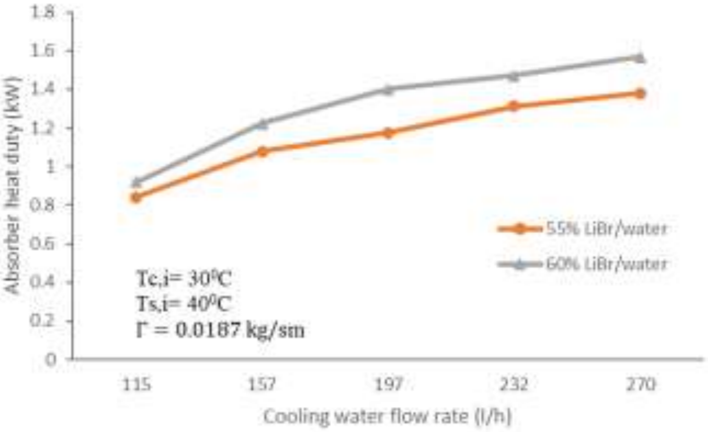

Figure 4. Absorber heat duty with cooling water flow rate

Mass flux is shown in Figure 5 with respect to solution flow rate for 55 % and 60 % of LiBr/water solution concentration. It is found that more mass is absorbed at higher LiBr/water concentration and solution flow rate. At higher flow rate, more surface area of the tube is covered with the solution film resulting in the higher absorption of the vapours. Additionally, at higher concentration, the absorbent has more affinity to absorb the vapours. For instance, water absorption rate is found 0.0020 kg/m^{2}s and 0.0027 kg/m^{2}s respectively, at 0.0202 kg/m.s solution flow rate. This depicts that the water absorption can be improved if LiBr/water concentration increases. This will be of particular interest to examine [Dimm][Cl] as additive in LiBr/water solution giving opportunity to work at higher concentration of LiBr/water mixture to absorb more vapours.

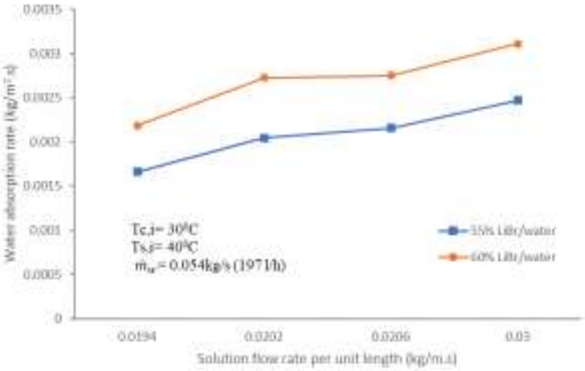

Figure 5. Mass flux with solution flow rate

4. NEXT STEPS

Similar experimental tests, (e.g., the wettability study and the absorption process) will be done using 1,3- Dimethylimidazolium Chloride [dmim][Cl] as additive in the water/LiBr mixture. Results obtained will be compared with the achieved by the water/LiBr mixture. Due to the higher viscosity and lower surface tension of the new mixture, the minimum solution flow rate to achieve the full tube wetting is expected to be lower. However, despite the better wetting behaviour, due to the lower thermal conductivity and mass diffusivity, the heat duty and the water absorption rate achieved by the new mixture could be similar to achieved by the water/LiBr mixture.

5. CONCLUSIONS

This is a preliminary work to study the wettability and absorption process using water/LiBr mixture in a horizontal tube falling-film absorber which intends to utilize 1,3-Dimethylimidazolium Chloride [dmim][Cl] as additive for heating and cooling purposes. The performance of the absorber is evaluated in this study using LiBr/water at 55 % and 60 % of concentration. The current results show a significant effect of concentration on the performance of absorber. Working on higher concentration i.e. more than 60 % create problems for the system due to the potential risk of crystallization of LiBr in water. To provide heat above 40 °C is limited by the solubility of LiBr in water, so the new mixture is intended to provide the required heating. To improve the solubility and absorption, the ILs as additives [dmim][Cl] in the LiBr/water solution will be the focus of further study. It is expected that the performance of the absorber will increase using IL as additives in the mixture, allowing it to work at higher concentrations of LiBr/water solution.

NOMENCLATURE

A= area, m^2
c_p=specific heat capacity, J/kg °C
$\dot{m}$ = mass flow rate, kg/s L=tube length, m
$\dot{Q}$ =heat transfer rate, kW
U=overall heat transfer coefficient, kW/m^2 °C T=temperature, °C
ΔT= temperature difference, °C
Γ= solution mass flow rate per unit of wetted tube length, kg/m s

Subscript
abs=absorber
c=cooling water
s= solution i=inlet
o=outlet
v= vapor
w=water
lm= log mean
y= surface

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