Experimental Investigation of a Falling Film Horizontal Tube Bundle Absorber for Thermal Absorption Storage with H$_2$O/LiBr

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Abstract

Compared to state-of-the-art sensible and latent heat storage techniques, thermal absorption storage systems can theoretically achieve a significantly higher energy storage density, which increases with the concentration difference between diluted and concentrated sorbent solution. In the absorption process, the concentration difference can be increased by reducing the sorbent volume flow at the absorber. From first principles, this causes a reduction of the absorbed water vapor and therefore also of the heat removed from the absorber. Furthermore, a low sorbent volume flow can reduce the wetting of the absorber surface, which leads to a further reduction of the absorbed water vapor. Therefore, in the scope of developing a novel absorption cold storage process with H$_2$O/LiBr, we experimentally investigated the impact of reducing the salt solution volume flow on the mass and heat exchange on a falling film horizontal tube bundle absorber. In the experiments, we stepwise reduced the specific salt solution volume flow distributed over the absorber from 100 l/(h·m) to 20 l/(h·m) and determined the mass and heat transferred. We thereby experimentally quantified the dependence of the specific salt solution volume flow on the concentration difference and the area-specific heat flow for the tested absorber. The results indicate that reducing the specific salt solution volume flow is an effective way to significantly raise the concentration difference on a falling film horizontal tube bundle absorber. Hence, this absorber type seems to be suitable for thermal absorption storage systems with H$_2$O/LiBr.

Keywords: thermal absorption storage, absorption cold storage, absorber, H$_2$O/LiBr

1. Introduction

In recent years, there has been an increasing interest in thermal absorption storage systems particularly due to their potentially high energy storage densities and low energy losses during the actual storage period. Mainly, the research activities focused either on the seasonal storage of solar heat or on the flexibilization of solar driven absorption chillers, see e.g. Ibrahim et al., 2018; N'Tsoukpoe et al., 2009 and Wang et al., 2013. Another promising application scenario in the future could also be the recovery of waste heat, e.g. from industrial processes as described by Miro et al., 2016.

In principle, the energy storage density of thermal absorption storage systems increases with the concentration difference between diluted and concentrated sorbent solution realized in the absorption process. The technical implementation of the absorption process, however, is quite complex since it consists of a combined heat and mass transfer. In the past decade, there have been various studies on both the absorption process and the absorber design of thermal absorption storage systems. Overall, from these studies can be drawn that it is crucial to choose an absorber type appropriate for the sorbent used. Otherwise, the absorber suffers from an insufficient wetting resulting in low concentration differences associated with low area-specific heat flows, see e.g. Daguenet-Frick et al., 2017 and Le Pierres et al., 2017. This also applies for the working pair H$_2$O/LiBr. For example, N'Tsoukpoe et al. (2013) experimentally investigated a vertical falling film tube bundle absorber to be used in a seasonal solar driven absorption heat storage with H$_2$O/LiBr. They reported concentration differences of only 0.6-1.8 % and that no heat was transferred between salt solution and external heat transfer fluid. They concluded that the investigated absorber design is inappropriate for thermal absorption storage. A further investigation of the absorption tests by means of a numerical model indicated that the poor performance of the absorber was caused by insufficient wetting of the exchange surface (Huaylla et al., 2018).

Although H_2O/LiBr is a promising working pair for thermal absorption storage, so far, no proper absorber design is known in the literature which meets the requirements of low specific salt solution volume flows typically applied in thermal absorption storage processes. Therefore, the aim of this study was to experimentally analyze whether falling film horizontal tube bundle heat and mass exchangers, typically used in conventional absorption chillers, principally are a suitable absorber type for H_2O/LiBr in thermal absorption storage applications. For this purpose, we experimentally investigated the effect of reducing the specific salt solution volume flow from 100 l/(h·m) to 20 l/(h·m) on both the concentration difference and the area-specific heat flow for a falling film horizontal tube bundle absorber in a 10-kW experimental plant.

2. Methods

2.1 Experimental plant

For the experiments of this study, we used a 10-kW-experimental plant of a thermal absorption storage. It is depicted in Fig. 1. The plant consists of three main components: one storage tank each for aqueous LiBr-solution and water, and a reactor. The solution storage tank is a vertically installed cylindrical vessel containing around 500 l of aqueous LiBr-solution. It includes various internal components, e.g. a stratification unit to prevent mixing of diluted and concentrated salt solution in the storage tank and a floating device to extract diluted salt solution from the uppermost layer in the solution storage tank. The water storage tank is horizontally installed and has a volume of 250 l. The reactor contains two heat exchangers separated by a radiation shield. When the plant is operated in absorption mode, they work as evaporator and absorber. In desorption mode, they are used as condenser and desorber. The experimental plant was fitted with extensive measuring equipment in order to ensure its functionality and to measure the absorption process properly.
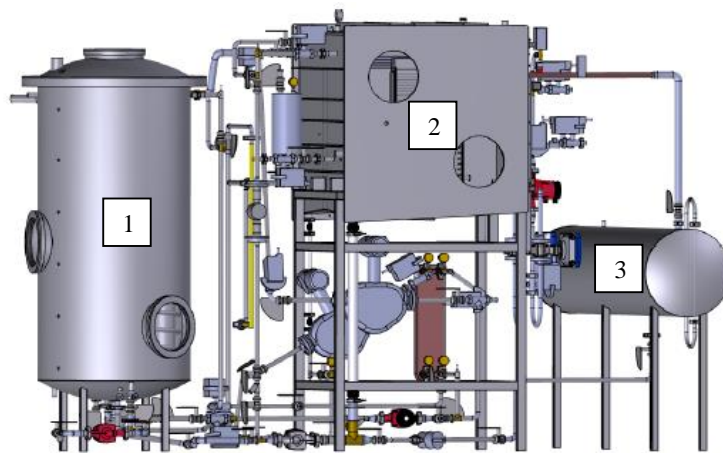

Fig. 1: Experimental plant of the thermal absorption storage with the main components: solution storage tank (1), reactor (2) and water storage tank (3)

2.2 Investigated absorber

The experimentally investigated absorber can be seen in Fig. 2. In general, the absorber is a conventional falling film horizontal tube bundle heat and mass exchanger similar to those used in commercial absorption chillers. It is built of stainless-steel tubes with an outer diameter of 18 mm and a wall thickness of 1 mm. It consists of 3 rows and 20 passes and its total exchange surface amounts to 1.5 m^2, see also Tab. 1.
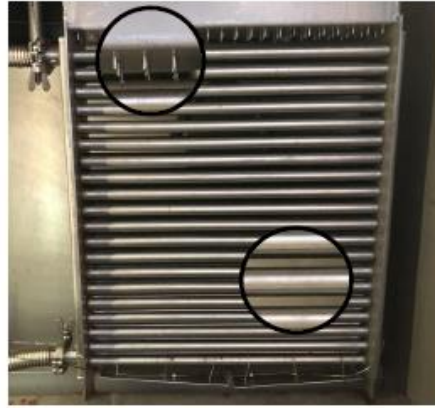
Fig. 2: Experimentally investigated falling film horizontal tube bundle absorber with an exchange surface of 1.5 m²

Tab. 1: Main data of the experimentally investigated absorber

	Unit	Value
Surface	m²	1,5
Tube outer diameter	mm	18,0
Tube inner diameter	mm	16,0
Number of rows	-	3
Number of passes	-	20

2.3 Design of experiments

In the experiments, the specific salt solution volume flow γ given on the absorber was varied between 20 l/(h·m) and 100 l/(h·m) in steps of 20 l/(h·m). A value of 100 l/(h·m) is typically applied in conventional single-stage absorption chillers with H_2O/LiBr. In general, the specific salt solution volume flow is defined as

$$\gamma = \frac{\dot{m}_{S,in}}{\rho_{S,in} \cdot L},$$

with the mass flow $\dot{m}_{S,in}$ and the density $\rho_{S,in}$ of the salt solution distributed over the absorber and the total length L of the first row of tubes of the absorber. For each set point of γ, we determined both the concentration difference Δw_S and the area-specific heat flow $\dot{q}$ achieved in the absorption process. The temperature of the salt solution at the reactor inlet $T_{S,in}$ and the inlet salt mass fraction $w_{S,in}$ of the concentrated salt solution entering the reactor were kept constant in all experiments, see also Tab. 2. The temperature $T_{S,in}$ corresponded to the equilibrium temperature regarding its salt mass fraction $w_{S,in}$ at the reactor inlet and the water vapor pressure in the reactor resulting from the dewpoint T_p of the absorbed water vapor. This prevented the salt solution from absorbing or desorbing water before getting in contact with the exchange surface, which would cause an overestimation or underestimation of the mass transfer on the absorber. Additionally, we adjusted the inlet temperature of the external heat transfer fluid flowing inside the tubes of the absorber in order to achieve a temperature of 35 °C of the salt solution at the end of the absorption process. Thereby, the equilibrium salt mass fraction of the salt solution at the end of the absorption process was equal for all specific salt solution volume flows γ applied in the experiments. The volume flow rate of the external heat transfer fluid flowing through the absorber amounted to 0.42 l/s in all experiments.

Tab. 2: Setpoints of the internal process parameters in the experiments

Parameter	Unit	Value
Specific salt solution volume flow γ	l/(h·m)	20, 40, 60, 80, 100
Salt mass fraction of salt solution at reactor inlet $w_{S,in}$	%	60
Temperature of salt solution at reactor inlet $T_{S,in}$	°C	50
Temperature of salt solution at reactor outlet $T_{S,out}$	°C	35
Dewpoint of the absorbed water vapor T_p	°C	10
Volume flow rate of the external heat transfer fluid	l/s	0.42

3. Results and discussion

The experimental results are depicted in Fig. 3. As can be seen from the two graphs, there is a significant dependence of both the concentration difference Δw_S and the area-specific heat flow $\dot{q}$ on the specific salt solution volume flow γ. Reducing the salt solution volume flow γ results in an increase of the concentration difference Δw_S, while the area-specific heat flow $\dot{q}$ is reduced. For example, reducing the specific salt solution volume flow from 100 l/(h·m) to 60 l/(h·m) leads to an increase of the concentration difference from 3.9 % to 6.1 % and a decrease of the area-specific heat flow from 8.7 kW/m² to 8.0 kW/m². This is to say, a reduction of γ from 100 l/(h·m) to 60 l/(h·m) results in an increase of the concentration difference by 56 %, while the area-specific heat flow only decreases by 8 %.
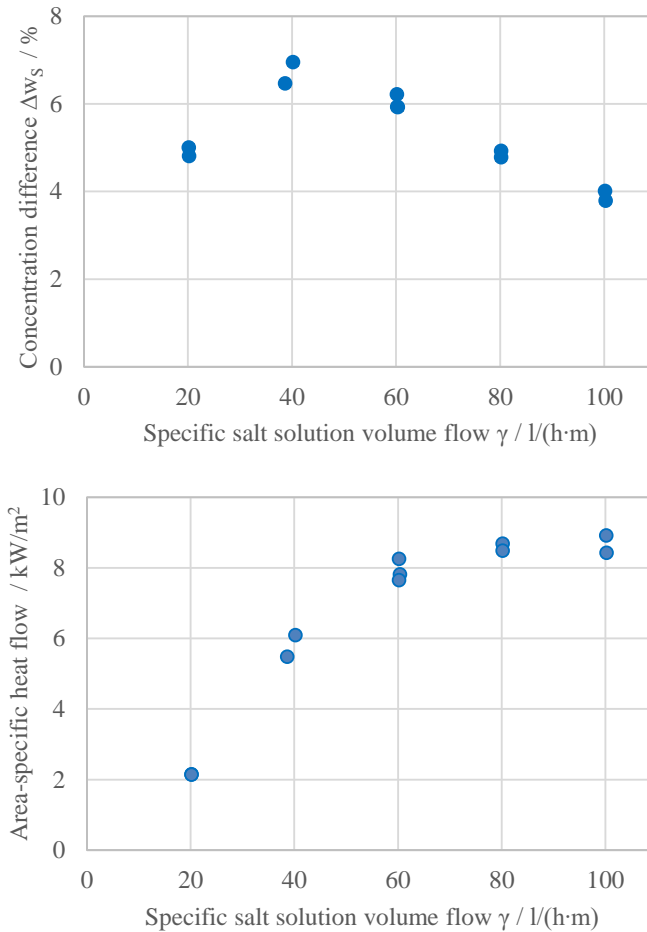
Fig. 3: Concentration difference Δw_S and area-specific heat flow $\dot{q}$ as function of the specific salt solution volume flow γ

A significant decrease in area-specific heat flow $\dot{q}$ is seen when γ is reduced to 40 l/(h·m): in this case, $\dot{q}$ only amounts to 5.8 kW/m². Due to this significant loss in area-specific heat flow, a reduction of the specific salt solution volume flow to values $\gamma \leq 40$ l/(h·m) seems not to be reasonable for thermal absorption storage systems. It is also apparent from the graphs that the investigated absorber is limited towards low specific salt solution volume flows: the concentration difference steeply decreases when γ is reduced from 40 l/(h·m) to 20 l/(h·m). This was mainly caused by the distribution unit of the absorber. At $\gamma = 20$ l/(h·m), the salt solution only leaked from the left part of the distribution unit, which meant that a considerable part of the exchange surface could not be wetted. This can be seen in Fig. 4. As a result, both the concentration difference and the area-specific heat flow decreased steeply. Hence, the distribution unit of the tested absorber is not suitable for specific salt solution volume flows $\gamma \leq 40$ l/(h·m).

Fig. 4: Insufficient wetting of the exchange surface of the tested absorber in the experiments with a specific salt solution volume flow of $\gamma = 20$ l/(h·m)

In conclusion, the results suggest that horizontal tube bundle heat exchangers principally are an appropriate absorber type for thermal absorption storage systems with the working pair H_2O/LiBr. However, an even distribution of the LiBr-solution on the exchange surface is of main importance. For the absorber tested, a specific salt solution volume flow in the range of 60 l/(h·m) seems to be a good compromise between achievable concentration difference and loss in area-specific heat flow.

4. Conclusions

This study set out to evaluate whether falling film horizontal tube bundle heat and mass exchangers are a suitable absorber type for thermal absorption storage systems with H_2O/LiBr. We therefore experimentally investigated the effect of reducing the specific salt solution volume flow on the concentration difference and the area-specific heat flow at the absorber. Thereby, we found that reducing the specific salt solution volume flow is an effective method to significantly increase the concentration difference in the absorption process. The decrease of the area-specific heat flow is comparatively low for specific salt solution volume flows in the range of 60 l/(h·m). In conclusion, the experimental results indicate that horizontal tube bundle heat and mass exchangers principally are a suitable absorber type for thermal absorption storages based on H_2O/LiBr.

5. Acknowledgments

6. References

Daguenet-Frick, X., Gantenbein, P., Müller, J., Fumey, B., Weber, R., 2017. Seasonal thermochemical energy storage: Comparison of the experimental results with the modelling of the falling film tube bundle heat and mass

exchanger unit. Renewable Energy 110, 162-173. https://doi.org/10.1016/j.renene.2016.10.005.

Huaylla, F., Stutz, B., Le Pierres, N., 2018. Numerical and experimental analysis of falling-film exchangers used in a LiBr-H₂O interseasonal heat storage system. Heat Transfer Engineering 40, 879-895. https://doi.org/10.1080/01457632.2018.1446850.

Ibrahim, N.I., Al-Sulaiman, F.A., Nasir Ani, F., 2018. Solar absorption systems with integrated absorption energy storage – A review. Renewable and Sustainable Energy Reviews 82, 1602-1610. https://doi.org/10.1016/j.rser.2017.07.005.

Le Pierres, N., Huaylla, F., Stutz, B., Perraud, J., 2017. Long-term solar heat storage process by absorption with the KCOOH/H₂O couple: Experimental investigation. Energy 141, 1313-1323. https://doi.org/10.1016/j.energy.2017.10.111.

Miro, L., Gasia, J., Cabeza, F., 2016. Thermal energy storage (TES) for industrial waste heat (IWH) recovery: A review. Applied Energy 179, 284-301. https://doi.org/10.1016/j.apenergy.2016.06.147.

N'Tsoukpoe, K.E., Liu, H., Le Pierrès, N., Luo, L., 2009. A review on long-term sorption solar energy storage. Renewable and Sustainable Energy Reviews 13, 2385-2396. https://doi.org/10.1016/j.rser.2009.05.008.

N'Tsoukpoe, K.E., Le Pierres, N., Luo, L., 2013. Experimentation of a LiBr-H₂O absorption process for long-term solar thermal storage: Prototype design and first results. Energy 53, 179-198. https://doi.org/10.1016/j.energy.2013.02.023.

Yu, N., Wang, R.Z., Wang, L.W., 2013. Sorption thermal storage for solar energy. Progress in Energy and Combustion Science 39, 489-514. https://doi.org/10.1016/j.pecs.2013.05.004.