ARTICLE IN PRESS

Renewable Energy xxx (2016) 1–13

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Evaporator development for adsorption heat transformation devices – Influencing factors on non-stationary evaporation with tube-fin heat exchangers at sub-atmospheric pressure

Rahel Volmer*, Julia Eckert, Gerrit Füldner, Lena Schnabel

Fraunhofer Institute for Solar Energy Systems ISE, Division Thermal Systems and Buildings, Sorption Technology – Component Development, Heidenhofstrasse 2, 79110 Freiburg, Germany

A R T I C L E I N F O

Article history:
Received 23 May 2016
Received in revised form
5 August 2016
Accepted 10 August 2016
Available online xxx

Keywords:
Thin film evaporation
Water evaporation
Non-stationary evaporation
Sub-atmospheric pressure
Adsorption chiller
Adsorption heat pump

A B S T R A C T

Evaporators for adsorption heat pumps, chillers and storage devices mostly use water as refrigerant and work at sub-atmospheric pressures. However, there are hardly any applicable performance correlations or sizing guidelines for these rather unusual operating conditions.

Within this study geometric and process-related impacts on non-stationary evaporation performance of copper tube-fin heat exchangers are investigated to start filling that gap. Cyclic condensation/evaporation measurements were performed in a thin film evaporation mode and in partially flooded operation with changing refrigerant filling level to cover different applications. For thin film evaporation a thermal resistance model was developed to quantify resistance contributions and identify performance-limiting factors.

The presented measurement results reveal that evaporation performance in thin film operation is crucially governed by fluid side heat transfer (UA raise by 146% within tested Reynolds numbers) and wetting conditions while fin sheet thickness plays a marginal role (8% increase of UA). In partially flooded operation performance strongly depends on filling level. Apart from some refinement potential of the thin film model, the simulations reflect evaporation dynamics and effects of influencing factors fairly well which indicates that the employed model approach could be a suitable tool for an effective optimization of evaporator geometry and process parameters.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Thermally driven heat transformation devices as adsorption heat pumps, chillers and heat storage systems, which represent a promising technology in terms of rational and sustainable energy use, often use water as a natural refrigerant [1–3]. Due to the comparably low saturation vapor pressure of water the evaporation process needs to take place at sub-atmospheric pressure conditions [1] which implicates fundamentally different evaporation and boiling characteristics compared to elevated pressures [4–6]. In order to design effective evaporators for these devices it is therefore essential to better understand the occurring physical principles of sub-atmospheric pressure evaporation and heat transfer mechanisms in the heat exchanger and to identify how geometry- and process-related factors influence evaporation performance. However, compared to the abundantly available literature on evaporation of standard refrigerants at elevated pressures there are only few publications on evaporation characteristics of water at sub-atmospheric pressures. Most of the existing publications deal with evaporation in the form of pool boiling (and specifically nucleate boiling), describing heat transfer characteristics related to different influencing parameters, boiling phenomena and analyzing measures for improving heat transfer. Feldmann and Luke [7], for instance, compared different empirical heat transfer correlations from literature which characterize nucleate boiling of different refrigerants (including water) at different pressures (including sub-atmospheric pressures) and related them to own experimental results. They found significant deviations between the correlations and emphasized the sensitivity of the resulting heat transfer coefficient on fluid surface tension and boiling surface characteristics. Giraud et al. [5] explored the characteristic boiling phenomena associated with the low pressure conditions for

* Corresponding author.
E-mail address: rahel.volmer@ise.fraunhofer.de (R. Volmer).

http://dx.doi.org/10.1016/j.renene.2016.08.030
0960-1481/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: R. Volmer, et al., Evaporator development for adsorption heat transformation devices – Influencing factors on non-stationary evaporation with tube-fin heat exchangers at sub-atmospheric pressure, Renewable Energy (2016), http://dx.doi.org/10.1016/j.renene.2016.08.030

nucleate pool boiling, such as bubble formation dynamics. Other researchers focus on techniques to improve heat transfer in pool boiling: McGillis et al. [4] investigated the effects of rectangular fins, particulate beds and different surface finishes applied on horizontal heating surfaces while Choon et al. [8] performed experiments with partially flooded copper foams.

Compared to pool boiling operation, thin film evaporation mode at sub-atmospheric pressures seems to be even less subject of research activities despite its potential for high heat transfer coefficients [9]. Schultz [10] investigated configured surface tube bundles as a falling film evaporator for absorption chillers, however, this evaporation concept requires auxiliary energy for a refrigerant pump and is therefore less attractive for adsorption systems. Witte and Schnabel et al. [11,12] present results on thin film evaporation from partially flooded horizontal copper tubes which exhibit an external and internal macro- or microstructure in the form of fins, needle-like arrays or dents. Compared to plain tubes as reference the structured tubes yielded an up to 10 times higher evaporation power due to capillary assisted formation of refrigerant thin films on the outer tube structure [12]. Lanzerath et al. [9] conducted similar experiments, using tubes with an external fin and/or microporous coating structure. As Witte and Schnabel, they found a direct relation between filling level and overall heat transfer coefficient and could achieve a significant increase of the overall heat transfer coefficient compared to plain tubes. Witte [13] carried out detailed investigations on evaporation from copper fiber structures, both in a pool boiling and capillary assisted thin film mode. Especially for low driving temperature differences he observed high heat transfer coefficients for the capillary assisted operation due to the formation of thin film domains and microzones.

Most publications on evaporation of water at sub-atmospheric pressures focus on the fundamental boiling principles taking place on heated surfaces. Application-related issues and consideration of heat transfer mechanisms in a whole heat exchanger are scarcely addressed, just as impacts of geometric heat exchanger characteristics on evaporation performance. Correspondingly, there are no approved design and sizing guidelines for appropriate heat exchangers. However, in order to engineer effective sorption modules it is crucial to choose an appropriate evaporator design, considering the requirements of the particular application and corresponding adsorber and module concept, in regard to geometry, power density, refrigerant capacity and operation mode: A sorption heat pump system might require a cyclic evaporation of small amounts of refrigerant at high power output. To cover these prerequisites evaporation from refrigerant thin films represents a promising alternative to nucleate boiling which requires relatively high driving temperature differences under sub-atmospheric pressure conditions [9,13]. On the contrary for a storage system it might be advantageous to evaporate large refrigerant capacities during one cycle at moderate power. Here a partially flooded operation mode could be the method of choice.

Within this study both a high power and a high capacity approach should be investigated in form of thin film evaporation and partially flooded operation. At the same time a focus is set on non-stationary evaporation processes. Reason for that is the prospect of simple sorption modules consisting of only one adsorber/desorber and one single heat exchanger covering both the evaporation and condensation functionality. Such modules benefit from their constructional simplicity and permit small construction volumes [14,15]. On the other hand they require a cyclic evaporation and condensation sequence which can be realized by non-stationary processes in terms of refrigerant quantity and distribution. For the investigations the tube-fin heat exchanger type was chosen as exemplary heat exchanger model since it exhibits a simple geometry and is commercially available in various geometric configurations. Measurements with different specimens were conducted in a non-stationary thin film evaporation mode and partially flooded mode. Furthermore a resistance model was established as a first attempt to describe the dynamic evaporation performance during thin film evaporation. A critical comparison of the simulations with measurement results was supposed to evaluate the model's general suitability.

Goal of this survey was to analyze impacts of geometric and process parameters on evaporation performance, to understand the interdependencies of heat transfer mechanisms and to identify limiting parameters. Results could possibly be transferred to more complex evaporator geometries and thus contribute to a methodology which allows systematic optimization of evaporator designs in consideration of the particular application.

2. Experimental methods

2.1. Test setup

All measurements were performed on a test setup for stationary and non-stationary evaporation and condensation measurements which is depicted in Fig. 1. Main components of the setup are two vacuum chambers which are both evacuated before the measurement by using a scroll vacuum pump and only contain a vapor atmosphere: The heat exchanger to be tested is mounted inside the "measurement chamber" while the "secondary chamber" contains a permanently installed large tube-fin heat exchanger which is partially flooded by refrigerant (deionized water) and thus serves as a refrigerant reservoir. Each heat exchanger is connected to a circulation thermostat which allows the heat exchangers to be brought to a defined temperature level. Both chambers can be connected or separated by switching the valves of the two connecting lines. The secondary chamber always acts as a counterpart to the measurements chamber: If refrigerant vapor should be condensed on the test object the secondary chamber can be operated as an evaporator to generate the required vapor. For that purpose the secondary chamber fluid temperature must be set higher than that of the measurement chamber to create a saturation pressure difference. Vice versa the secondary chamber is set to condensing mode – by applying a lower fluid temperature – in case evaporation takes place on the test object in the measurement chamber.

The test setup is equipped with several sensors. Pt100 sensors (labeled with a "T" in Fig. 1, calibrated to an accuracy of 0.02 K) measure fluid inlet and outlet temperatures of the two heat

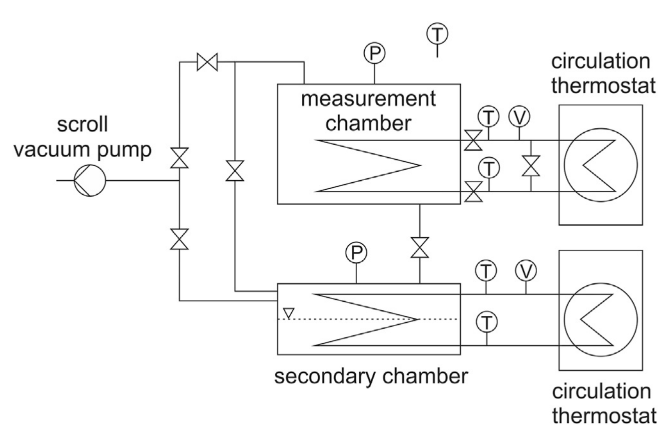

Fig. 1. Schematic chart of the measurement setup.

Download English Version:

https://daneshyari.com/en/article/4926269

Download Persian Version:

https://daneshyari.com/article/4926269

Daneshyari.com