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Experimental study on the flash evaporation process of LiBr—H_2O solution in an absorption heat pump

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ABSTRACT

Recently, more and more absorption heat pumps have been applied in district heating systems, especially with industrial waste heat used as the driving heat source. This type of heat pumps utilizes flashing as an alternative to generators. The performance of a LiBr solution-based flashing process in an absorption heat pump is discussed in this paper. Flashing experiments were conducted in an absorption heat and mass transfer test bench. Observation results highlighted various types of flashing jets, i.e. the non-shattering jets, partially shattering jets, and completely shattering jets. Experimental results also showed that the initial superheat pressure significantly influenced transitions of the flow regimes. The whole spraying flash phenomenon is divided into three processes, and the flashing performance in each process was discussed. The flashing rate was simplified to be proportional to the superheat pressure in the first stage. And the mass transfer coefficients for the second stage were calculated, which is about 2×10^{-4}–7×10^{-4} m/s. It is hoped that these results will help predict the flashing results of LiBr—H2O solutions in future research.

Etude expérimentale du processus d'évaporation flash d'une solution de LiBr-H2O dans une pompe à chaleur à absorption

Mots clés : Evacuation ; Pompe à chaleur à absorption ; Générateur ; Transfert de masse

1. Introduction

Nowadays, novel district heating processes that depend on absorption heat pumps are widely used (Jiang et al., 2010). In these processes, the hot water in the primary and secondary networks is characterized by higher temperature changes compared to traditional systems. To realize the significant temperature increase of the hot water in the secondary system, or decrease in the primary system, a multi-stage structure is used. If a pool boiling or falling film generator (commonly found in conventional systems) is replaced by a flashing generator in

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Nomenclature

C	perimeter [m]
D	diameter of liquid jet [m]
F	area [m^2]
h	enthalpy [kJ/kg]
k_a	mass transfer coefficient [s/m]
m	mass flow rate [kg/s]
p	pressure [kPa]
Re	Reynolds number [–]
t	centigrade temperature [°C]
T	Kelvin temperature [K]
U	uncertainty [–]
v	velocity [m/s]
x	mass fraction [–]
z	distance from the orifice [m]
ΔP	superheat pressure difference [kPa]
ρ	density [kg/m^3]

Subscripts

i	the ith volume
s	saturated
v	vapor
l	liquid
c	critical point
h	at the height of h

Superscripts

$'$	pure water

a vertical multi-stage absorption heat pump, the solution flows down into the next stage with a lower pressure due to gravity, and flash evaporation occurs. Thus, flashing generation processes can make the most of the limited space inside each stage. In addition, the heaters may be moved outside the generator, which reduces costs.

When a saturated liquid undergoes a sudden reduction in pressure, flash evaporation occurs. This phenomenon can be observed in chemical plants, seawater desalination systems, and vapor-compression refrigeration cycles. Research on flashing began decades ago, most of which relied on experiments. Miyatake et al. (1973, 1977) and other researchers (Guo et al., 2008; Saury et al., 2002) studied static flashing, and these investigations introduced important parameters to describe changes in temperature and flashing flux, such as the non-equilibrium function (NEF) and the non-equilibrium temperature difference (NETD). Peterson et al. (1984) examined Freon-11 liquid film under sudden pressure reductions using a series of interferograms taken by a Mach–Zehnder interferometer and high-speed cameras. The results showed that the flashing liquid was a mixture of superheated, subcooled, and saturated liquids, and the evaporation was 10–12 times faster than normal evaporation. Other research orientation involves simulating the flashing process in a real plant. For example, Thomas et al. (1998) built a mathematical model of multi-stage flashing desalination using mass conservation equations. Other studies (Yan et al., 2010; Zhou, 2000) have focused on the improvement of multi-stage seawater desalination through mathematical models.

The main focus of this paper is spray flashing. Many studies in this field have been conducted for seawater desalination applications. As a result, the working fluids in most experiments have been either saline of low concentration or distilled water. Ikegami and his colleagues (Ikegami et al., 2006; Mutair and Ikegami, 2009, 2010) conducted a series of experiments with different injection directions. The results suggest that the upward jet method has the potential to make spray flash desalination systems more compact and efficient. El-Fiqi et al. (2007) experimented with pure water at 40–70 °C with different flow rates and vacuum degrees to determine the factors that influence flashing flux. Peter et al. (1994) classified flashing liquid jets into four categories: non-shattering liquid jets, partially shattering liquid jets, completely shattering liquid jets (in stage-wise sequence), and flare flashing liquid jets. In this particular study, the characteristics of each category were examined in detail. In other examples from the literature (Shao, 2007; Zhang et al., 2011), mathematical models were used to construct spray flashing processes.

Although existing research is abundant, most previous studies have focused on pure substances. For binary solution, both the temperature and concentration change simultaneously during evaporation. Consequently, the aforementioned experimental results and mathematical models cannot be applied directly to these types of solutions. On the other hand, the temperature of heat source in desalination is usually lower than 100 °C, while in the applications of absorption heat pumps, temperature of heat source varies, and can be higher than 100 °C in some occasions. This paper attempts to address these shortcomings. First, a unified mathematical model was established, and experimental systems were subsequently built for the LiBr—H2O binary solution to evaluate the basic performance of the spraying flashing generation process.

2. Experimental system

2.1. *Heat and mass transfer test bench*

All the experiments mentioned below were conducted in a vacuum heat and mass transfer test bench (Jiang et al., 2011). The test bench covers an area of 20 m^2, it is divided into upper and lower layers, with an overall height of 8 m. Different kinds of test units can be set up with the test bench under a vacuum cover. During the experiments, the test bench provided the test units with a stable vacuum environment, sources of both heat and cooling (e.g., hot and cooled water) at the required temperature, and LiBr—H2O solution at the required temperature and concentration.

The vacuum cover system is connected to a chilled water tank, a solution tank, a cryogenic water tank, and a hot water tank (Fig. 1). All these parts can be heated by electric heaters or cooled by heat exchangers with chilled water, respectively, so that the temperature of the water and solution can be controlled according to the experimental requirements. The test bench is also connected to a vacuum pump.