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Drop formation of swirl-jet nozzles with high viscous solution in vacuum-new absorbent in spray absorption refrigeration

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Abstract

In this paper, the drop formation properties of a lithium bromide salt solution Trane [Trane, Private communication, 1997, [1]], which is utilized in a new concept of spray absorber, is investigated. In the spray absorber of the absorption refrigeration cycles, the feasibility of forming droplets with an optimum diameter of 300 μm, calculated by the drop absorption model, were studied. To achieve above, a single nozzle spray chamber able to attain a low-pressure of 1.23 kPa (0.178 psia) pressure was built. The nozzles experimentally tested were swirl-jet nozzles. The differential pressure across the nozzles was varied from 50 to 200 kPa (7.25–29 psia). The flow rate in the experiment was varied between 0.018 and 0.043 kg/s (2.376–5.676 lb/min). The flow number that define the effective flow of the selected nozzles were 7.6×10^{-7}, 1.5×10^{-6} and 2.3×10^{-6} and the viscosity ratio of this disperse/continuous phase flow was 1300. The nozzles tested were able to produce drop sizes having a mean volumetric diameter (MVD) between 375 μm and 425 μm. Comparison of drop absorption model results to conventional absorber results shows a significant improvement in absorption.

Keywords: Absorption; Absorption chillers; Absorption models; Atomization; Sprays

1. Introduction

In multi-effect high performance absorption cycle chillers, the high temperature loops operate with highly concentrated salt solutions that are relatively viscous and corrosive. Consequently, the design of the corresponding apparatus, especially the absorber, presents engineering and material challenges. Currently, this system component is associated with an undesirable cost premium and reduction of effectiveness due to the size of the absorber.

The methodology that has been used in the absorber of conventional large commercial absorption chillers is falling-film heat exchangers. In an absorber, the rate which the refrigerant (i.e., water in a LiBr–H_2O system) in the form of vapor is absorbed by the concentrated salt solution is important. It has long been recognized that if this rate could be increased beyond that occurring in the falling film type of absorbers, this component could be reduced in size and its performance can be enhanced.

It is apparent that if the total absorption area of the salt solution could be increased, the rate of absorption of the water vapor by the salt solution would also increase. One obvious way of doing this is to introduce the absorption fluid in the form of the fine droplets, which could increase the rate of the absorption by an order of magnitude. It is known that the size of these droplets decreases, the total area exposed to the vapor increases, and the rate of absorption increases accordingly. Numerous studies by Benbrahim et al. [2], Morioka et al. [3], Ryan [4] and Flamensbeck et al. [5], have confirmed above effects demonstrating the improvement with experiments, analytical and numerical calculations. As shown in Fig. 1, a conventional absorber consists of a bundle of tubes covered with the absorbing solution which are surrounded by the water vapor to be absorbed. The rate of the absorption is directly proportional to the total tube area. If all the solution on these tubes can be converted into the drops with an average

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Nomenclature

a, b, c, d	parametric constants
$\dot{m}$	mass flow rate
ΔP	differential pressure
ρ	density of solution
σ	surface tension
v	kinematic viscosity

Subscript

L	liquid

of diameter of 300 μm, the total area would be increased by more than 200 times. Therefore, the rate of absorption could theoretically be increased by a similar factor. This spray absorption system is shown in Fig. 2. In the spray absorption system, the size of the absorber would be much smaller than that of the falling film absorber.

In this work, as a first step of investigation of the performance of the spray absorbers, the feasibility of creating the optimum drop sizes defined by the previously mentioned investigators Benbrahim et al. [2], Morioka et al. [3] and Ryan 1995 [4] and Flamensbeck et al. [5] with a new absorbent solution was studied. As a second step of investigation, analytical study to find the absorption rates of this process was performed and then compared it with conventional absorber performance. To find the absorption rates, "the Newmann model", the best available model that represent the flow condition and absorbent properties in this experiment and drop formation results found from experiment, were used. Furthermore, conditions typically encountered in a commercial absorber were used. Based on previous studies De Corso [6], Wang and Lefebvre [7], Lefebvre [8] and Jones [9], the most appropriate atomization for the applications that handles high viscous solutions can be considered as the liquid sheet disintegration. Even with high viscous solutions, this form of atomization forms a conical liquid sheet, which gives higher flow rates and smaller droplets. This type of disintegration can be effectively achieved with pressure-swirl atomizers.

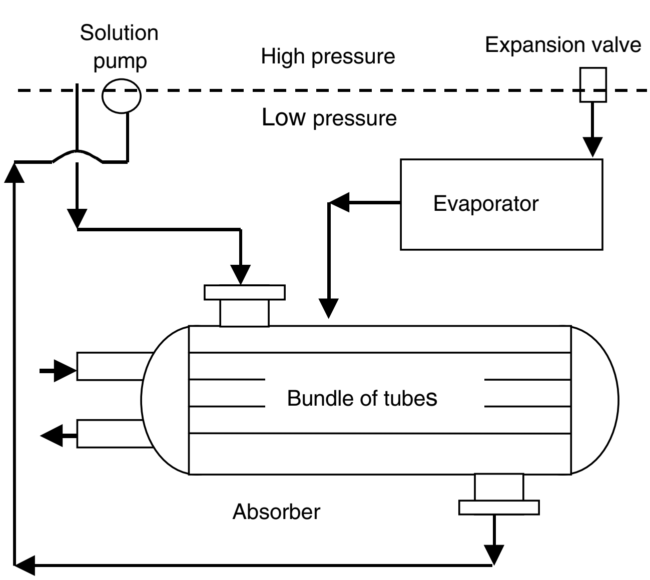

Fig. 1. Conventional absorber.

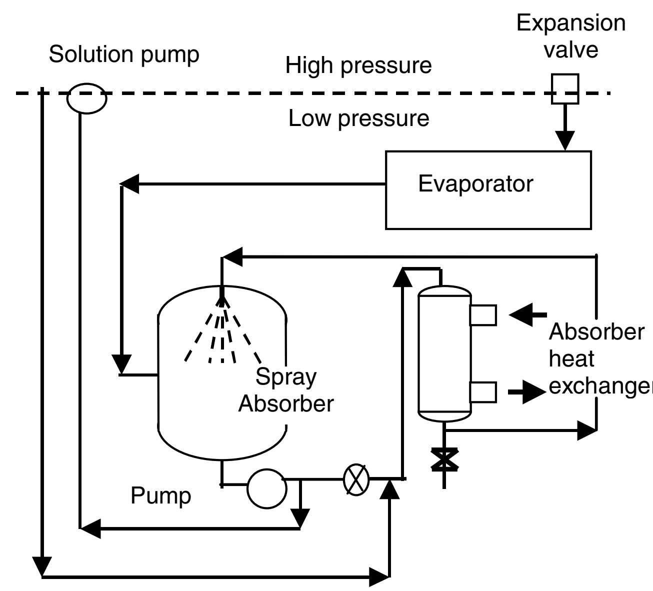

Fig. 2. Spray absorber with solution sub-cooler.

To generate the smallest possible droplet sizes keeping higher flow rates, when selecting pressure-swirl atomizing nozzles to conduct the experiments, recommendations given by all the above investigators, specifications given by the manufacturer and results obtained from the previous research carried out by authors for different kinds of pressure nozzles for similar operating conditions were used.

2. Drop formation theory

The development of the jet or sheet and the growth of the disturbances, which eventually leads to the disintegration into ligaments and drops, is the most effective method of atomization. There are several basic factors and processes associated with all methods of atomization, such as hydrodynamics of the flow within the atomizer, influence of aerodynamic forces in the surroundings, vital fluid properties such as viscosity and surface tension and turbulent liquid forces within the emerging liquid stream.

The parameters of importance for the spray investigated in this research are the resulting drop size, drop velocity,