Applied Thermal Engineering 86 (2015) 43–48

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research paper

Experimental investigations on the pumping performance of bubble pumps with organic solutions

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HIGHLIGHTS

- Pumping performance of bubble pumps with R134a-DMF solutions was tested.
- Bubble pumps with lifting tubes of inner diameters (6, 8, 10) mm were selected.
- The pumping performance of the bubble pump with 6 mm lifting tube was the worst.
- Pumping performances of bubble pumps with 8 mm and 10 mm lifting tubes were similar.
- Mass fraction of R134a in solutions affected little on the bubble pump performance.

ARTICLE INFO

Article history:
Received 4 October 2014
Accepted 9 April 2015
Available online 22 April 2015

Keywords:
Bubble pump
Refrigeration
Diffusion absorption
Experiment

ABSTRACT

The pumping performances of bubble pumps for the diffusion absorption refrigerators were investigated on the purpose made experimental setup. The R134a-DMF (N, N-dimethylformamide) solution was used as the working fluids and R134a mass fractions of 20%, 25%, 30% and 35% were selected for three lifting tubes of different inner diameters (6 mm, 8 mm and 10 mm). The results showed that: (1) The pumping ratio of the bubble pump with the lifting tube of 6 mm inner diameter was the smallest while those of 8 mm and 10 mm lifting tubes were similar. (2) The pumping ratio decreased with the increase of the gas flow rate but increased with the increase of the concentration of R134a. (3) The generating temperature increased approximately linearly with the increase of the heat input, decreased little with the increase of the concentration of R134a and decreased obviously with the increase of the inner diameter of lifting tube. (4) The system pressure increased slightly with the increase of heat input but increased obviously with the increase of the concentration of R134a. The results will be helpful to the design of bubble pumps for the diffusion absorption refrigerators.

1. Introduction

The diffusion absorption refrigerator (DAR) was first invented by von Platen and Munters [1] in 1926, which operated with three kinds of working substances including the refrigerant, absorbent and inert gas. Unlike other conventional absorption refrigeration cycle, DAR utilizes the diffusion of refrigerant liquid into inert gas to produce the cooling effect. The working substances in the system can be easily driven by the thermosyphonic bubble pump because the pressure drops mainly caused by the density difference or flow resistance of the working substances are very small in the system. Thus, the DAR can be driven by the low-grade thermal energy without any mechanical work input, which has developed rapidly attributing to the growing concerns about worldwide energy and environmental sustainability.

The bubble pump is one of the most important components in the DAR and its pumping performance has a great impact on the operation and efficiency of the DAR. Therefore, a lot of researches have been conducted by researchers in recent years.

Chen et al. [2] designed and fabricated a new generator with a heat exchanger for the conventional ammonia/water/hydrogen DAR. It reused the waste heat from the rectifier to heat the rich solution from the absorber and COP was improved as much as 50%. Delano [3] proposed an analytical model to evaluate the performance of the bubble pump for the Einstein refrigeration cycle and conducted experiments with ammonia and water to check the analytical model. Vicators and Bennett [4] made a bubble pump with multiple lifting tubes to increase the volume flow rates of the

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http://dx.doi.org/10.1016/j.applthermaleng.2015.04.028
1359-4311/

fluids. The results showed that it had no limitation to the fluid flow rate and depended solely on the amount of heat input. Zohar et al. [5] and Jakob et al. [6] investigated the effects of generator and bubble pump configuration on the performance of the system for the ammonia-water DAR with hydrogen and helium as the auxiliary inert gas respectively.

Pfaff et al. [7] numerically and experimentally investigated the bubble pump used in the LiBr–H_2O DAR. The experimental setup was built with the glass to observe the flow patterns, in which several bubble pumps with different tube diameters were set in parallel to compare the performance, but the system operated discontinuously. Zhang et al. [8] proposed the bubble pump with lunate channel and investigated experimentally with LiBr–H_2O solution. It was found that the solution of the lunate channel one could be boiled and lifted at lower temperature and the pumping ratio of the bubble pump with lunate channel was larger than that of the circular tube one. Saravanan and Maiya [9] investigated the influence of the motive head for several water-based working fluid bubble pumps. White [10] modeled the air-lift pump and built an experimental system in which the flow was inducted by air source at high pressure instead of boiling the solution. Chung et al. [11] developed a new solar water heater system using a solar bubble pump instead of an electric pump which achieved higher system efficiency.

Different models were also proposed to predict the pumping performance of the bubble pump and to incorporate design parameters of the bubble pump, in which ammonia and water was used as the working fluids mostly [12–17]. The influences of design parameters, such as the diameter of the lifting tube, the submergence ratio and flow pattern, on the pumping performance of the bubble pump in different geometrical and operational conditions were investigated. However, the theoretical analyses played a limited role in the design of the bubble pump.

The above researches all employed the commercialized working pairs like ammonia-water and water-lithium bromide which were limited by their weaknesses of toxicity and vacuum working pressure respectively. Therefore, some new organic working pairs have been proposed and studied for the DAR system.

Koyfman et al. [18] developed a continuous experimental system to test the performance of the bubble pump with the solution of R22 as refrigerant and DMAC as absorbent. It was found that the performance of the bubble was mainly determined by the motive head and heat input. The signing of 1987 Montreal Protocol and relative international agreements in recent years quickened the phase-out of hydrocholofluorocarbons (HCFCs) with environmentally accepted alternatives, such as hydrofluorocarbons (HFCs) with an ODP of zero.

Zohar et al. [19] numerically investigated the performance of the DAR cycle with 5 non-toxic refrigerants (R22, R124, R134a, R125 and R32) using organic working fluids (DMAC – dimethylacetamide) and helium as the auxiliary gas. Compared with ammonia/water/hydrogen system, it was found lower COP, higher evaporator temperature and lower condenser temperature for all systems. Ben Ezzine et al. [20] experimentally studied a bubble pump with a binary light hydrocarbon mixture (C_4H_{10}/C_9H_{20}) as working fluids to be used in a solar driven diffusion absorption cooling machine for air-conditioning.

N, N-dimethylformamide (DMF) was also a good absorbent for R134a, R32 and R23. Han et al. [21,22] and Gao et al. [23] conducted researches on the vapor–liquid phase equilibrium of R134a-DMF, R32-DMF and R23-DMF, which has been used for the design of the absorption refrigerator. The results showed that a diffusion absorption refrigerator operating with R134a as refrigerant and DMF as absorbent will be very promising in low temperature refrigerating applications.

Since the two-phase flow of the working fluids inside the bubble pump was very complex, it was difficult to accurately describe the pumping performance of the bubble pump by theoretical simulation. Experimental test was still the most effective way so far, therefore, the pumping performance of a bubble pump was investigated by experiment in this paper, which can provide useful data for the design of an R134a-DMF diffusion absorption refrigerator.

2. Experiment

2.1. Experimental apparatus

An experimental apparatus has been built to test the performance of the bubble pump for the DAR in continuous operating conditions. Fig. 1 showed the schematic diagram of the experimental apparatus.

In this work, R134a was used as the refrigerant, DMF was used as the absorbent. Rich R134a solution from the receiver of the bubble pump was heated and generated in the generator. After rised in the lifting tube, the refrigerant vapor generated and poor R134a solution were separated in the solution separator. The poor R134a solution was cooled in the solution cooler and then went into the absorber. Most of the refrigerant vapor became liquid in the condenser and then flowed to the refrigerant separator. The refrigerant liquid from the refrigerant separator flowed to the receiver while the refrigerant vapor remained was absorbed by the poor R134a solution in the absorber and also flowed to the receiver.

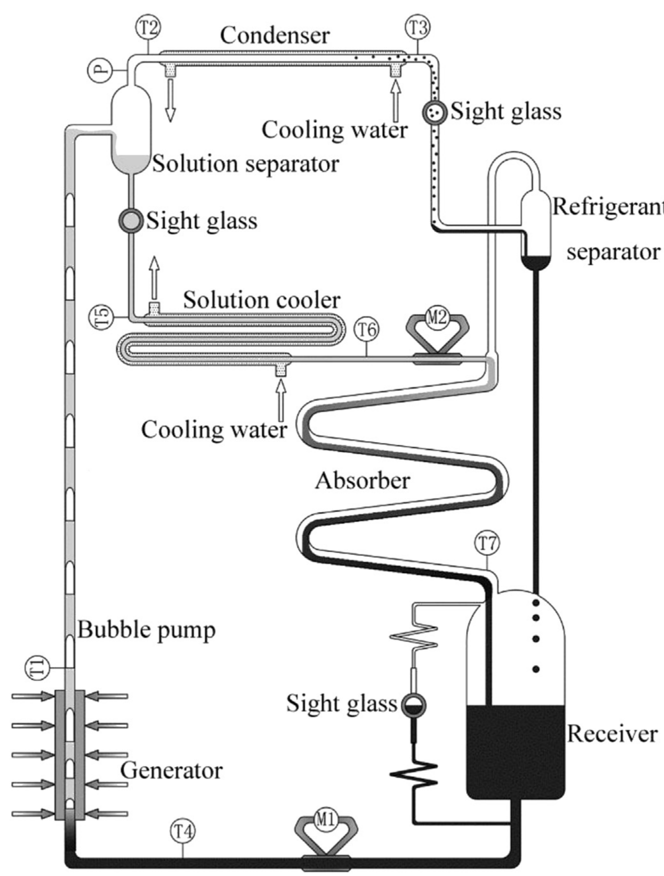

Fig. 1. Schematic diagram of the experimental apparatus.