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Experimental investigation on the influence of bubble pump on the DAR performance

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Abstract

Diffusion absorption refrigeration (DAR) system is driven by thermal energy supplied to the bubble pump. The refrigerant is heated and regenerated while flowing through the bubble pump. For this reason, the operating characteristics of the DAR cycle significantly depend on the bubble pump performance. This study focuses on the influence of the bubble pump on the operation of DAR cycle on the aspects of the cross-sectional area and the heat input. The DAR cycle uses a mixture of low GWP refrigerant and organic absorbent as the working fluids: R1234ze(E) and N,N-dimethylacetamide(DMAC). Experiments are conducted with various conditions to estimate the operating performance. The results show that the evaporation temperature tends to decrease as the cross-sectional area of the bubble pump increases, though it increases when the cross-sectional area exceeds a certain optimum level. It also turns out that the increased heat input lowers the evaporation temperature in the overall cross-sectional area range of $7.917\text{mm}^2 - 17.814\text{mm}^2$.

Keywords: DAR, Refrigeration cycle, Absorption, Bubble pump, Measurement

1. Introduction

A diffusion absorption refrigeration(DAR) cycle is used for creating a cooling effect only with a heat supply. Conventional working fluids used in this system are ammonia and water which are used as refrigerant and absorbent, respectively. However, without compressor nor electric pump, this cycle has relatively a low coefficient of performance(COP). Besides, the toxicity of ammonia and high system pressure are other unfavorable characteristics.

Derived from these practical problems, there have been numerous studies focusing on enhancing COP and substituting ammonia with new refrigerants. Zohar et al. [1] announced improvements in COP when using a partially detached bubble pump compared to the one with integrated structure. Zohar et al. [2] also numerically simulated the DAR cycle operation using five different refrigerants (R22, R32, R124, R125 and R134a) and DMAC as a common absorbent, then compared the results to the ammonia/water system. Wang et al. [3] performed a numerical investigation on the DAR cycle performance operating with a binary refrigerant, R23/R134a, and an organic absorbent, DMF. Koyfman et al. [4] conducted experiments using R22 and DMAC as working fluids and analyzed the results with respect to heat input.

However, due to the serious global warming problems, adopting the low GWP refrigerants instead of the conventional refrigerants with high GWPs is taken as an important concern. And there is still a need for further research to apply such refrigerants to the DAR system. Motivated from these issues, this study focuses on experimental investigation on the operation characteristics of a low GWP refrigerant based DAR cycle. R1234ze(E) is used as refrigerant and N,N-dimethylacetamide(DMAC) is used as absorbent. Helium is chosen as auxiliary gas. After constructing the refrigeration cycle with bubble pumps with various cross-sectional

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areas, the evaporation temperature is measured for each case. Heat input is also varied in order to find its influence on the evaporation temperature.

2. Experiments

2.1. Experimental setup and procedure

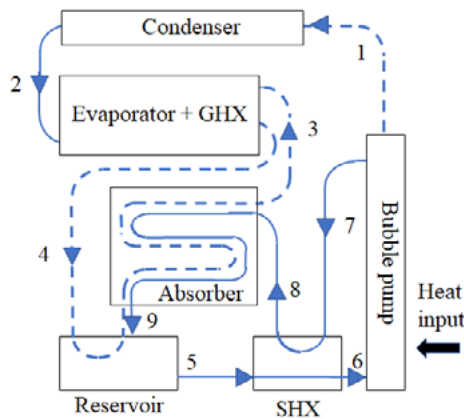


Fig. 1. Schematics diagram of the DAR cycle

Fig. 1 shows the schematic diagram of the DAR cycle. The insulated bubble pump is placed on the right side, in which the refrigerant vapor is generated(1). The condenser is installed at the top where the saturated liquid refrigerant comes out and enters the evaporator(2). The auxiliary gas and the unabsorbed refrigerant vapor also join at the evaporator(3), and evaporation takes place due to the low partial pressure. After the evaporation process, the gas mixture flows to the absorber(4) through the gas heat exchanger. Flowing upward inside the absorber, the refrigerant vapor is absorbed to the solution and the strong solution drips into the reservoir(9). The strong solution is supplied to the bubble pump after flowing through the solution heat exchanger(5, 6). After the refrigeration vapor generation, the remaining weak solution returns to the absorber(8, 8) from the top of the bubble pump(7).

The experiment is conducted by the following procedure:

- (1) Separate the bubble pump from the system and set it with a new bubble pump of desired cross-sectional area.
- (2) Prepare a mixture of absorbent and refrigerant to make up the concentration of experiment condition.
- (3) Make the experimental setup to a vacuum state and inject the working fluid.
- (4) Charge helium gas so that the internal system pressure reaches 4.5bar.
- (5) Supply heat to the bubble pump with an electric heater.
- (6) Measure the temperature of the evaporator using thermocouples attached to the wall.

2.2. Cross-sectional area of bubble pump

A set of experiments are conducted in order to investigate the influence of cross-sectional area on the operating temperature characteristics of DAR cycle, especially the evaporation temperature. For each test, bubble pump is replaced with a new one with different cross-sectional area. The rest of the system components and experiment conditions are maintained. The detailed experimental conditions are summarized in Table 1.

Table 1 Experiment conditions for comparisons of different cross-sectional areas

Cross-sectional area [mm ²]	Pressure [bar]	Heat input [W]	Concentration [wt%]
7.9	4.5	70	35
17.8	4.5	70	35
31.7	4.5	70	35

2.3. Heat input

Another set of experiments are performed to see the effect of heat input to the bubble pump on the cycle operation. Maintaining the basic experimental conditions of Experiment 2.2, different values of heat input are given for every type of bubble pump. The detailed conditions are given in Table 2.

Table 2 Experiment conditions for comparison of different heat inputs

Heat input [W]	Pressure [bar]	Cross-sectional area [mm ²]	Concentration [wt%]
50	4.5	7.9, 17.8, 31.7	35
70	4.5	7.9, 17.8, 31.7	35

3. Results and discussion

3.1. Cross-sectional area of bubble pump

Fig. 2 presents the evaporation temperature versus the cross-sectional area of bubble pump. Three different cross-sectional areas were tested, and the evaporation temperature was measured after the system reached a steady state. From the experimental results, it turns out that the evaporation temperature initially decreases when the cross-sectional area increases. But continuous area increase eventually leads to the increment in the evaporation temperature. Provided with the heat input of 70W, the evaporation temperatures are measured as -2.1°C, -5.2°C and 1.1°C when the cross-sectional area changes from 7.9mm² to 31.7mm². As the bubble pump gets larger, the pressure drop along the bubble pump decreases. It results in the bubble pump efficiency enhancement and more refrigerant vapor is generated, thus reducing the evaporation temperature. However, with further increasing area, the solution can only be heated up to lower the temperature under same heat input condition, causing the reduction in the refrigerant vapor generation. Also, the large cross-sectional area disrupts the formation of slug flow inside the bubble pump, which is essential in order to pump up and circulate the solution through the vertical pipe. These factors together contribute to lower refrigerant generation and higher evaporation temperature at 31.7mm².

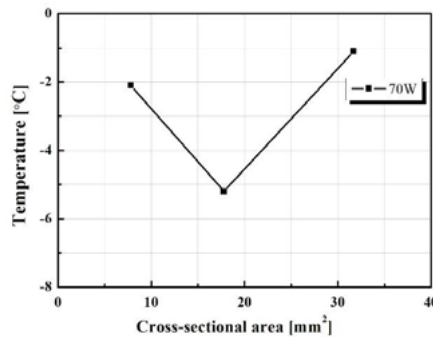


Fig. 2. Measured evaporation temperature with bubble pumps of different cross-sectional areas

3.2. Heat input

Maintaining the fundamental experimental conditions, a decreased amount of heat input is given to evaluate the influence of heat input on the evaporation temperature. The heat input value is initially set as 50W. Generally, with the increased heat input, the evaporation temperature shows a meaningfully decreasing tendency. Fig. 3 shows the evaporation temperature change when the bubble pump has a cross-sectional area of 7.9mm^2 . The temperature is measured to be 0.99°C with 50W of heat input. But it reaches a lower temperature of -2.1°C when 70W of heat is supplied. This behavior is also observed when the cross-sectional area is increased to 17.8mm^2 , as depicted in Fig. 4. As more heat is given to the bubble pump, the evaporation temperature decreases from -1.08°C to -5.2°C . However, as seen in Fig. 5, an exceptional temperature change is observed when using a bubble pump with a larger cross-sectional area of 31.7mm^2 . It turns out that the system fails to operate as a refrigerator when only 50W of heat is provided. Moreover, the system is incapable of reaching a steady state during the test time. The system shows a normal operational behavior when a larger heat input, 70W, is given. The evaporation temperature is measured as 1.1°C . Regarding the COP, the growing temperature difference between the evaporator and the surrounding leads to the increase of heat transfer. Therefore, for both heat inputs, 50W and 70W, highest COPs were obtained at lowest evaporation temperature and the values were 0.1356 and 0.1157 respectively.

The consequential temperature drop by the increased heat input is due to the increased generation of refrigerant vapor. As more thermal energy is consumed, the refrigerant mass flow rate increases, thus lowering evaporation temperature. However, when the cross-sectional area is enlarged too far, minimum value of heat needed to generate enough amount of refrigerant vapor also grows. For this reason, it is not able to obtain the cooling effect with a heat input of 50W when the cross-sectional area is 31.7mm^2 .

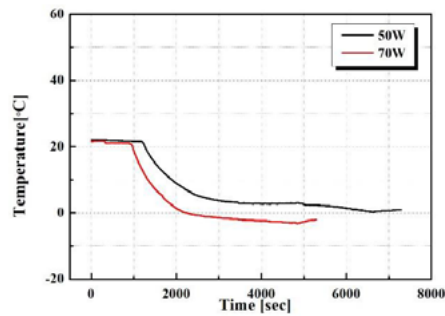


Fig. 3. Measured evaporation temperature with different heat inputs to 7.9mm^2 bubble pump

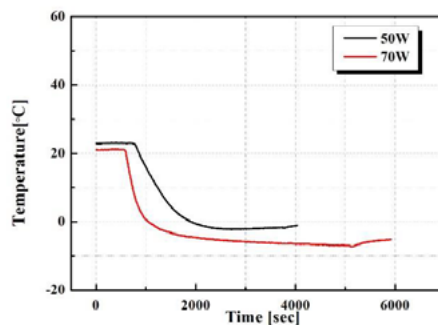


Fig. 4. Measured evaporation temperature with different heat inputs to 17.8mm^2 bubble pump

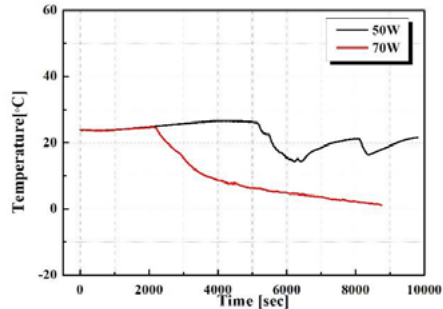


Fig. 5. Measured evaporation temperature with different heat inputs to 31.7mm² bubble pump

4. Conclusions

In this study, the evaporation temperatures of the DAR system using R1234ze(E) and DMAC are measured depending on the variations of cross-sectional area of bubble pump and heat inputs. The tested cross-sectional areas are 7.9mm², 17.8mm² and 31.7mm². Both 50W and 70W of heat inputs are given to all types of bubble pumps for comparisons. The following conclusions are drawn from the present study.

- The optimum cross-sectional area for 70W of heat input is 17.8mm² and the achieved evaporation temperature is -5.2°C.
- Using the bubble pump with the cross-sectional area of 7.9mm², the evaporation temperature decreases from 0.99°C to -2.1°C as heat supply increases from 50W to 70W.
- Using the bubble pump with the cross-sectional area of 17.8mm², the evaporation temperature decreases from -1.08°C to -5.2°C as heat supply increases from 50W to 70W.
- Enlarged cross-sectional area requires a higher heat supply for normal operation of the system. The system is unable to reach a steady low temperature when only 50W is given to the bubble pump with the cross-sectional area of 31.7mm².

Acknowledgements

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