CHAPTER IV

An Experimental Study of Bubble Pumps

In the DAR, circulation of the working solution employs natural circulation. A mechanical pump is not required which is an outstanding feature of the DAR. It is found that performance of a DAR system depends strongly on characteristics of a bubble-pump. Therefore, it is necessary to study the bubble pump characteristics. It is a key parameter for the mathematical model, which is going to be presented in the following chapter.

From the literature [Maiya, 1985], it is known that the important parameters of the bubble pump are pump tube diameter, driving head, lift head and pump heat input. In this study a bubble pump was tested using water instead of aqueous ammonia solution and compressed air instead of vaporized solution. This eliminated the need of heat input for vaporization of working solution. Moreover, it was more convenient to quantify the actual amount of air supply. The pumping performance was found to depend on four parameters i.e. tube length, tube diameter, head-ratio, and airflow rate. Two sizes of pump-tube were tested. A curve-fitted equation of tube having same size as that used in the DAR set-up was obtained.

4.1 The experimental set-up

The experimental set-up was constructed with a simple design. A photograph of the set-up and a schematic diagram are shown in Figures 4.1 and 4.2 respectively. The set-up was tested with four parameters that varied independently. The tests were conducted under atmospheric pressure. Pure water was used instead of ammonia-water solution and air was used instead of vaporized solution. Therefore, the working condition could be varied conveniently as required. Airflow rate was easily controlled by adjusting a valve installed at the airflow-meter inlet.

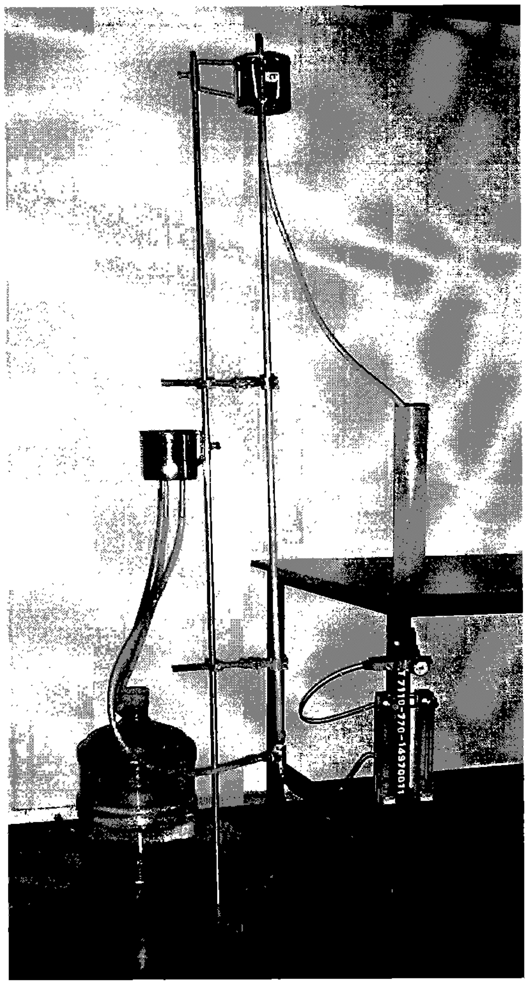

Figure 4.1 A photograph of the bubble pump set-up.

Two sizes of pump tube were tested. One was 3/8 inch outside diameter (OD 9.52 mm, ID 7.7 mm) and another was a 1/2 inch OD (OD 12.7 mm, ID 10.75 mm). Each size was tested with three different lengths, 1.00 m, 1.65 m, and 2.00 m. Effects of airflow rate and head ratio were studied. The head ratio is defined as:

$$HR = \frac{\text{driving head}}{\text{lift head}} \tag{4.1}$$

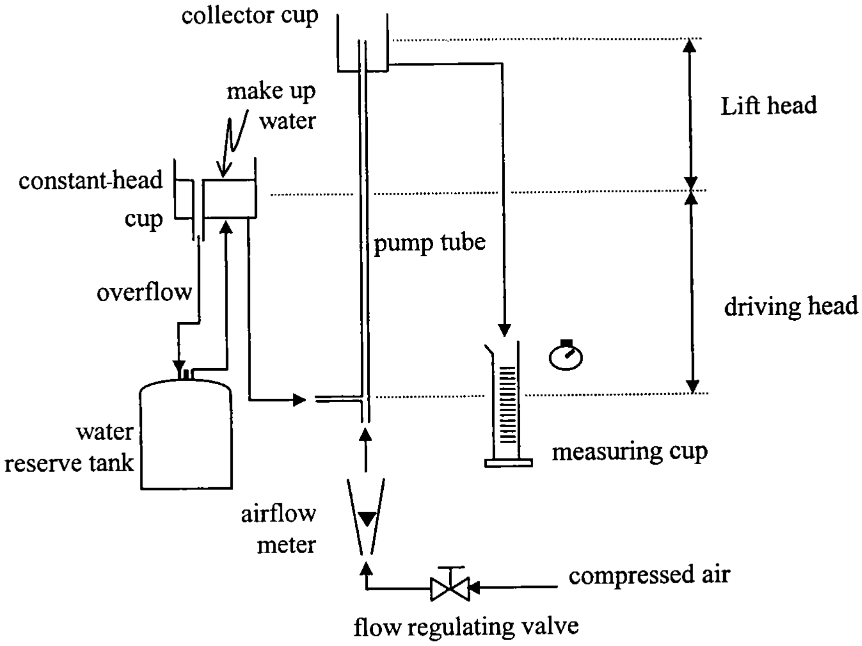

Figure 4.2 A schematic diagram of the bubble-pump test rig.

Referring to the schematic diagram, the head ratio could be adjusted by leveling the constant-head cup until the lift head and the driving head correspond to the required head ratio. Airflow rate could be adjusted by a metering valve installed at the airflow meter inlet. Pumped water flow rate could be determined from the obtained amount of water within a period of recorded time. The constant-head cup, pump tube, and collector cup were put along the set-up column by fixtures. All fixtures could be adjusted along the column so that levels of all equipment attached could be adjusted as required.

4.2 Experimental procedures

Adjust the head ratio to a required level by sliding the constant-head cup along the column. The airflow rate was adjusted by regulating pressure of compressed air to a level somewhat higher the atmospheric pressure, 1.5 bar. Then, it could be finely adjusted to the required value by adjusting the needle valve at the airflow meter inlet. Water was pumped to the collector cup and flowed downward through a plastic hose. During each test, the water and airflow rates were recorded. The pumped water was collected and timed. Then, the pumped water flow rate could be determined. Air was supplied with variation step of 0.2 $l \cdot min^{-1}$ from 1 $l \cdot min^{-1}$ to 5 $l \cdot min^{-1}$. Then, the head-ratio was altered and the experiments were repeated. Variation of head-ratio was done with 7 values i.e. 80:20, 70:30, ..., 20:80. Then, the pump tube was changed with another tube size and the experiments were repeated. Comparison of the pumped water flow rate with variation of tube size, tube length, and head ratios of selected cases are presented as in Figures 4.3 to 4.5 respectively.

4.3 Effect of tube diameter

Figure 4.3 shows effect of tube diameter to the pump performance at a fixed head ratio. For each tube size, the obtained results showed similar trend of pumped water with variation of airflow rate. However, the amount of pumped water was different. It should be noted that with the small tube, 3/8 inch, the amount of pumped water was increased with increased air supply until a certain point. At this point, the pumped water flow rate was maximum. Increment of airflow rate caused reduction of pumped water flow rate. It was clearly shown that the maximum water flow rate was reached with 3/8inch pump tubes. For pump tube of 1/2inch, the pumped water flow rate was found to increase with increased airflow rate throughout the tested range. No maximum water flow rate appeared. If a higher airflow rate was available, it would be expected that the results would be similar to the case of 3/8inch tube. From the Figure, it can be seen that at low airflow rate, a smaller tube performed better pumping effect than a larger one. However, the operating range of 1/2inch tube was wider.

It should be noted that with the small tube, the start of pumping effect occurred at a lower airflow rate than the larger one. It is easier for slug flow to occur in the smaller tube due to smaller cross sectional area of the tube. However, the operating range of the smaller tube was less. Air in the small tube flows faster than that in the large tube for the same airflow rate. It is clearly shown that to start the pumping effect for the large tube, more airflow is required comparing with that of the small tube. This should result from larger cross sectional area of the tube, which is harder for slug flow to occur. Similar trends were obtained for different tube length but with different values of flow rate.

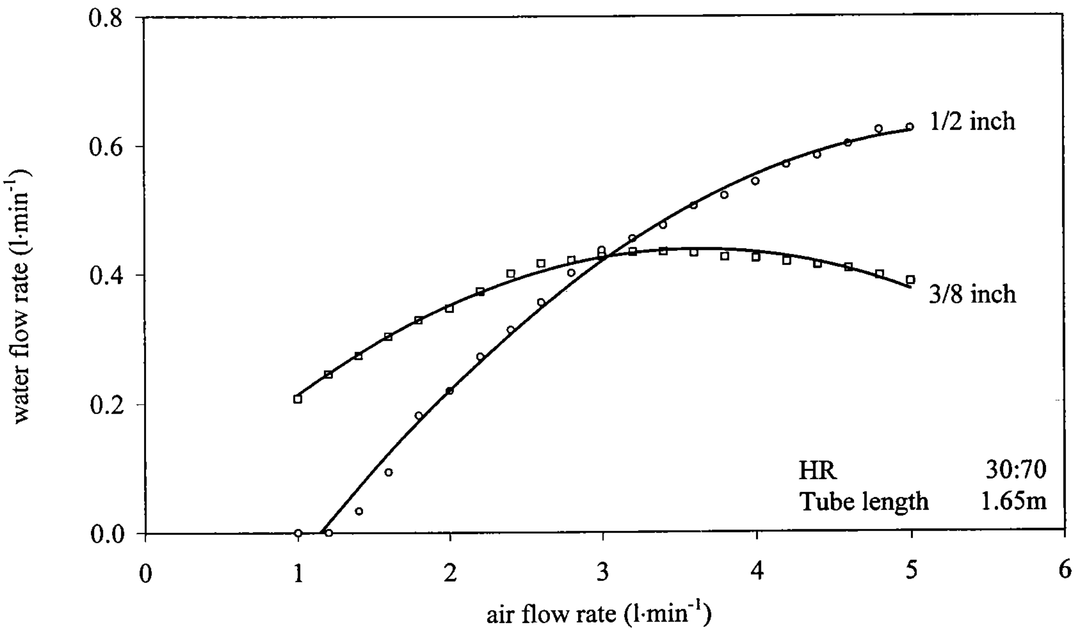

Figure 4.3 Effect of tube diameter on pumping performance of bubble pump

4.4 Effect of tube length

Figure 4.4 shows effect of tube length to the pump performance. Performance of the pump was found to improve with the tube length. However, increments of the pumping effect decreased with the length. The pumped water flow rates at the same supply airflow rate of each tube length are differed. For example with half inch tube at airflow rate of 5 $l \cdot min^{-1}$, pumped water was 0.4 $l \cdot min^{-1}$ with 1m long tube, 0.63 $l \cdot min^{-1}$ with 1.65 m long tube, and 0.68 $l \cdot min^{-1}$ with 2.00 m long tube. It is clearly shown that pumped water flow rate is not directly proportional to the length of tube. Comparing between 1.00 m tube and a 1.65 m tube, the pumped water flow rate increased around 50%. For the 1.65 m tube and 2.00 m tubes, the pumped water flow rate increased around 8%.

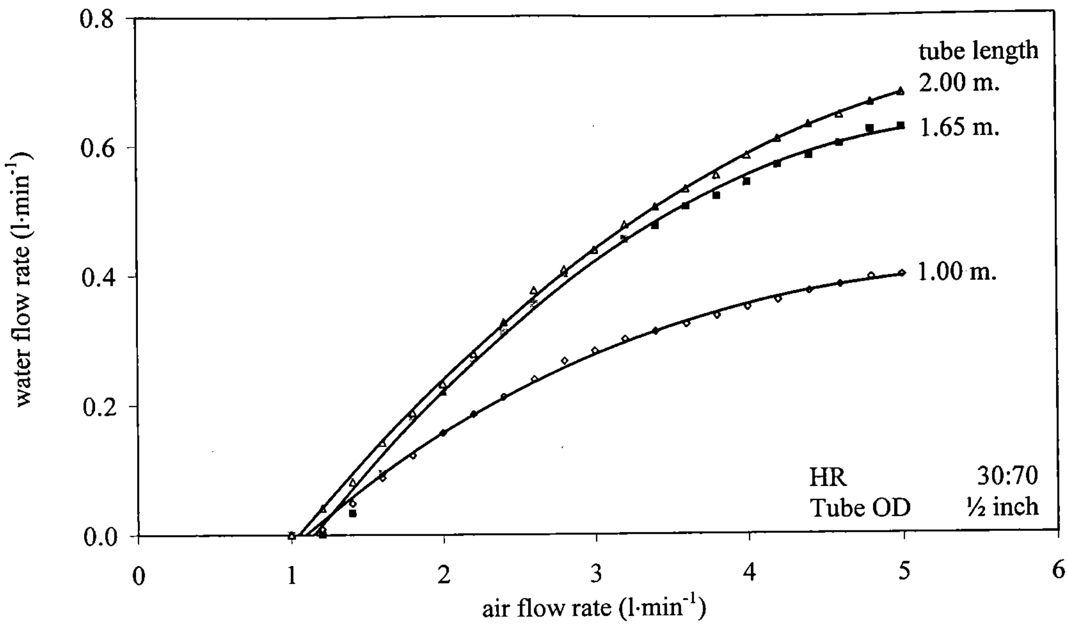

Figure 4.4 Effect of tube length on performance of bubble-pump.

The increment of pumped water flow rate might be considered as a result of greater volume occupied by the water in the pump tube during each pumping cycle. Greater volume of water could be accumulated in a longer pump tube with a similar head ratio. This amount of water would be pumped in each pumping cycle. However, the longer distance that water must flow through the tube causes greater friction loss during the flow. Therefore, the pumped water flow rate was found to increase with longer pump tube. While the incremental rate with longer pump tube was reduced as a result of higher pressure drop occurring from friction loss of water in the tube.

4.5 Effect of head ratio

Figure 4.5 shows effect of head ratio on the pump performance. It was found that the pump performance improved with increased head ratio. At the same airflow rate, the water flow rate increased almost linearly with the head ratio.

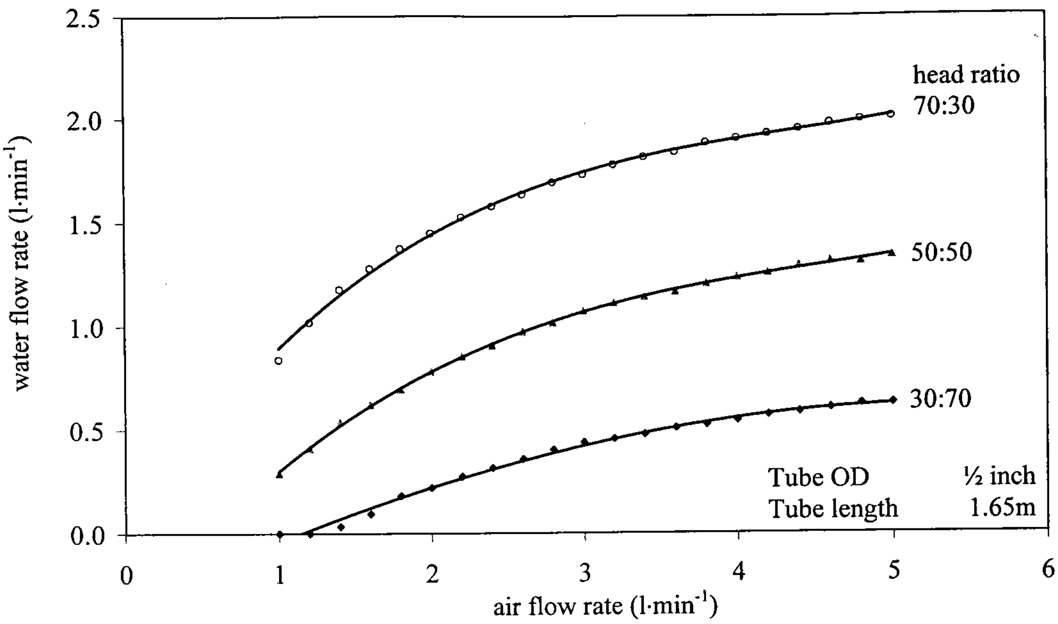

Figure 4.5 Effect of head ratio on performance of bubble pump.

Higher pumped water flow rate was obtained with increased head ratio. According to the definition of head ratio, it could be considered as a driving pressure. The amount of water accumulated in the tube should be more at a higher head ratio as shown in figure 4.5. The greater depth causes higher pressure difference, which resulted in higher pressure to push water into the pump tube. It could be imagined that with higher head ratio, water could be pushed into the tube easier. A new batch of water could be pushed to occupy the volume of water just being pumped in the prior pumping cycle. Therefore, the pumping performance should be improved with head ratio.

4.6 The pump tube used in the experimental refrigerator

In this study,1/2 inch tube (12.7 mm OD and 10.9 mm ID) was arbitrarily chosen as a pump tube for the experimental refrigerator. The lift head was 1.0 m and the driving head is 0.65 m. The operating range was extended to be 1-15 $l \cdot min^{-1}$ so as to be fitted as an equation for using in the calculation model (in Chapter 5).

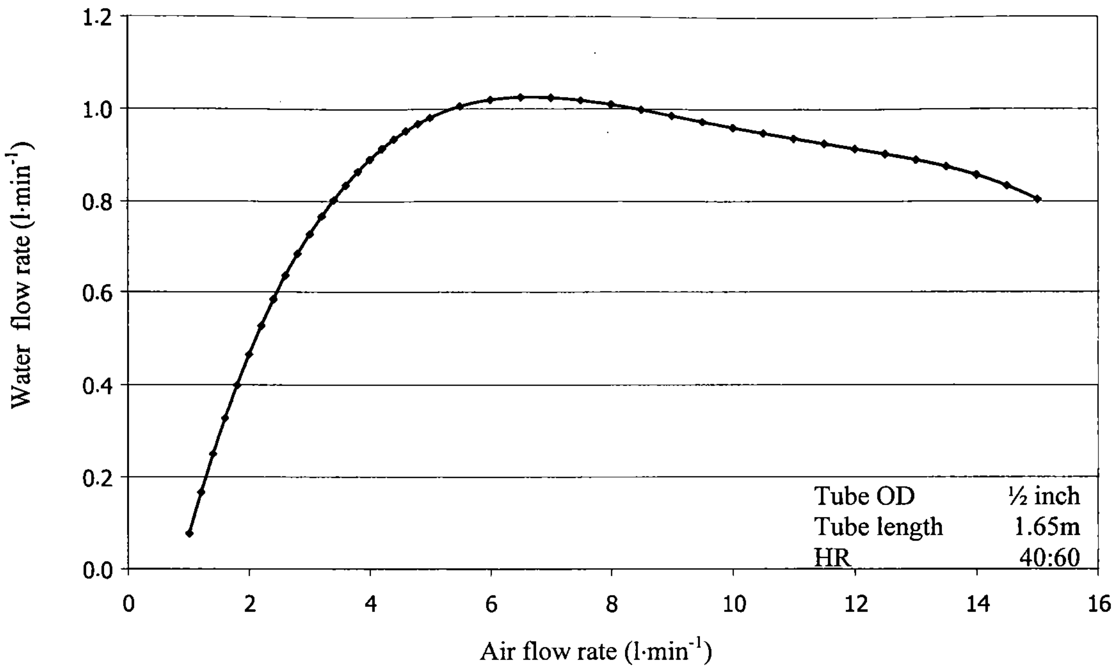

Figure 4.6 Performance of the bubble-pump used in the experimental refrigerator.

The performance curve is provided in figure 4.6. By using least square method, the relation between air and water flow rate through the pump tube is:

$$\dot{V}_{wat} = -0.00014\dot{V}_{air}^4 + 0.00625\dot{V}_{air}^3 - 0.09706\dot{V}_{air}^2 + 0.63772\dot{V}_{air} - 0.46802 \qquad (4.2)$$

This fitted equation is validated to the experimental data with the R-squared value of 0.997.

4.7 Conclusion

It can be concluded that performance of a bubble pump is strongly dependent on the airflow rate and tube dimensions (diameter, length, and head ratio). For a diffusion absorption refrigeration system, performance of a bubble pump is important. It can be used to determine the refrigerant circulating in the condenser and evaporator, and the solution circulation rate between the generator and the absorber.

In this chapter experimental studies of a bubble-pump were conducted. A simple rig was designed and constructed. Air was used as driving vapor and water was used as pumped liquid. The tests showed that the pump performance was depended on the tube dimensions, airflow rate, and head-ratio. The pump-tube with the same dimensions with that used in the experimental refrigerator was also tested. A curve-fitted equation was obtained.