EXPERIMENTAL ANALYSIS OF BUBBLE PUMP WATER-BASED WORKING FLUIDS

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Abstract

A conventional vapour absorption cycle requires mechanical energy to circulate the refrigerant–absorbent solution from the low-pressure absorber to the high-pressure generator. For pumping working fluid from low pressure to high pressure in absorption cycles mechanical pumps which work with electrical force are used. Using these pumps caused increasing cost & noise. This research used the bubble pump instead of mechanical pumps for solving these problems. Bubble pump is a kind of pump which works with thermal energy instead of electricity and works based on two-phase flow. An experimental research on the performance of bubble pump with two working fluid (water and Lithium Bromide) has been done. In this study the effect of various parameters such as heat input, submergence ratio (H/L), diameter of lift tube on the operation of bubble pump are analyzed. Increasing the power of internal and external heater increases the liquid flow rate, where increasing the diameter of tube reduces the liquid flow rate. It has seen that that the submergence ratio has a positive impact on liquid flow rate so that increasing the submergence ratio (H/L) increases the liquid flow rate

Key words: bubble pump, diameter of tube, submergence ratio,

Presenting Author's biography

Mohammad Naghashzadegan. I am an assistant professor in mechanical engineering in Guilan University in Iran. My major interested area is air-conditioning, refrigeration and heat-transfer where I involve with several research projects including the design a pump-less absorption system, build a computer simulation program, modeling and simulating cooling and heating load calculation for Iranian climate.

1. Introduction

A bubble pump is a fluid pump that operates on thermal energy to pump liquid from lower level to the higher level Figure 1. At the bottom of the pump tube small bubbles form and join together forming bigger vapor bubbles. The rising vapor bubble acts like a piston and lifts a corresponding liquid slug to the top of the bubble pump tube.

Studies on bubble pump both analytically and experimentally were developed by Pfaff et al. [1] where a bubble pump was modeled for intermittent slug flow of solution and vapor mixture. In order to study the effect of pipe diameter on the performance of the bubble pump. Pfaff et al. [1] built the test rig with several bubble pumps that were connected in parallel. The bubble pump operated at slug flow regime in cyclic intervals. It is found that the pumping ratio is independent of the bubble pump heat input within the operating ranges studied but increase with higher driving head, lower pump lift and smaller tube diameter. It is shown that a bubble pump with a tube diameter of 10 mm and heat input of 40 W is suitable for a refrigerator of about 100 W cooling capacity. Koyfman et al. [2] presented an experimental investigation to study the performance of the bubble pump for diffusion absorption refrigeration units. A continuous experimental system was designed, built and successfully operated. In the experiments, some of the parameters affecting the bubble pump performance were changed. It was figured that the bubble pump operates at slug flow regime with a churn flow regime at the entrance of the bubble pump tube. This research analyzed the bubble pump component so that design for optimum performance can be achieved. . The important parameters of the bubble pump are pump tube diameter (d_0), driving head (h), pump lift (L) and pump heat input (Q_0). The main characteristic values to judge the performance of the bubble pump are solution flow rate and the pumping ratio.

2. Methods of Analysis

The methods used for analyzing a two-phase flow are extensions of those already well tried for single phase flows. The procedure invariably is to write down the basic equations governing the conservation of mass, momentum, and energy, often in a one-dimensional form and to seek to solve these equations by the use of various simplifying assumptions. The two-phase flow is assumed to be a single-phase flow having pseudo-properties arrived at by suitably weighting the properties of the individual phases. The flow also was considered to be artificially segregated. Two sets of basic equations can now be written, one for each phase. Alternatively, the equations can be combined. The two phases are considered to be arranged in one of three or four definite prescribed geometries. These geometries are based on the various configurations or flow patterns found when a gas and a liquid flow together in a channel. The basic equations were solved within the framework of each of these idealized representations. Following flow patterns are encountered when a mixture of vapor and liquid flows through a vertical pipe.

3. Mathematical model

Continuity equation, momentum conservation equation and energy equation have been used to simulate the performance of bubble pump (Andy Delano)

Following assumptions were made in the modeling.

1. The liquid level in the liquid reservoir does not oscillate during the operation.
2. All the properties are measured at steady state.
3. The variation in the ambient conditions is negligible.
4. The liquid is at a saturation temperature at the entry of the bubble pump.
5. The liquid is uniformly heated at the bottom of the bubble pump.

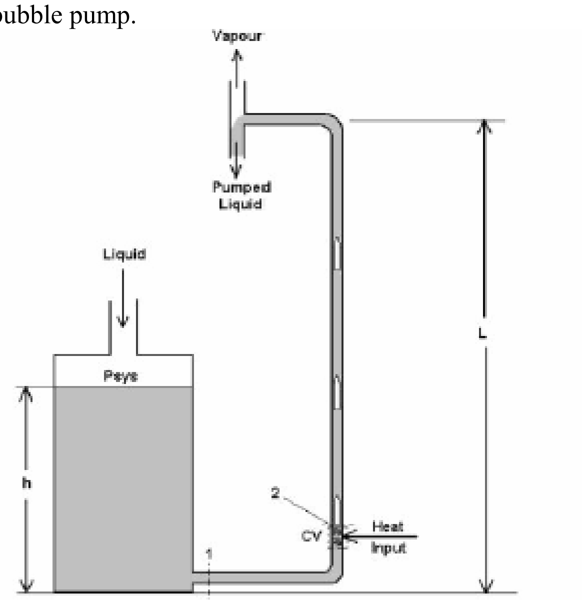

Figure 1. Schematic of a bubble pump

A bubble pump operates most efficiently in the slug flow regime. The maximum diameter tube in which slug flow occurs is given by the following equation (Chisholm, 1983) [3]:

$$d \le 19.\left(\frac{\sigma . v_f}{g.\left(1 - \frac{v_f}{v_g}\right)} \right) \quad (1)$$

Where v_f and v_g are the specific volumes of the liquid and vapor respectively, and σ is the surface tension.

Note, for a given fluid in a tube of diameter greater than that predicted by the above equation, slug flow will never occur.

Applying energy's equation between the surface of the reservoir and point 1 (Figure 1) yields:

$$P_1 = P_{system} + \rho_f .g.h - \rho_f . \frac{V_1^2}{2} \quad (2)$$

Assuming that the mixture of vapor bubbles and liquid exit this control volume at a mixture velocity, V2,:

$$\dot{m}_2 = \dot{m}_1 \quad (3)$$

Manipulating the parameters

$$V_2 = \frac{v_2.V_1}{v_f} \quad (4)$$

The specific volume at point 2 is assumed to be the specific volume of a vapor-liquid mixture with a quality x. The specific volume at point 2 can be expressed as

$$v_2 = v_f + x.(v_g - v_f) = v_f.\left(1 + x.\left(\frac{v_g - v_f}{v_f}\right)\right) \quad (5)$$

Where

$$x = \frac{\dot{m}_g}{\dot{m}_f + \dot{m}_g} \quad (6)$$

Combining equations 4, 5 and 6,

$$V_2 = V_1.\left[1 + \left(\frac{\dot{m}_g}{\dot{m}_g + \dot{m}_f}\right).\left(\frac{v_g - v_f}{v_f}\right)\right] \quad (7)$$

The vapor mass flow rate is assumed to be negligible relative to the liquid mass flow rate and the liquid specific volume is neglected relative to the vapor specific volume.
Therefore:

$$V_2 = V_1.\left(1 + \frac{\dot{V}_g}{\dot{V}_f}\right) \quad (8)$$

The conservation of momentum is applied to the control volume in Fig. 1. Neglecting the friction pressure drop over this short distance then:

$$P_2 = P_1 - \rho_f.V_1.(V_2 - V_1) \quad (9)$$

Substituting equation 8 into equation 9,

$$P_2 = P_1 - \rho_f.V_1.\left[V_1.\left(1 + \frac{\dot{V}_g}{\dot{V}_f}\right) - V_1\right]$$

$$\therefore P_2 = P_1 - \frac{\rho_f.V_1.\dot{V}_g}{A} \quad (10)$$

Substituting equation 10 into equation 2,

$$P_2 = P_{system} + \rho_f.g.h - \frac{\rho_f.V_1^2}{2} - \frac{\rho_f.V_1.\dot{V}_g}{A} \quad (11)$$

Applying the conservation of momentum to the bubble pump's tube connecting, the lower and upper reservoir then:

$$P_2 - P_{system} = \frac{1}{2}f.\rho_f.V_2^2.\left(\frac{L.B}{A}\right) + \frac{W}{A} \quad (12)$$

Where B is the perimeter of the bubble pump tube and W is the fluid weight in the bubble pump tube. W can be expressed as the combined weight of liquid and vapor in the tube.

$$W = L.g.(\rho_f.A_f + \rho_g.A_g) \quad (13)$$

Where A_f is the superficial area through which the liquid flows and A_g is the superficial area through which the vapor flows. Assuming that the density of the vapor phase is negligible compared to that of the liquid.

$$W = L.g.\rho_f.A_f \quad (14)$$

Where.

$$\dot{V}_f = A_f.V_f = A.V_1 \quad (15)$$

$$\dot{V}_g = A_g.V_g \quad (16)$$

$$A = A_f + A_g \quad (17)$$

Substituting these equations into equation 14,

$$\frac{W}{A} = \frac{L.g.\rho_f}{1 + \frac{A_g}{A_f}}$$

$$\therefore \frac{W}{A} = \frac{L.g.\rho_f}{1 + \left(\frac{\dot{V}_g}{\dot{V}_f}.\frac{1}{s}\right)} \quad (18)$$

Substituting equation 18 into equation 12,

$$P_2 - P_{system} = \frac{1}{2}f.\rho_f.V_2^2.\left(\frac{L.P}{A}\right) + \frac{L.g.\rho_g}{1 + \left(\frac{\dot{V}_g}{\dot{V}_f}.\frac{1}{s}\right)} \quad (19)$$

Substituting equation 8 into equation 19,

$$P_2 = P_{system} + \frac{4.f.L}{d}.\frac{\rho_f.V_1^2}{2}.\left(1 + \frac{\dot{V}_g}{\dot{V}_f}\right) + \frac{L.g.\rho_g}{1 + \left(\frac{\dot{V}_g}{\dot{V}_f}.\frac{1}{s}\right)} \quad (20)$$

Manipulating equation 20 and 11,

$$\frac{h}{L} - \frac{1}{\left(1 + \frac{\dot{V}_g}{\dot{V}_f . s}\right)} = \frac{V_1^2}{2.g.L} . \left[K . \left(1 + \frac{\dot{V}_g}{\dot{V}_f}\right)^2 + 2 . \frac{\dot{V}_g}{\dot{V}_f} + 1 \right] \quad (21)$$

Where

$$K = \frac{4.f.L}{d} \quad (22)$$

A laminar region is assumed for flow through the tubes and f is a laminar friction factor.

In the conventional diffusion-absorption refrigeration system, vapor bubbles are produced by the addition of heat to the lower portion of the bubble pump tube. Assuming the fluid in the lower reservoir and the tube to be saturated, and no heat transfer over the length of the pump tube, heating power required to produce the desired vapor flow rate is,

$$\dot{Q}_{evap} = \dot{V}_g . \dot{\rho}_g . h_{fg} \quad (23)$$

The amount of the liquid pumped by the bubble pump can be expressed as

$$\dot{m}_f = \dot{V}_f . \dot{\rho}_f \quad (24)$$

This mass flow rate of liquid can be expressed as a function of the heat input using the above equations. Neglecting the mass of the condensate, the velocity of the liquid, V1 at the entrance of the bubble pump (point 1) can be calculated as

$$V_1 = \frac{\dot{m}_f}{\rho_f . A} \quad (25)$$

The pumping ratio is calculated as

$$r_p = \frac{\dot{V}_f}{\dot{V}_g} \quad (26)$$

Thus all the bubble pump parameters can be calculated mathematically. But the comparison with the experimental results is necessary for estimation of K [4].

4. Results

The bubble pump with one tube is studied. Three Pyrex tubes of diameters 15, 20 and 25 millimeter are selected to do the experiments. The tubes length is 110 centimeters. One heater exists in bottom contain where for a better performance a second heater with low power is twisted around the pipes. The variable parameters are heat input, submergence ratio (H/L) and diameter of lift tube. Figure 2 shows Schematic of the tested bubble pump.

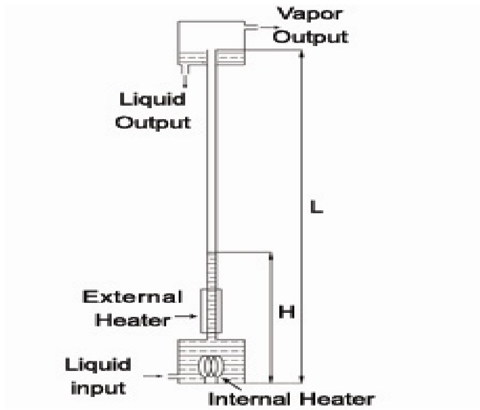

Figure 2. Schematic of the tested bubble pump

The effects of the variation of these parameters on vapor flow rate and liquid flow rate were studied where the working fluid was water.

The figure 3 shows the variation of vapor flow rate versus of the internal heat power. The power of the external heater is kept 300 watt; the length of tube is 110cm and submergence ratio (H/L) is 0.5. The figure shows the same behavior where the vapor flow rate increases as the power of the internal heater increases to a maximum value. Increasing the internal heat power then reduced the vapor flow rate.

The reason is that the internal power first increases the volume of vaporized resulting increase in vapor flow rate to a maximum value where after that due to change in flow regime from churn to annular which divide one large bubble to smaller bubbles, causing the vapor flow rate decreases. The other reason is because of increasing the temperature of tube surface close the external heater boiling regime; convert nuclear boiling to transient and film boiling which will reduce the vapor flow rate.

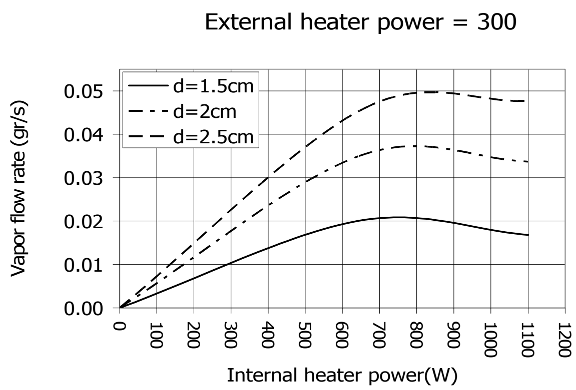

Figure 3. Variation of vapor Flow rate versus internal heater power

Figure 4 show the vapor flow rate versus the power of the internal heater where the power of the external heater is 600 watt; the length of tube is 110cm and submergence ratio (H/L) is 0.5.

The results are similar to that with 300(W) external heater. Comparing these two figures shows that increasing in external power has an important effect on vapor flow rate

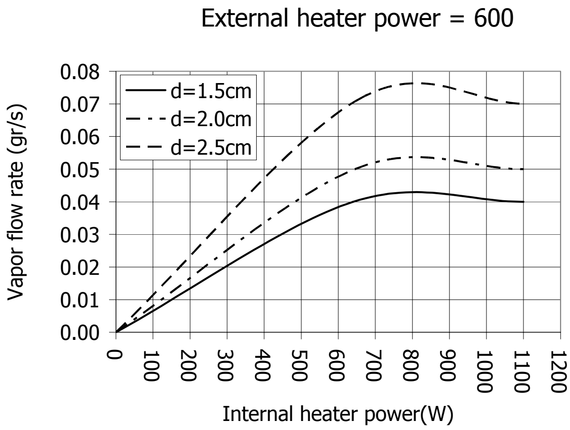

Figure 4. Variation of vapor Flow rate versus internal heater power

Figure 5 shows the variation of liquid flow rate to the power of the internal heater where the power of the external heater is 300 watt; the length of tube is 110cm and submergence ratio (H/L) is 0.5.

It is shown that the liquid flow rate increased as the power of internal heater increased. Increasing the internal heat power increased the bubble production rate resulting increasing the liquid flow rate. .

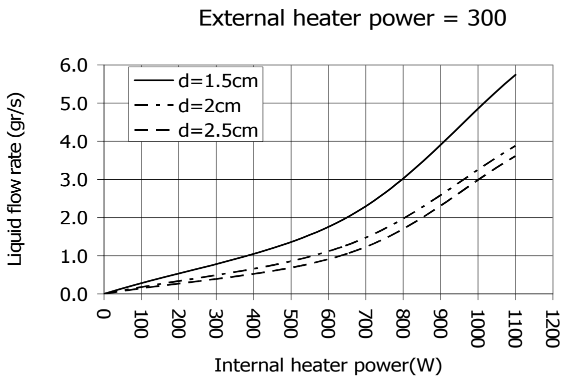

Figure 6. Variation of liquid Flow rate versus internal heater power

Figure 7 shows the variation of liquid flow rate to the power of the internal heater when The power of the external heater is 600 watt; the length of tube is 110cm and submergence ratio (H/L) is 0.5.

Comparing figures 6 and 7 shows that increasing the power of external heater increases liquid flow rate, because external heater keeps the temperature of liquid up, therefore it prevents heat transfer between the vapor of the bubbles and surrounded liquid which can reduce the size of bubble. The figure shows that the power of external heater has not special effect on the place of slope change.

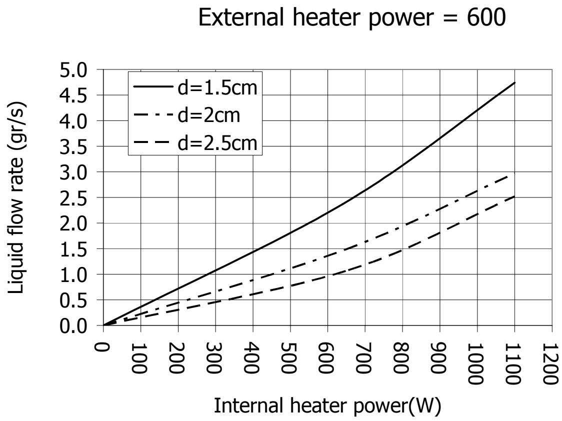

Figure 7. Variation of liquid Flow rate versus internal heater power

The effect of submergence ratio (H/L) on the flow rate of fluid is shown in figure 8 Increasing in submergence ratio increased outlet flow rate. The liquid flow rate increased as power of internal heater and external heater increased

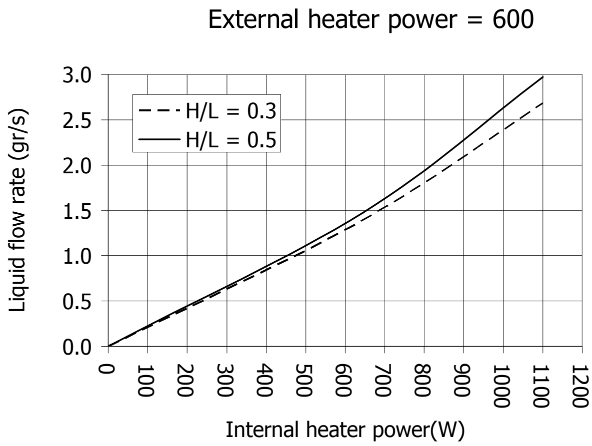

Figure 8. Variation of liquid flow rate with different submergence ratio

5. Conclusions

The results show that increasing the tube diameter increases the vapour flow rate whereas it decreases the liquid flow rate. It is also has been seen that the submergence ratio has a positive impact on liquid flow rate so that increasing the submergence ratio (H/L) increases the liquid flow rate

6. Nomenclature

Table 1. List of symbols

Symbol	Description	SI Unit
A	Cross-sectional area	m^2
B	Perimeter of the pump tube	m
D_0	Diameter of the pump tube	m
f	Friction factor	-
g	Acceleration due to gravity	m/s^2
ρ	density	Kg/m^3
h	Driving head	m
L	Height of the bubble pump tube (Pump lift)	m
$\dot{m}$	Mass flow rate	kg/s
P	Pressure	N/m^2
V	Velocity	m/s
$\dot{V}$	Volume flow rate	m^3/s
W	Weight	N
x	Dryness fraction	-
v	Specific volume	m^3/Kg
S	Velocity constant	-
X	Solution percentage	%

7. References

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