Numerical Studies On Bubble Pump
With Alternate Working Fluids

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Abstract – The importance of energy conservation in the context of growing global population and dwindling fossil fuel resources cannot be overemphasized. Energy can be conserved by using it more efficiently. The energy spent for an application should be of the correct amount and type. It would make more sense to spend heat energy for heating rather than the high grade electricity as most of the electric power in the world is generated from driving heat engines, for which heat is supplied from the combustion of fossil fuels. At the same time, depletion of these conventional resources also poses a serious problem in meeting energy requirements. In this paper, the bubble pump, which is an integral part of diffusion-absorption refrigeration system, has been investigated numerically. A thermally driven bubble pump, which can be powered by solar thermal energy, is used to lift the liquid. The bubble pump runs on solar energy and reduces the amount of energy spent by replacing the compressor in conventional vapour absorption refrigeration system. As a result of the absence of any mechanical moving part, the refrigerator is silent and very reliable in addition to an economical and environmental friendly device. The concept of such a pump is already in existence but optimization studies are yet to be extensively investigated. This paper deals with the comparison of various parameters of the bubble pump using water and Nonane as the working fluid. Numerical simulation of the bubble pump is carried out using simple numerical equations which assume slug flow in the bubble pump. The mass flow rate, the sensible heating time and position of heating element are varied and the effect it has on diameter of the pipe, pumping ratio and the heat required is studied for both the working fluids.

Keywords— bubble pump, diffusion-absorption refrigeration, Nonane, water.

I. INTRODUCTION

The main application of bubble pump is in vapour absorption refrigeration system. While using bubble pump in refrigeration system the pumping fluid acts as the absorbent. The absorbents to be used will differ based on the refrigerant used in the refrigeration systems. For Nonane the refrigerant used is butane whereas ammonia is used as a refrigerant in case of water. Ammonia/water systems are most commonly used in vapour absorption refrigeration systems. Ko Matsunaga (2002) compared the environmental impacts and physical properties of various refrigerants. Ammonia has a COP which is lesser than that of butane, moreover prolonged exposure of ammonia effects human health whereas butane is completely safe. Thus this paper deals with the comparison of various parameters of the bubble pump by using water and Nonane as working fluids. In the bubble pump heat addition to the fluid at the base of a vertical tube creates vapour, thereby increasing the buoyancy of the fluid causing it to rise through the vertical tube under two phase flow conditions. This heat energy can be provided with solar energy thereby eliminating the use of an electric heater. Delano (1998) designed a model, based on the air-lift pump analysis of Stenning and Martin (1968), and analyzed the performance of the bubble pump of the Einstein cycle. It uses momentum balances and assigns a value recommended by Stenning and Martin (1968) for the slip between phase velocities to model the two-phase involved. Susan white (2001) designed and analyzed various parameters of the bubble pump. N. Ben Ezzine and R. Garma (2009) published a model on bubble pump operated diffusion absorption machine based on light hydrocarbons for solar cooling which suggested use of light hydrocarbons for solar cooling.

Conventional vapour compression and absorption refrigeration systems are dual pressure cycles where the saturation temperature difference between the condenser and evaporator is produced by a system pressure difference. This requires a mechanical input to drive the compressor or pump needed to generate this change in pressure, which adds significantly to the noise level and
cost of the system while reducing the reliability and portability. On the other hand single pressure absorption refrigeration systems, such as the Platen and Munters (1928) diffusion-absorption cycle and the Einstein cycle (1928), use at least three working fluids to create temperature changes by imposing partial pressures on the refrigerant. While termed “single pressure” there are still slight overall pressure variations within these cycles due to flow friction and gravity. So, despite there being no need to pump the fluid to a much higher pressure to create a change in saturation temperature, a mechanism is needed to move the fluid through the cycle against flow friction and gravity. To eliminate the need for a mechanical input, a solar heat driven bubble pump is used for this purpose. In this study, the bubble pump component is analyzed so that design for optimum performance can be achieved.

![Fig. 1 Schematic representation of Bubble Pump](image)

II. WORKING OF BUBBLE PUMP

The liquid in the liquid reservoir initially fills the tube to the same level (h). Heat is applied at the bottom of the tube at a rate sufficient to evaporate some of the liquid in the tube. The resulting vapour bubbles rise in the tube. Due to the small diameter of the pump tube, the vapour bubbles occupy complete cross-section of the tube and are separated by small liquid slugs. Each bubble acts as a gas piston and lifts the corresponding liquid slug to the top of the pump tube. The bulk density of the liquid and vapour mixture in the pump tube is reduced relative to the liquid in the liquid reservoir, thereby creating an overall buoyancy lift. The energy sources generally used are (i) electric heat and (ii) flame heat. In the latter case, the entire length of the bubble pump or boiler is heated to increase the heat transfer area. At the bottom of the pump tube small bubbles form and join together forming bigger vapour bubbles. The rising vapour bubble acts like a piston and lifts a corresponding liquid slug to the top of the bubble pump tube. After a certain pump tube diameter is exceeded, the flow behavior changes from the slug flow regime to that of the mixed flow. The important parameters of the bubble pump are pump tube diameter (dp), driving head (h), pump lift (L) and pump heat input (Qp). The main characteristic values to judge the performance of the bubble pump are solution flow rate and the pumping ratio.

![Fig. 2 Schematic diagram of numerical model](image)

The pressure at the section XX in the figure 2(a) is given by

\[ P_x = P_a + \rho_{s,a} g Z_d = P_c + \rho_{s,h_x} g Z_s \]  

Thus the static head is given by

\[ Z_s = \frac{P_a + \rho_{s,a} g Z_d - P_c}{\rho_{s,h_x} g} \]  

For analysis Zs is equal to Zd as both the ends of the pump are open to atmosphere. In each cycle of operation, the solution occupied in static head of the tube is pumped. The mass of the liquid vapour mixture pumped per operation is thus given by

\[ m_w = Z_s A \rho_{s,h_x} \]  

Let \( t_{sat} \) be the saturation temperature of the solution. Since the liquid is at a sub cooled state, the bubbles formed at the hot surface will condense before they reach the upper part of the liquid column. So it is assumed that the supplied heat is utilized only for the sensible heating of the solution until it reaches the saturation temperature \( t_{sat} \) when the bubbles become stable. For the bubble pump heat input of \( Q_p \), the time taken for sensible heating of the solution from \( t_{sat} \) to \( t_{sat} \) is

\[ T_{sh} = m_w (h_{sat} - h_{hx}) / Q_p \]
The height of the vapour column in the bubble pump tube is 
\( Z_L - Z_s \). Dividing the vapour column into \( N \) equal elements, the height of each element is given by

\[
\Delta Z = \frac{(Z_L - Z_s)}{N} \quad (2.5)
\]

The volumetric rate of vapour bubbles produced can be calculated as

\[
V_{p,t} = \frac{Q_p}{(h_{fg} + H_m)} \rho_{v,t} \quad (2.6)
\]

Here \( H_m \) is neglected as we consider only the bubble pump for analysis and not the entire absorption refrigerator. The rising velocity of the bubbles in the pump tube for the slug flow is given by

\[
U_{v,t} = K \rho_{s,t} - \frac{1}{2} \left[ g D_1 (\rho_{s,t} - \rho_{v,t}) \right]^{\frac{1}{2}} \quad (2.7)
\]

Where \( K \) is dimensionless bubble velocity = 0.345 for round tubes.

The volumetric vapour going out of the solution vapour interface at any height is obtained as

\[
V_{o,tz} = U_{v,t} \varepsilon_z A \quad (2.8)
\]

Where \( \varepsilon_z \) is the void fraction when the level of the solution vapour mixture reaches the height \( Z \). For a mixture to rise to a height \( Z \), the required void fraction is

\[
\varepsilon_z = \frac{Z}{Z_s + Z} \quad (2.9)
\]

The final void fraction obtained from geometry is

\[
\varepsilon = \frac{(Z_L - Z_s)}{Z_L} \quad (2.10)
\]

The volumetric rate of vapour accumulation in the region of solution vapour mixture is given by

\[
V_{a,t} = V_{p,t} - V_{o,tz} \quad (2.11)
\]

The period of boiling to reach the final void fraction in tube is given by

\[
T_b = \frac{A (Z_L - Z_s)}{N \sum_{i=0}^{N} V_{a,t}} \quad (2.12)
\]

Thus the total time required for one complete cycle of pumping operation is obtained as

\[
T_f = T_{sh} + T_b \quad (2.13)
\]

The various mass and volume flow rates are calculated from the following relations:

**Liquid Vapour Mixture:**

\[
\dot{m}_w = \dot{m}_w / T_1 \quad (2.14)
\]

**Vapour:**

\[
\dot{m}_v = T_b V_{p,t} \rho_{v,t} / T_1 \quad (2.15)
\]

**Vapour:**

\[
V_{v,t} = \dot{m}_v / \rho_{v,t} \quad (2.16)
\]

**Liquid solution:**

\[
\dot{m}_s = \dot{m}_w - \dot{m}_v \quad (2.17)
\]

\[
V_{s,t} = \dot{m}_s / \rho_{s,t} \quad (2.18)
\]

The pumping ratio (b) is given by:

\[
b = V_{a,t} / V_{v,t} \quad (2.19)
\]

**III. RESULTS AND DISCUSSION**

**EFFECT OF MASS FLOW RATE**

Fig 3 effect of mass flow rate on pumping ratio

The fig 3 shows the variation of the pumping ratio of the bubble pump with respect to the mass flow rate while the parameters such as sensible heating time, total pumping time and the height above the heating element all remain constant.

From the graph it can be seen that pumping ratio remains constant with increase in the mass flow rate for both water and Nonane. It can be said that the pumping ratio does not depend on the mass flow rate. The pumping ratio is the ratio of volumetric rate of liquid pumped to volumetric rate of vapour pumped. Thus both values increase proportionately with increase in mass flow rate because the heating time remains constant for both. Thus the pumping ratio remains constant. We see that pumping ratio of Nonane is lower than that of water because Nonane has a lower enthalpy which results in higher volumetric rate of vapour production than water. Since sensible heating times are the same the heat required by Nonane will be more so after saturation is
reached the higher power leads to higher vapour production.

From the graph it is seen that the heat required varies linearly with the mass flow rate. This can be explained by the fact that for greater the mass flow rate, more will be the energy required to pump the fluid up and hence more heat energy is required.

It is also seen that the heat required for Nonane is slightly greater than that of water. This can be explained by the fact that the heat required directly depends on difference in enthalpy. Nonane having higher enthalpy will require higher power than water as observed in the graph.

EFFECT OF SENSIBLE HEATING TIME

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The fig 7 shows the variation of heat required with respect to the sensible heating time while the parameters such as mass flow rate, total pumping time and the height above the heating element all remain constant.

It can be seen from the graph that the amount of heat required decreases with the increase in the sensible heating time. This can be explained by the fact that when the power supplied decreases then the rise in temperature of the mass per second also decreases. As the rise in temperature decreases the time taken for the mass of the liquid to rise from the initial temperature to the saturation temperature increases. The decrease in the power supplied owing to the increase in sensible heating time is thus explained.

It can also be seen from the graph that there is slight difference in the values of power supplied in the range of 5W between the two liquids for the same amount of sensible heating time. Sensible heating time is the time required to heat the liquid from its initial temperature to its saturation temperature. Since the saturation temperature of Nonane is greater than the saturation temperature of water, the sensible heating time required for Nonane will also be slightly greater than the sensible heating time required for water.

The fig 8 shows the variation of the pumping ratio of the bubble pump with respect to the sensible heating time while the parameters such as mass flow rate, total pumping time and the height above the heating element all remain constant.

From the graph it can be seen that the pumping ratio of the pump increases with increase in the sensible heating time. The sensible heating time increases while the total time required for the pumping action remains a constant. This means that the mass pumped or the mass flow rate is achieved in less time when the sensible heating time increases. This is possible because the mass of the liquid lifted per bubble increases as the sensible heating time increases. This action produces two effects, one is that the amount of vapour pumped decreases and the other is that the mass flow rate of the liquid phase increases. This results in the increase of pumping ratio of the bubble pump as the sensible heating time increases.

For the same degree of increase in the sensible heating time it can be seen that the pumping ratio of Nonane increases more than the pumping ratio of water. This is due to the fact that the power decreases for Nonane at a faster rate than water the rate of decrease of volumetric rate of vapour production for Nonane is faster accounting for the higher rate of increase in pumping ratio.

EFFECT OF POSITION OF HEATING ELEMENT

The fig 9 shows the variation of the pumping ratio of the bubble pump with respect to the position of the heating element while the parameters such as sensible heating time, total pumping time and mass flow rate all remain constant.

From the graph it can be seen that pumping ratio remains constant with increase in the height of the liquid column above the heating element for both water and Nonane. As the mass flow rate is constant the volumetric rate of liquid and vapour production remain the same. Pumping ratio is the ratio between volumetric...
rate of liquid production to volumetric rate of vapour production and since both remain constant the pumping ratio also remains constant.

We can see from the graph that it remains constant for both fluids regardless of the position of the heating element. Thus heat required is independent of the height of the column above the heating element. This is because the mass flow rate remains constant along with sensible heating time. Nonane has a higher saturation temperature than water. Since the sensible heating time remains constant the power required to heat Nonane to its saturation state is more. Thus this explains the higher power requirement for Nonane.

V. CONCLUSION

Numerical studies have been carried out on the performance of bubble pump for varying operating conditions using water and Nonane pumping fluids. A computer simulation model has been developed to predict the pumping performance. The following conclusions have been drawn from the simulation studies.

- For the same mass flow rate Nonane has lesser pumping ratio, requires higher diameter and more heat energy than water.
- For the same sensible heating time Nonane has lesser pumping ratio, requires higher diameter and more heat energy than water.
- For the same position of heating element Nonane has lesser pumping ratio requires higher diameter and more heat energy than water.

Depending on the application of the bubble pump the mass flow rate can be increased by decreasing the diameter of the pipe. Hence the bubble pump has the added advantage of flexibility in design. These numerical studies provide a simple and effective approach for optimum sizing of bubble pump to give better performance. Pumping ratio of Nonane is lower than that of water which means it provides less effective pumping than water. As seen from the above analysis, even though use of Nonane requires slightly higher heat energy it is used along with Butane as the refrigerant which provides higher refrigerating effect when compared to water/ammonia systems. Thus the overall COP of the Butane/Nonane system is higher compared to that of water/ammonia system. So they can be used as an effective replacement to water/ammonia systems used in refrigeration systems. Thus, this paper “Numerical Studies on Bubble pump With Alternate Fluids” provides a keen insight into the bubble pump which is one of the few alternatives for electrical energy in diffusion –absorption refrigeration system at this point of time.
**NOMENCLATURE**

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