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The aim of the present numerical study is to investigate the influence of tube diameter, heat input, tube length and mass flow rate on the pumping action of solar bubble pump. A one-dimensional two-fluid model was developed under constant heat flux for predict the behaviour of pumping ratio under permanent regime. At a fixed bubble pump tube length of 1m, and ammonia mass fraction of 0.4 and pressure 18 bar at the inlet, numerical results show that, the pumping ration is mostly influences by heat input. Its maximum is directly related by the mass flow rate and tube diameter.

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Investigation of Pumping Action of Bubble Pump of Diffusion-Absorption Cycles

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1. INTRODUCTION

Conventional vapour compression and absorption refrigeration systems are based on cycles in which the refrigerant is circulated by a compressor or a mechanical pump, correspondingly. Compressor or pump operation requires a mechanical input, which adds significantly to the noise level and cost of the cooling system and reduces its reliability and portability [1].

A pumpless diffusion absorption refrigeration cycle is of great importance in silent refrigeration applications because it does not use a mechanical pump. The circulation of the fluid in the diffusion absorption cycle is ensured by a bubble pump under the effect of thermal energy [2]. Indeed the pump a bubble pump is a fluid pump that operates on thermal energy to pump the liquid from the lower level to the upper level. When heat is applied to the pump tube, the rich solution turns into two phases, liquid and vapour; this creates a two-phase flow. Dynamiting the gas creates a pump-like effect that pushes the boiling water to a higher elevation.

There are several parameters of the bubble pump which can be adjusted to optimize its pumping action. These parameters include: the diameter of the lift tube [1,3,4], the heat input [5,6], working fluid [7] and the level of pressure. For tube lift diameter range, since a

bubble pump operates most efficiently in the slug flow regime [8]. The maximum diameter tube in which slug flow occurs is given by the Chisholm equation [9]. When the maximum lift-tube diameter is exceeded, the flow pattern changes from slug flow to an intermittent churn-type flow [10]. After a certain pumping height is exceeded, the pumping action stopped. But under effect heat fluctuation, such as for heating solar, it's difficult of bubble pump to stay in this regime. In this topic While [10] shows that a smaller than optimal diameter lift tube will experience churn flow and a much higher than optimal diameter tube will produce bubbly flow.

Pfaff et al. [11] studied the bubble pump operating with Li-Bre-H₂O. They found that for a tube diameter of 10 mm, the pumping action accrued at 30W; however the heat input is around 40W for a diamond of 14mm. And the frequency of the pumping action increases as the heat input to the bubble pump increases or the tube diameter decreases. Using a water-ammoniac system, the authors showed that the diameter which maximizes the efficiency of the bubble pump is between 4 mm and 26 mm for a liquid pumping rate of between 0.0025 kg / s and 0, 02 kg / s. However, efficiency decreases rapidly when diameters below optimal values are used; they recommend, therefore, that the diameter should be slightly higher than the optimum value found.

Another widely studied factor is the variable heat input to the bubble pump. In this subject, two parameters were studied as a function of the heat input: liquid and vapour mass flow which characterize the efficiency of the bubble pump [12-16]. These studies showed that the mass flow rate of the steam increased linearly with the heat input, while the mass flow rate of the pumped liquid increased before it reached a maximum value, after which it decreased with the increase in heat input. Thus, the optimum heat input is which corresponding to the amount of maximum pumped liquid. The optimum heat input range is function of working fluid concentration [17], submersion ratio [16, 18] and bubble pump characteristics [15,19].

Faisal [20] studied the performance of LiBr-H₂O pumpless absorption refrigeration system. A simulated test rig of the thermal bubble pump was fabricated using water as a test fluid. For a tube length of 1.5m, author tested 3 diameters 6.5, 10 and 14mm. He found that at a temperature of between 102 ° C and a tube diameter of 10

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mm, the pumping capacity reached its maximum of 0.0295kg / s and 0.043kg / s respectively for the submersion ratios 0.5 and 0.7. In addition the pumping capacity decreases for large drop in heat input. The same tendency of the variation for the pumping ratio with the heat yielded for the other tube diameters. The experimental results show that the slug regime is dominant for the maximum pumping ratio of the bubble pump.

Numerical study conducted by Benhmidene et al. [12] were defined the minimum heat input required of pumping action. They have been correlated in function of tube diameter. In the same work authors had correlated the optimum heat input to require a maximum of amount of pumped liquid. The optimum heat input is correlated in function of tube diameter and mass flow rate. As results of the same numerical modeling, Benhmidene et al. [21] had justified the relation between pumping action and flow regime transition by studied the variation of liquid velocity as function of vapor velocity. That cans allowed defining the maps flow regime as function of heat input.

The aim of present work is to study the influence of operating conditions such as heat input, tube diameter and mass flow rate on the pumping action. A numerical study based on two-fluid model was carried out to achieve our goals. The bubble pump subject of the present study was a vertical uniformly heated tube with an ammonia-water mixture (40% ammonia of ammonia).

II. MATHEMATICAL MODEL

In the present study ammonia water solution is used as a working fluid. The main components of an absorption-diffusion refrigeration cycle and flow configurations in the bubble pump are showing in Figure 1.

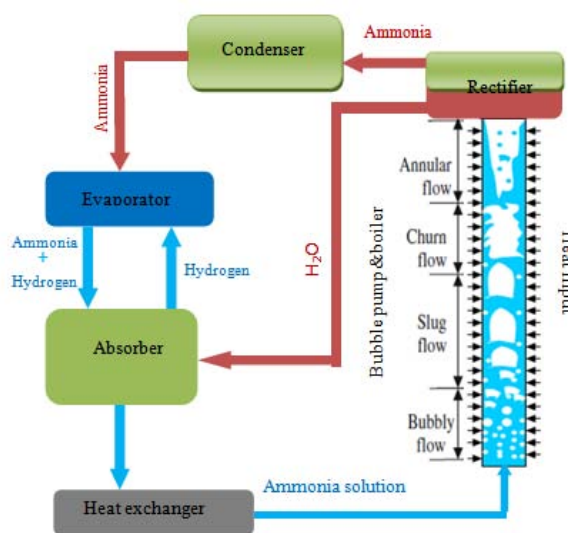


Fig. 1: Absorption diffusion machine and their compounds

The pumping ratio is defined as the ratio of mass flow of the pumped liquid and the vapour. To study the pumping action, requires the knowledge of mass pumped liquid and flow. Heat applied to the bubble pump tube causes a two-phase region. In the two-phase region, the general conservation equations of mass, momentum and energy were formulated by Ishii and Mishima [22]. For the steady state with negligible kinetic and potential energy, the conservation equations are reduced to the following five equations:

- Phase mass equations

$$\frac{d}{dz}(\alpha \rho_G u_G) = \Gamma_G \quad (1)$$

$$\frac{d}{dz}[(1-\alpha)\rho_L u_L] = \Gamma_L \quad (2)$$

- Phase momentum equations

$$\frac{d}{dz}(\alpha \rho_G u_G^2) + \alpha \frac{dP}{dz} + \alpha \rho_G g = -F_{WL} - F_{GL} - F_{GI} \quad (3)$$

$$\frac{d}{dz}[(1-\alpha)\rho_L u_L^2] + (1-\alpha)\frac{dP}{dz} + (1-\alpha)\rho_L g = -F_{WL} + F_{LG} - F_{LL} \quad (4)$$

- Mixture energy equation

$$\frac{d}{dz}[(1-\alpha)\rho_L u_L H_L + \alpha \rho u_G H_G] = \frac{q_w P_h}{A} \quad (5)$$

Closure relation and description of method resolution is detailed in [23]. Resolving of two-fluid model equation allowed to determine void fraction, liquid and vapour mass flow, pressure and enthalpy of liquid.

To validate the two-fluid model results a comparison of the calculated values for void fraction versus vapour quality using this model was compared with those obtained from three other models [24,25].

A good agreement between these results indicates that the two-fluid model is suitable for the prediction of refrigerant two-phase flow in bubble pumps [23].

III. RESULTS AND DISCUSSION

Several operating parameters can influence the pumping action of the bubble pump. The studies are concentrated on the pumping ratio as the magnitude characterizing this pumping action. Studies carried out by Benhmideh et al. [17] are showing a weak influence of ammonia mass fraction on the pumping ratio. The same result was obtained for the influence of the pressure at the inlet.

In the present study, we focus on the effect of the tube diameter and the heat flow on the pumping ratio. The bubble pump tube length is fixed at 1m, pressure at the inlet is of 18bar and mass fraction of

ammonia in strong solution is 40%. The range of heat flux is chosen according to the solar intensity at the zone of Gabès in Tunisia where it is between 150 and 800W/m² [26].

Since the pumping action is optimal for the slug regime, we have used the Chisholm relation (Eq.6) [9] which fixes the upper tube diameter to have a slug regime.

$$D \leq \left[\frac{\sigma \cdot V_f}{g \cdot \left(1 - \frac{V_f}{V_g}\right)} \right]^{1/2} \quad (6)$$

Therefore, the behaviour of the pumping ratio is investigated for the tube diameters from 2mm to 14mm by increment of 2mm. In this diameter range, heat flux received by the tube of bubble pump without taking into account the losses will be taken between 5 and 50 kW/m².

To define the working mass flow rate in this study, we follow the evolution of the pumping ratio as a function of mass flow rate this for a heat flux of 20kW/m². According to Fig.2, the pumping ratio increases if the mass flow rate increased, this is an expected behaviour since the liquid flow rate increases with this parameter too. However, it should be noted that the variation decreases with tube diameter. A small variation in the pumping ratio between the diameters 10, 12 and 14 mm can be observed.

Regarding those results, the mass flow rate choice is 50kg/m².s because it's the middle.

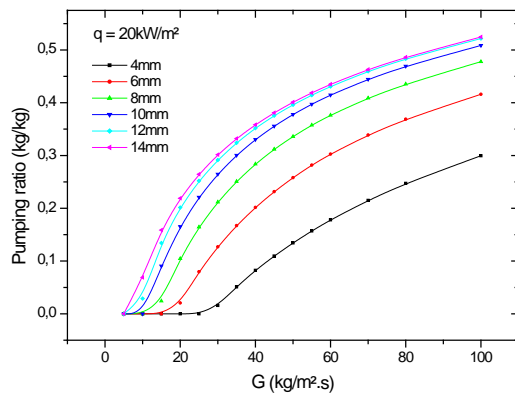
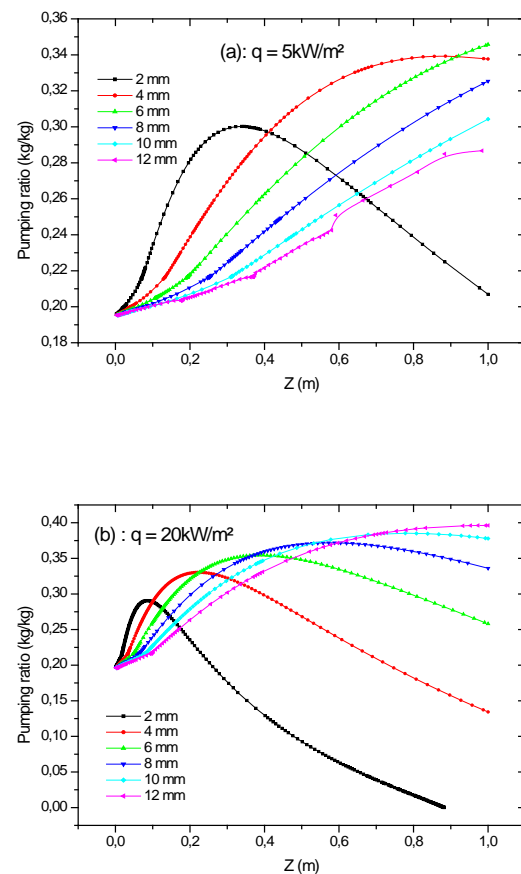


Fig.2: Pumping ratio vs mass flow rate

The pumping ratio is also studied in function of tube height. These variations are studied for tube diameter from 2 to 12mm. For a constant mass flow rate of 50kg/m².s, Figure. 3 (a), (b), (c) shows the variation of the pumping ratio along tube respectively for 5, 20 and 50 kW/m². These figures show a similar general behaviour for the different tube diameters and for the three heat flux, i.e., an increase, reaches a maximum and then a decrease, its value depends on heat flux.

The first result emerging from these curves is that the tube length where pumping ratio increase, decreases with the heat flux and increases with the tube diameter. For example, for the heat flux of 5kW / m², except for the diameter of 2mm, the pumping ratio increases for the others diameters. By increasing the heat flux, zone of increasing will be between 10 and 40cm (Fig. 3.c). In addition, a higher pumping ratio is required at the outlet of the pump where the liquid is pumped to the separator. By examining the pumping ratio value at the outlet one notices its decrease as a function of heat flux as well as for descending tube diameter. Indeed for the diameter of 2mm, the ratio is about 0.2, and becomes null for the other heat fluxes, results allow us to limit the studies to the diameter of 4mm as lower value. It should be noted that the maximum pumping ratio increases along the tube to reach a maximum value of 0.4. The influence of heat flux will be studied in the next section.



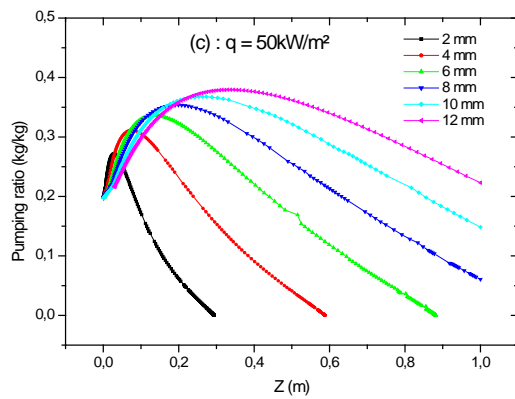


Fig. 3(a), (b), (c) : Pumping ratio vs tube high: (a) 5kW/m²; (b) 20kW/m²; (c) 50kW/m²

In this section, pumping ratio is studied in function of heat flux for different tube diameters. Figure 4 shows how the pumping ratio variation with the heat flux and tube diameter. It can be seen that the pumping ratio increases with increasing the amount of the heat input until it reaches a maximum discharge point. Then any further increase in the supplied heat will cause the pumping ratio to become lower. The increase in pumping ratio for the low heat fluxes is due to the increase of the mass flow rate of pumping liquid with the increase of the steam flow rate. Indeed this zone will be characterized by a slug regime. The amount of vapour generated is capable of lifting the liquid. The heat flux corresponding to this zone varies 5 and 20 kW / m². The maximum value of the pump ratio is not too much influence by the diameter of the tube it is between 0.33 and 0.4, however the rate of increase of the maximum value decreases by increasing the tube diameter.

Under the effect of additional heat, the mass flow of the liquid pumping decreases. This leads to the apparition of an area for which the pumping ratio decreases. As an explanation of this behaviour is attributed, in greater proportion, to the increase of the frictional pressure drop (see Figure 5) due to the increase of the vapour mass flow rate and the variation of flow regime from slug to annular. In fact, in the annular flow pattern, the liquid dragged up mainly by the action of shear stress between high velocity vapour and the liquid and partially by the buoyancy action at which condition the slip ratio is too high. [27]. In this topic, a comprehensive study of flow regimes transition was carried out by Benhmide et al.[21], in which authors show the reduction of the zone occupied by the slug regime vis-a-vis the churn and annular regimes when the heat flux increases. Our observations in this study coincide well with those of Jacob et al. [28], Shihab [29], Sathe [16]. When the received heat flux below an optimum value (corresponding to the maximum value of the pumping ratio), the buoyancy effect of the steam still has the

ability to overcome the additional frictional pressure drop. This capacity appears in an additional increase of the pumped liquid to the maximum point. Bigger the tube diameter, bigger the optimum heat, where it increase from 7 to 25kW/m² where tube diameter increase from 4 to 12mm.

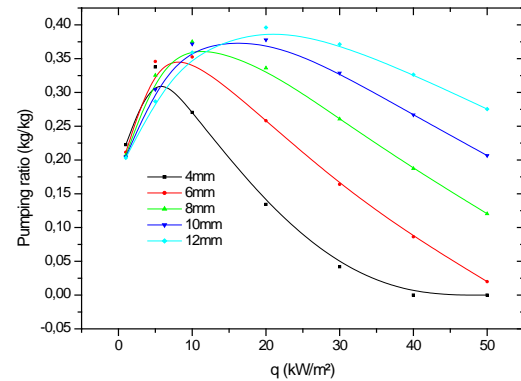


Fig. 4: Pumping ratio vs heat flux at different tube diameter

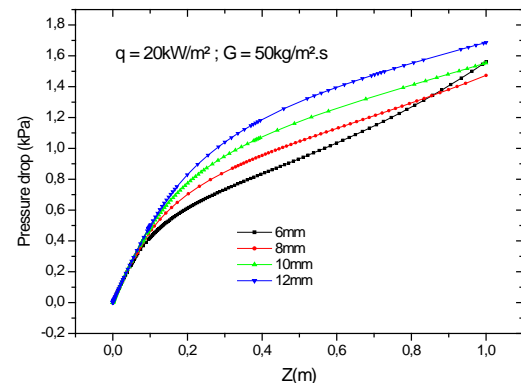


Fig. 5: Influence of tube diameter on pressure drop in bubble pump

Nomenclatures

- F_{GI} : Interfacial force for the vapour due to the mass exchange (N m⁻³)
- F_{LG} : Interfacial force between the two phases (N m⁻³)
- F_{LI} : Interfacial force for the liquid due to the mass exchange (N m⁻³)
- F_{WG} : Force between the wall surface and the vapour (N m⁻³)
- F_{WL} : Force between the wall surface and the liquid (N m⁻³)
- g : Gravity acceleration (m s⁻²)
- G : Mass flow in the tube (kg m⁻² s⁻¹)
- H : Enthalpy (J kg⁻¹)

u: Velocity (m s^{-1})

Greek symbols

α : Void fraction

ρ : Density (kg m^{-3})

Γ : Vapor or liquid generation rate per unit mixture volume ($\text{kg m}^{-3} \text{s}^{-1}$)

Index

L: Liquid

G: Vapor

W: Wall

IV. CONCLUSION

The pumping action of the bubble of diffusion absorption machines is numerically studied by using the two-fluid model. Equations balance of mass, momentum and energy of each phase are resolving with Matlab software. Numerical resolution allowed to define the pumping ratio, which is studied in function of tube length, mass flow rate, heat flux that for different tube diameter. The following conclusions have been drawn:

- According its definition as a parameter characterised the pumping action, the pumping ration at the outlet of the bubble pump must be higher than zero, and thus the tube diameter minimum must be more than 4 mm.
- The influence of tube diameter on pumping ratio by varying mass flow rate becomes lower for tube diameter higher than 10mm.
- The pumping ratio is mostly function of heat flux. It increases for the range of heat flux where slug is the flow regime. The maximum pumping ratio for each studied diameter tube is between 0.33 to 0.4. For the higher heat flux pumping ratio increase for all tube diameters under the influence of frictional pressure drop and flow regime transition from slug to annular.
- The bubble pump optimum functioning are defined when the pumping ratio is maximal. The results shows, the value of heat flux corresponding to the optimal functioning are more influenced by tub diameter (3kW/m^2 for a 4mm of tube diameter and 5, 10, 13 and 17 kW/m respectively for 6, 8, 10 and 12 mm of tube diameter). It increase with tube diameter, but it's weak influenced by varying of inlet pressure or ammonia fraction.

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