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A Review of Bubble Pump Technologies

A. Benhmidene, B. Chaouachi and S. Gabsi
Research Unit Environment, Catalysis and Process Analysis,
The National School of Engineering of Gabès, Omar Ibn El-Khattab Street, Gabes 6029, Tunisia

Abstract: This study provides a literature review on bubble pump using in diffusion-absorption refrigeration technology. A numbers of bubble pump configurations are provided and discussed. Many parameters influencing the performance of the bubble pump are presented. It is hoped that, this study should be useful for any newcomer in this field of refrigeration technology.

Key words: Bubble pump, configurations, diffusion-absorption cycles, refrigeration, heat pump

INTRODUCTION

A Diffusion-Absorption Refrigeration (DAR) cycle was first invented around 1920 by Platen and Munters (1928), students at the Royal Institute of Technology, Stockholmin Sweden. It's a self-circulate absorption system using H_2O/NH_3. As NH_3 is the working fluid, differential pressure between the condenser and the evaporator is too large to be overcome by a bubble-pump. An auxiliary gas is charged to the evaporator and the absorber. In 1928, Einstein and Szilard also patented a single pressure absorption cycle. Unlike the diffusion-absorption cycle, however, the Einstein cycle uses a pressure-equalizing absorbate fluid rather than an inert gas. In the Einstein cycle, butane is the refrigerant, water remains the absorbent and ammonia becomes the pressure-equalizing fluid (White, 2001). An outstanding feature of this system is that it can be operated in places where no electricity is available. There are no moving parts; system maintenance, noise and vibration are at minimum. This system has been used for more than 70 years (Stierlin and Ferguson, 1990). The diffusion-absorption cycle has a niche market in the recreational vehicle and hotel room refrigerator markets (Herold *et al*., 1996). It is manufactured in many parts of the world today. Since its invention, several attempts have been made to make it more competitive with dual-pressure cycles by improving its efficiency, but at refrigeration temperatures, a COP of approximately 0.3 is the best attained (Chen *et al*., 1996).

Previous studies (Gabsi, 1981; Vicatos, 1995; Vicatos and Zulu, 2002; Zulu, 2000) indicate that the absorption machines are sensitive to their working environment and produce the desired performance only if the components operate within their designed parameters. Therefore, it can be strongly stated that the poor performance of the experimental refrigeration unit was not due to experimental errors and construction inaccuracies, but due to taxing the performance of each component of the unit beyond its design characteristics.

In diffusion-absorption cycles, the bubble pump is the motive force and is a critical component of the absorption-diffusion refrigeration unit. The purpose of the bubble pump (besides the circulation of the working fluid) is to desorb the solute refrigerant from the solution. The performance of the diffusion-absorption cycles depends primarily on the efficiency of the bubble pump (Srikhirin and Aphornratana, 2002).

The disadvantage of these systems is a very low COP. Therefore, the configuration of the generator and bubble pump is of great importance. In order to increase the COP, it must utilize minimum heat as possible and desorb as much refrigerant as possible from the solution (Zohar *et al*., 2008). Different generator configurations are adopted in absorption-diffusion machine such as solar or another driving bubble pump.

In solar driving bubble pump, the solar collector acts as the generator. Evacuated tube collectors are characterized by their high efficiency, medium price, commercial availability and that their future market is promising. A single and multiple lift tube indirectly or directly solar heated bubble pump are used.

The gas, kerosene or electrically driven diffusion-absorption refrigerators were theoretically and experimentally investigated in numerous research projects concerning refrigeration applications (Gabsi, 1984; Narayankhedkar and Maiya, 1985; Kouremenos *et al*., 1994; Smirnov *et al*., 1996; Al-Shemmeri and Wang, 2002).

Corresponding Author: Ali Benhmidene, Research Unit Environment, Catalysis and Process Analysis,
The National School of Engineering of Gabès, Omar Ibn El-Khattab Street, Gabes 6029, Tunisia
Tel: 0021698642512

In the other hand, many configurations of directly electric or flame driving heat bubble pump are investigated.

The bubble pump operates most efficiently in the slug flow regime in which the vapour bubbles are approximately the diameter of the tube. The important parameters of the bubble pump are: pump tube diameter, driving head, pump lift and pump heat input. Many authors have been interested in studying the influence of heat input to the bubble pump, the tube diameter and the submergence ratio (ratio of the pump lift on the driving head) on the performance of the bubble pump.

The aim of this study is to provide basic background and review existing literatures on the bubble pump in the absorption refrigeration technologies. A numbers of bubble pump configurations are provided and discussed. Many parameters influencing the performance of the bubble pump are presented.

BUBBLE PUMP CONFIGURATIONS

Flam or electric driving bubble pump: The directly driven bubble pump of diffusion-absorption refrigerators usually consists of a single lifting tube where the heat input is restricted to a small heating zone by a heating cartridge or the flame of a gas burner with a high heat flux density. In the latter case, the entire length of the bubble pump or boiler is heated to increase the heat transfer area.

The thermally heated generator with its bubble pump was investigated in previous work using gas fired domestic diffusion absorption refrigerators (Wang and Herold, 1992; Herold and Chen, 1993; Kim *et al*., 1994; Herold, 1996) as an improved, directly heated, gas driven diffusion-absorption heat pump. Another group of researchers (Stierlin and Ferguson, 1990; Stierlin *et al*., 1994) developed a directly gas heated diffusion-absorption heat pump with a heating capacity between 3.0 and 3.5 kW at heating temperatures of 150°C and evaporator temperatures from -15°C up to +5°C. COPs between 1.4 and 1.5 were reached. Chen *et al*. (1996) have developed a new generator configuration that increased the COP of the cycle by 50%. The original design combines the generator and the bubble pump into one component, with only one heat addition. Their generator consists of heating elements, a bubble pump and a coaxial heat exchanger. This configuration allowed the reduction of heat losses thus increasing the efficiency of the heating process thus increasing the COP. Another industrial conversion of the diffusion-absorption heat pump has been done by Entex Energy Ltd. They realized diffusion absorption heat pumps with 2.6 kW up to 8.0 kW heating capacity with a COP heat of about 1.5. They also realized a directly gas driven diffusion absorption cooling machine with 1.0-3.5 kW cooling capacity (Entex, 2005).

In DAR system manufactured by Electrolux Sweden (currently known as Dometic), the bubble pump heated in the bottom, is made up by two coaxial tubes, being used for the generation and pumping at the same time. The interior tube is shorter than the external tube. The heat which applies to the external tube heats the rich solution which supplies the interior tube through the poor solution circulating in annular space. When the slug regime is developed the vapour-liquid mixture arrives at the end of the first tube and the poor solution falls down in annular space while the vapor carries on its way towards the condenser. With The bubble pump configuration the influence of the ammonia concentration has been studied for a generator temperature between 195 and 205°C (Zohar *et al*., 2005). In another work, the actual DAR system configuration operated with organic working fluids. The results were compared to an ammonia-water system working at similar conditions (Zohar *et al*., 2009).

To ameliorate the performance of DAR (Zohar *et al*., 2008), numerically studied three configurations of the generator and bubble pump presented in Fig. 1a-c. In 1st configuration (a) they are total separation: heat input into the rich solution with no heat transfer from the bubble pump. Both tubes are insulated from the surroundings. In the 2nd (b) partially attached is adopted: heat input into the rich solution with heat transfer from the bubble pump tube to the outer tube. The outer tube is insulated from the surroundings. But in the 3rd configuration (c) they are fully attached: heat input into the rich solution through the poor solution, thus also desorbing refrigerant from the down flowing poor solution, while heat is being. The performance of three DAR systems, which differ in

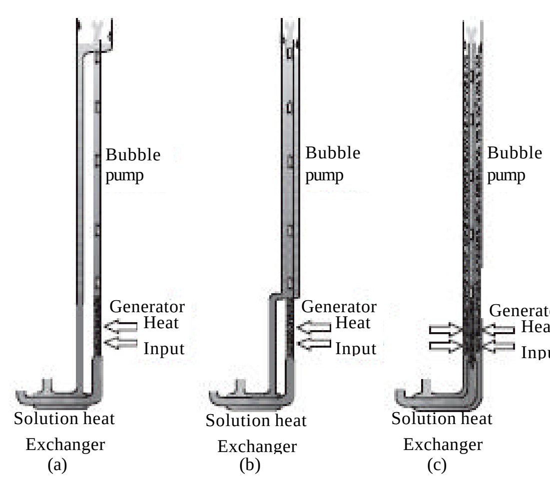

Fig. 1: (a-c) Different configurations used by Zohar *et al*. (2008)

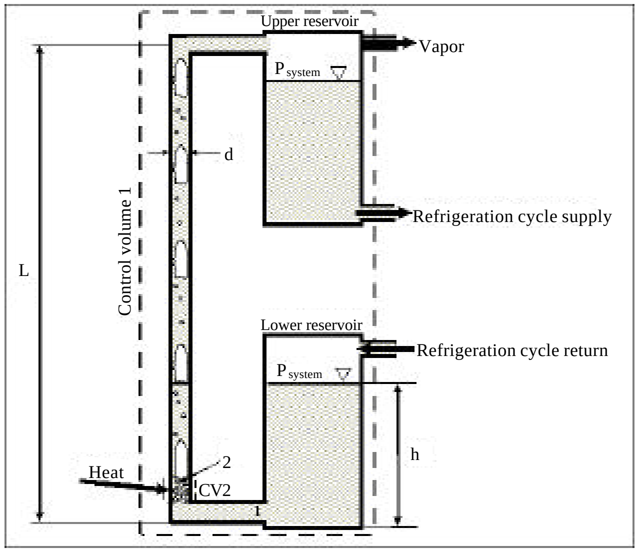

Fig. 2: Bubble Pump Schematic in Einstein cycle refrigeration (Delano, 1998)

their generator and bubble pump configuration, was studied numerically. They found that for the same heat input (Q = 160 W), the second configuration desorbed the highest amount of refrigerant and the first configuration desorbed the lowest. The third configuration proved to be less efficient compared to the second configuration in terms of COP. The first configuration resulted in the lowest performance, although heat is supplied directly to the rich solution (Zohar *et al*., 2008).

Using a similar bubble pump configuration, an experimental investigation of an air-cooled diffusion-absorption machine operating with a binary light hydrocarbon mixture (C_4H_{10}/C_9H_{20}) as working fluids and helium as pressure equalizing inert gas is presented. The experimental results show that the bubble pump exiting temperature as well as those of the major components of the machine but the absorber is very sensitive to the heat power inputs to the bubble pump. For bubble pump heat inputs from 170 to 350 W, the driving temperature varies in the range of 120-150°C. The lowest temperature reached at the evaporator entrance is -10°C provided by a driving temperature 138°C and a power inlet Q_{bp} = 260 W. The COP of the machine has reached a maximum of 0.14 for T_{water} = 9°C and Qbp = 275W (Ezzine *et al*., 2010).

The Einstein refrigeration cycle was studied extensively in Georgia Institute of Technology (Delano, 1998; Schaefer, 2000; White, 2001). In the Einstein refrigeration cycle, the bubble pump is a heated tube that lifts fluid from a lower reservoir to a higher reservoir, as shown in Fig. 2. Heat applied at the bottom of the tube causes vapor bubbles to form and to rise. This creates a balance between the buoyancy and the friction forces, which pumps the liquid to the upper reservoir (Schaefer, 2000). Analytical models are developed for study the influence of heat input in the bubble pump on the performance of cycle.

To increase its refrigeration capacity, a multiple lift-tube bubble pump can be used, in order to increase the volume flow rates of the fluids, which are directly related to the amount of refrigerant produced. Vicatos and Binnet (2007) testing on a diffusion-absorption plant using a multiple lift tube bubble pump and the effects of additional tubes on the system's performance have been recorded. Although a full range of heat inputs could not be implemented, because of the limitations of the components of the unit itself, it was observed that the refrigeration cooling capacity was increased without a significant drop in Coefficient of Performance (COP). It was concluded that the multiple lift tube bubble pump has no limitation to the fluid flow rate and depends solely on the amount of heat input. This gives the freedom to design the lift tube pump according to the refrigeration demand of the unit and not the other way round which is the current approach by the manufacturers world wide (Vicatos and Binnet, 2007).

Solar driving bubble pump: Absorption refrigeration has been most frequently adopted for solar refrigeration. It requires very low or no electric input and, for the same capacity. Besides, the fluidity of the absorbent gives greater flexibility in realizing a more compact and/or efficient machine.

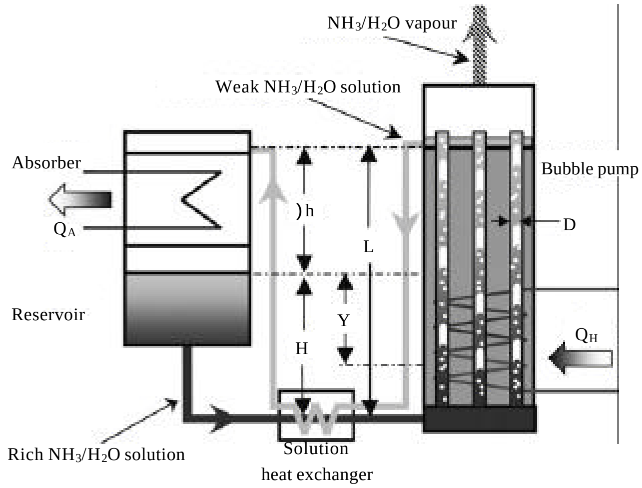

Fig. 3: Bubble pump configuration using in diffusion absorption machine (Jakob *et al.*, 2008)

Current absorption technology can provide various absorption machines with COPs ranging from 0.3 to 1.2. Choice of an absorption cooling machine is primarily dependent on the performance of the solar collector to be used (Kim and Ferreira, 2008).

Effect of a solar driven vapour lift pump on the performance of ammonia-water cycle is investigated experimentally by Bourseau *et al.* (1987). The results showed that the composition of the refrigerant-absorbent must be chosen accurately; a choice that requires the knowledge of the ambient conditions in which the machine will work. Gutierrez (1988), demonstrated experimentally the feasibility of operation of a solar refrigerator of this type with a flat-plate solar collector as the generator. In these studies, COPs of 0.2 to 0.3 and cooling capacities between 16 and 62 W were reached at heating temperatures between 160 and 230°C and evaporator temperatures of -6°C down to -18°C (Keizer, 1979; Bourseau *et al.*, 1987; Gutierrez, 1988; Ajib and Achultheis, 1998). Solar operated absorption diffusion refrigerating system was reported by Sabry *et al.* (1993), to be a promising system for the application of solar energy. In that study, the design of a commercially vapour absorption electrical refrigerator was changed to make it suitable for running on solar energy. The system was tested and operated in Shebin-El-kom, Egypt. An average system COP was estimated to be in the order of 0.02. Braun and Hers (2002) and Stürzebecher *et al.* (2004) used a modified diffusion-absorption heat pump, by substituting the direct gas fired generator by an indirectly heated generator. The solar thermal heating capacity of 1.8 kW is provided by vacuum tube collectors. The cooling capacity is approximately 1 kW and the COP is given with 0.59 at a heating temperature of 175°C and an evaporator temperature of 2°C.

The performance of three different indirectly heated, solar powered bubble pumps/generators were investigated and discussed (Jakob and Eicker, 2002; Jakob *et al.*, 2003, 2005). The developed bubble pumps/generators of the diffusion absorption cooling machine prototype are basically vertical shell-and-tube (19 tubes (8 mm×1,5 mm)) heat exchangers where the solution flows inside the tubes of small circular cross-section forming slug-flow at best and the heating medium flows through baffled tube bundles on the shell side (Fig. 3).

The diffusion-absorption cooling machine (Fig. 4) showed that the values of COP ranged from 0.12 to 0.38 and the evaporator cooling capacity was between 0.7 and 3.0 kW. Heating temperatures of the generator in a range between 100 and 150°C were obtained. After the redesign of the diffusion absorption machine, the latest performance of the machine showed cooling capacities of 2.0 and 2.4 kW at evaporator inlet/outlet temperatures of 12/6 and 18/15°C, respectively. The average COPs are 0.3 at heating inlet temperatures of 125°C. The performance of the investigated bubble pumps/generators shows that they work in a wide operation range at varied heating temperatures as well as external mass flows (Jakob *et al.*, 2007; Jakob and Eicker, 2006).

There are also some simulations studies of solar driving diffusion-absorption machine. Chaouachi and Gabsi (2007) used a solar collector as a generator. They found that best performance in terms of COP would be obtained when they work with low generator temperature and high pressure. In the other hand, the values of COP

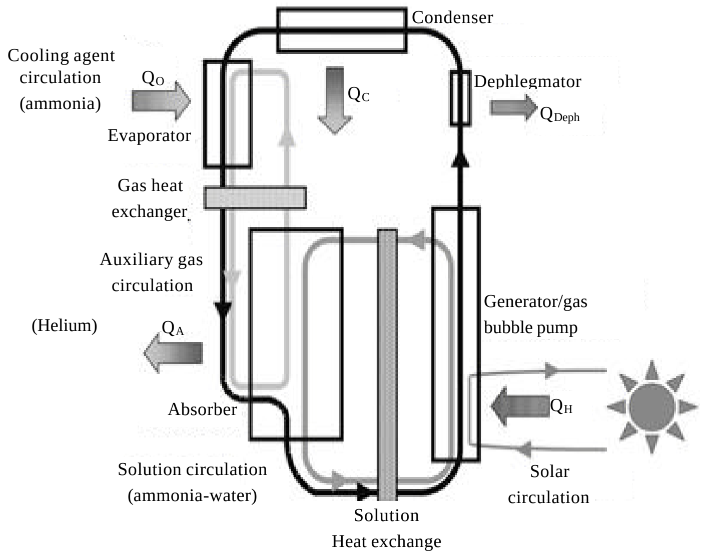

Fig. 4: Principe of the diffusion absorption machine (Jakob *et al.,* 2003)

remain weak and depend of the power solar babble pump. Qenawy *et al.* (2004) studied the Einstein refrigeration cycle powered by solar energy; to combine the advantages of using solar energy and single pressure absorption refrigeration cycle. They formulated a thermodynamic model of the solar powered refrigeration cycle to describe the cycle's performance. The results show also that the system pressure has a working range the cycle should work within. For ammonia-butane mixture, which is the working fluid of the investigated cycle, the pressure ranges from 4.2 to 9 bar. The cycle has a COP of 0.1207 to 0.1025 for that range of pressure. The performance of the cycle is evaluated throughout summer and winter days. Effect of various design and operating parameters on the COP is also investigated. It is found that as the cycle pressure increases the cycle COP also increases. Increasing both generator and evaporator temperatures cause the COP to increase. But increasing the condenser temperature makes the COP to decrease.

To study the boiling flow stability in solar bubble pump, Benhmidene *et al.* (2007) used a drift model. The pressure drop in the bubble pump is predicted. The result simulation shows the influence of heat flux input in the bubble pump and the mass flux on the stability of flow in bubble pump.

For all studies, Stenning and Martin (1968) theoretical method is used as the starting point to set-up the relationship between the submergence ratio and the velocities (through momentum and mass balances). Additionally, each model (except for Delano's) uses Beattie and Whalley's, (1982) method to find the two-phase friction factor and the drift flux method (Zuber and Findlay, 1965) to find the gas void fraction. The difference between these models is the value of the coefficients used in the drift flux model (White, 2001).

In numerical study, Benhmidene *et al.* (2008) used the two-fluid model to simulate boiling flow in the bubble pump. The bubble pump is simulates by the vertical uniformed heated tube. The void fraction, the liquid and vapour velocities and the pressure along tube bubble pump are predicted using two-fluid model. The influence of heat input on the performance of the bubble pump is study. It vas found that for the flow regime is function of heat input in the bubble pump.

PARAMETERS INFLUENCING THE PERFORMANCE OF BUBBLE PUMP

The bubble pump operates most efficiently in the slug flow regime in which the vapour bubbles are approximately the diameter of the tube (white, 2001). Bubble pump tube diameter, pump lift, driving head and heat input to the bubble pump tube were varied in many works to study the bubble pump performance.

There is a maximum tube diameter above which slug flow will not occur is predicts by Chisholm (1983) correlation. The phenomenon predicted by the above correlation has also been observed in experimentation and was found that after a maximum lift-tube diameter has been exceeded, there is a change in the flow pattern from slug flow to an intermittent churn-type flow (Siyetlng and Sang-Kyun, 1998; Lister, 1996; Pfaff *et al.*, 1998).

Excessively large tube diameters caused pumping to stop altogether. Pfaff *et al.* (1998) found an 18 mm diameter tube for their particular set-up. They found also the frequency of the pumping action was observed to increase with rising heat input to the bubble pump, increase in driving head and decrease in pump lift and tube diameter.

SiyetIng and Sang-Kyun, (1998) found a similar type of phenomena and classified this restriction as the discharge limit. They also found that after a certain pumping height is exceeded, the pumping action stopped. They noted that as the lift tube diameter increases the maximum pumping height decreases. This further restricts the diameter of the lift tubes if it is to be used on tall machines. The equation of Chilshom and Taitel is used by Jakob *et al.* (2008) to dimension the tube diameter pump. For the operating conditions chosen, slug flow was calculated for tubes with an inner diameter ranging from 5 to 41 mm.

The Einstein refrigeration cycle was studied extensively in Georgia Institute of Technology. Delano interest of the heat input and tube diameter. He found that increasing the heat input to the bubble pump for a fixed submergence ratio will increase the flow rate of the liquid through the bubble pump to a maximum and then further increase in the heat input will decrease the liquid flow rate. Delano (1998) showed that increase in the tube diameter would increase the flow rate through the bubble pump. It was shown that increase in the tube diameter would decrease the friction factor and therefore increase in the flow rate through the bubble pump.

The optimum efficiency diameter occurs while operating in the slug regime (White, 2001). White shows of the bubble pump component rapidly decreases when diameters smaller than the optimum value are used. Therefore, it is recommended to use a slightly larger diameter than the optimum value. For the influence of submergence ratio, the optimum efficiency value is most sensitive to the submergence ratio. Changing by a factor of about ten as the submergence changes from 0.4 to 0.8 at a fixed liquid flow rate. Changing the liquid flow rate at fixed submergence ratio has a lesser effect, changing the efficiency by about a factor of two as the flow rate is varied by a factor of three.

A continuous experimental system was designed, built and successfully operated by Koyfman *et al.* (2003). It was obtained that the motive head is one of the most dominant parameters influencing the bubble pump performance. Changing the motive head by 10% will result in about 40% change in the mass flow rates. It was concluded that a low motive head is recommended to achieve higher refrigerant flow rates thus higher cooling capacity.

CONCLUSIONS

The diffusion-absorption machine relies on a bubble pump to pump the solution from lower level to the higher level. The performance of the diffusion absorption cycle depends primarily on the efficiency of the bubble pump.

In diffusion-absorption machine, the bubble pump has many configurations it can be:

- Consists of a single lifting tube where the heat input is restricted to a small heating zone by a heating cartridge or the flame of a gas burner with a high heat flux density. In the latter case, the entire length of the bubble pump or boiler is heated to increase the heat transfer area
- Consists of multiple tubes integrated in the flat-plate solar collector
- Consists of multiple lift tubes indirectly heated by heat exchangers

The bubble pump operates most efficiently in the slug flow regime. The more parameter influencing the flow regime is the tube diameter. It must be quite selected. Another parameter can influence the operation of the bubble pump it is the submersion ratio.

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