A STUDY ON BUBBLE PUMP PERFORMANCE FOR DIFFUSION ABSORPTION REFRIGERATION SYSTEM WITH ORGANIC WORKING FLUIDS

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ABSTRACT

The performance of a diffusion absorption refrigeration system is depending on the various system components, which are interconnected by a few circulation loops. The motive forces of these circulations are provided by the differences of density of the working fluids influenced by the gravitation force and the heat supplies to the working fluids at the bubble pump. It is well known that the critical component of the absorption diffusion unit is the bubble pump. The flow rates and thermophysical characteristics of the working fluids are mainly influencing the bubble pump performance.

In the present study, the performance of a bubble pump with organic working fluids was carried out experimentally. A continuous absorption diffusion unit was built to investigate the influence of the bubble pump parameters on its performance.

KEYWORDS
Bubble pump, Organic fluids, Absorption, Diffusion-Refrigeration, Flow pattern

1. Introduction

A conventional vapor absorption cycle is running primarily on heat energy, but requires mechanical energy to circulate the absorbent solution from the low pressure absorber to the high pressure generator. It is known that a bubble pump can replace the solution pump for small capacities and the cycle driven only by heat is the diffusion absorption refrigeration cycle. The system has the following advantages in comparison with the conventional absorption cycle[1]:

1. Silent operation.
2. No moving parts: no fans or pumps, the cycle is very reliable.
3. Portability: the unit can utilize any low potential heat source like a gas burner, steam, waste heat etc… and can operate anywhere even in countries without electric utility infrastructure.

To use the bubble pump as a circulation device, the cycle is operated at a single pressure[2]. The most familiar single pressure refrigeration cycle is the ammonia-water-hydrogen cycle patented by Platen and Munters [3] in 1928. In the following sections the most common absorption diffusion refrigeration systems which incorporate bubble pumps as the circulation device are presented.

1.1 Ammonia-water-hydrogen cycle

Figure 1 presents a schematic illustration of an ammonia-water-hydrogen cycle. Single pressure refrigeration cycles achieve cooling by lowering the partial pressure of the refrigerant (ammonia) in the evaporator (*Figure 1)* allowing it to evaporate and extract heat from the environment. The ammonia is driven from its mixture with water in the generator by heat supply. Some of this heat drives the bubble pump, where vaporized ammonia is used to lift slugs of poor mixture (low in refrigerant) up the vertical tube and back into the absorber. The nearly pure ammonia vapor enters the condenser. In the condenser, the ammonia vapor is condensed at its saturation temperature according to the system's total pressure. In the evaporator the liquid ammonia diffuses through gaseous hydrogen, which lowers the partial pressure of the saturated ammonia liquid. This reduction in the partial pressure allows the ammonia to be evaporated at low temperature according to its partial pressure in the evaporator. This effect eliminates the need of an expansion valve and the use of a mechanical pump. The cool-evaporated ammonia and hydrogen vapors flow into the absorber, where the poor solution coming from the generator (via the solution heat exchanger) absorbs the ammonia vapor from the gaseous mixture. The light hydrogen flows back to the evaporator. Finally, the liquid ammonia-water mixture flows back to the generator (via the solution heat exchanger).

The COP of a diffusion absorption refrigerator is very low (around 0.2-0.3) due to three main reasons. First,

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the cycle operates at evaporator temperature below 0^0C and utilizes heat sources below 200^0C. Second, the inert gas at the evaporator is cooled by the evaporation process and requires some of its cooling capacity. Third, the rectifier is exposed and looses heat to the surrounding.

A study by Chen et al (1996) [4] dealt with the improvement of COP and came with a new configuration of a generator unit that utilized the heat of the ammonia vapor leaving the bubble pump to preheat the rich solution that enters the generator. In the old bubble pump configuration (*Figure 2),* the heater does not heat the rich solution directly. The heater supplies heat through the wall of the outer tube to the poor solution and the poor solution heats the tube wall of the inner tube (the bubble pump tube). This mechanism of heat transfer is not effective and economic. The proposed new configuration of Chen et al (1996) [4] for the generator bubble pump configuration is shown in (*Figure3).* Hot ammonia vapor from the bubble pump flows into the cylindrical shell. It preheats the strong solution flowing from the absorber to the generator in the outer tube of the spiral heat exchanger. In the inner tube, the hot weak solution flows from the generator. By replacing the old generator unit with the modified generator unit Chen et al (1996) [4] reported that a gain of 50% in the COP was achieved. The power input range during the test on the modified generator unit was 76-200W and the COP was 0.28.

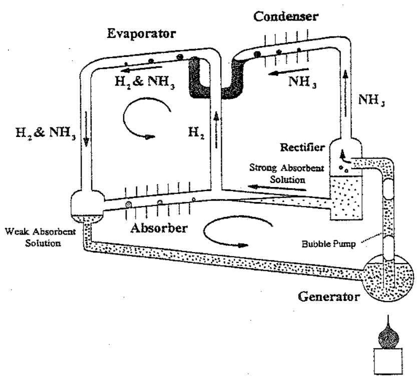

Figure 1 - Schematic ilustration of an absorption diffusion regrigerator [5]

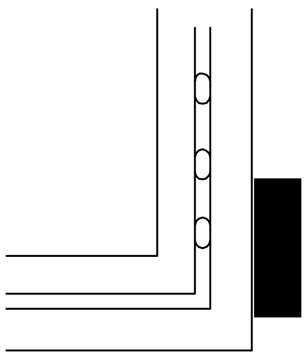

Figure 2 - The standart configuration of bubble pump

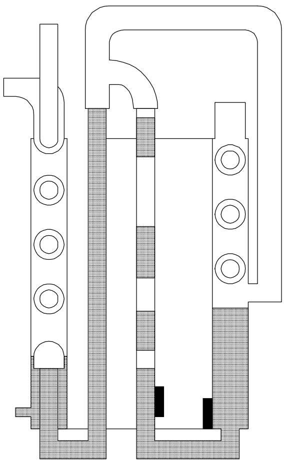

Figure 3 - The new configuration generator with heat exchanger

1.2 Lithium-Bromide cycle

Another cycle that requires a bubble pump is the two-fluid Water - Lithium Bromide cycle. In this cycle, the hydrostatic principle is used to maintain the pressure difference that allows the expansion of the refrigerant (water) trough the expansion valve. Schematic illustration of the lithium-bromide cycle is shown in (*Figure 4*).

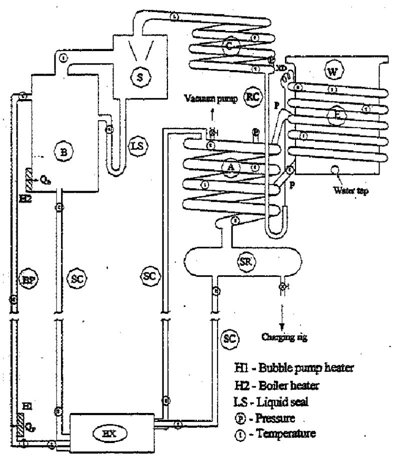

Figure 4 - Lithiume-bromide cycle [7]

Extensive research on the (pumpless) lithium-bromide cycle was carried out by Pfaff et al [5] and Saravanan & Maiya [6]. The weak solution (weak in LiBr) flows from the absorber due to gravity trough the solution heat exchanger to the bubble pump. Heat is supplied to the solution generating water vapor and strong solution (strong in LiBr). The boiling process creates water bubbles that are joining and forming a bigger bubble. The rising big bubble forms plugs that occupies the whole cross section of the tube (at small tube diameter) and lifts a slug of solution to the generator (boiler). At the generator (boiler) the solution was further heated. From the generator (boiler) the strong solution flows back to the absorber trough the heat exchanger and the generated water vapor rises to the condenser where it is liquefied. The condensed water flows trough the expansion device to the evaporator. After the evaporator, the water vapor flows into the absorber where it is absorbed by the strong solution. The weak solution flows trough the heat exchanger and gains heat from the strong solution coming from the generator (boiler). This cycle is limited to very low working pressure (vacuum) required for the evaporation process. This cycle is also limited to an evaporator temperature above 0^0C because the refrigerant in this cycle is water. The advantage of this cycle is that it allows utilization of low potential heat sources (about 80^0C).

1.3 The Einstein refrigeration cycle

Albert Einstein offered another single pressure refrigeration cycle [7],[8],[9], which utilizes the ability of water to absorb ammonia in a different way. The Einstein cycle is illustrated in (*Figure 5*). In the evaporator the partial pressure of butane is reduced by ammonia vapor flowing from the generator. The reduction in the partial pressure causes evaporation of the butane to its saturation temperature at its partial pressure. The evaporation process creates a refrigeration effect, which cools the ammonia and the surrounding. The ammonia-butane mixture then flows through the precooler to the absorber\condenser, poor solution flows from the generator (boiler) to the absorber and absorbs the ammonia from the gaseous mixture. The absorption of the ammonia from the gaseous mixture increases the partial pressure of the butane allowing the butane to condense. The butane and the ammonia separate due to respective density differences and the fact that ammonia-water and butane are immiscible with butane at the absorber temperature and pressure. The liquid butane is lighter than the ammonia water solution thus it floats on top while the ammonia water solution lies on the bottom of the absorber. The butane flows to the evaporator and the ammonia-water solution flows down trough the solution heat exchanger to the generator.

Delano [10] and Scheafer [11] carried out extensive research on Einstein cycle and offered a model based on mass and momentum balance equations and correlations for flow patterns for the bubble pump. Based on the analytical results some conclusions regarding the bubble pump were made: increase in submergence ratio will increase the flow rate (submergence ratio is the ratios between the lengths of the bubble pump tube and the initial level of fluid in the tube before heating). Increase in heat input increases the flow rate and the liquid/vapor ratio increases with increase of the diameter of the bubble pumps tube.

Delano investigated the performance of the bubble pump with water as working fluid. He used a stainless steel tube with inner diameter of 7.62 mm and with length of 0.736 m.

To create the saturation conditions at the entrance to the bubble pump a large reservoir of boiling water was used. The heater was clamped to the tube wall and a dimmer switch controlled the power input to the tube. The flow in the bubble pump tube was assumed to be slug flow [12] but no one offered a way to verify this assumption. It should be noted that the fluid in the bubble pump that was used for these experiments was water and not ammonia-water solution like in his prototype system. When using solution as the working fluid in the bubble pump mass transfer due to absorption is occurring, while flowing up the bubble pump tube the mixture cools and therefore increases the absorption ability of the solution.

Examining the above presented cycles we can point out that the ammonia-water-hydrogen cycle and the Einstein cycle requires high generator temperature but it can work below 0^0C and the lithium-bromide cycle does not require high generator temperature but cannot operate below 0^0C.

2. The present study

In order to utilize low temperature heat source (below 120^0C) to drive diffusion absorption units and to gain the ability to operate at temperature below 0^0C research was carried out on utilizing organic working fluids. At present, we use the refrigerant monochlorodifluorometane, R-22, with organic absorbents.

The first step was to build a continuous experimental system for investigating the influence of the bubble pump parameters (such as diameter, length, heat source, etc.) on its performance. Schematic illustration of the experimental system is shown in *Figure 6*.

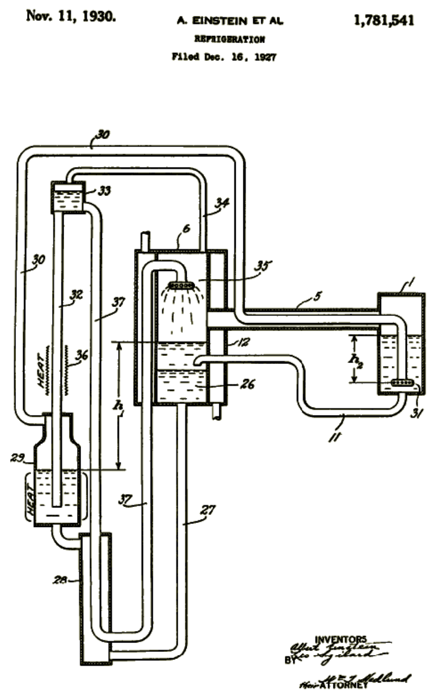

Figure 5 - Einstein refrigeration cycle [11]

2.1 Experimental set up.

The experimental system was built in a way that allows changes in geometry of the system (location of units) with minimal losses of working fluids. The bubble pump tube is made of glass to allow observation of the flow pattern and to determine the flow regime. Bending ½ " copper tube into a spiral made heat exchangers. The separating vessel has a large sight glass that allows observation of the separation process. Temperature is measured by T type thermocouples at different points of the system. Two pressure transmitters measure the absolute pressure and the pressure difference along the bubble pump.

Two electronic flow meters measure the flow rate of the rich and the poor solution. A data logger connects all the probes to a computer. All data is shown on line on the monitor and saved to the computers hard drive. The heat is supplied by three electrical heaters (each 80watt\220v). A variable transformer controls the heaters power supply manually from 0 to 240 watt.

The system was charged with an organic solvent DMAC (Dimethylacetamide) and R-22 to create the necessary weight fraction. The systems volume is about 4 liters. From the geometry of the system the volume of the rich and the poor solution were estimated. Knowing the properties of the fluids, the weight of the solvent and the refrigerant were estimated to be 775gr and 950gr respectively. The working fluids were charged after applying vacuum to the system.

The experimental system is not a complete refrigeration cycle due to lack of an evaporator in the cycle. This system was built only to investigate the bubble pump in a continuous process.

2.2 System operation

As can be seen in *Figure 6*, rich solution coming from the reservoir to the generator unit gains heat and starts the boiling flow process. The desorption process at the generator creates small vapor bubbles which merge into larger bubbles. The rising bubbles form plugs that occupy the whole cross section of the glass tube and are lifting slugs of poor solution to the separating vessel. From the separating vessel, the gaseous phase flows up to the gas heat exchanger and the poor solution flows to the solution heat exchanger. Due to the large difference of the normal boiling temperature between the absorbent and the refrigerant, the presents of absorbent vapor in the gas phase may be neglected. The cooled (not condensed) refrigerant vapor and the poor solution enter the absorber and the absorption process takes place. The rich solution from the absorber flows back into the reservoir.

Power is supplied to three 80W electric heaters by a variable transformer 0-220V. For a quick start of the system, maximum power is supplied to the heaters. Because the fluid at the outlet of the reservoir is saturated or subcooled, the heat supplied is first used to bring the solution to equilibrium and then to begin formation of bubbles. The flow pattern of the working fluids at the bubble pump is shown in *Figure 7-11*. At the beginning, small bubbles are formed (*Figure 7*). The bubbles rise in the tube and are absorbed back to the solution. No pumping action occurs. As the heating process continues the bubbles are becoming larger, (*Figure 8*) and finally they merge and form bullet shape bubbles (slugs) (*Figure 9-10*) at the bottom of the tube, still no pumping action occurs. Pumping action occurs, only when at the bottom of the bubble pump tube turbulence occurs and churn flow is observed (*Figure 11*). The upper part of the bubble pump is a stainless steel tube and the changes of flow regime cannot be observed. At the separation vessel, the separation of the two-phase flow from the bubble pump can be observed. The solution coming out from the upper end of the bubble pumps tube in a pulsing manner depends on the flow regime and the heat flux supplied to the generator. Since the outlet flow from the bubble pump is not continuous, it could be assumed that the flow regime in the upper part of the bubble pump is a slug flow (slugs of liquid separated by large gas bubbles). *Figures 12* present the outlet flow pattern of the weak solution from the bubble pump at various time intervals, starting from the first pumping action (*Figure 12a)* to the full stabilized flow pattern (*Figure 12d)*.

An attempt was made to observe the flow through the stainless steel tube wall using a thermal camera but it was not successful – the tube wall is to thick and it "smears" the isotherms.

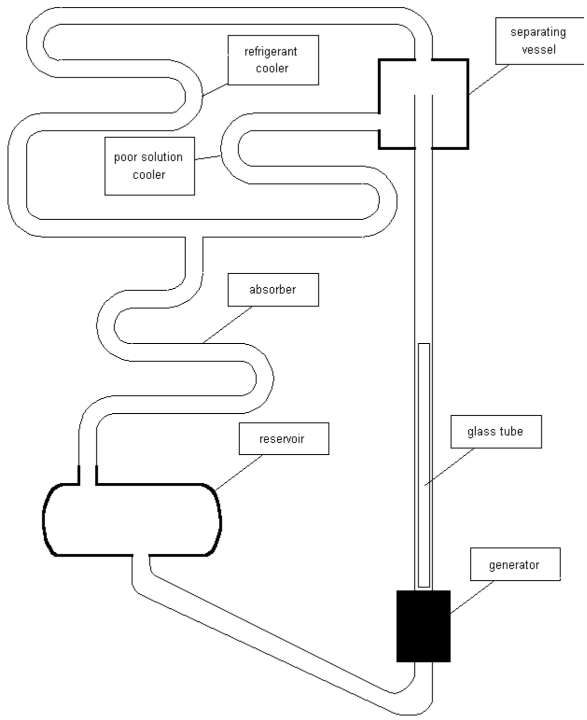

Fig – 6 Schematic illustration of the experimental system

Fig - 7
Bubble flow

Fig - 8.
Formation of big bubbles

Fig - 9.
Slug & bubbly flow

Fig - 10.
Slug flow

Fig - 11
Churn flow

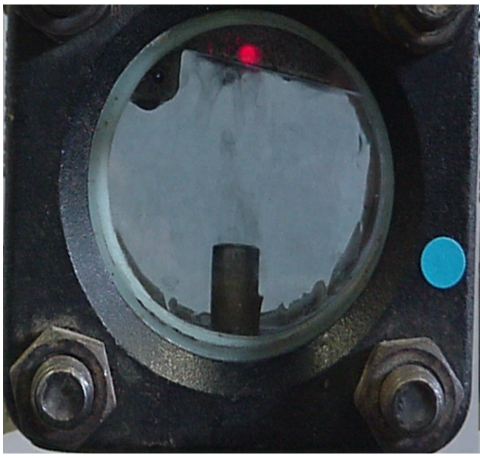

Fig - 12a

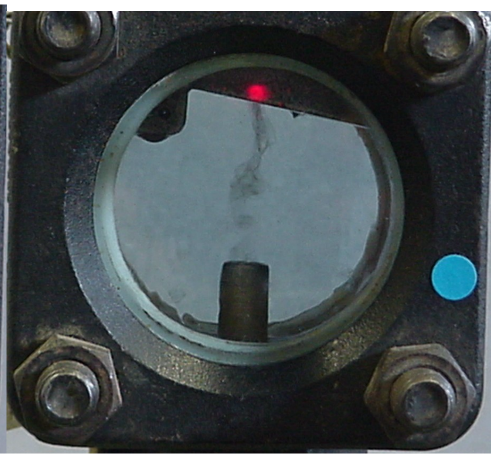

Fig - 12b

Fig - 12c

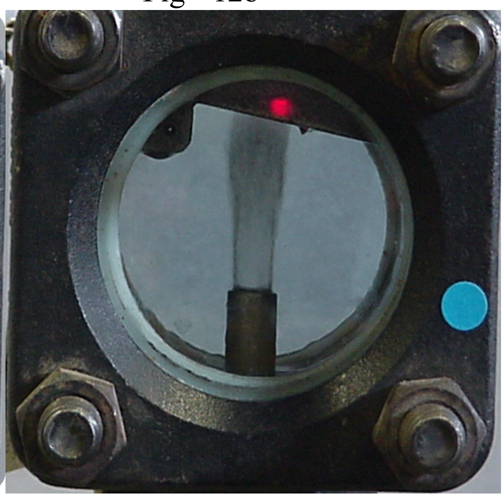

Fig - 12d

Figure 12: Outlet flow pattern of the weak solution from the bubble pump at various time intervals, starting from the first pumping action (*a)* to the full stabilized flow pattern (*d).*

3. Conclusions and discussion

Some primarily tests were made to help us to examine the system. The first test was to try different power levels and to observe the changes in the flow regime. When the power supply decreased from 240W down to a value of about 100W the flow regime did not change but the pumping action was decreased. It could be determined visually by looking into the separating vessel. When the power supply dropped under 100W the pumping action was stopped. The flow regime at the bottom of the bubble pump tube becomes slug flow that could not lift the solution all the way up to the separating vessel. A confirmation to this fact was received by a thermal camera that shows different temperatures of the stainless steel tube. The temperature difference was because no solution could reach the top of the bubble pump.

The thermal camera could not show the flow regime quantitatively but we could observe the change in temperature of the bubble pumps tube wall with the rise of the liquid level in the bubble pump.

3.1 Further research

In the future, study the influence of the bubble pump parameters (such as diameter, length, heat sources, etc.) on the bubble pump performance will be investigated experimentally.

A mathematical model will be developed for the bubble pump performance based on flow pattern correlations. Experiments with various organic fluids will be carried out to determine which fluid is the most suitable for low temperature refrigeration and numeric simulation will be preformed.

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ETUDE DES PERFORMANCES DES POMPES A BULLES POUR LES SYSTEMES DE REFRIGERATION A ABSORPTION PAR DIFFUSION AVEC FLUIDES DE TRAVAIL ORGANIQUES

RESUME

Les performances d'un système de réfrigération à absorption par diffusion dépendent des différents composants du système lesquels sont interconnectes par des circuits de circulation restreints. Les forces motrices de ces circulations sont engendrées par les différences de densité des fluides de travail influences par la gravitation et les apports de chaleur aux fluides de travail a la pompe a bulles. Il est bien connu que le composant critique d'une unité d'absorption par diffusion est la pompe a bulles. Les débits et les caractéristiques thermophysiques des fluides de travail sont principalement influences par la performance de la pompe a bulles.

Dans cette présente étude, les performances de la pompe a bulles avec des fluides de travail organiques ont été obtenues expérimentalement. Une unité d'absorption par diffusion continue à été construite pour examiner l'influence des paramètres de la pompe a bulles sur ses performances.