A REVIEW OF “PUMPLESS” ABSORPTION REFRIGERATION CYCLES

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Abstract

Electrically driven compressors and refrigerant circulating pumps for refrigeration and air conditioning systems are partly responsible for greenhouse gas emissions currently being addressed globally. According to the Intergovernmental Panel on Climate Change (IPCC) the strong warming of the last 50 years cannot be explained by natural climate variations alone, but requires the inclusion of the effects of human emissions leading to a 0.6 K increase in average global surface temperature during the 20th century. The current climate models predict that global temperatures will rise by a further 1.4 to 5.8 K by the end of the 21st century. Therefore, the use of heat powered refrigerators has the potential to produce a significant reduction of damaging emissions, particularly when the driving power comes from renewable or low-grade waste heat sources. However, many conventional cycles are limited in application as they either require additional electrical supply or have low efficiency. This paper describes pumpless absorption systems and introduces a state of art novel stand-alone high efficiency pumpless LiBr-H_2O absorption cycle.

KEYWORDS
Lithium Bromide; Pumpless; Absorption; Diffusion; Regenerator

1. INTRODUCTION

According to the International Institute of Refrigeration, air conditioning and refrigeration produced around 10 % of the total radiative force worldwide in 1993. Approximately 20 % of this was due to direct leakage of greenhouse gas refrigerants from systems [1]. However, 80 % is due to indirect emissions through the release of carbon dioxide in the generation of electricity to power refrigeration systems. In terms of energy used, around 11% of all electricity consumed is for Refrigeration and Air Conditioning (RAC) [2]. However, in the near future the impact of RAC on global warming is predicted to increase above these levels. This is due to the fact that, there has been a big growth in the use of air conditioning in cars. In the UK alone, the number of new cars with air conditioning has increased from 5 % in 1990 to 95 % a decade later [3], whereas a similar but slightly lower growth has been experienced in USA and Canada [4]. The use of air conditioning in cars results in a 12 % increase in fuel consumption and consequent carbon emissions [5] and also, the increased availability of vehicle comfort cooling has led to a change in perception. Therefore, consumers and manufacturers no longer view automobile air conditioning as a luxury but a necessity for every new car. As a result of this change in perception, there is now an increase in demand for the use of air conditioning in domestic applications. These facts clearly suggest that RAC will be at the forefront in terms of cause and solution to the problem of global warming and climate change.

It is therefore essential to consider the exploitation of more sustainable alternatives to mechanical cooling that are available such as making use of the cooling effect from ground water, evaporative cooling, the ground itself and outdoor air. Using any or all of these strategies will contribute to cooling buildings, vehicles and products, hence reducing energy costs.

However, adopting these strategies may not provide a single solution to building cooling requirements due to the fact that their cooling outputs are limited to between 0.030 to 0.050 kW/m^2 [6], in relation to BSRIA empirical cooling requirements of between 0.075 to 0.400 kW/m^2 [7]. Therefore, a conventional response is to supplement the strategies with high COP and low grade heat energy RAC systems capable of meeting the recommended requirements.

Alongside the above low energy cooling strategies, there are vapour compression and absorption refrigeration cycles that have been in use for over a century. Due to the fact that, these systems cannot completely be avoided, their COP should further be improved together with reduction of dependence on energy from fossil fuels. The use of heat powered refrigerators has the potential to produce a significant reduction of damaging emissions, particularly when the driving power comes from low-grade waste or renewable heat sources.

Regardless of their contribution to the green environment, the main draw back to the wider application of conventional absorption cycle refrigerators is their high capital cost, which can be twice that of an equivalent electric vapour compression system. For systems with cooling capacities less than 20 kW the cost of circulation pumps alone tends to inhibit wider application. For this reason, absorption cycle machines have found relatively few applications and therefore, any improvement that would alleviate the need for electrically powered pumps, particularly in small-scale machines, would be of a benefit. This paper reviews the technology of pumpless heat powered cycles, it describes the developments that have taken place and specifically highlights one new cycles that is currently under development.

2. PUMPLESS ABSORPTION REFRIGERATION CYCLES

The term ‘pumpless’ signifies the absence of an electrically driven mechanical pump. Vapour Diffusion Absorption (VDA) systems that are pumpless mainly use thermally driven pumps (bubble pumps) requiring high grade heat for their operation. The need for high grade heat slightly favours the use of conventional absorption refrigerators. Several pumpless refrigeration systems have been developed and researched. The Platen-Munters and the Einstein-Szilard refrigeration cycles more commonly known as “Diffusion Absorption Refrigeration” cycles were the very first systems.

The single pressure pumpless refrigeration cycle that utilised ammonia for the refrigerant and water for the absorbent, was invented in 1928 by Platen and Munters [5]. The cycle consists of bubble pump, generator, absorber, evaporator and condenser with ammonia-water-hydrogen as working fluids. When heat is introduced to the generator, the bubbles of ammonia gas are produced from ammonia-water mixture. The bubbles rise and with it lift the weak ammonia-water solution through the bubble pump lift tube. The strong solution flows back to the absorber while the ammonia vapour progresses to the condenser where it condenses thereby flowing to the evaporator to undergo a vaporization process at low temperature. This is achieved by introducing hydrogen gas that lowers the partial pressure of liquid ammonia hence allowing the refrigeration effect to occur. The mixture of ammonia vapour and hydrogen gas is then sent to the absorber where ammonia vapour is absorbed in water leaving hydrogen gas un-dissolved. While the hydrogen escapes back to the evaporator, the ammonia-water solution flows to the generator for the cycle completion. However, due to its low COP of the order of 0.15 to 0.20 and the generator’s high working temperature requirement of about 150 °C [5], the DAR system that had the potential of attracting a wider application was mostly used in camping vans and some hotels, driven by either electricity or gas.

At around same time Einstein and Szilard [5] invented another single pressure thermally driven refrigeration cycle (Fig. 2) that used butane instead of ammonia, water and ammonia instead of hydrogen as working fluids and the cycle was patented in UK, USA and German in between 1927 and 1933. The Einstein cycle uses a pressure equalizing absorbate fluid instead of an inert gas, butane being a refrigerant, water as an absorbent and ammonia as a pressure equalizing fluid. The generator, bubble pump and evaporator are of the same configurations as those in Platen-Munters cycle (Fig. 1), however, with the condenser and absorber combined into a single unit. The heat is introduced in the generator containing weak ammonia in water solution and ammonia gas generated is passed into the evaporator via a pre-cooler. The remaining solution is further heated in the tube enhancing the formation of vapour which acts as a bubble pump by lifting the liquid to the reservoir. The extra ammonia gas generated during the lifting of the solution is passed on to the absorber. Under the influence of gravity, the hot weak ammonia in water solution is passed into the absorber via a solution heat exchanger followed by a cooling jacket into which the heat is dumped. The gaseous mixture of ammonia and butane from the evaporator comes in intimate contact with the solution from the generator at this point within the absorber. The ammonia gas is absorbed into a solution by water thus

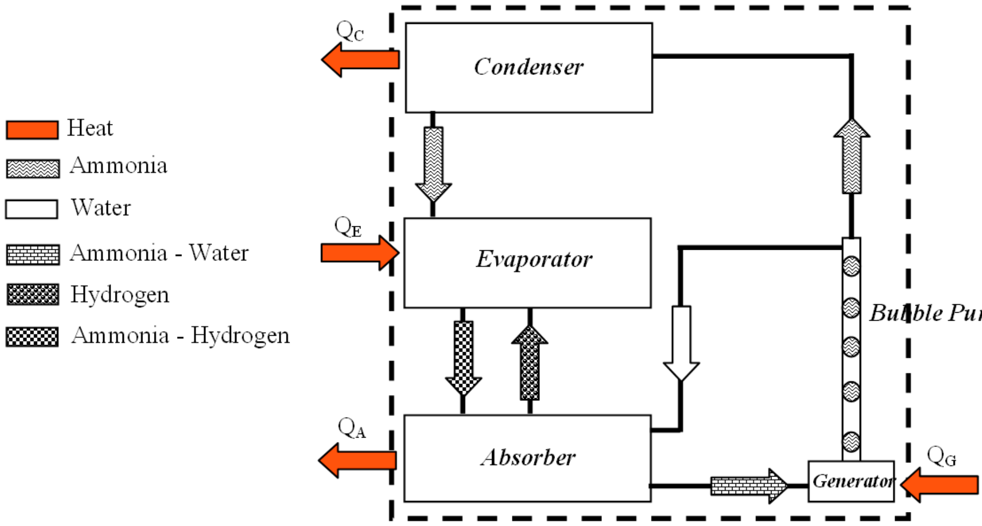

Fig. 1. The Platen-Munters cycle [5]

freeing butane gas which is quite insoluble in water from the gaseous mixture. The pressure within the absorber is substantially dictated by the refrigerant butane, which therefore will be the pressure sufficient to cause the liquefaction of butane at the temperature maintained by the cooling water in the jacket. Since the specific gravity of liquefied butane is lower than that of ammonia in water solution, stratification will occur, hence resulting in liquid butane floating above the ammonia in water solution. Under the direct influence of head h_1 and h_2, the cool ammonia in water solution will be passed to the generator via a solution heat exchanger and liquid butane to the evaporator respectively.

These variations in system configurations and working fluids account for an improved COP of 0.25 in comparison with that of $0.15 \leq COP \leq 0.2$ achieved in an original Platen & Munters cycle.

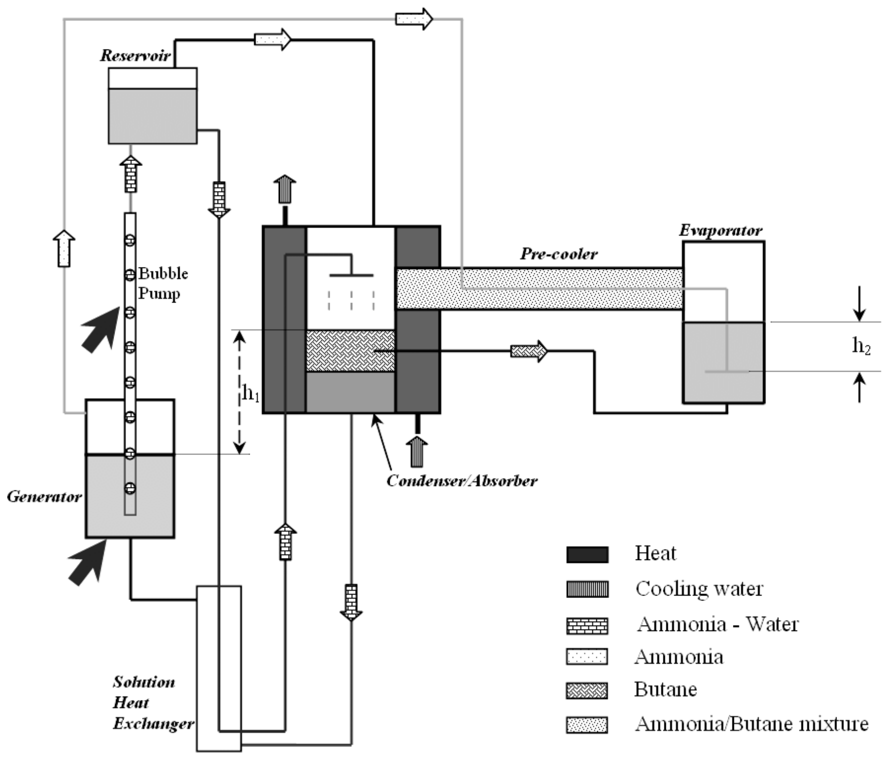

Fig. 2. The re-drawn Einstein DAR Cycle

In order to develop diffusion-absorption systems by improving their coefficient of performance and to encourage their usage while attracting potential investors in the technology, researchers have suggested improvements to the original inventions.

Several systems have been developed based on the original Platen-Munters diffusion absorption refrigeration cycle (Fig. 1) each with one or a combination of the following variations

- The type of flow inside the evaporator and the absorber may be counter flow or parallel flow.
- The gas heat exchanger may be attached to the evaporator
- The weak solution may flow in the shell or in the tube of the solution heat exchanger.
- The condensed refrigerant may be sub-cooled
- The types of working fluids may vary
- The pressure equalizing fluid may be other than inert gases
- The pumping mechanism may be other than bubble pump which is used by most conventional pumpless systems as reviewed and described below.

Researchers summarized in table 1 below carried out a design analysis in order to improve the COP based on the Platen & Munters cycle with the variation of only one or a combination of parameters. Among these were Narayankhedkar and Maiya [9] who investigated the working fluids of the original system by varying the concentration of the strong solution and the charge pressure of inert gases with the generator’s working temperature kept at above 150 °C. The conclusion of their investigation was that increase in concentration decreases the generator’s working temperature, increasing the evaporator’s temperature. It was also established that an excessive inert gas charge pressure will reduce the refrigerating effect and as a result affect the overall system COP.

Other researchers were specifically interested in investigating the effect of an inert gas as one of the three working fluids on the cycle’s COP. Pongsid et al [8] used the same principles as those of Platen – Munters cycle with the exception that their system was of a different configuration with hydrogen/helium as one of the working fluids. Besides other parameters discussed below, the system has three working fluids with known concentrations i.e. ammonia 35 %, water 65 % concentration and initially hydrogen. To further investigate the characteristics of the system, variations of some operating parameters were considered. Among these parameters, helium was selected as an auxiliary gas for lowering the partial pressure of liquid ammonia instead of hydrogen mainly for safety reasons. The solution in the generator was heated to 180 °C unlike the Platen - Munters cycle where the working temperature in the generator was not specified. In addition the ammonia vapour leaving the bubble pump, usually containing a quantity of water, was purified at the additional rectifier (Fig.3) and cooled to 70 °C.

Moreover, the study carried out by Zohar et al [10] showed that helium as a working fluid was superior to hydrogen as the inert gas and therefore the coefficient of performance of a DAR unit working with helium was higher by up to 40 % than a cycle working with hydrogen.

Some of the authors considered replacing only ammonia as a refrigerant with butane based refrigerants while maintaining the absorbent and pressure equalising fluids as the per original cycle. Delano also investigated in conjunction with other variations the use of butane as one of the three working fluids instead of ammonia, and a COP of 0.4 [5] was reported.

In order to investigate further the significance of the working fluids on the cycle’s COP, some authors have considered replacing the three common original working fluids with completely different refrigerants. Together with other variations, the authors Saravanan & Maiya [11] and Eames & Wu [12] considered and used in their refrigeration cycles, H_2O-LiBr as a working fluid instead ammonia - water - hydrogen and they reported higher coefficients of performance. However, the refrigerant was being used in conjunction with other parameters that are summarised in table 1.

Two authors reported the use of inorganic refrigerants as working fluids instead of ammonia - water - hydrogen and these were used in conjunction with the variation of other parameters. These were Koyfman et al who used refrigerant dimethylacetamide and R22 with generator’s operating temperature between 50 and 90 °C and Karthikeyan et al who used refrigerants R22-DMA or R22-DMF & R22-DMETrEG with generator’s operating temperature at around130°C [13]. In both cases, higher COP was reported in comparison with the original system.

Based on the results reported by different researchers, it was established that the property variation or complete replacement of only working fluid(s) contributed little or no improvements in COP. It was therefore important for some researchers to consider the variation of working fluids in conjunction with addition of a heat exchanger for higher efficiencies.

Pongsid et al added to the original system a solution heat exchanger (Fig. 3), the main purpose being to recover heat from the solution flowing to the absorber hence minimising the amount of heat input to the generator and therefore increasing the COP of the system. Despite these changes, the COP at a generator operating temperature of 180 °C was found to be around in the range of 0.09 to 0.15 [13], which is slightly lower than that of the original cycle.

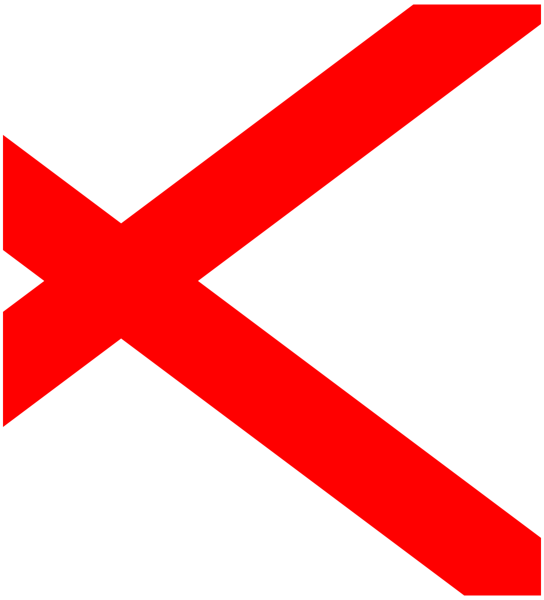

Fig. 3. A schematic Diagram of the DAR cycle by Pongsid et al.

Saravanan and Maiya also added to the original system a solution heat exchanger (Fig. 4) with the intention of increasing the system’s efficiency by recovering heat from a solution; and therefore decreasing the amount of heat input to the generator. However in conjunction with another parameter considered and discussed above, a COP of 0.5 at a generator operating temperature of 85 °C was reported [11].

Karthikeyan et al [13] considered and added to their transfer tank operated vapour absorption refrigeration cycle a solution heat exchanger, the purpose being also to minimise the generator’s heat input hence increasing the COP.

The application and addition of heat exchangers was further investigated by a number of authors and among these, Chen et al considered a different approach by adding a solution heat exchanger and an auxiliary gas heat exchanger attached to the evaporator. Although a higher generator’s working temperature of around 210 °C was used, Chen et al achieved a system COP of around 0.35 [14], which was higher than that experienced in the original cycle. The authors Zohar et al also added to the system a solution heat exchanger and a gas heat exchanger attached to the evaporator in a shell-and-tube configuration (Fig. 5). Despite this and other changes made, at the generator’s operating temperature in the range of 195 to 205 °C and a COP of the order of 0.09 to 0.15 [10] which is slightly lower contrary to expectations was reported.

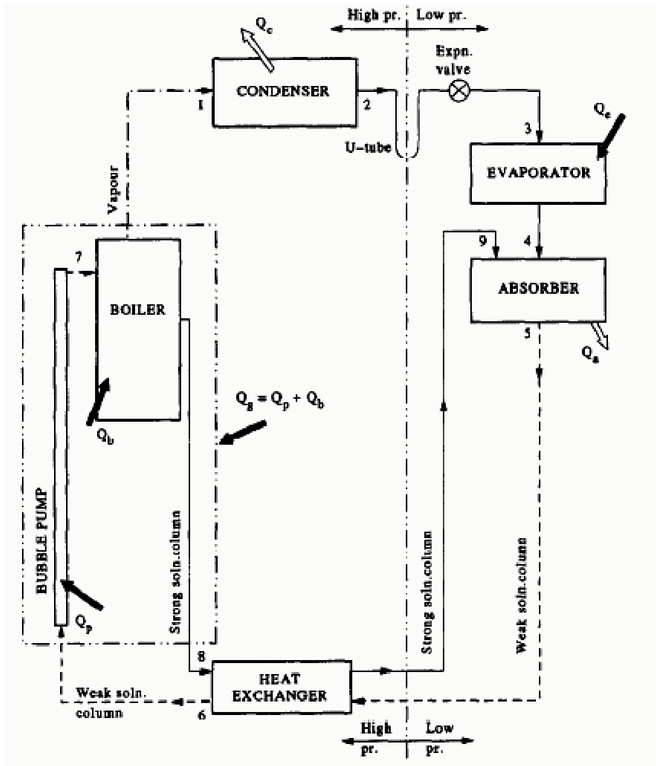

Fig. 4. A schematic Diagram of a Pumpless VAR cycle

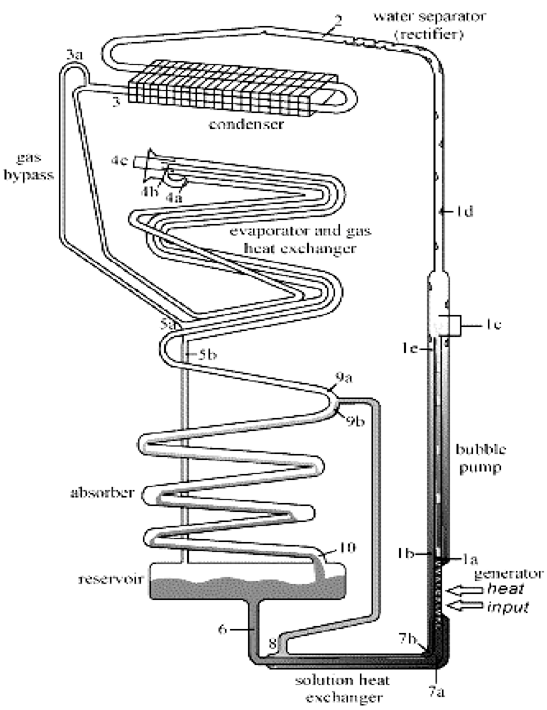

Fig. 5. A schematic Diagram of the DAR cycle

Further variations were considered and Delano considered adding two regenerative heat exchangers to the Einstein and Szilard cycle, the purpose being to minimise the generator's heat input hence increasing the COP of the system [5].

Amongst other efforts made to improve the DAR COP was the variation of the working fluids and pumping mechanism. It was established by Koyfman et al [16] that the actual operating conditions of a bubble pump were not simulated well by previous experiments carried out by Pfaff et al [15], Delano [5] and White [17]. The main differences between a real system and those of theirs being;

- The experimental system used by both Pfaff et al, Delano did not operate continuously.
- Both Delano and White did not use practical working fluids and the system was open to the atmosphere.
- The experimental system presented by White was built as an air-lift pump. The flow was induced by high pressure air source instead of boiling process.

To simulate the actual operating conditions of a bubble pump, a continuous system was built. The design allowed the bubble pump to operate continuously while keeping the pressure of the system at the desired level and the maximum COP achieved was 0.35 [16]. Although the COP achieved was higher than that of the original cycle, the refrigerant R22 used in the experiment is being phased out and therefore the result achieved will only remain experimental and thus the system can no longer be considered as a viable refrigeration solution.

Some researchers attempted to vary three different parameters at one time and among those who worked on the improved version of the original DAR cycle by Platen & Munters was Delano in 1998. Delano performed a design analysis using the same approach as that of Einstein and Szilard for his experiment; however with the addition of an air lift instead of vapour lift pump in conjunction with other parameters as shown in Fig. 6. The changes made lead to a high COP of 0.4 [5] which was almost double that achieved in Einstein and Szilard cycle and much higher than that of the original Platen & Munters cycle.

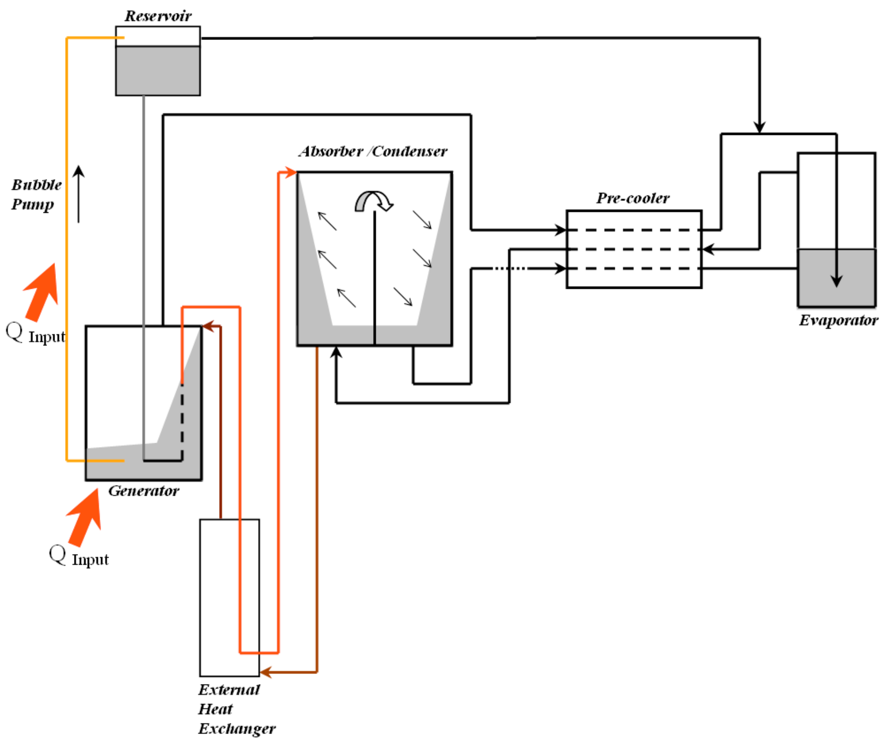

Fig. 6. DAR Cycle by Delano (1998) [5]

Unlike all but one of the conventional DAR cycles summarized in table 1, the system in Fig. 7 by Eames and Wu is unique and does not employ the idea of a bubble pump. The working fluid in the system being H_2O-LiBr is intermittently pumped from the generator to the absorber by pressure difference between them that is achieved by controlling the opening and closing of the valves V_0 and V_1 which are always closed during the pumping phase. As heat continues to be supplied to the generator, it causes the vapour pressure to rise till it is high enough to push the concentrated solution up the fluid transfer tube into the absorber. At the end of the pumping phase, the valves V_0 and V_1 are opened hence the system entering a desorption phase where the generator pressure falls until it equals the condenser pressure and the weak solution flows from the absorber to the generator by virtue of its hydrostatic head. Due to greater pressure difference, the flow of water vapour from the generator to the condenser will be more rapid and the energy stored in the solution will accelerate the desorption process when valve V_0 is opened. This phase stops when the solution level equals that at which the pumping phase started hence completing the solution circulation. Although the circulation of the working fluid is intermittent, the system can still provide continuous cooling, as the absorption process is not interrupted and the desorption process does not stop since the close of the valve V_0 does not stop the water vapour evolving from the solution in the generator. Therefore, apart from a slightly higher solution temperature required during the pumping phase in the generator, the overall performance of absorption and desorption in this system should be similar to that in the conventional absorption system of around 0.62 hence by far exceeding that of the original cycle [12]. However, electric power might be required in the operation of the two valves V_0 and V_1 hence diminishing the possibility of employing the system where electricity is not available.

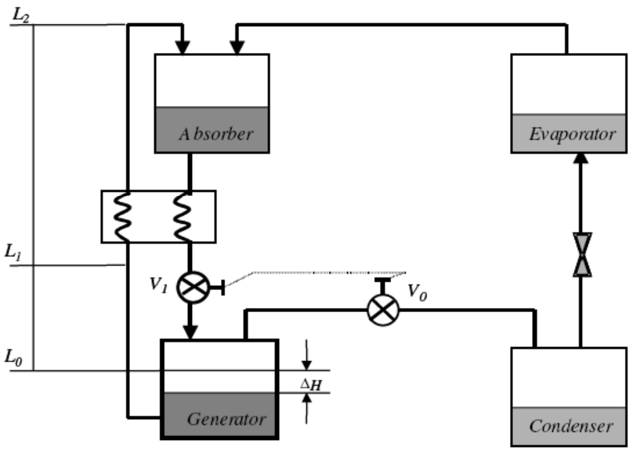

Fig. 7. Schematic diagram of a Valve Operated Absorption Refrigerator [12]

A transfer tank operated vapour absorption cycle by Karthikeyan et al summarized in the table below is another unique cycle that has the combination of three parameters variations. Together with other parameters that have been discussed above, the cycle uses a transfer tank instead of bubble pump for fluid circulation and the system’s COP achieved was found to be of around 0.65 [13] which is considered to be very high in comparison with most Platen & Munters based DAR systems that have been considered. Although the COP achieved was higher than that of most DAR cycles, the R22 based refrigerants used in the experiment are being phased out and therefore the result achieved will be of academic interest and the system may not be considered as a viable future refrigeration solution.

The novel single-effect pumpless DAR cycle by Paurine et al [17] also uses LiBr-H_2O as a working fluid. However, unlike all the systems discussed, this does employ neither bubble nor electrically powered mechanical pump instead the pumping mechanism is supplemented by the use of gravitational force in conjunction with physical and chemical properties of the fluids within the system. These processes are enhanced by the use of low grade waste heat from a combined heat and power (CHP) or renewable heat sources such as solar energy and geothermal.

The solution in Fig. 8 is constantly circulated between the absorber and generator through pipe 1. The direction of the flow is determined by the pressure difference between the generator and absorber and the hydrostatic head created by the difference in the solution levels in the two vessels. By positioning the absorber above the generator so that the vertical distance between the liquid levels in the two vessels is sufficient to maintain the necessary pressure difference, the flow of weak LiBr-H_2O from the absorber to generator by aid of gravity is achieved. This vertical distance depends upon the ambient temperature, which controls the pressure in the condenser and thereby the pressure in the generator.

At the start of an operating cycle the solution will flow from the absorber to the generator due to gravity causing the liquid level in the generator to rise. After a certain time a float ‘F’ positioned in the generator engages with a stop (S1). Further increase in level will cause valve (V1) to lift until it opens the steam transfer pipe 5 to the condenser. With valve (V1) opened and the heat input rate to the generator held constant, the steam flow between the generator and condenser will now be established resulting to the solution level falling. After a time, with the solution level in the generator still falling, the float (F) will engage with lower stop (S2) causing valve (V1) to completely shut off the steam transfer pipe 5. The high pressure as a result of trapped vapour will cause the concentrated solution in the generator vessel to flow to the absorber through pipes 1, 2 and 3 with the aid of a diverter valve V2. The pressure in the generator vessel throughout this stage of the operating cycle will be greater than that in the condenser and therefore, the valve V1 will be held in position by this pressure difference. The strong LiBr-H_2O in the absorber will absorb water vapour from the evaporator and hence the hydrostatic head will be created by the difference in the solution levels in the generator and absorber as indicated in Fig. 8. The absorber’s vapour pressure and the hydrostatic head will be just enough to overcome the pressure in the generator and therefore allowing the solution will flow under gravity from the absorber to the generator. In this way the concentration of the solution in the absorber is maintained at the required value. Once the liquid solution level has increased sufficiently the float bearing down on the lower stop (S1) will cause valve V1 to be pulled off its seat hence re-establishing the flow of steam from generator to the condenser.

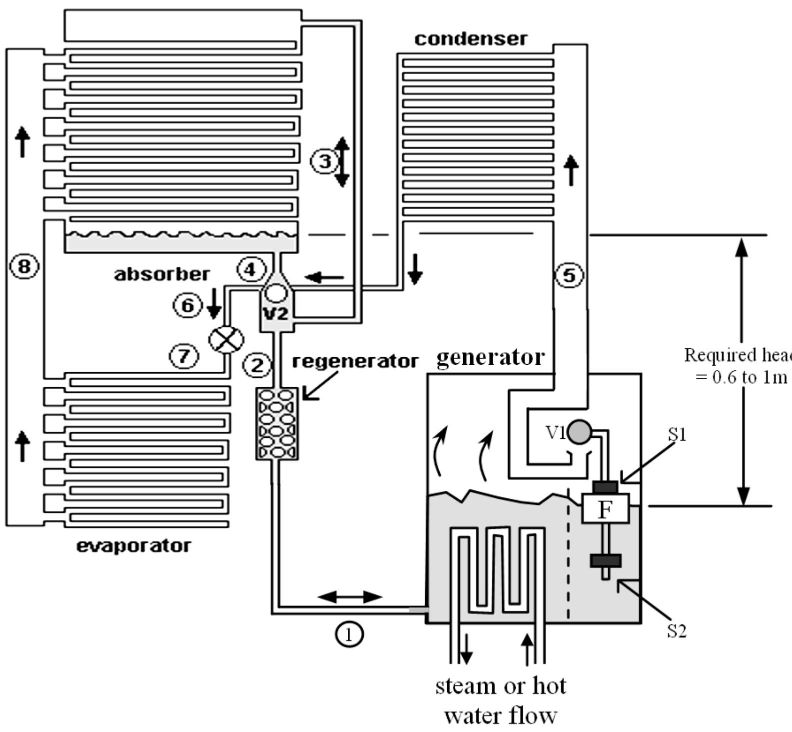

Fig. 8. A pumpless single effect VAR cycle schematic diagram

Fig. 8 also shows a regenerative heat exchanger in the solution pipeline between the generator and absorber. The purpose of this is to reduce the amount of sensible heating and cooling required for the solution at the generator and absorber, respectively. The sensible heating and cooling components produce the main inefficiencies within the operating cycle. Furthermore, because the generator temperature needs to be raised along with the solution temperature, when transferring liquid back to the absorber, it is important that the thermal mass of the generator be kept as small as is practicable to reduce its sensible heating component. Although the solution flow between the absorber and generator is intermittent, with a regular cycling period, the capacitance effects of the system will ensure that the refrigerating effect will be constant. The evaporator in Fig. 8 consists of a bank of externally finned tubes. Process air is cooled directly by the tubes that contain refrigerant water evaporating at absolute pressures less than 1 kPa. Because of the low vapour pressures it is necessary to create and maintain a thin liquid film over the inside of the tubes in order to promote evaporation. To achieve this, the refrigerant water enters the top of the evaporator coil through a metering valve from where it flows downwards through the series of horizontal tubes. A weir, positioned at the outlet end of each evaporator tube, ensures that a quantity of water is held back, ensuring that the tube inner wall, lined with an absorbent material, is always wetted. Excess water flows over the weir and drains downward to the next tube and so on. Water vapour generated through evaporation then flows to the vertical manifold, shown to the left of the evaporator in Fig. 8, from where it passes to the absorber tubes. The number of evaporator tubes is chosen so that their total water storage capacity, behind the weirs, exceeds the total volume of liquid water in the system. By doing this the need for a circulation pump is avoided. It should also be pointed out that the system is self-compensating. If the quantity of water stored within the evaporator increases then the concentration of the lithium-bromide in solution in the absorber will also increase. This in turn will cause the vapour pressure in the evaporator to fall and the evaporation rate to increase, thus tending to reduce the quantity of water in the evaporator. Once again the need for a refrigerant water circulation pump is removed.

The absorber used in this novel system will be constructed in a similar way to the evaporator. Like the evaporator, for the absorber to work efficiently it is necessary to create and maintain a thin absorbent solution film over the inner walls of the tubes. To help this process the tubes will be lined with an absorbent mat. These researchers carried out a range of investigation in order to improve the COP based on the two original inventions by Platen & Munters [5] and Einstein & Szilard [5] with the variation of one or a combination of parameters. The common variations are illustrated in the summary Table 1.

Table 1. Pumpless absorption refrigeration cycles

DAR Systems Names	**Platen-Munters System Compared to:-**	**Generator Working Temp. (°C)**	**COP**	**Variations**
Einstein Refrigeration Cycle	Einstein and Szilard, 1928	-	0.25	**Working fluids:** -Butane instead of ammonia -Ammonia instead of hydrogen
Triple fluid VAR	Narayankhedkar & Maiya, 1985	Greater than 150	-	**Working fluids:** -Both hydrogen and helium used -Inert gas pressure varied -Concentration of strong solution varied
Original DAR	Razi et al	-	0.19	**Working fluids:** Iso-butane instead of ammonia
			0.13	**Working fluids:** n-butane instead of ammonia
	Rojey, 1984	-	-	**Working fluids:** Butane - water - carbon dioxide instead of NH_3 - H_2O - H_2
DAR	Pongsid et al, 2002	180	From 0.09 to 0.15	**Working fluids:** Inert gas was H_2 then He instead of H_2 **Heat exchangers:** Solution heat exchanger added
Two-Fluid Pumpless Continuous VAR	Saravanan & Maiya, 2003	85	0.50	**Working fluids:** H_2O-LiBr instead of NH_3 - H_2O - H_2. **Heat exchangers:-** Solution heat exchanger added
Platen-Munters Diffusion absorption cycle	Chen et al, 1996	Less than 210	Less than 0.35	**Working fluids:** Ammonia - water - hydrogen **Heat exchangers:** Auxiliary gas heat exchanger attached to the evaporator + solution heat exchanger

Platen-Munters Diffusion absorption cycle	Zohar et al, 2004	From 195 to 205	From 0.09 to 0.15	**Working fluids:** Inert gas was H_2 then He instead of H_2. **Heat exchangers:** Gas heat exchanger attached to the evaporator in a shell-and-tube configuration + solution heat exchange
Valve Operated Absorption Refrigerator	Eames & Wu , 2002	Less than 100	From 0.61 to 0.64	**Working fluids:** H_2O-LiBr instead of NH_3 - H_2O - H_2 **Pump type:** Instead of a bubble pump, pumping is achieved by pressure difference between generator & absorber & controlling of valves
Einstein Cycle.	Delano, 1998	-	0.40	**Working fluids:** -Butane instead of ammonia -Ammonia instead of hydrogen **Heat exchangers:** Addition of two regenerative heat exchanger to the original Einstein cycle **Pump type:** Used air lift instead of vapour lift pump
Pumpless DAR cycle.	Paurine et al, 2006	85	0.6 to 0.72	**Working fluids:** H_2O-LiBr instead of NH_3 - H_2O - H_2 **Pump type:** Instead of a bubble pump, circulating of the -refrigerant is achieved by vapour pressure in the generator -absorbent is achieved by a pressure difference between generator & absorber

These diffusion absorption systems always require a relatively high temperature heat source to drive the bubble pump used to circulate the solution between the generator and absorber. The presence of the balance vapour results in relatively low COP values, which are usually in the order of 0.30 to 0.64. Therefore, it is also the reason the paper reviews the use of a “novel low grade heat energy pumpless LiBr-H_2O absorption refrigeration cycle” concept to supersede all the existing systems.

4. RESEARCH OBJECTIVES

The pumpless DAR systems previously modelled as summarised in table 1 shown to have the potential to operate with a COP approaching that of conventional absorption chillers. To demonstrate the system further the following is proposed:

- To develop and test a novel experimental apparatus of a pumpless absorption refrigerator.
- To develop a novel computer model of the system that would simulate the operation and performance of the system.
- To validate the model based upon experimental results and investigate optimum characteristics of the novel pumpless design.
- To evaluate exploitation opportunities and disseminate the research.

5. CONCLUSIONS

Most of the DAR systems that have been previously developed and investigated share an environmentally friendly aspect of using natural working fluids. However, the low coefficients of performance were reported and hence making the technology less favourable in comparison with conventional vapour compression systems. The novel system described above can be driven by low-grade heat, at reasonably low temperatures of the order of 80 to 90 ºC and with COP theoretical values of the order of 0.60 to 0.72, making it more efficient and compact than other diffusion absorption refrigeration cycles for the same cooling rate. The novel low energy pumpless absorption cycle will be low in energy use and unlike vapour compression systems, will not pose a risk of hazardous refrigerant leakage; since, it will use water and lithium bromide solution which is a natural working fluid. Moreover, the capital cost for the novel pumpless system described above will be significantly less than that of a conventional absorption cycle machine.

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