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Development of a thermo-gravity pumping mechanism for circulating the working fluids in a novel LiBr–H_2O vapour absorption refrigeration (VAR) system

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ABSTRACT

VAR systems are heat powered refrigeration or air conditioning systems that can be operated without the use of mechanical or electrical energy. However, inefficiencies due to the high operating temperatures and/or additional electrical energy for operating mechanical pumps as well as high capital cost hinder the extensive use of these systems. The development of a novel VAR system incorporating a thermo-gravity pump and with reduced cost is the subject of this paper. An experimental apparatus consisting of a single stage LiBr–H_2O VAR system is described. The apparatus incorporates two novel thermally activated valves for aiding circulation of system working fluids and a novel regenerative heat exchanger for improving the generator's and absorber's effectiveness. This paper describes the design and operation of a thermo-gravity pump also referred to as thermally activated pumping mechanism for circulating the refrigerant $H_2O_{(l)}$, water vapour $H_2O_{(v)}$, weak and strong LiBr–$H_2O_{(l)}$ inside a novel VAR system.

1. Introduction

The rising demand for use of vapour compression systems represents a growing fraction of overall energy consumption due to refrigeration and air conditioning systems. Such systems contribute significantly to emissions with both direct and indirect environmental impacts. Therefore, the use of alternative systems such as diffusion and vapour absorption refrigeration (DAR and VAR) that use sources of energy other than fossil fuels has the potential to reduce carbon emissions. Particularly, the use of DAR and VAR systems that operate without using electromechanical pumps and instead with thermally activated pumping mechanisms for circulation of working fluids. These systems convert thermal energy into mechanical work (in lifting the working fluids) and like all other engines, the process is subject to irreversibilities. An inventory of VAR and DAR systems with thermo-gravity pumps that have been previously considered was established. The systems were investigated and reported to have low coefficients of performance (COPs) due to high operating temperatures. The researchers of these systems carried out the investigations with the intention of improving systems' COPs based on the two original DAR systems by Platen & Munters and Einstein & Szilard [2] with the variation of one or a combination of parameters. The common variations are illustrated in Table 1 below.

For these VAR and DAR systems to provide practical cooling outputs, they must be powered by high-grade thermal energy at temperatures significantly higher than those of the heat sinks so as to reduce the physical sizes of the pumping mechanism. This results in significant cost for the system which limits application. This paper describes a novel VAR system that overcomes these limitations and specifically focuses on development of key components that facilitate the pumping mechanism. The system's pumping method described in this paper was based upon an idea that was originally envisioned by Eames and for that, it automates the valve operated absorption refrigerator described by Eames & Wu [3]. The aim of developing the key components for facilitating the pumping mechanism is to enable the system to operate with high efficiency at low operating temperatures.

2. Operational description of a novel VAR system

The novel VAR system shown in Fig. 1 below is similar to other VAR and DAR systems listed in Table 1 above; in that, it consists of four main components i.e. generator, evaporator, condenser and absorber. However, the generator and absorber include special valves V1 and V2 that are fundamental for circulating the working fluids. In addition, a packed bed regenerative heat exchanger

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Table 1
VAR and DAR cycles incorporating thermally driven circulation pumps.

DAR systems names	Platen–Munters system compared to	Generator working temp. (°C)	COP	Variations
Einstein refrigeration cycle [4]	Einstein and Szilard, 1928	–	0.25	Working fluids ➢Butane instead of ammonia ➢Ammonia instead of hydrogen
Original DAR [7,8]	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
Triple fluid VAR [5]	Narayankhedkar & Maiya, 1985	Greater than 150	–	Working fluids ➢Both hydrogen and helium used ➢Inert gas pressure varied ➢Concentration of strong solution varied
Platen–Munters diffusion absorption cycle [1]	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
Einstein cycle [2]	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
DAR [6]	Pongsid & Aphornratana, 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
Valve operated absorption refrigerator [3]	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
Two-fluid pumpless continuous VAR [9]	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 [10]	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

(regenerator) is used instead of a conventional solution or gas heat exchanger. It should be noted that, the manner in which the novel system converts thermal energy into mechanical energy for lifting the LiBr–H_2O, is novel.

Contrary to the VAR and DAR systems detailed in Table 1 above, the novel system employs neither bubble nor electromechanical 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 a low-grade heat source at temperatures of the order of 75 to 85 °C.

In conventional absorption refrigerators, the solution is constantly circulated between the absorbers and generators by means of mechanical pumps. In the new system shown in Fig. 1 below, the solution is transferred between the two vessels through Pipes 1, 2, 3 and 4.

The direction of flow is determined by the pressure difference between the generator and absorber and the hydrostatic head