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Experimental studies on absorption heat transformer coupled distillation system

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ABSTRACT

A Vapor Absorption Heat Transformer (VAHT) working with water–lithium bromide (LiBr) solution, coupled with a seawater distillation system of 5 kg/h distilled water capacity has been tested to evaluate its performance. Operating parameters such as the heat source, condenser, evaporation temperatures, gross temperature lift and feed water flow rate were varied. The influence of these operating parameters on the performance parameters namely the coefficient of performance (COP), absorber heat load, distillate flow rate, recovery ratio and overall specific thermal energy consumption (OSTEC) was obtained. The results of the operation of the laboratory scale pilot unit shows, that for heat delivery temperatures up to 100 °C, temperature lifts up to 20 °C could be realized. For this system, the COP of 0.3 to 0.38 was obtained with the maximum distillate flow rate of 4.1 kg/h and a recovery ratio of 0.17 to 0.23, under tested conditions. The distilled water obtained was found to be within the permissible limits of properties and dissolved salts and solids for potable water.

1. Introduction

Water is an important natural resource for human beings. The scarcity of good quality drinking water exists in many regions of the world, due to environmental issues such as global warming, pollution of air and land, and emission of green house gasses, the yearly rainfall which is Earth's main fresh water supply, has been mal-distributed. Moreover, the demand for potable water has increased significantly due to the increase in the world's population and rapid economic development. According to the World Health Organization (WHO), at least one billion people do not have access to clean and fresh water, and about 41% of the Earth's population lives in the water-stressed areas, and this depressed population may climb to 3.5 billion by the year 2025. Hence, there is urgency for new and sustainable sources and the associated technologies for practical and economical solution to produce potable water.

An inexhaustible source of raw water for the production of drinking water is seawater which needs to be desalinated. Desalination processes can be divided into two major groups: the first group is a heat-driven process (distillation) such as multi-stage flashing (MSF), multiple effect distillation (MED) and solar distillation. The second method employs electric power driven processes that include freezing, mechanical vapor compression, electro-dialysis and reverse osmosis. Heat driven thermal distillation processes require energy input in the form of heat because the main requirement is to supply the latent heat of evaporation of water. When the energy required for distillation is consumed from conventional fossil fuels, it leads to thermal pollution and global warming.

At the same time, many industrial sectors such as power, chemicals, food, petroleum and process industries consume large amounts of energy in the form of heat, and release waste heat at comparatively low temperatures. A part of this waste heat can be upgraded to higher levels by using vapor absorption heat transformers or temperature boosters. Heat transformer is a type of heat pump of great interest from the energy point of view. It delivers part of the waste heat input at a higher temperature and the rest at a lower temperature. Waste heat and renewable energy sources such as solar thermal energy or geothermal energy can be used as heat input for heat transformer while the high grade thermal energy delivered by the heat transformer can be used as heat source for water desalination. The use of water–lithium bromide as a working fluid combination is preferred in absorption heat transformers, because water is an excellent refrigerant with low viscosity and high latent heat. Lithium bromide is a good absorbent with negligible vapor pressure, the affinity between water and lithium bromide is very high, and the mixture is safe and environmental friendly.

Risto Saari [1] has proposed seawater desalination using waste heat, and found that if waste heat is available at relatively high temperatures, 50 °C higher than the ambient, its utilization is more competitive than using a first-rate energy. George and Srinivasa Murthy [2] have conducted experiments on a 3 kW R21-DMF vapor absorption heat transformer, to study the influence of the operating source and condenser temperatures on performance. COPs in the range of 0.2–0.35 and heat delivery temperatures and temperature lifts up to 85 °C and 20 °C, respectively, were achieved. A 10 kW experimental absorption heat transformer operating with self

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circulation was tested by Abrahamsson et al. [3]. The self-circulation was obtained according to the thermosyphon principle. A reference heat transformer plant, delivering 100 kW, has been designed and installed in a major pulp and paper mill. The plant operation data obtained under real industrial conditions have been presented.

Barragan et al. [4] have presented the experimental results of an absorption heat transformer with a water/calcium chloride working pair. The highest experimental gross temperature lift obtained was 19 °C at an absorber temperature of 84 °C. The coefficient of performance of the order of 0.45 was obtained. Rivera et al. [5] have evaluated a single stage heat transformer powered by a solar pond. Gross temperature lifts as high as 44 °C were obtained. The maximum temperature of the useful heat produced by the heat transformer operating with the water/lithium bromide mixture was 124 °C. The maximum coefficient of performance for the unit was 0.16.

Dominique Alonso et al. [6] have presented the operation of a laboratory scale innovative absorption heat transformer, using partially miscible working mixtures. A temperature lift of 8 °C with a thermal efficiency of 30% to 40% has been reported. Ma et al. [7] have reported the test results of the first industrial-scale absorption heat transformer equipment, to recover the waste heat released from the mixture of steam and organic vapor at 98 °C in the coacervation section of a synthetic rubber plant. The recovered heat has been used to heat hot water from 95 to 110 °C, feeding back to the coagulator as the supplementary heating source. The results showed that, when the mean COP was 0.47, while a gross temperature lift of 25 °C is achieved.

Faisal Mandani et al. [8] have presented a new configuration of a single effect evaporation process combined with water–lithium bromide solution absorption heat pump. The results showed that the system performance at higher operating temperatures was attractive. Huicochea et al. [9] have presented the results of the experimental tests applied to a portable water purification system integrated with a heat transformer, where the low quality waste heat is simulated, and water–lithium bromide was used as the working solution. The system worked well with waste heat temperatures in the range of 68–78 °C.

Bourouis et al. [10] have simulated numerically a water purification system integrated with a single stage heat transformer with LiBr + LiI + $LiNO_3$ + LiCl working fluid combination. An absorber operating at 100 °C, waste heat supplied to the generator and the evaporator operating at temperatures ranging from 60 to 80 °C and a heat sink cooling the condenser operating at a temperature between 10 and 40 °C were considered for the analysis.

Siqueiros and Romero [11] have proposed a system to increase the COP of a heat transformer used in water purification system. This was done by increasing the original heat source temperature when recycling the steam latent heat from the purification process. Absorber temperatures from 104 to 115 °C for atmospheric pressure water purification were obtained from the heat transformer. The results showed that the proposed system was capable of increasing the original value of COP to more than 120%. The proposed system was also practical for any other distillation system integrated to a heat transformer and was independent of the working fluid–absorbent pair.

Hernandez et al. [12] have proposed a predictive model for a water purification process integrated with an absorption heat transformer, using an artificial neural network, to obtain on-line predictions of the coefficient of performance (COP). This model takes into account the input and output temperatures for each one of the four components (absorber, generator, evaporator, and condenser), as well as two pressure parameters of the absorption heat transformer and LiBr + H_2O concentrations. The developed models can be used for a reliable on-line state estimation and control of a water purification process integrated with an absorption heat transformer. Romero and Martinez [13] have proposed a rational energy saving, using wasted heat. A thermodynamic mathematical model is presented, as an effort for water purification from waste heat. The absorber temperature for the system was valued as 105 to 115 °C, which is suitable for the purification of brackish water. An enthalpy based coefficient of performance can arise from 0.3 to 0.429 water purification coefficient of performance, and in a similar way the theoretical limit case may raise the COP from 0.5 to 1.0.

Escobar et al. [14] have presented on line COP estimation for a waste energy recovery heat transformer, by a water purification process using different algorithms. The applied thermodynamic model is considered satisfactory to predict the COP, with the assumptions considered. Hernandez et al. [15] have compared neural network and thermodynamic models to estimate the on-line coefficient of performance (COP) of absorption heat transformer integrated with a water purification process. The results from both the proposed models show the improvement of the performance of the AHT-WP for other configurations of energy recycling and purification. In a short time the neural network gives an understanding of the behavior of the COP, when experimental data are used with different working mixtures in the experimental system.

A combination of flat plate solar collectors, a single effect heat transformer and a desalination system used to provide a beach house with drinking water, has been studied by Rabah Gomri [16]. The system produces about 500 l of drinking water per day. Rivera et al. [17] have analyzed theoretically the performance of vapor absorption heat transformer using the first and second law methods. In order to find the components of the system with the highest irreversibilities, plots of the irreversibilities for each one of the main components of the system are reported against the main temperatures and operating parameters of the heat transformer. Rabah Gomri [18] has compared theoretically, single effect and double effect absorption heat transformers for seawater desalination. The summary of results reported by various researchers in the area of absorption heat transformer is provided in Table 1. The comparison of various reports in the area of absorption heat transformer coupled desalination system is presented in Table 2. In the present work the results of experiments conducted on a vapor absorption heat transformer driven distillation system of 5 kg/h capacity are reported. The low quality waste heat for the heat transformer is simulated and water–lithium bromide working fluid has been used in the heat transformer. Effects of operating parameters on the performance of the system are presented.

2. Experimental set up

The schematic diagram of the experimental set up is shown in Fig. 1. The components of VAHT and distillation system are designed as per the standard design procedure. All the components were fabricated and pressure-tested at 20 bar. The integrated system was tested under complete vacuum for leakage. The specifications of the

Table 1
Results reported by various researchers in the area of absorption heat transformer.

Authors	Working pair	COP	GTL	Maximum absorber temperature
George et al. (1993) [2]	R21-DMF	0.2–0.35	20 °C	85 °C
Barragan et al. (1996) [4]	$H_2O–CaCl_2$	0.45	19 °C	84 °C
Rivera et al. (2000) [5]	H_2O–LiBr	0.16	44 °C	124 °C
Alonso et al. (2003) [6]	n-heptane/DMF	Thermal efficiency of 30 to 40%	8 °C	–
Ma et al. (2003) [7]	H_2O–LiBr	0.47	25 °C	–
Present work	H_2O–LiBr	0.38	20 °C	100 °C