TECHNOLOGICAL AND SCIENTIFIC CHALLENGES IN HEAT PUMPS

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ABSTRACT

Last year, a major multidisciplinary project was set up that included researchers from Mexico and Spain with different backgrounds and interests. The project would involve the major technological and scientific challenges around absorption heat pumps and their application. The project goals include: a) gain knowledge of the thermodynamic properties of different heat-absorbing solutions used in heat pumps, b) determine the aggressive corrosion conditions of such solutions in different metallic materials used as components under different operating conditions and test and develop corrosion-control alternatives, c) conduct experimental and simulation studies on the mass-transfer phenomena conditions of the different solution alternatives and the effects on material and heat pump performance to aid in selecting the most suitable unit, d) instrument a heat pump for on-line monitoring to be used for further application such as water purification. In this paper, we present some preliminary results of the recent work on the different lines of research that converge in the topic of heat pumps made inside the Center of Research in Engineering and Applied Sciences (CIICAp) of the Autonomous University of Morelos (UAEM) in Mexico. These investigations can be divided into the following: components materials, operational conditions, and component thermodynamic limitations and corrosion rates. In Centre d'Innovació Tecnològica en Revalorització Energètica i Refrigeració (CREVER) of the Universitat de Rovira I Virgili (URV) in Spain, some research areas include the proposal of new solutions, their thermodynamic characterization, industrial applications, and combined cycles. The paper describes materials that have been used in the construction of these heat pumps, the coolant and pairs of absorbent – working fluid that heat pump have been used, the operational conditions for the different configurations of the heat pumps, the operational conditions considered for these systems, and the corrosion rates encountered in the metallic materials used in these heat pumps. Also discussed are the technical and scientific challenges that must be overcome to implement new configurations, solutions and additive substances to improve operations, increase operational conditions of the existing systems, the physicochemical characterization of new substances, and heat pump corrosion rates.

Keywords: ***Heat pumps, sensors, new configurations, new solutions, operation limits, corrosion.***

1 INTRODUCTION

Mexico has a population of 100 million, and a great part of the Mexican territory presents favorable conditions for the use of solar collectors for water heating; however, the temperatures of the plane solar collectors are not enough. The plane solar collector's temperatures are lower than 90 °C this temperature level is although available for waste industrial heat.

Absorption heat pump/transformers are the only heat-exchanger/recovery systems capable of increasing waste-heat temperature to make it useful in an environmentally friendly way (Rivera 2001). Its main use is in operations where latent heat is discharged, especially in drying, evaporation, and distillation unitary processes and in heat recovery of cooling plants (Rivera 1998a).

These systems consist basically of a generator, a condenser, an evaporator, an absorber, and a heat exchanger. They use a solution of two chemical substances called working fluid and absorbent, the latter with the function to transport the working fluid from the absorption unit to the generation unit where vapor is separated from the absorbent for further processing and heat recovery. The common mixture solutions used such as LiBr (absorbent)/water (working fluid), which under system working operating temperature conditions, had been reported as highly corrosive for stainless steel and other materials making it necessary to use corrosion inhibitors.

1.1 HEAT PUMP

The project would involve the major technological and scientific challenges around absorption heat pumps and their application. The aims of this project include: a) gain knowledge of the thermodynamic properties of different heat absorbing solutions used in heat pumps, b) to determine the aggressively corrosion conditions of such solutions in different metallic materials used as components under different operation conditions, and test and develop corrosion control alternatives, c) experimental and simulation studies into the mass transfer phenomenon conditions of the different solution alternatives and its effects on material and heat pump performance to select the most suitable, d) to instrument a heat pump for on line monitoring to be used for further application such as water purification and in hybrid solar-heat pump systems.

1.1.1 Compression heat pumps

To analyze the compression system a multipurpose system has been constructed and installed in the "Applied Thermal Engineering Laboratory (LITA in Spanish language acronym)." The multipurpose system has the capability for operate as compression heat pump and get in low energy and deliver at water purification temperature level. This systems can be integrated to industrial waste heat source for obtain pure water as new self consumed product.

1.1.2 Absorption heat pumps

In a part of the heat pump research a hi-efficiency heat pump has been designed for operation, with plate heat exchangers constructed in 316SS for any pair operation. This heat pump is now in installation and has 4-kW heat capacity for research into heating, cooling, and heating-cooling simultaneous modes. This new configurations can be applied to potential industrial processes with waste heat.

1.1.3 Absorption heat transformer

The main and first part of the present project are water purification with absorption heat pump operation, for this purpose two heat pumps were operated as heat transformers for water purification objective. This work intends the coupling of single stage heat transformers (SSHT) to increase energy of low temperature at a level that is enough to guarantee the water purification [Holland, 2000].

One of the heat transformers was totally constructed 316SS of 2-kW heat capacity, designed to be able to be transported in a small truck as a demonstrative industrial project. The second heat transformer was carbon steel – stainless steel constructed for a 10-kW heat capacity at a pilot industrial plant. Both heat transformers have been instrumented with basic analog instrumentation and both were operated and tested for water purification intention.

1.2 USED PAIRS

To carry out the study of the behavior of the system, simulations were performed with two appropriate mixtures for their use in heat transformers. The even dilutes lithium bromide in water was used and the other one diluted Carrol (lithium bromide and ethylenglycol 3.5:1 weigh ratio) solution in water was considered [Rivera, 1998a].

In CREVER (Spain) several pairs were chemically characterized and thermodynamic simulated [Bourouis, 2004] and previous desalinations process were studied for heat pumps [Blanco, 2003]. Meanwhile the experimental evaluations of both heat transformers were carried out with lithium bromide – water solutions pair, for analysis of the thermodynamic correlation.

1.2.1 Absorption Heat Pump Water Purification

Under steady-state considerations the heat transformers were tested and correlated for the coefficient of performance, defined as:

$$COP = Q_{AB} / Q_T$$

where Q_{AB} is the water purification heat power and Q_T is the waste added heat, defined as:

$$Q_T = (Q_{GE} + Q_{EV})$$

Because Q_{GE} is part heat for the process into generator and Q_{EV} is the left part for evaporation process. For comparison of performance between both systems Exergetic index (I_E) was used [Abrahamsson, 1993], this is expressed as follow:

$$I_E = COP / COP_C$$

where Carnot's COP (COP_C) is used as independent efficiency of a used pair. The production of purified water has been calculated as function of the useful heat liberated in the absorber. The simulation results are show in Fig. 1, for I_E and water production as a function of generator temperature (T_{GE}). In this figure it can be observed, that it is possible to obtain temperatures (T_{AMB}) with waste heat at 60 - 90 °C for different atmospheric conditions.

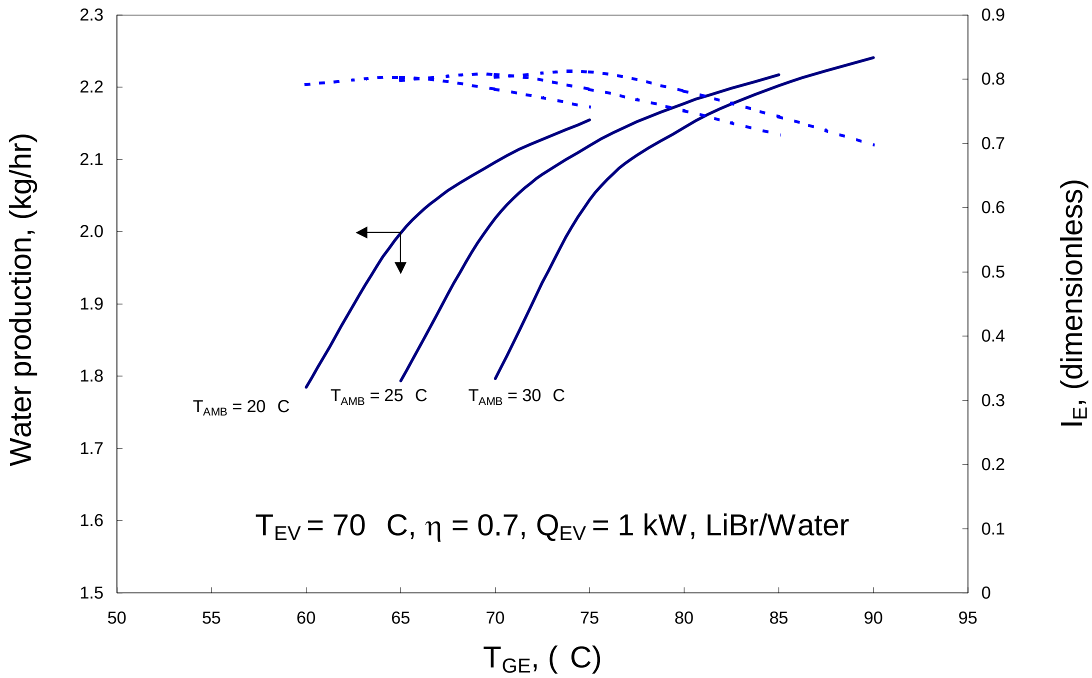

Fig. 1. I_E and water production per kW against generator heat transformer.

After the operations of heat transformers both main conclusion were obtained: water purification with waste industrial heat is possible and obtained water has of good quality compared with the one obtained with electrical distillers [Huicochea, 2004]. The water production per kW for both systems is shown in Fig. 2. It is observe a proportional increase of COP as a function of water production.

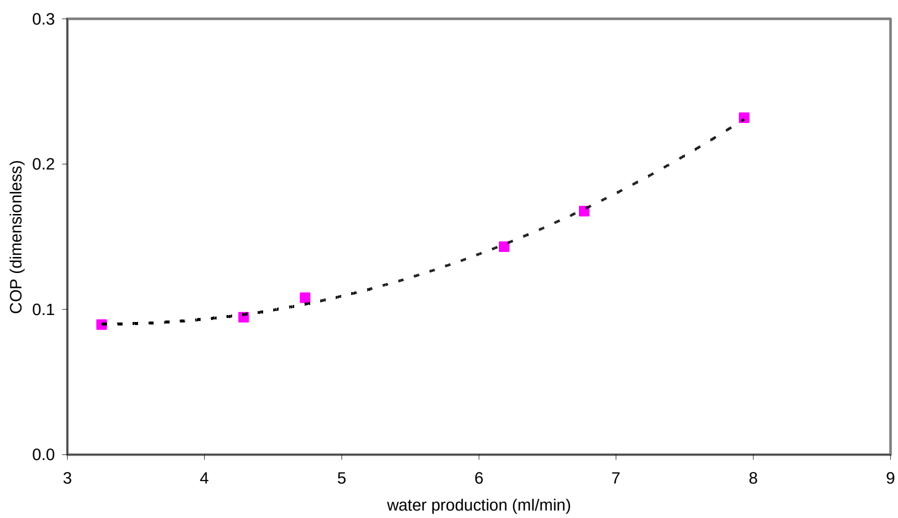

Fig. 2. COP against water production per kilowatt in heat transformers.

The chemical analysis for the obtained purified water is presented in Table 1. These results demonstrate the good quality as compared to obtained distilled water by electric distillation.

Table 1. Compared quality purified water

Parameter	Distilled water	Electrical distilled water
Chlorides	0.72 mg/L	0.7 mg/L
Sulphides	< 5 mg/L	0 mg/L
pH	5.34 unities	5 unities
Electrolytic conductivity	11 µmhos/cm	7 µmhos/cm

Future work for these heat transformers is the COP increase for water purification modifications in present day systems [Romero, 2004].

1.2.2 Absorption Heat Pump Corrosion

Studies of the corrosion evaluation of SS-304 stainless steel exposed in aqueous lithium bromide solution have been carried out applying the weight loss and electrochemical methods. The test temperatures were ambient to 80 °C, and the exposure was for fifteen days. The main objective was to determine the corrosion rates and the type of corrosion that SS-304 suffers under Li Br solution under the mentioned conditions, with the purpose of evaluating its application to heat pumps/transformers. The corrosive solution was prepared with lithium bromide analytical grade regents and distilled water.. The sample electrodes were made of a sheet of stainless steel, which was of commercial specification with composition (wt %): 18Cr-8Ni-BalFe.. The procedure for weight loss method was made according to ASTM Standard G1 and G31 [1,2], using specimens (in duplicate) of the same size than that for electrochemical techniques. After weight loss tests, the specimens were cleaned and weigh in an analytical balance. Electrochemical methods, namely polarization curves (PC) and electrochemical noise measurements (ENM) were performed.

The experimental details and results have bee reported elsewhere; In this communication, only partial results are presented for the sole purpose of showing the kind of corrosion studies being carried out (Cuevas & Uruchurtu, 2004b).

Table 2 shows the experimental mass loss in time obtained for SS-304 stainless steel exposed to 50 wt. % BrLi-H_2O at 25, 50, 60, and 70°C. To calculate the overall mass loss at each day, it was necessary to integrate all data records obtained from the beginning to the end for each day. The instantaneous mass loss presented obtained show that the mass loss is a function of the temperature. This behavior can be explained in terms of the probable formation of corrosion products over the surface, which interferes with the metal dissolution, and consequently yielding to a decrease in corrosion rate with temperature. On the other hand, the oxygen diffusion is associated with an increase with temperature, also indicating less participation of oxygen as electro-active specie at the higher temperatures (Cuevas & Uruchurtu, 2004a).

The sort of information presented allow decisions to be made regarding the use of inhibitors or other materials, taking into consideration the corrosion behavior as well as thermodynamic and mass transfer conditions.

Table 2. Comparison of corrosion rates between mass loss and electrochemical noise technique for different temperatures

Exposure Temperature (°C)	Electro-chemical Noise (mg/cm^2)	Weight Loss Method (mg/cm^2)
25	1.25E4	0.00125
50	0.06002	0.26
60	0.0772	0.3
70	0.13317	0.202
80	0.15041	0.31

1.2.3 Heat Pump Sensors

Electronic sensor development has wide applications for lower cost, but in some places where other sensor cannot be used due to explosives gases high concentration, influence magnetic fields or corrosive places. In that, optic fiber can be option for sensing. Into heat pumps with lithium bromide – water pairs, metallic and electronic devices can not be safely operated by corrosion problems and then optic fiber can be applied for this data acquisition.

Actually, it has been detected two measurement necessities in absorption heat pumps: in situ concentration and instantaneous temperature. The first measurement problem has been studied and analyzed for several lithium bromide concentration transmittance and a first theoretical approach was reported [Basurto, 2004] and now, after a previous work [Basurto, 2000] a single method for optic measurement temperature is implemented and characterized to be tested into lithium bromide heat pumps. Figure 3 presents the different wavelength transmittance behavior against lithium bromide concentration for atmospheric temperature. It is observed, that transmittance exhibits an increase for each concentration increase.

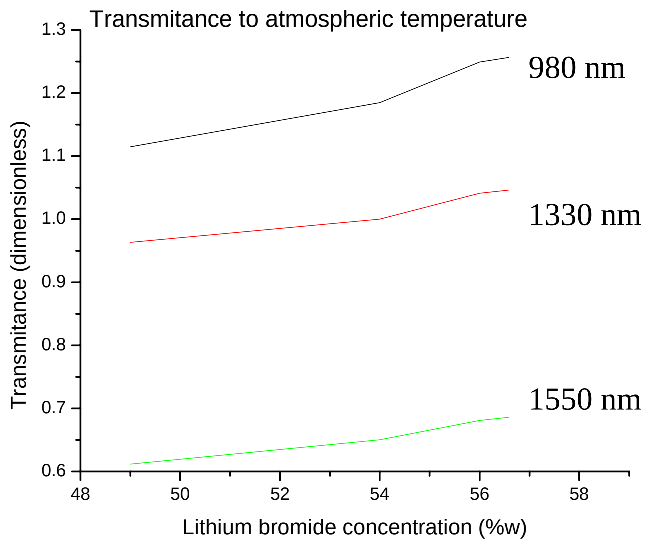

Fig. 3. Transmittance against lithium bromide concentration for tested optical method.

Another objective in the project is to monitor on-line, different corrosion conditions. For this purpose electrochemical sensor are developed to be installed within the heat pump circuit system. In Fig. 4, an example is presented, where thermocouple, reference, and working electrodes are incorporated.

Fig. 4. On-line monitoring electrochemical sensor.

2 CONCLUSION

Conditions have been shown for the production of purified water using temperatures lower than 90 °C for the environmental conditions of the central part of Mexico. Best conditions have been determined for different values of the atmospheric temperature, based on the concept of thermodynamic efficiency (I_E).

It is shown that when giving 1 kW of thermal energy to low temperature (75°C) to the evaporator of the SSHT, it can be obtained among 1.77 to 2.1 kg/hr of purified water under typical conditions of the central part of Mexico.

The multipurpose equipment of a heat pump integrated to a portable water purification system, operated in heat transformer mode, it was able to distill impure water with a flow of 7.9 ml/min with 55.8 % lithium bromide - water concentration and the obtained distilled water quality was similar to those obtained in an electrical distiller.

Optic and electrochemical sensor can be installed into absorption heat pump to monitor temperature and concentration, as well as corrosion conditions near future. Corrosion is a problem for absorption heat pumps and determination of on-line corrosion conditions can be modified by obtained results.

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