ELSEVIER

Desalination 165 (2004) 385–391

DESALINATION

www.elsevier.com/locate/desal

Portable water purification system integrated to a heat transformer

A. Huicochea[a], J. Siqueiros[b*], R.J. Romero[b]

[a]Centro Nacional de Investigación y Desarrollo Tecnológico (CENIDET), Interior Internado Palmira S/N, Col. Palmira, C.P. 62490, Cuernavaca, Morelos, México

[b]Centro de Investigación en Ingeniería y Ciencias Aplicadas (CIICAP), Universidad Autónoma del Estado de Morelos, Av. Universidad 1001, Col. Chamilpa, C.P. 62210, Cuernavaca, Morelos, México

Tel/Fax +52 (777) 3297084

Received 29 January 2004; accepted 10 February 2004

Abstract

Water is a natural resource essential for life and for most economic activities developed on earth. Population growth and lack of water in some regions of the world has led humans to design and implement new technologies to use water in an efficient way. Water quality requirements in the industrial sphere are higher everyday. Development of desalination technology through a water purification system integrated to heat pumps has taken more than two decades. Absorption heat pumps use low quality energy in a waste heat form and a small quantity of high quality energy. This characteristic has made possible using these systems in quite a few places. The following work presents the results of the experimental tests applied to a portable water purification system integrated to a heat transformer (TTAPPA), where the low quality waste heat is simulated and LiBr-water is used as a working solution.

Keywords: Water purification system; Heat transformer; Desalination

1. Introduction

Water is an essential factor for life and for economic activities developed on earth because its presence is vital for agriculture, industry and social growth. In regions where its consumption is vast, water depuration and desalination allow an acceptable social rise. Unfortunately, those technologies require huge economic investments and, therefore, only high development countries can afford them.

In national and international industrial processes an important amount of energy is con-

*Corresponding author

Presented at the EuroMed 2004 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean. Sponsored by the European Desalination Society and Office National de l'Eau Potable, Marrakech, Morocco, 30 May–2 June, 2004.

doi;10.1016/j.desal.2004.06.044

sumed for the thermal treatment of the product. Most of this energy is obtained from fossil combustion, and some non-desirable gases and low temperature-waste heat are obtained as sub-products, which contribute to atmosphere pollution.

In order to diminish and prevent atmosphere pollution, several investigations have been carried out to use low temperature-waste heat. The first basic ideas about design and function of heat transformers were presented earlier in the 20th century [1].

In Mexico the first development of water purifying units assisted mechanic-compression heat pump took place in 1987 [3], with satisfactory experimental results. A second purification unit integrated to an absorption heat pump was designed, constructed and operated by a team of researchers from the Geothermal department at the Instituto de Investigaciones Eléctricas of Mexico, with satisfactory experimental results [11].

Purification systems-assisted absorption heat pumps have several advantages over conventional purification systems:

- They can be operated with low quality-waste thermal energy. For instance, a heat transformer can work with a low quality-waste heat of 65°C and send it to the purification system at a temperature higher than 97°C.
- They are simple and can be portable in a small transport.
- The requirement of a low electric energy supply and a waste heat of 65°C or higher.
- Its maintenance requirements are of low cost.
- They produce a high purity product.
- They can be adapted to another chemical process.

2. Heat pump

A heat pump is a machine that extracts heat from a heat supply at a certain temperature and leaves it in a heat drain at a higher temperature. It works on the same principles as a refrigerator, both of them produce heating and cooling at the same time. The difference is that refrigerators are specifically designed to cool while heat pumps are designed to produce high temperature heat from the extraction of low temperature heat, which can come from waste heat industrial processes.

To raise the temperature obtained from a low quality source, it is necessary to apply a small quantity of high quality energy to the heat pump, such as mechanical or thermal energy, at a relative high temperature [4]. This contributes to the reduction of contaminant emissions, such as carbon dioxide (CO_2) and methane (CH_4), main gases on the green house effect, besides sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), which contribute to the acid rain.

There are three principal categories of heat pumps:

- Vapor mechanical compression.
- Absorption.
- Inverse absorption (heat transformer, thermal transformer or heat amplifier).

2.1. Vapor mechanical compression heat pump

Due to its high yield this is the most useful heat pump. It can be used for heating as well as for cooling. The main components of this kind of pump are: a compressor, an evaporator, a condenser, an expansion valve and a working fluid.

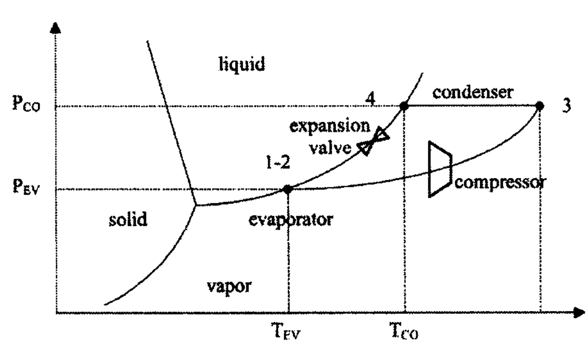

Fig. 1. Schematic diagram of a compression heat pump.

Its thermodynamic cycle is shown in Fig. 1. This pumps works as follows: The working fluid evaporates in the evaporator (line 1–2) at T_{EV} temperature, extracting an amount of heat Q_{EV} from the environment which can be in solid, liquid or gas state. The working fluid is compressed (line 2–3) and gives latent heat Q_{CO} at a higher temperature T_{CO} in the condenser (line 3–4). Compressed working fluid is expanded through an expansion valve (line 4–1) and returns to the evaporator. At this moment the cycle is complete.

Coefficient of performance (*COP*) is the ratio between the heat flow given at the condenser Q_{CO} and the power supplied to the compressor *W*, (Eq. 1).

$$COP = \frac{Q_{CO}}{W} \tag{1}$$

2.2. Absorption heat pump

The absorption heat pump works with the thermodynamic cycle shown in Fig. 2. High temperature energy is supplied (T_{GE}) to the generator, in which the working fluid is partially separated from the absorbent. Working fluid changes to liquid phase in the condenser (T_{CO}) and goes to the evaporator (which is at a lower pressure than the condenser) where it changes to the gas phase at a lower temperature (T_{EV}) given by the waste energy supplied.

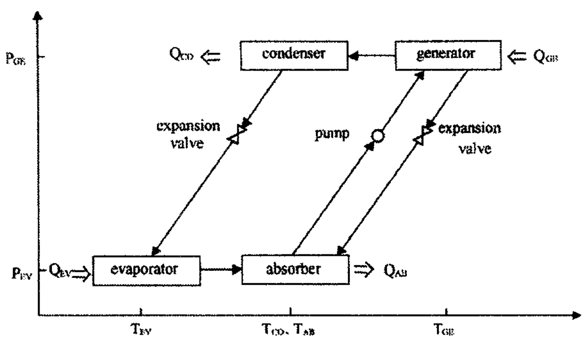

Fig. 2. Schematic diagram of an absorption heat pump with 3 temperature levels and 2 pressure levels.

Steam coming from the evaporator is conducted to the absorber where it comes into contact with a working fluid-absorbent stream coming from the generator, producing heat at a temperature T_{AB} higher than T_{EV}.

The coefficient of the performance of a conventional absorption heat pump can be defined by the following equation:

$$COP = \frac{(Q_{CO} + Q_{AB})}{Q_{GE}} \tag{2}$$

2.3. Heat transformer

The thermodynamic cycle of the heat transformer is shown in Fig. 3, where medium temperature energy is supplied (T_{GE}, T_{EV}) to the generator and evaporator. In the generator a partial separation of the working fluid from the absorber concentrated solution in working fluid, takes place. In the condenser the working fluid changes to liquid phase and then is pumped to the evaporator (which is at a higher pressure than the condenser and the generator) where it is evaporated and then conducted to the absorber, where it comes into contact with the mixture pumped from the generator, producing heat at a temperature T_{AB} higher than T_{EV}. Its coefficient of performance is defined as [Eq. (3)]:

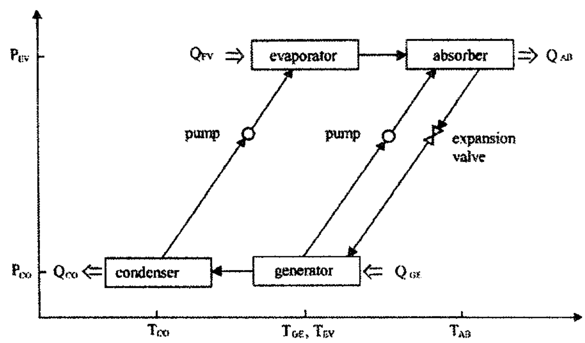

Fig. 3. Schematic diagram of an absorption heat transformer with 3 temperature levels and 2 pressure levels.

$$COP = \frac{Q_{AB}}{Q_{GE} + Q_{EV}} \tag{3}$$

2.3.1. Refined heat transformer

A refined cycle of an absorption heat transformer of one stage (Fig. 4) consists of one basic cycle with a heat exchanger situated between the generator and the absorber. Its objective is to preheat the solution that is conducted to the absorber by using part of the fluid's energy coming from the absorber. This exchanger raises the cycle's efficiency depending on its effectiveness [7].

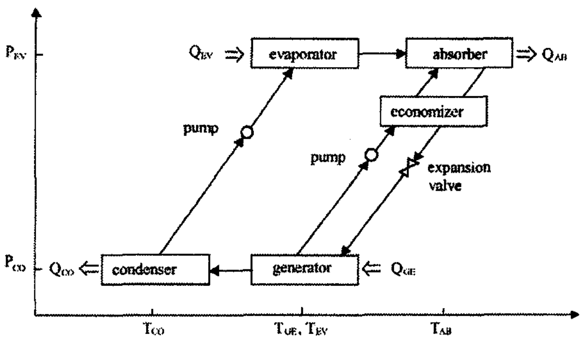

Fig. 4. Schematic diagram of an absorption heat transformer refined cycle with 3 levels of temperature and 2 levels of pressure.

The coefficient of performance of a refined heat transformer is defined by Eq. 4:

$$COP = \frac{Q_{AB}}{Q_{GE} + Q_{EV}} \quad (4)$$

3. Experimental equipment description

The TTAPPA was designed using a simulator [8]. The power considerations were: 1 kW in the evaporator, 1 kW in the condenser, 0.7 kW in the generator and 0.7 kW in the absorber. Stainless steel 316L was used for its construction. Its dimensions were 120 cm × 80 cm × 150 cm. A thermostatic bath was used in order to simulate waste heat [2].

Fig. 5 shows the diagram of water purification assisted heat transformer. Water from the impure water tank takes heat from the absorber (Q_{AB}), returning to the tank in a liquid-steam mixture. The steam is sent to the auxiliary condenser, where it is condensed to obtain distilled water. Then the heat obtained in the auxiliary condenser is recycled to the heat transformer [6].

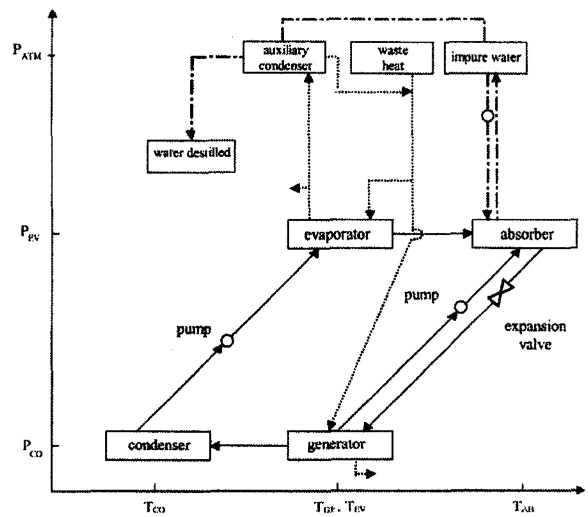

Fig. 5. Schematic diagram of water purification integrated to a heat transformer.

In this case, where total absorption heat (Q_{AB}) is recycling, the heat supply required for the heat transformer ($Q_{GE} + Q_{EV}$) is diminished by the quantity Q_{AB}. Then a new *COP* is defined as follows (Eq. 5) [9,10]:

$$COP_{WP} = \frac{Q_{AB}}{Q_{GE} + Q_{EV} - Q_{AB}} \quad (5)$$

4. Experimental tests description

- The steady state condition was considered when temperature, absolute pressure, electric energy and mass flow rate did not show higher than 5% in their lecture variations amongst each other, over a period of 30 min.
- When a steady state was reached in the TTAPPA, the parameters' values were registered for a period higher than 20 min.
- A previously refraction index test was measured for each mixture obtained from the absorber and generator for each experi-

mental test. The concentration was obtained through a refraction index correlation obtained for the concentration values between 50–61% of the LiBr-water solution [6].

5. Results

Temperature behaviors for each experimental test are similar to the ones illustrated in Fig. 6, where the transitory and steady state can be appreciated.

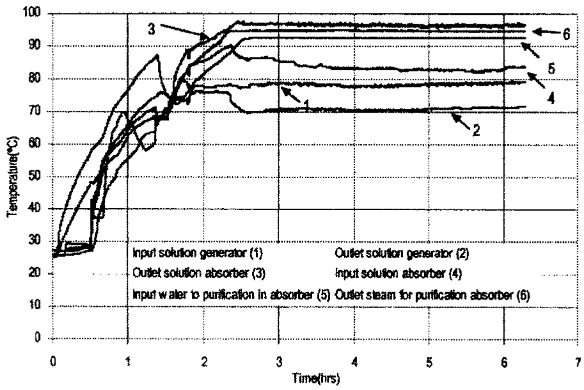

Fig. 6. Temperature behavior for a 55% LiBr-water solution.

Thermodynamic water properties used in the TTAPPA experimental evaluation were taken from the NIST/ASME steam software, version 2.2. Thermodynamic properties of LiBr-water mixture were taken from Alefeld [12].

A resume of the operation parameters used in the experimental test is shown in Table 1.

Fig. 7 shows that the *COP* is raised when it mixes with the increased concentration of solution in the absorber. This is explained by the fact that at higher concentrations, the absorbent's exothermic capacity is higher too, raising the absorber's heat. The *COP* value increases because it is directly proportional to the absorber heat and inversely proportional to the total heat supplied in the generator and evaporator.

In Fig. 8 when X_{AB} increased, the heat obtained by heat transformer (Q_{AB}) is also increased then the COP_{WP} increases when X_{AB} also increased (see Eq. 5).

Table 1
TTAPPA operation limits

Operation parameters, °C	Minimum	Maximum
T_{GE}	70.7	75.8
T_{CO}	31.7	34
T_{EV}	62.5	72.5
T_{AB}	96.3	98.4
Operational parameters, %		
X_{GE}	52	56.3
X_{AB}	49.8	55.5
Operational parameters, kPa		
P_{GE}	7.4	9.9
P_{AB}	26.7	34.4
Operational parameters, W		
Q_{GE}	871	1124
Q_{CO}	332	975
Q_{EV}	659	1048
Q_{AB}	161	368
Operational parameters, ml/min		
M_{AB}	167.9	388.1
M_{GE}	152.4	366
M_{CO}	8	23.4
Impure water	181	418
Operational parameters		
COP_{WP}	0.099	0.296
COP	0.09	0.228

Fig. 9 shows the *COP* behavior regarding distilled water production. When *COP* increases, distilled water production increases too. The same results were obtained using a compression heat pump [3] and an absorption heat pump [11] for water purification.

Raw water used in the water distillation circuit and distilled water obtained from the experimental test, were chemically analyzed to determine the chlorides and sulfate concentrations, pH and electrolytic conductivity, using the standard norms. The results were satisfactory and are shown in Table 2.

Water analysis results are shown in Table 2. It can be appreciated that chlorides and pH values are lower for the distilled water.

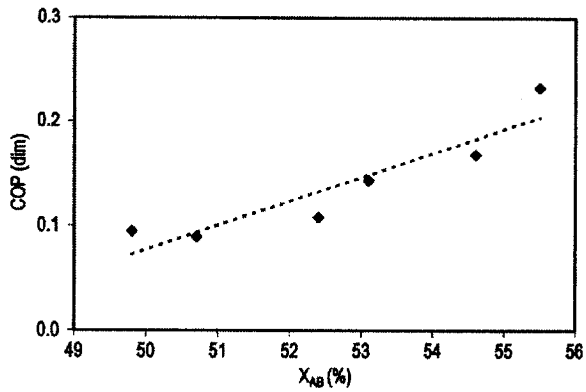

Fig. 7. *COP* as function of X_{AB}.

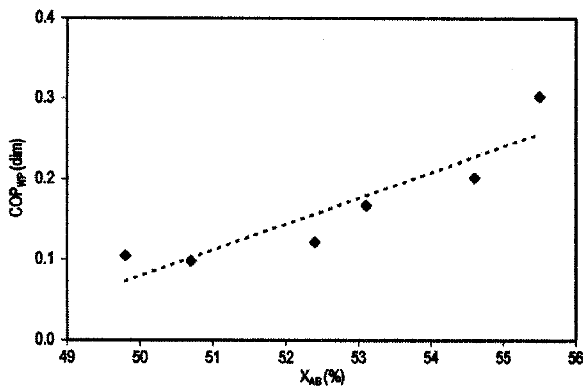

Fig. 8. COP_{WP} as function of X_{AB}.

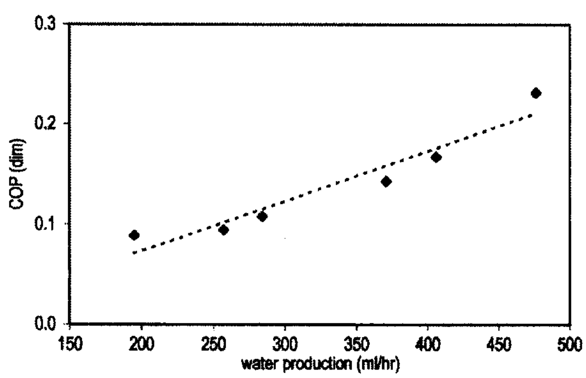

Fig. 9. *COP* as a function of distilled water production.

Electrolytic conductivity in distilled water drops by 90% with respect to raw water. Distilled water quality is similar to that obtained in a laboratory distiller. Water purification using heat pumps gave similar results [3,11].

Table 2
Water analysis results of the portable water purification system

Parameter	Raw water	Distilled water
Chlorides, Cl	2.15 mg/L	0.72, mg/L
Sulfates, SO_4	<5 mg/L	<5 mg/L
pH	7.3 unidades	5.34 unidades
Electrolytic conductivity	121 μmhos/cm	11 μmhos/cm

6. Conclusions

Analyzing the results obtained with the TTAPPA, we can conclude that:

- The heat transformer integrated to a water purification system works with waste heat temperatures from 68–78°C.
- The distilled water quality is similar to those obtained from a laboratory's electrical distiller.
- The system is able to use other working mixtures in order to improve the *COP* values.

Symbols

COP — Coefficient of performance, dimensionless
P — Pressure, kPa
Q — Heat flow, *W*
T — Temperature, °C
W — Power, *W*
X — Concentration, % weight

Sub-Index

AB — Absorber
CO — Condenser
EV — Evaporator
GE — Generator
SOL — Solution
WP — Water purification system

Acknowledgments

The authors thank the University of California, Campus Riverside, for building the TTAPPA (Subcontrat 02-04). Thanks to Loic Nameche, Melissa Mendoza and Karime Martínez for their invaluable support in the development of the project. Thanks to the Consejo Nacional de Ciencia y Tecnólogia (CONACYT) for their economic support (31299-U project). Special thanks to the Centro Nacional de Investigación y Desarrollo Tecnológico (CENIDET) for allowing their students to work on research projects of related institutions. Thanks to the Industrial Analysis Laboratory from the Universidad Autónoma del Estado de Morelos for their collaboration with water analysis.

References

[1] E. Altenkirch, Reversible absorptions machine, Zeitschrift fur die gesamate Kalte/Industrie, (1913). 1–9.

[2] C.M.J. Barroso, Diseño y construcción de un sistema portátil de purificación de agua integrado a un transformador de calor, BA. Thesis, UAEM, México, 2003.

[3] J.L. Frías, J. Siqueiros, H. Fernández, A. Garcia and F.A. Holland, Development in geothermal energy in Mexico-part thirty six: the commissioning of a heat pump assisted brine purification system, Heat Recovery Systems and CHP, (1991) 297–310.

[4] F.A. Holland, Fundamentos y Aspectos Económicos de las Bombas de Calor, Manual sobre Tecnología de Bombas de Calor, Instituto de Investigaciones Eléctricas, México, (1990) 9–19.

[5] F.A. Holland, Economic Evaluation of Heat Recovery Systems, Seminario sobre recuperación de Calor Industrial por medio de Bombas de Calor, Cuernavaca, México. 1993.

[6] A. Huicochea, Puesta en marcha y evaluación experimental de un sistema portátil de purificación de agua integrado a un transformador térmico, Ms. Thesis, CENIDET, 2004.

[7] W. Rivera, Estudio teórico de transformadores de calor por absorción operando con la mezcla de bromuro de litio y agua, Ms. Thesis, UNAM-CIE, México, 1991.

[8] R.J. Romero, Estudios teóricos y experimentales de transformadores térmicos por absorción y sistema optimado de absorbedores en películas descendentes, PhD. Thesis, DEPFI-UNAM y CIE-UNAM, México, 2001.

[9] J. Romero, J. Siqueiros and R.A. Huicochea, Increase of COP for heat transformer in water purification systems, Part II – COP_{WP} Increase, submitted to Appl. Therm. Eng., 2004.

[10] J. Siqueiros and J.R. Romero, Increase of COP for heat transformer in water purification systems, Part I – Temperature Increase, submitted to Appl. Therm. Eng., 2004.

[11] S. Santoyo, J. Siqueiros, C.L. Heard, E. Santoyo and F.A. Holland, An experimental integrated absorption heat pump effluent purification system. Part I. Operating on water/lithium bromide solutions, Appl. Therm. Eng., (1999) 461–475.

[12] M.J. Torre, Contacteurs gaz-liquide pour pompes á chaleur a absorption multi-étagées, PhD. Thesis, L'institut National Polytechnique de Lorraine, France, 1997.