Portable water purification system integrated to a heat transformer

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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-
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 (CO₂) and methane (CH₄), main gases on the green house effect, besides sulfur dioxide (SO₂) and nitrogen dioxide (NO₂), 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.](image-url)
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).

$$COP = \frac{Q_{CO}}{W} \quad (1)$$

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.

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:

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

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)]:

$$COP = \frac{Q_{AB}}{Q_{GE} + Q_{Ev}} \quad (3)$$
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].

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

\[
\text{COP} = \frac{Q_{AB}}{Q_{GE} + Q_{EV}}
\]  

(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 x 80 cm x 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].

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]:

\[
\text{COP}_{WP} = \frac{Q_{AB}}{Q_{GE} + Q_{EV} - Q_{AB}}
\]  

(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.](image)

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. 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.](image)

![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.](image)
Table 2
Water analysis results of the portable water purification system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw water</th>
<th>Distilled water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorides, Cl</td>
<td>2.15 mg/L</td>
<td>0.72, mg/L</td>
</tr>
<tr>
<td>Sulfates, SO₄</td>
<td>&lt;5 mg/L</td>
<td>&lt;5 mg/L</td>
</tr>
<tr>
<td>pH</td>
<td>7.3 unidades</td>
<td>5.34 unidades</td>
</tr>
<tr>
<td>Electrolytic conductivity</td>
<td>121 μmhos/cm</td>
<td>11 μmhos/cm</td>
</tr>
</tbody>
</table>

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

\( \text{COP} \) — 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

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].
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References