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Environmental Impact Assessment for an Absorption Heat Transformer

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Abstract

This study presents the environmental impact assessment of an absorption heat transformer designed to recover 1 kW of thermal energy from each 2 kW of waste heat supplies. The net contribution of the heat transformer is a load avoided of 0.665 kg CO_2 equivalents; the recovery process avoids 0.729 kg CO_2 equivalents and the major contribution to the environment impacts is the pumping process with 0.0437 kg CO_2 equivalents for each 1 kWh recovered. The study results show that absorption heat transformer is a good environmental option because it produces useful energy from waste heat and the final result is an environmental impact diminution.

Keywords

1. Introduction

The electricity consumption by the industry is 42.3% which is equivalent to 709 Mtoe (million tonnes of oil equivalent) [1]. The industrial sector requires energy for pumping systems, cooling and heating systems and illumination systems.

A heat transformer is a device which can deliver heat a higher temperature than the temperature of the fluid which is fed, normally waste heat energy from industrial processes or renewable energy such as solar or geothermal energy [2].

Energy recovery is an important topic in industries where high amounts of heat are wasted. Many industrial processes require large amounts of steam or hot water to heat the process streams.

Absorption heat transformers (AHTs) are thermo-mechanical devices in which the main feature is the recovery of waste heat. AHTs are capable of recovering a large amount of energy and increase its temperature, using part of the same energy as power in a thermodynamic cycle. The increased temperature inside any closed thermodynamic system is a consequence of the increment of pressure. The difference of pressure in an AHT is obtained by means of a relatively small amount of mechanical energy supplied by a mechanical pump to move a fluid [3].

Large quantities of heat from industries have been rejected to the atmosphere, which not only wastes energy but also pollutes the environment [4].

As a very effective device, the AHT can be applied to improve low-grade waste heat with temperatures ranging from 60°C to 100°C. The AHT system can effectively recover about 50% of this waste heat and give an opportunity to reuse it in industrial processes [5]

The European Commission presented the Life Cycle Assessment (LCA) as an important framework for evaluating the environmental impact of products, processes or systems [6].

LCA quantifies energy, materials and wastes released to the environment and performs the impact assessment of those inputs and outputs. The application of LCA follows a standardized procedure described in ISO 14040: 2006 [7] and ISO 14044:2006 [8].

LCA studies help to avoid resolving one environmental problem while creating others: this unwanted "shifting of burdens" is where you reduce the environmental impact at one point in the life cycle, only to increase it at another point. Therefore, LCA helps to avoid, for example, causing waste-related issues while improving production technologies, increasing land use or acid rain while reducing greenhouse gases, or increasing emissions in one country while reducing them in another. Life Cycle Assessment is therefore a vital and powerful decision support tool, complementing other methods, which are equally necessary to help effectively and efficiently make consumption and production more sustainable [9].

Many theoretical and experimental studies of AHT have been carried out [10] [11], and in those completed reviews there is not any LCA for AHT to show the CO_2 equivalent for each recovered energy unit.

2. AHT System Description

The AHT system consists basically of five plate heat exchangers (generator, condenser, evaporator, recovery and absorber), piping and accessories, two pumps and Lithium Bromide (LiBr) solution as a working fluid.

A constant heat waste is supply to the generator in order to vaporize a part of the working fluid (water) to the aqueous LiBr solution at low pressure. The vaporized working fluid flows to the condenser, delivering an amount of heat at close ambient temperature. The liquid leaving the condenser is pumped, to the evaporator at a higher-pressure zone. The working fluid is then evaporated at high pressure into the evaporator using a second quantity of heat waste at an intermediate temperature. At same time, the vaporized working fluid goes to the absorber, inside of which, it is absorbed by the concentrated in absorbent solution; this stream comes from the generator. The absorption process delivers useful heat at higher temperature. **Figure 1** shows a schematic block diagram of the AHT function system.

3. Methodology

The increased awareness of the importance of environmental protection, and the possible impacts associated with products (including services), both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts. One of the techniques used for this purpose is LCA [7] [8]. There are four phases in an LCA study:

1) the goal and scope definition phase.

2) the Life Cycle Inventory analysis phase (LCI phase), it is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study.

3) The Life Cycle Impact Assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance. LCIA phase aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product. The method

use for this study is IPCC 2007 which is a method developed by the International Panel on Climate Change. This method lists the climate change factors of IPCC with a timeframe of 20, 100 and 500 years [12], the timeframe chosen was 100 years.

4) Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

Figure 2 shows a schematic diagram of the LCA of an AHT.

4. Life Cycle Assessment of AHT

4.1. The Goal and Scope Definition Phase

The Goal: The purpose of this study is assessment the environmental load of an absorption heat transformer. The intended application is to identify environmental improvements opportunities in the process involved.

The scope: The product system is an absorption heat transformer which recovers heat waste from an external source in the evaporator and generator.
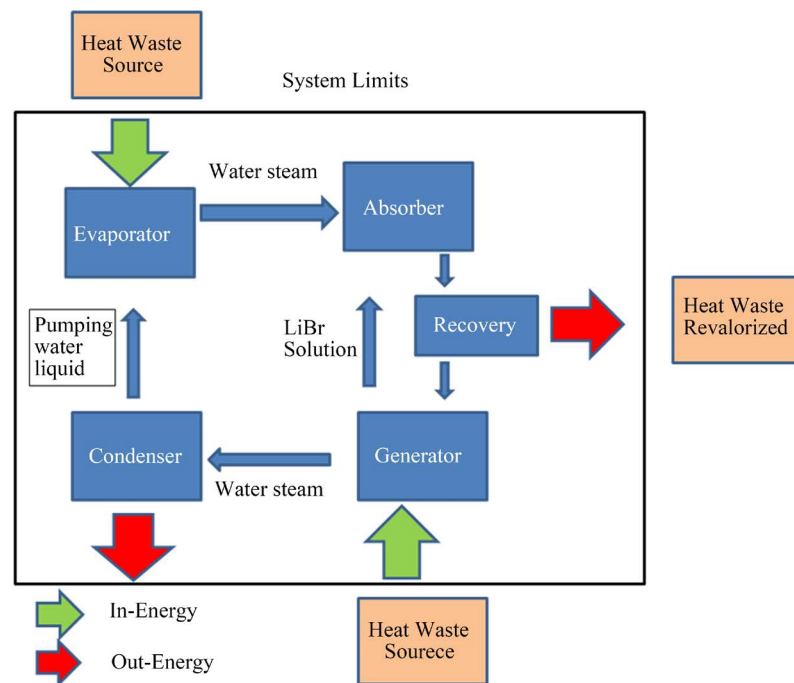

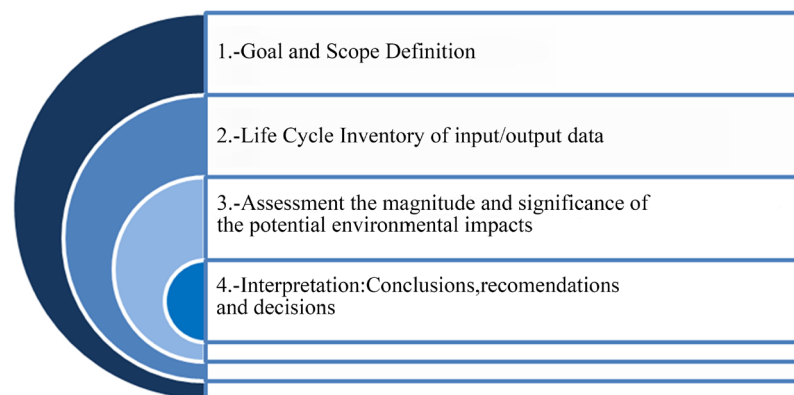**Figure 1.** Absorption Heat Transformer system limits, schematic diagram.

Figure 2. LCA of an AHT schematic diagram.

The system boundary: Four processes are considered in this study (assembly, recovery, pumping and LiBr (Lithium Bromide) solution) and shown in **Figure 1**. The generator, condenser, evaporator and absorber process works in a cycle where the incoming Energy is the same than the salient Energy.

Allocation: there is not process shared with other products.

Functional Unit: The functional unit is 1 kWh recovered for the system.

Data quality requirements: the data for assembly process were taken directly from the equipment and the data for all the other process were obtained from SimaPro software [13].

Assumptions:

- No energy loss in the system.
- The recovered energy is considered as electrical energy avoided.
- Assembly, lifetime: 40,000 hours.
- LiBr Solution, lifetime: 1000 hours.

4.2. The Life Cycle Inventory Analysis Phase

The Heat Transformer processes are: assembly, recovery, pumping and LiBr (Lithium Bromide) solution.

Tables 1-4 show the material list and input/output energy for each process.

Table 1. Material list of heat transformer assembly.

Material	Quantity	Unit
Steel, low-alloyed	90.538	kg
Steel, chromium steel18/8	11.343	kg
Elastomere (Tube insulation)	0.260	kg
Tetrafluoroethylene	0.402	kg
Vinyl fluoride	0.402	kg
Nylon 6-6	0.038	kg
Cable	0.070	kg
Copper	0.200	kg

Table 2. Material list of LiBr solution reaction.

Material	Quantity	Unit
Ethylene glycol	0.3324	kg
Lithium hydroxide	0.4125	kg
Bromine	1.3935	kg
Tap water	1.2187	kg

Table 3. Input/output of energy in the recovery process.

Process	Quantity	Unit
Generator	−1	kWh
Condenser	+1	kWh
Evaporator	−1	kWh
Recovery	−1	kWh

Note: The net contribution of energy of the system is in the Recovery Process. The negative value means that electrical energy (kWh) is avoided.

Table 4. Input/output of energy in the pumping process (direct measurement in the system).

Process	Quantity	Unit
Pumping 1	0.030	kWh
Pumping 2	0.030	kWh

4.3. Life Cycle Impact Assessment Phase

Life cycle impact assessment phase (LCIA), aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product [7]. The impact potential assessment (IPA) is calculated with (1).

$$IPA = \sum_{i=1}^{n} \text{Substance } i * CFi. \tag{1}$$

The Substances *i* for climate change category are shown in **Table 5**. In **Table 6**, it shows the characterization factors (CFi) for climate change impact category. Equation (1) calculated the IPA is shown in **Table 7**.

In this phase the environmental effects of each process (assembly, recovery, pumping and LiBr solution reaction) are quantified and evaluated for the impact category Climate Change considered in this study, the impact is expressed in a common unit (kg CO_2 equivalents)/(kg of Substance). The SIMAPRO software [13] was used to evaluate the impact potential assessment.

The negative values means the quantity avoided; as an example, in the heat transformer, the substance carbon dioxide from fossil fuel (−621.8310824 g) means than this quantity is avoided. In the assembly process the substance carbon dioxide from fossil fuel (5.596467 g) means than this quantity is emitted to environment.

4.4. Life Cycle Interpretation

The AHT system net contribution is an emission avoided of 0.665 kg CO_2 eq (see **Figure 3**).

Table 5. Inventory of substances of AHT [13].

Substance	Unit	Heat Transformer	Assembly	Pumping	Solution LiBr	Recovery
Methane, chlorodifluoro-, HCFC-22	mg	0.9930	1.0007	0.00051	0.0002308	−0.008433
Methane, trifluoro-, HFC-23	µg	63.746	63.766	0.00140	0.0021461	−0.023326
Sulfur hexafluoride	µg	−144.638329	0.193051	9.27570	0.4879222	−154.5950
Methane, fossil	mg	−826.836511	17.58988	55.55473	25.9310568	−925.9122
Dinitrogen monoxide	mg	−75.2300337	0.150714	4.844296	0.51322689	−80.73827
Carbon dioxide, fossil	g	−621.830824	5.596467	40.65573	9.51253638	−677.5956

Table 6. Characterization factors [13].

#	Sustance	Factor	Unit
1	**Methane, chlorodifluoro-, HCFC-22**	1810	kg CO_2 eq kg
2	**Methane, trifluoro-, HFC-23**	14800	kg CO_2 eq/kg
3	**Sulfur hexafluoride**	22800	kg CO_2 eq/kg
4	**Methane, fossil**	25	kg CO_2 eq/kg
5	**Dinitrogen monoxide**	298	kg CO_2 eq/kg
6	**Carbon dioxide, fossil**	1	kg CO_2 eq/kg

Table 7. Impact potential assessment results of AHT.

| Substance	Unit	Heat Transformer	Assembly	Pumping	Solution LiBr	Recovery
Total	kg CO_2 eq	−0.6652	0.00929	0.043715	0.01035	−0.72859
Other substances	kg CO_2 eq	0.00024	0.00045	1.47E−05	2.04E−05	−0.00025
Methane, chlorodifluoro-, HCFC-22	kg CO_2 eq	0.00180	0.00181	9.2E−07	4.2E−07	−1.53E−05
Methane, trifluoro-, HFC-23	kg CO_2 eq	0.00094	0.00094	2.07E−08	3.12E−08	−3.45E−07
Sulfur hexafluoride	kg CO_2 eq	−0.0033	4.40E−06	0.000211	1.11E−05	−0.00352
Methane, fossil	kg CO_2 eq	−0.0207	0.00044	0.001389	0.000648	−0.02315
Dinitrogen monoxide	kg CO_2 eq	−0.0224	4.49E−05	0.00144	0.00015	−0.02406
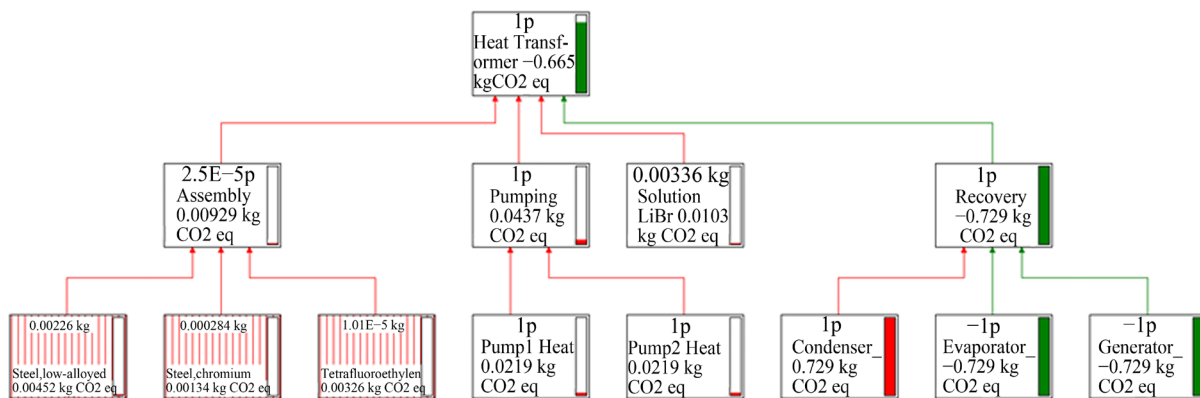
Figure 3. Results (kg of CO_2 equivalents) of the environmental impact of the heat transformer system.
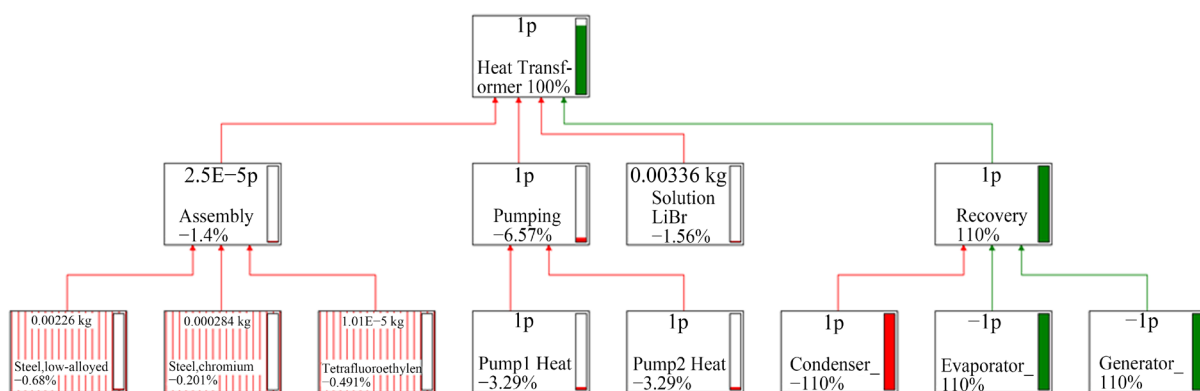

Figure 4. Results (%) of the environmental impact of the heat transformer system.

The pumping process is the highest contributor to the environmental load (see **Figure 3**) with 0.0437 which correspond to 6.57% of the net contribution (see **Figure 4**). This process uses a source of electrical energy in the case of use another cleaner energy we can diminish the total impacts.

5. Conclusions

The efficient use of energy and minimum environmental impact of chemical processes are an important task today. By means of energy recovery systems, it is possible to improve the energy efficiency and the life cycle assessment is possible to evaluate the environmental impact of chemical processes. In the present work, the life cycle assessment of an absorption heat transformer which is designed to recover 1 kWh of heat in 1 hour from each 2 kWh of waste heat supplies in the generator and evaporator equipment was performed.

The life cycle assessment of the Absorption Heat Transformer shows that the substance with major emission is from carbon dioxide fossil to air. The net contribution of heat transformer is an emission avoided of 665 g CO_2 eq. and the recovery process avoids 728.6 g CO_2 eq. and the major contribution to the environment impacts is the pumping process 43.7 g CO_2 eq. The pumping process is the main contribute to the environment impact emitted. This process uses a source of electrical energy that can be replaced with solar energy.

The environmental impact assessment of this Absorption Heat Transformer has shown that this technology can be a good option to recover waste energy in a sustainable way.

Acknowledgements

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