CHEMICAL ENGINEERING TRANSACTIONS

VOL. 91, 2022

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Valerio Cozzani, Bruno Fabiano, Genserik Reniers

ISBN 978-88-95608-89-1; **ISSN** 2283-9216

DOI: 10.3303/CET2291063

Risk of Overwarming for Flow Variation into an Absorption Heat Transformer for Waste Heat Recovery Process

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For waste heat recovery process there are some thermodynamic options with efficiencies depending on some equilibrium parameters. The global warming is a permanent concern in the industries with thermal process at any temperature level. One of the promiser systems for recover waste energy from relative medium temperature level (70°C – 100 °C) is the absorption heat transformers. These thermodynamic devices are under research for several technical aspects: efficiency, corrosion, economic benefit and social impacts. These devices are a kind of heat pump: inverse absorption heat pump. The main advantage of these devices is the increment of the temperature using half part of the heat load to increase a third part of that heat at a higher temperature level (i.e., 140°C). The use of additives to achieve this process is mainly part of the success of the process. However, the control of the device is under research and development to get the higher heat recovery at the higher hemodynamic equilibrium temperature. The flow increment leads to variation of the Absorption Heat Transformer's Coefficient of performance (COP). This variation may cause an undesirable overwarming into the absorption cycle that cause diminish of the COP and it is a risk for the thermodynamic cycle for increase of the highest-pressure zone in the process. This paper shows the thermodynamic operating conditions based on Flow Ratio calculation with the lower risk for operation based on the flow control of the refrigerant for a Carrol – Water absorption heat transformer.

1. Introduction

The main concerns for world's population, before the COVID19 were: poverty, employment, violence, politics and health. The interaction with nature carries a global problem for the environmental effects (Shcheblyakov, 2019). For the evaluation of the CO_2 total amount the Kaya identity (Hakim, 2019),(He, 2018) are widely used, and the impellers factors are obtained from each country and the International Energy Agency shows for each year the global amount.

The main concerns nowadays are health and climate change. Vaccines have taken specific attention for the first one and renewable energies for the second one. For engineering thermal processes, there are several processes for efficiency. Each thermal process has CO_2 or equivalent emissions in line with time and technology. Waste or residual heat is the heat present in the products and by-products of a process that can be recovered to be reused in the same process or in others (Redko, 2020).

The evaluation is only one part for solve the environmental problem: technologic devices must be designed and constructed for diminish the CO_2 emissions. One of the future technology options is the efficient absorption heat transformers (AHT) than are a kind of heat pump capable to use waste thermal energy for increase the temperature concern of another fluid for several uses, as example for water purification (Romero, 2008). To

Paper Received: 1 March 2022; Revised: 16 March 2022; Accepted: 27 April 2022
Please cite this article as: Vazquez - Aveledo S., Diaz-Gonzalez L., Montiel-Gonzalez M., Romero R.J., 2022, Risk of Overwarming for Flow Variation Into an Absorption Heat Transformer for Waste Heat Recovery Process, Chemical Engineering Transactions, 91, 373-378 DOI:10.3303/CET2291063

reduce CO_2 emissions there is effort by several institutions to analyze the heat recovery applications for all processes. Almost 180 million heat pumps were used for heating in 2020 (IEA,2021).
The components of AHT are basically heat exchangers, named: Generator, Condenser, Evaporator, and Absorber, which work in a thermodynamic cycle with heat exchange in all of them and simultaneous material and heat exchange in two of them. These types of equipment work with three levels of temperature and two levels of pressure and present characteristics of the work cycle since these absorption systems operate with a working mixture that is a combination of a working fluid and an absorbent, as can be seen in Figure 1. Therefore, the behavior of the absorption cycle depends on the thermodynamic, chemical, and physical properties of the working fluid and the absorbent.
Different variables such as temperature, pressure, concentration, power, and fluid flows at different densities are present in the absorption cycle, resulting in a very complex process. The operation of the thermodynamic cycle is influenced by disturbances such as the ambient temperature, which limits the behavior of the condenser since it necessarily requires an exchange with the environment. In addition to this, the equipment cannot be self-regulating, resulting in the system going to the most unfavorable conditions such as crystallization, pressure increase, and condensation flow. These three conditions mentioned above lead to the thermodynamic cycle being inhibited and consequently not achieving its objective, in addition to the damage to equipment and operators. In this work, a risk for the operating design for an absorption heat transformer is shown, the main risk is due to the heat load increment from absorber that may overwarm the generator unit. A strategy to avoid it for Carrol – water pair used into a single stage heat transformer is based on the temperature values with lower delivered heat from absorption compared with COP variation.

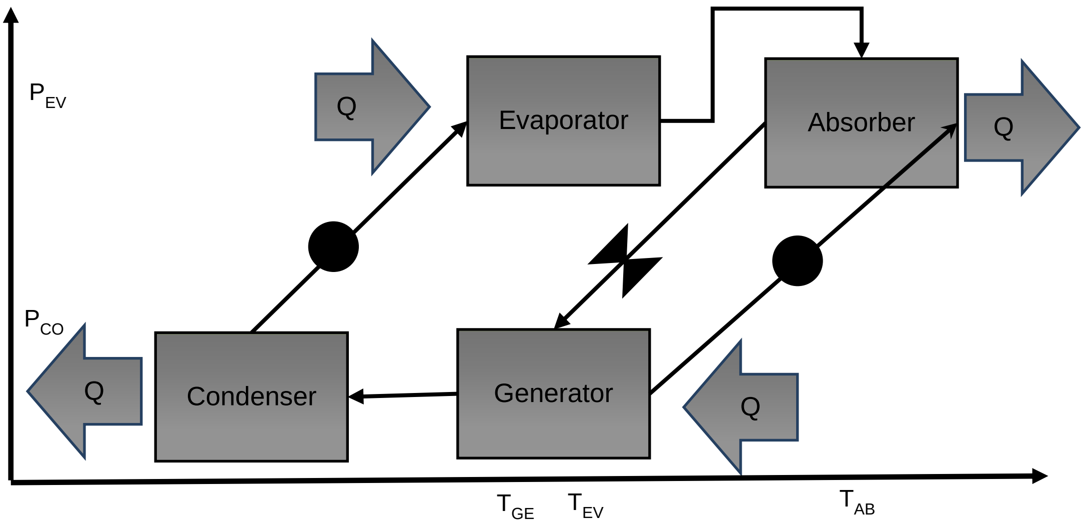

Figure 1. Schematic diagram for single stage absorption heat transformer

2. Methodology

Different technologies are available for heat recovery from a low-temperature waste source. Absorption systems are one of the technologies used for heat recovery; and particularly Absorption Heat Transformers, which are a type of absorption heat pump whose function is to increase the temperature of low-temperature heat sources to more useful levels (Rivera, 2015). AHT recover industrial waste heat with higher efficiency, lower environmental impact, and can be adapted to renewable energies such as solar or geothermal energy. In addition, they can be coupled to industrial processes, either for heat recovery for a secondary process (food drying, etc.) or the re-entry of heat to the process (in the textile industry, in the chemical industry, and the production of paper, etc.).
The performance of a heat pump, in general, is expressed by the operating coefficient (COP), which is the relationship between the energy delivered by the heat pump and the energy supplied. Thermodynamic model and artificial neural network are used to estimate the Coefficient of performance for an absorption heat transformer (Hernández, 2009) where this parameter is calculated as the ratio of useful heat for the absorption process (Q_{AB}) by the total amount of the waste thermal energy used into the vapor generator (Q_{GE}) and heat into the relative high pressure evaporator (Q_{EV}) and the power of the positive displacement pump (PD) located into the vapor generator and absorber (PD_1) and into the condenser and evaporator (PD_2). Eq(1).

$$COP = \frac{Q_{AB}}{Q_{GE} + Q_{EV} + PD_1 + PD_2} \quad (1)$$

where Q_{AB}: is the useful heat for the absorption process [kW], Q_{GE}: represent the amount of the waste thermal energy used into the vapor generator [kW], Q_{EV}: is the heat into evaporator [kW] and PD_1 and PD_2 : is the power of the positive displacement pump into pump 1 and 2 [kW].

The COP is a measure of the saved energy for each thermal process with an absorption heat transformer. In 2019, nearly 20 million households purchased heat pumps (IEA, 2020). Most of them were connected to fossil fuel, but for sustainable future, the compression heat pump must be substituted with absorption heat pumps. Each heat load for absorber, condenser, vapor generator and evaporator, are calculated based on enthalpies for the Carrol – water pair, this work is based take the data from a previous paper (Romero, 2008) from our facility. It is calculated as Eq(2):

$$\Delta Q_i = \sum_{j=1}^{n} m_j h_j \quad (2)$$

where: i: represents the number of each device, ΔQ_i: represents the variation of thermal power in each device [kW], m: refers to mass flow [kg/s], j: inputs or outputs of each device, n: number of devices, and h: enthalpy [kJ/kg]

The useful heat is recovered in the higher temperature of the thermodynamic cycle with mineral oil at secondary circuit flow. This flow is usually designed as function of the power of the single stage heat transformer. The ideal behavior for this heat transfer process is assumed as a product of mass flow (m), heat capacity (Cp) and temperature variation, Eq(3):

$$Q_i = m_i Cp_i \Delta T_i \quad (3)$$

where: Cp: is the heat capacity [kJ/kg °C] and ΔT: is the temperature variation [°C]

For absorption process, the heat balance is based on the enthalpy values. The enthalpy is a thermodynamic magnitude function of mass concentration and the instantly temperature for each steady state condition into an operating condition. For Carrol – water similar to lithium bromide – water pair (Romero, 2011) the highest temperatures into the absorption are close to crystallization risk as reported in a previous work (Rivera, 2002). To avoid this risk, it is desirable to evaluate the variation of Q_i for absorption process as function of COP. If the heat is not removed as fast the absorption process occurs then the pressure into the absorber unit would increase by thermodynamic equilibrium.

3. Results

For the risk analysis, operating conditions for a single stage heat transformer (SSHT) were calculated with an absorption temperature at 140 °C as objective, from waste heat close to 100 °C, and surrounding to allow condensation process at 30 °C. The evaporation temperature variation is the only possibility in the experimentation. The temperature data is shown in Table 1. This risk is not previously analyzed for authors.

Table 1: Temperatures, Pressure and Carrol - water concentration for selected operating conditions for risk analysis

Case	T_{GE} °C	T_{CO} °C	T_{EV} °C	T_{AB} °C	P_{CO} mmHg	P_{EV} mmHg	X_{AB} %w	X_{GE} %w
1	100	30	70	140	31.9	233.6	74.8	79.4
2	100	30	75	140	31.9	288.9	72.5	79.4
3	100	30	80	140	31.9	354.9	70.1	79.4
4	100	30	85	140	31.9	433.1	67.8	79.4
5	100	30	90	140	31.9	525.4	65.4	79.4
6	100	30	95	140	31.9	633.4	62.9	79.4
7	100	30	100	140	31.9	759.4	60.3	79.4

The Carrol – water mass concentration and the equilibrium pressure for selected conditions are show also in Table 1 and the mass flow for the selected heat load is show in Table 2, for 7 analyzed cases with evaporator power was defined as constant power.

Table 2: Mass flow from SSHT components at constant heat and steady state.

Case	$M_{GE \to CO}$ kg/s	$M_{AB \to GE}$ kg/s	$M_{GE \to AB}$ kg/s	Q_{GE} kW	Q_{EV} kW	Q_{CO} kW	Q_{AB} kW
1	4.00E-04	6.90E-03	6.50E-03	0.620	1.000	1.023	0.597
2	3.99E-04	4.59E-03	4.19E-03	0.765	1.000	1.019	0.746
3	3.97E-04	3.39E-03	2.99E-03	0.834	1.000	1.016	0.818
4	3.96E-04	2.71E-03	2.31E-03	0.868	1.000	1.012	0.856
5	3.95E-04	2.24E-03	1.84E-03	0.888	1.000	1.009	0.878
6	3.93E-04	1.89E-03	1.50E-03	0.897	1.000	1.006	0.892
7	3.92E-04	1.63E-03	1.24E-03	0.901	1.000	1.003	0.898

The variation of the mass flow from all process into the SSHT does not exhibit linear behavior. The variation for the water goes from condenser to evaporator has lower value than Carrol / water flow. This is particularly unusual because the variation of the Carrol /water has variation from 13 % to 35 %. So, for almost constant water flow from condenser to evaporator mean a dilution, as can be seen in table 2. Figure 2 show the variation from 70°C to 75°C plotted in 72.5 °C for easy reading of the six variations for the seven cases. The nonlinear functions indicate the delivered heat in absorption process has risk for Q_{AB} overwarming because the water flow form generator to condenser (red dots) has variations in different way compared with flows from generator to absorber units as can be seen in Figure 2 with green and purple lines.

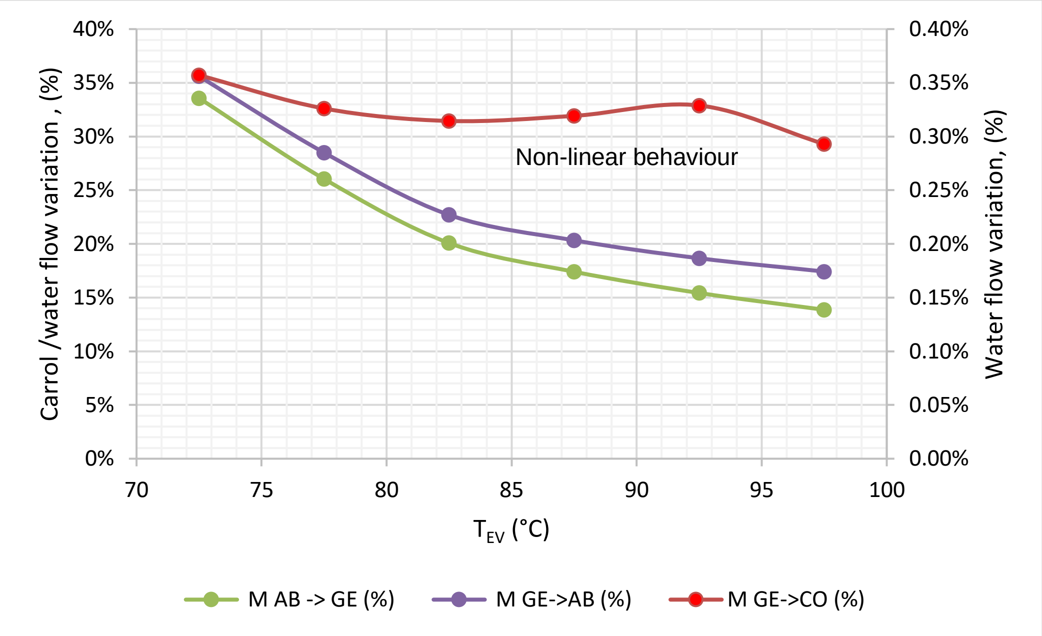

Figure 2. Mass flow variation as function of the evaporator temperature for cases in Table 1.

For the calculation of the Q_{AB} at selected conditions, the Carrol – water variations lead to nonlinear variation with a coincident increase of COP. This behavior war already reported in all studies for steady state operating conditions in Carrol – water (Rivera, 2015) but the variation of the flow free of Carrol, see Figure 3, is expected as second grade function. Instead, the variation of the absorption heat power is conducted as Eq(4):

$$\Delta Q_{AB} = k_1 \, \Delta M_i^n \quad (4)$$

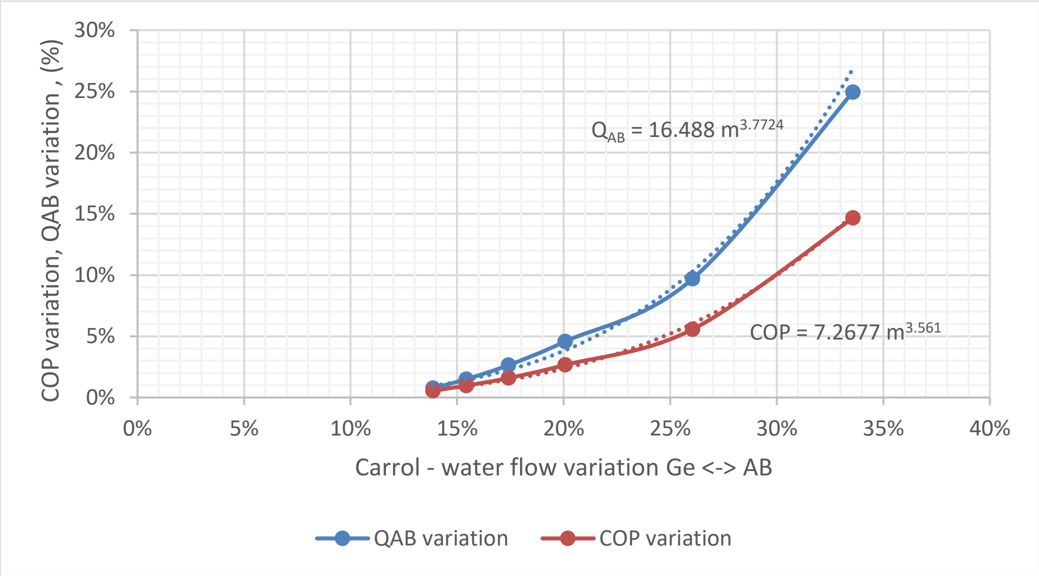

Figure 3. COP and Q_{AB} variations as function of the Carrol – water flow variation for cases SSHT.

Where k_1 is a proportional factor and n is the power of the function, for the “i” flow variation. Similar behavior for COP is it expected Eq(5):

$$\Delta COP = k_2\ \Delta M_i^o \tag{5}$$

Where k_2 is other proportional factor and o is the power of this function.

The unexpected variation and the risk for the inhibition of the equilibrium operating conditions are show as a consequence of the great variation as function of flow of vapor from generator to condenser in the maximum point for the QAB variation and the maximum point on the COP variation into the Figure 3. The variation leads to great delivered heat in absorption process, as show in Figure 4. If the delivered heat from the absorber is not exchanged then that heat will entering to generator unit, at higher temperature value, and the equilibrium process will be affected in negative way: vapor generation would be stop and the absorption will be inhibited.

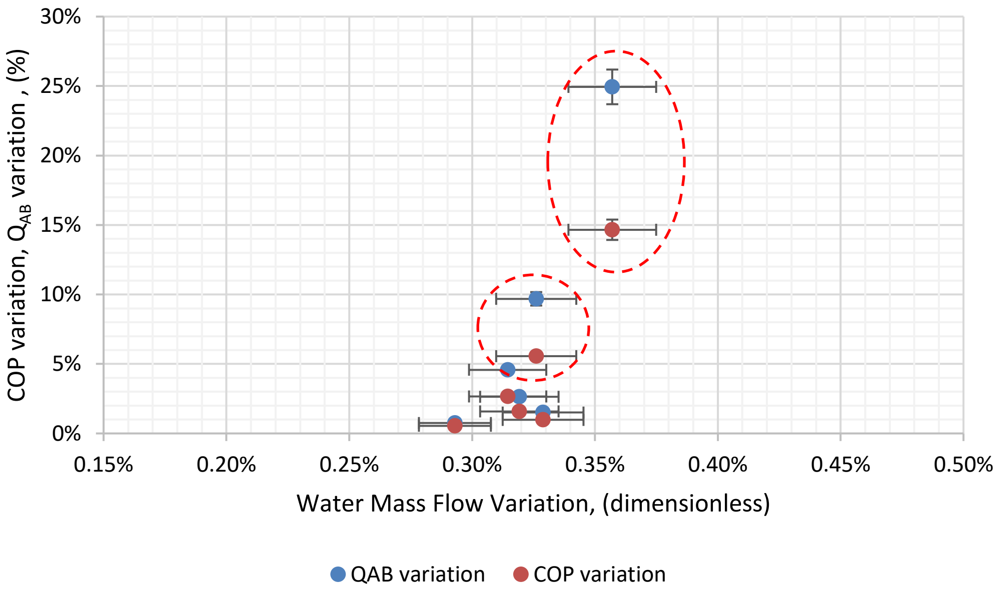

Figure 4. Percentage variation for COP and Q_{AB} for the selected cases into a SSHT.

4. Conclusions

The variation of the delivered absorption heat as function of the variation of the Carrol – water flow into a single stage heat transformer is nonlinear function. The factor for deliver absorption heat variation is 16.488 while the factor for COP is 7.2677. The values for power function variations are n = 3.7724 and o = 3.561.
Also, the variation of the heat of absorption and the variation of the COP as a function of the variation of the flow of the working fluid shows a notable increase for values of variation of the flow of the working fluid greater than 0.33%, which can lead to the inhibition of the AHT absorption cycle, causing damage to the equipment and risks to the operators.
Finally, single stage heat transformer safe operation are limited into the linear zone with evaporator temperature higher than 77.5°C and lower than 92.5°C, for selected operation conditions reported in Table 1, where the increase of the deliver absorption variation is predictable with the proposed equation for the estimation of the COP.

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