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Absorption Heat transformer Study: nested helical coils and two shells

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Abstract

A heat transformer by absorption (AHT) is a thermal equipment, which contributes for the environmental sustainability. Its main purpose is to increase the thermal level through a thermodynamic cycle using residual or renewable sources. The CIICAp-UAEM studies different configurations about AHT since the year 2000 and, its attention focus is currently to develop smaller equipments with high efficiency, where the heat transfer area for every component is relevant. A compact AHT of 2 kW was designed and characterized with only two shells (low and high pressure) and their components were made with nested helical coils. Heat transfer coefficients for evaporator were determined considering several temperatures and mass flux rates.

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Nomenclature

A	Heat transfer area, m ²
C_p	Specific heat capacity, kJ/kg K
D	Diameter, m
h	Local heat transfer coefficient, (W/m ² K)
\dot{m}	Mass flux rate, kg/s
Nu	Nusselt number, dim
Pr	Prandtl number, dim

\dot{Q}	Heat flux rate, kW
Re	Reynolds number, dim
T	Temperature, °C
U	Overall heat transfer coefficient, (W/m ² K)

Subscripts

EVA	Evaporator
H	Hydraulic
hea	Heating
hel	Helical
In	Inlet
inn	Inner
lm	Mean logarithmic
$steam$	Steam
out	Outlet
ref	Refrigerant

Greek letters

κ	Thermal conductivity, W/m K
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Introduction

The Helical Heat Exchanger (HHE) enhances the heat transfer characteristics due to the secondary flow, which is perpendicular to the axial fluid direction [1] by the centrifugal force because of the coil curvature [2, 3]. However, this does more complex the understanding about the heat transfer phenomena. *Some advantages of HHE:* the heat transfer coefficients are higher [4], spaces saving, and costs reduction for building and maintenance. *Some disadvantages of HHE:* The maximum operating pressure is 10000 psig, while the operating temperatures are limited by the materials and the corrosion rate [5]. Different configurations have been used for heat recovering processes, spaces conditionings, refrigeration systems, chemical and nuclear reactors, medical equipments, chemical and food processing [6,7].

Overall and local heat transfer coefficients have been proposed by using theoretical and experimental studies for specific operating parameters [6-14], in which the information about Nested Helical Heat Exchangers (NHHE) for an Absorption Heat Transformer (AHT) are limited. An AHT uses basically four heat exchangers at different temperatures and pressures to upgrade the temperature with respect to the heat source (residual heat or renewable energy). This work presents the experimental results for the evaporator, which was built as a NHHE of 2 kW and its operation is as falling film. The local and overall heat transfer coefficients are discussed considering several operating parameters.

Absorption Heat Transformer

A schematic diagram about AHT is shown in Figure 1. The refrigerant is separated from binary mixture in the generator, when the heat source is supplied at low pressure and medium temperature. The steam is condensed at low temperature and pressure in the condenser. This liquid receives heat in the evaporator to obtain steam at high pressure and medium temperature. The strong binary mixture, which come from generator is mixed with the steam inside the absorber, in order to obtain useful heat at high temperature. The weak working solution preheats the strong binary mixture through the solution heat exchanger (SHE) and returns to the generator for repeating the cycle again.

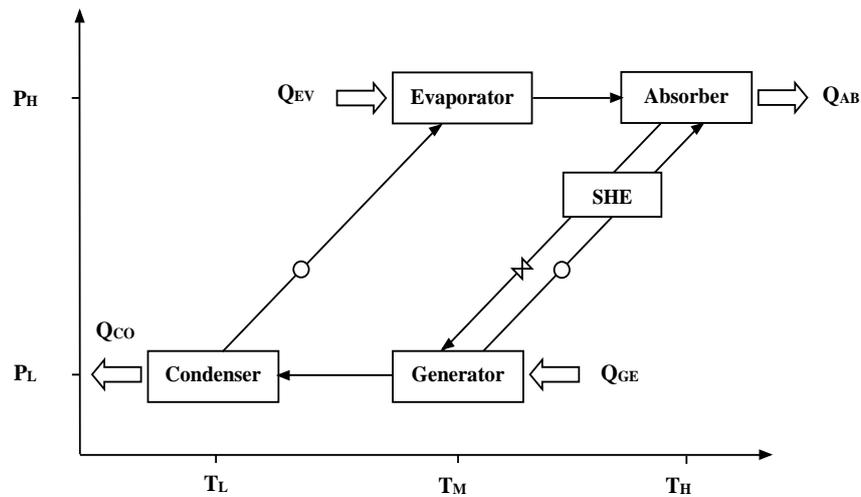


Figure 1. Schematic Diagram for an AHT

Experimental setup

The experimental equipment is integrated by two shells depicts in Figure 3. Two nested coils with different heat transfer area have every shell. The whole system is built with stainless steel 316L and cooper. Two digital gauges excites by voltages were installed for high and low pressure. PT-100's were required to measure the inlet and outlet temperatures for every component. The mass flux rates were quantified by means of seven analogic flux meters with different characteristics and the binary mixture concentration was determined by using a refractometer. A data acquirer was used to know the temperature and pressure variables in almost real time. The heat supply for the evaporator and generator was simulated by electric resistances, which were controlled by a voltage regulator at 120 v and 10 a. A chiller was utilized as sink for the condenser and the absorber. The heat losses were reduced by using a commercial thermal insulation with a thermal conductivity of 0.040 W/m K. The evaporator consists of four nested helical coils interconnected in series. A 316L tubing of ½ in was used to build the four turns in each coil. This component was analyzed as a part of an AHT, whence the operating parameters depends on the other components. The heating source goes inside tubes and the refrigerant falls over the tubing as falling film.



Figure 3. Experimental equipment facility

Analysis for measured data

The heat flux rates for the hold and cold lines were calculated with the following equation

$$\dot{Q} = \dot{m}Cp(T_{in} - T_{out}) \quad \text{Eq. 1}$$

The overall heat transfer coefficient was determined thorough this equation

$$\dot{Q} = UA\Delta T_{lm} \quad \text{Eq. 2}$$

For an evaporation process, the phase change significantly contributes in the heat transfer. The mean logarithmic temperature difference is a function of the heating temperature and the refrigerant boiling temperature,

$$\Delta T_{lm} = \frac{(T_{hea,in}-T_{steam})-(T_{hea,out}-T_{steam})}{\ln\left(\frac{T_{hea,in}-T_{steam}}{T_{hea,out}-T_{steam}}\right)} \quad \text{Eq. 3}$$

Also, the overall heat transfer coefficient is mainly affected by the local heat transfer coefficients, since the heat transfer by conduction is minimum because of the stainless steel material and its thickness.

$$U \approx \frac{1}{\frac{1}{h_{steam}} + \frac{1}{h_{hea}}} \quad \text{Eq. 4}$$

Several experimental correlations have been reported in order to know the $Nu_{hea} = f(Re, Pr)$. The Dittus Boelter equation [15] is used

$$Nu_{hea} = 0.023Re^{0.8}Pr^{0.3} \quad \text{Eq. 5}$$

$[Re \geq 10000, 0.7 \leq Pr \leq 160]$

An adjustment for the helical coils with $Re > 10000$ is made through the straight tubes equation [16]:

$$Nu_{hea,hel} = Nu_{hea} \left[1 + 0.35 \left(\frac{D_{inn}}{D_{hel}} \right) \right] \quad \text{Eq. 6}$$

The effectiveness of convective heat transfer is known by means of the Nusselt number,

$$Nu_{hea,hel} = \frac{h_{hea}D_h}{k} \quad \text{Eq. 7}$$

And the thermodynamic and transport properties for the liquid and steam refrigerant were taken from IAPWS IF97 standard [17].

Results and discussions

The four outlet temperatures for every component and the two pressure levels are indicated in Figure 2. Initially, the cycle has a lower pressure at environmental temperature in whole system. After starting the mass and heat interchanges, the transitory state starts until reaching the steady state, in which the equipment performance is done. The duration for each state depends on the equipment design and how the critical variables changes are controlled. For this experimental test, the initial binary mixture was of 52 % and the Coefficient of Performance was of 0.352.

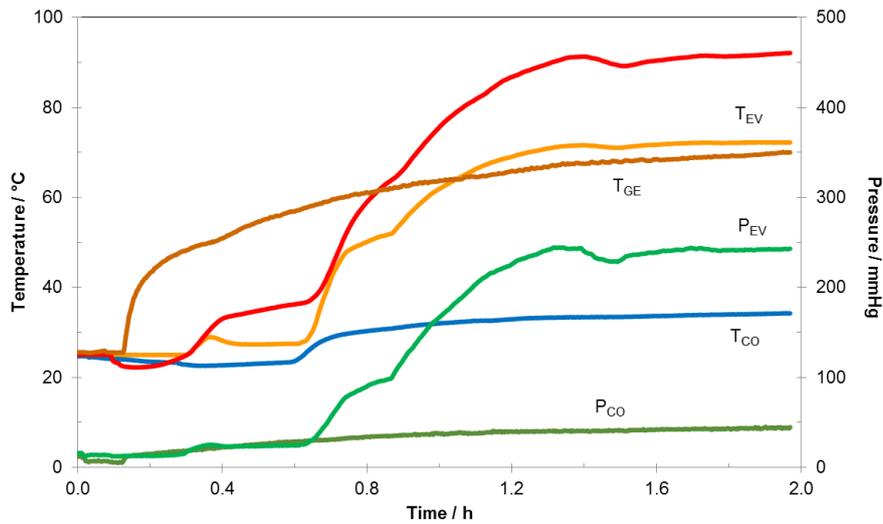


Figure 2. Experimental test of AHT

Figure 4 illustrates the variations of overall heat transfer coefficient for the evaporator as a function of refrigerant at different heating temperatures. The falling film thickness and the wetting area depends on the liquid refrigerant quantity, which circulates over the coils. It is clear that the refrigerant mass affects more to the U than the heating temperature, since the falling film thickness and wetting area improve, while this one does not have a significant change with respect to the temperature.

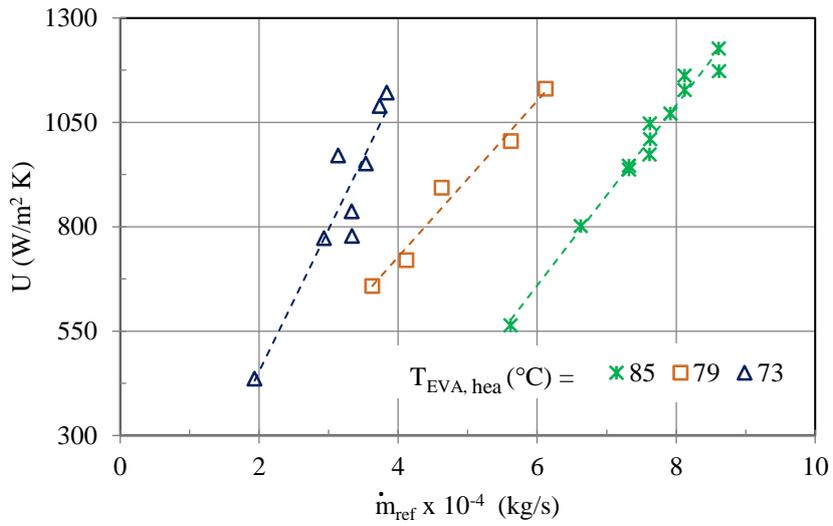


Figure 4. Variations of U at different \dot{m}_{REF} and heating temperatures

The mass fluxes changes and the boiling temperatures in the refrigerant directly affect its surface tension, viscosity and falling film thickness. On the other hand, a maximum refrigerant at high temperature increases the specific volume, which takes advantage to the absorber, because all heat interchange area is covered and the exothermic reaction improves. In accordance with the results seen in Figure 5, the best results are obtained when the temperature and the mass flux rate of the refrigerant are maximum. However, the heat slope is similar when anyone is increased.

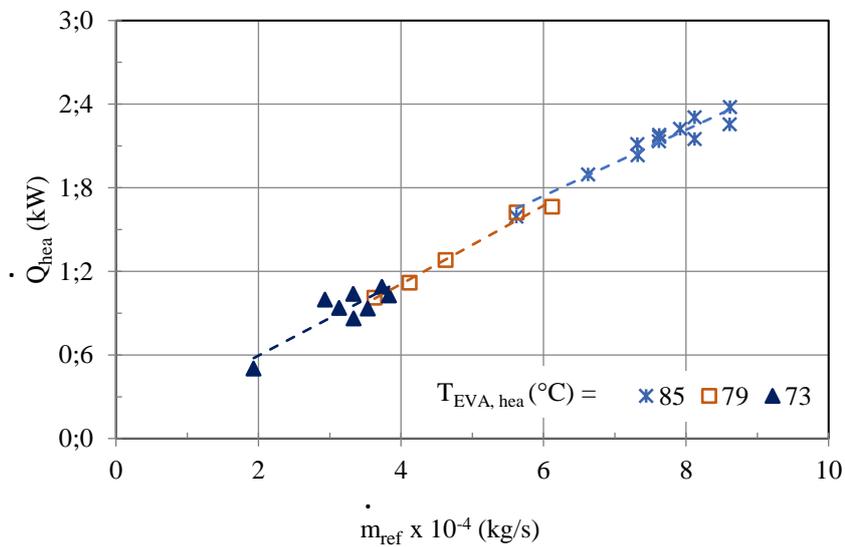


Figure 5. Heat flux rate versus \dot{m}_{ref} considering several activation temperatures

Figure 6 shows the local heat transfer coefficients considering several Re and $T_{EVA,hea}$. The performance for every component is influenced by endogenous and exogenous aspects, in other words the refrigerant quantity and its boiling temperature are mainly limited due to the strong working solution and mass flux rate in the generator. For this reason the Reynolds number varies from 16.5 to 72.5. Based on Equation 4, the overall heat transfer coefficient is directly proportional at the local heat transfer coefficients from hot and cold lines, however its change is more significant because of the cold line coefficient, which is more complex to determine by the phase change.

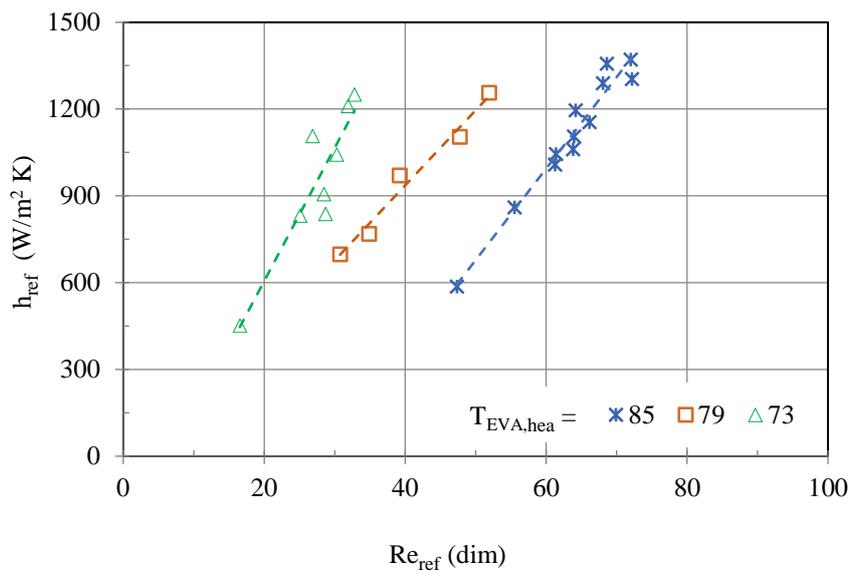


Figure 6. Local heat transfer coefficient for the cold line considering different Re and $T_{EVA,hea}$

Figure 7 illustrates the local heat transfer coefficient against Nusselt number. For this case, the convective phenomena increases at any temperature because the heat transfer area is more wetting because of the drops increment. However, the thermodynamic proprieties of steam changes slightly considering a temperature delta of 9 °C. Once the boiling conditions for the refrigerant are reached, the mass flux rate has more contribution about the local heat transfer coefficient.

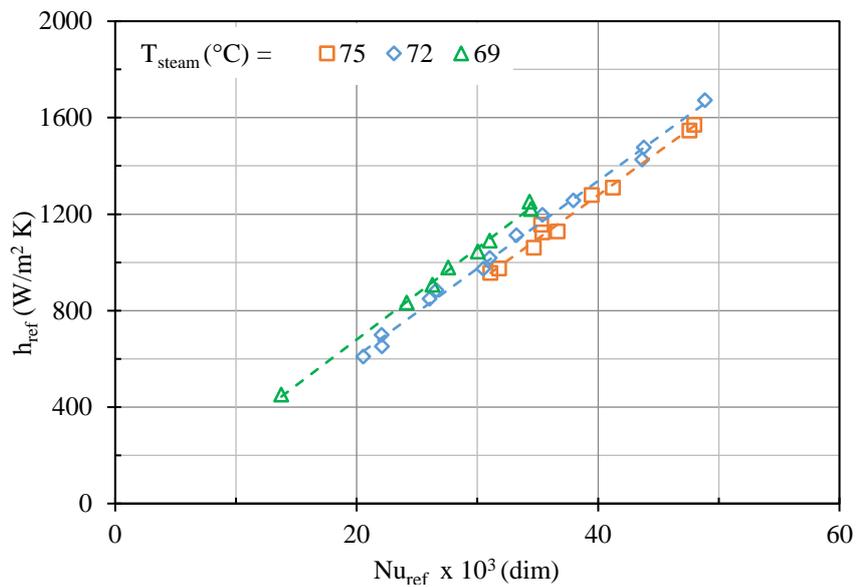


Figure 7. Refrigerant heat transfer coefficient in function of Nusselt number

Conclusions

The AHT performance depends on its design and manufacture about their components. The overall heat transfer coefficient is a characteristic for the process and the geometry of each heat exchanger. This study is focused to determine some parameters for the heat transfer in the evaporator with nested helical coils. This one works inside an AHT at specific operating parameters and water operates as falling film. Empirical Correlations are used to determine the local and global heat transfer coefficients. Based on the results, the U is more sensible to the mass flux rate than heating temperature changes, since the falling film thickness and the wetting are improved. The U increases up to 1227.6 W/ m² K at T_{EVA,hea} of 85 °C and an refrigerant of 8.62 kg/s.

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