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Energy efficiency assessment in the generator of an absorption heat transformer from measurement falling film thickness on helical coils

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HIGHLIGHTS

- Optimal hole diameter of design in the distributor was determined.
- Operation flow in the generator was obtained.
- Experimental falling film thickness of LiBr/H_2O was measured.
- Convective heat transfer coefficient on the film side of LiBr/H_2O was calculated.
- Energy efficiency in the generator was estimated.

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Heat transfer coefficient
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ABSTRACT

Heat exchange systems based on the falling film configuration need a detailed analysis of the design variables and operation of the distributor, which will ensure a homogeneous falling film pattern on a tube bank. The objective of this research was to determine the falling film thickness of the LiBr/H_2O at 55 wt%, as a function of the convective heat transfer coefficient on the film side. Different hole diameters and mass flow velocities were evaluated to analyze the falling film thickness behavior. The falling film analysis was carried out on a double concentric coil located in the generator (*GE*) of an absorption heat transformer (*AHT)* coupled to a water purification system (*WP*). The falling film thickness was experimentally measured from the digital image processing technique. The fall pattern favored a homogeneous distribution falling film in dropwise form with which was obtained wetted efficiency values of 97% on the outer coil and 94% on the inner coil. From the definition of the design and operation variables in the distributor (hole diameter and mass flow velocity), some of the main variables that intervened in the heat transfer process were determined: the falling film thickness; the falling film average velocity; and the convective heat transfer coefficient on the film side. Under these operating conditions and design, the heat transfer efficiency values in the *GE* increased up to 95%. Consequently, the heat load was increased by 64% with respect to the original design of the helical bank of the *GE*.

1. Introduction

The increase in energy demand in all sectors of society requires increasingly an intelligent use of the available energy. Research aimed at the development of technologies that make efficient use of renewable energy such as solar energy and the use of waste heat in industrial processes are of great interest today. Even though the absorption heat transformer (*AHT*) has been reported as a favorable candidate by its capacity to recover about 50% of low-temperature waste heat from an industrial source or a solar collector and to increase its thermal level to be used in different industrial processes. Oluleye et al. [1] developed methods for the conceptual screening and incorporation of low-temperature heat upgrading technologies in process sites. Novel simplified models of mechanical heat pumps, absorption heat pumps and *AHT* were proposed to support this analysis. They analyzed also the diverse range of waste heat sources and sinks for upgraded heat without

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Nomenclature

A	poorly wetted area (m^2)
AHT	absorption heat transformer
A_o	total heat transfer area (m^2)
A_w	heat transfer effective area (m^2)
C_i	inner coil
C_o	outer coil
D_h	hole diameter (cm)
D_i	outside diameter of the inner ring (cm)
D_o	outside diameter of the outer ring (cm)
g	acceleration due to gravity (m/s^2)
GE	generator
H	height of double concentric coil (m)
h_o	convective heat transfer coefficient on the film side (W/m^2 K)
h_{ot}	theoretical heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
$LiBr/H_2O$	fluid mixture water/lithium-bromide
L	coil length (m)
$\dot{m}$	flow velocity (kg/s)
N_h	holes number
$\dot{q}$	heat flux (W/m^2)
$\dot{Q}$	heat load (W)
$\dot{Q}_{in}$	heat load that circulates inside the coils (W)
S_h	distance between holes (cm)
T_{aw}	average tube wall temperature (K)
$T_{H2O,o}$	heating water outlet temperature (K)
$T_{H2O,i}$	heating water inlet temperature (K)
$T_{LiBr/H2O}$	temperature of the water/lithium-bromide (K)
$\bar{u}$	falling film average velocity (m/s)
WP	water purification system
WR	wetting ratio (dimensionless)
Γ	mass flow velocity per unit length (kg/sm)
δ_t	falling film theoretical thickness (cm)
δ	falling film thickness (cm)
μ	dynamic viscosity (kg/sm)
θ	angular position on a horizontal tube (rad)
ρ	density (kg/m^3)
η	wetted efficiency (%)
ε	heat transfer efficiency (%)

additional complexities, the screening of technology options, the selection of operating temperatures (heat source and sink) and the use to which the recovered energy was put. The results of the analysis reported that of the four thermodynamic cycles compared in the study, the *AHT* showed the highest potential to reduce primary fuel.

Parham et al. [2] developed a simulation model with which investigated and compared three main categories of heat transformers: systems comprising single, double and triple effect *AHT* coupled to a water purification system (*WP*). The results of the performance optimization showed that the highest increase of fresh water by residential units were achieved with the of *AHT* systems comprising single design. For this reason, these heat exchangers are considered an attractive research aim. Therefore, there exists a need for identifying suitable working fluid combinations and for evaluating their relative performance characteristics. In this context, Yin et al. [3] presented a comparative thermodynamic analysis for an *AHT* with different combinations of work fluids: $LiBr/H_2O$; 2,2,2-trifluoroethanol/N-methy1-2-pyrrolidone; dimethylether tetraethylene glycol and 2-pyrrolidone. Of the four work fluids evaluated, the one that yielded the highest values of *COP* and the Exergy Efficiency was the LiBr solution.

As for the design of heat exchangers, it is necessary to adopt appropriate strategies for increasing heat transfer, making structures more compact heat exchange and better properties of heat transfer in order to reduce investment costs and energy consumption. Wang et al. [4] performed a general review of the shell-and-tube heat exchangers with different types of helical baffles. They concluded that these heat exchangers with helical baffled should be used to replace the conventional segmental baffled in industries, especially on the novel combined helical baffles.

The process of heat transfer through the falling film is performed in a wide variety of thermal applications, chemical and petrochemical systems, refrigeration, industrial desalination and water treatment, with compact structure and high energy efficiency. Heat exchangers that operate by falling film evaporation, with different arrangements of tubes, are mainly very attractive to provide high film side heat transfer coefficients and to operate in low flow velocity intervals. With the development of falling film technology, helical coils and flooded heat exchangers, are being replaced gradually since falling film technology has significant advantages such as: the pressure drop of the fluid along the tube is insignificant, the amount of refrigerant required is small, and the convective heat transfer coefficient on the film side is high. Helical geometry permits handling of high temperatures and extreme temperature differentials without high induced stresses or costly expansion joints. High-pressure capability and the ability to fully clean the service fluid area add to the exchanger's advantages. This type of interchanger is widely used in piping systems, heat exchangers, storage tanks, chemical reactors and many other engineering applications. Go et al. [5] developed a three-dimensional numerical analysis model to simulate the thermal behavior of a horizontal spiral-coil-loop heat exchanger. The geometry arrangements of the heat exchanger in spiral form provided an environmental benefit which the CO_2 emission amount can be reduced by up to 1.169 ton per year.

In spiral tubes o helical coils, the heat transfer coefficients are higher than in straight tubes due to the presence of secondary flow which increases the extent of mixing. The difference between the convective heat transfer coefficient (h_o) in coiled tubes and straight tubes is significant, being h_o greater in the coils [6,7].

Yoon et al. [8] presented experimental results of heat and mass transfer investigation of the $LiBr/H_2O$ falling film absorber for a small household absorption chiller/heater. Various components such as the low temperature *GE*, the absorber and the evaporator were arranged concentrically in helical form. This arrangement of the heat exchangers allowed a more compact system than the conventional system was obtained. As a result, the proposed helical absorber showed a good potential due its reduced size and weight for the future designs of small capacity absorption chillers/heaters.

Zhang et al. [9] simulated the heat and mass transfer in a falling film absorption process of $LiBr/H_2O$ to know the effects of various Reynolds number on the absorption progress. The simulation results indicated that with the smaller Reynolds numbers the thinner liquid films and the higher local heat transfer coefficients were obtained. On the contrary, with the increase of the Reynolds number of falling film was increased the interfacial mass transfer coefficient and the local mass transfer coefficient along the falling film was reduced. The larger numbers Reynolds led to shorter times for the falling film exposure which made less amount of water vapor was absorbed from the $LiBr/H_2O$ solution.

Pawar and Sunnapwar [10] validated also some experimental results with a numerical simulation software for various Reynolds number in laminar and turbulent flow regions, and observed the variations in the falling film patterns on helical coils for Newtonian as well as for non-Newtonian fluids. In their investigation, they analyzed that the heat transfer coefficient in laminar flow regime on helical coil is higher than in turbulent flow regime. This was due to the fact that in laminar flow the heat transfer was more effective from the wall to the tube