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Experimental study of a graphite disks absorber couple to a heat transformer

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ABSTRACT

An experimental study was performed on a graphite disk absorber coupled to an absorption heat transformer. The working solution used was H_2O/LiBr. Due to corrosion caused to materials such as carbon steel and stainless steel with the solution H_2O/LiBr, it was necessary to consider the use of another material such as tar impregnated graphite. This material has interesting properties of corrosion resistance, withstands high temperatures and presents a high thermal conductivity than the graphite without impregnation. However, there does not exist a well established methodology for designing heat exchangers with new geometries for its implementation in heat transformers. For this reason, the heat exchanger was designed with a stainless steel shell and graphite disks arranged internally in a column to carry out the absorption process. In the experimental tests carried out for a thermal load in the range from 625 to 1460 W, heat transfer coefficients in the absorber were obtained in the range from 723 to 1535 W/m^2 K. As the number of Reynolds increases from 110 to 144, the heat transfer coefficient increases up to a maximum value of 954 W/m^2 K, at Reynolds number at about 144, but when Reynolds number was increased above 147, the heat transfer coefficient decreased.

1. Introduction

Many industries depend on conventional fuels for the transformation of raw materials into products used by people for their most basic needs. The expansion of industries around the world and the emergence of new ones are the main reason for the consumption of conventional resources such as natural gas, petroleum and its derivates; therefore, the demand increases. In some processes it is possible to reduce the consumption of these conventional sources with the use of thermal devices which can yield high quality energy even when they use a low quality energy supply, it is the case of heat transformers.

The main component of an absorption heat transformer is the absorber, in which the absorption process and heat generation are carried out. In the absorber the heat released is proportional to the absorption process. During the last decades, the study of these absorbers has been well documented. Several experimental studies of the thermal behavior have been analyzed and compared with theoretical data in order to model other configurations based on parameters established during the operation of the system under steady-state conditions [1,2]. Several absorber geometries have been studied, such as vertical plate type exchangers [3–5], shell and spiral tube exchangers [6,7], vertical concentric tubes [8–10], shell and horizontal tubes [11], columns of brass disks [12] and horizontal tubes [13–15].

The materials used for construction of flat plate exchangers, vertical concentric tubes and tubes which may be arranged either vertically or horizontally inside a shell, were made of cooper, carbon steel, brass and stainless steel [16]. These materials are selected for their high thermal conductivity and some of them are resistant to the corrosion of certain chemical substances. However, in processes where the solutions are highly corrosive, the thermal conductivity of the material is sacrificed and it is changed for other material with a major resistance to corrosion [17]. Some researchers have experimented with materials resistant to highly corrosive working mixtures, such as cupronickel (copper–nickel alloy), graphite impregnated with phenolic cross-linked resin, high-temperature-treated carbon, and Teflon (PTFE) [18]. Several companies manufacture different types of heat exchangers with impregnated graphite materials using them as their internal structure. The impregnation technique provides the heat exchangers with a high mechanical resistance, resistance to corrosion and to high temperatures, all of which are useful in applications such as evaporators, condensers and reactors.

In absorption heat pumps the most commonly used solutions are H_2O/LiBr and NH_3/H_2O, due to their refrigerant–absorbent properties. The former solution is non-toxic, non-volatile, non-pollutant

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Nomenclature

A	heat transfer area, m^2
Cp	specific heat capacity, kJ/kg
d	diameter, m
h	heat transfer coefficient, W/m^2 K
k	thermal conductivity, W/m K
m	mass flow rate, kg/s
Q	heat rate, W
Re	Reynolds number ($4\ \Gamma/\mu$)
T	temperature °C or K
U	overall heat transfer coefficient, W/m^2 K
X	concentration (wt% LiBr)

Greek symbols

Γ	$m/\pi d_i$ mass flow rate per unit of wetted perimeter, kg/m s

Subscripts

AB	absorber
CO	condenser
EV	evaporator
GE	generator
i	internal
in	inlet
LM	logarithmic mean
o	external
out	outlet
s	solution
w	water

Superscript

e	equilibrium

and has a high latent heat. However, its great disadvantage is its corrosiveness. The solution NH_3/H_2O has high latent heat, is lightly toxic, and its operation pressures are relatively high; however, its main disadvantage is that it requires the use of a rectifier in order to remove the water vapor from the mixture that exits from the generator before it enters to the condenser. The solution H_2O/LiBr is used in heat transformers because the temperature levels are higher in comparison with the solution NH_3/H_2O.

There does not seem to be information in the literature concerning the use of heat exchangers built with disks of tar-impregnated graphite. In this paper we show the experimental results of a vertical stainless steel shell absorber and tar-impregnated graphite disks, which were accommodated internally in a column. This heat exchanger was mounted on an absorber test bench and during the experimental tests the parameters such as solution volumetric flow, the fluid temperatures that simulate waste heat, and concentrations of the working solution were modified. The main focus of this study was heat transfer analysis using a non-metallic material with an experimentally unanalyzed geometry in absorbers.

2. Experimental and measurement instruments

2.1. Absorber

The studies on absorbers have been largely carried out in vertical plates, vertical tubes (Fig. 1a) and horizontal tube bundles (Fig. 1b), in which the solution descends in falling film over the plate, the tubes or the tube bundles, where the solution distribution is not uniform over the whole surface. In this study the behavior is analyzed using disks with two different slope angles [18], which allow a better distribution of the solution throughout the whole area (Fig. 1c).

Fig. 2 shows the vertical absorber built with 18 tar-impregnated graphite disks. The absorber is formed externally by a 316L stainless steel tube joined in its upper and lower ends to two bridles coupled to two headers with screws that give the disks column rigidity and hermetic seal (with 0.17 m in diameter and 0.56 m in length). The upper header is internally designed for the solution to be distributed and to wet the upper and lower surface of the disks. Fig. 3 shows the design of a tar-impregnated graphite disk with 0.1 m in outside diameter. The slope of its surfaces with 7° in the upper and 14° in the lower and its rough surface to improve the distribution of the working mixture. This kind of material has a 50–80 W/m-K thermal conductivity [18]. Neoprenes packing were used as a hermetic seal between the disks and the shell. The concentrated working mixture enters through the upper part of the absorber and by gravity goes towards the disks where it gets distributed, while the water vapor enters through the lower part of the absorber and gets mixed with the solution descending from the disks. The working mixture then exits through a lateral connection as a diluted working mixture. The cooling water flows in the annular space formed by the tube and the outside disks.

2.2. Mechanism of heat and mass transfer

The overall efficiency of absorption machines depends particularly of the absorber on operating conditions and physical characteristics (heat exchange surface and internal geometry). The studies carried out in the absorbers have been theoretical and experimental. In some theoretical models, heat and mass transfer mechanism is analyzed based on formulations of continuity, diffusion and energy. In other studies, the models analyze the liquid film flowing over the horizontal tubes and inside them, there is a fluid flowing removing heat. For this particular case the boundary layer equations were resolved, which are equations of momentum, energy and mass of the liquid film assuming laminar flow [19]. Design tools for absorbers with H_2O/LiBr [20] and NH_3–H_2O mixtures in film falling on smooth tubes have been developed. Theoretical models assume ideal conditions so that the results show significant differences compared with the experimental results compared in 30% [21]. In experimental works, the analysis of the distribution of the solution in different geometries as banks of tubes, vertical tubes and others geometries has been performed. Effects of absorbed water vapor in lithium bromide falling film in vertical tubes of different geometries, temperature gradients and heat and mass transfer coefficients have been tested experimentally.

The mechanism of heat and mass transfer in different kinds of absorbers, occurs by the absorption of water vapor into direct contact with the film surface of the H_2O/LiBr solution. The absorbers may be concentric tubes, horizontal tube bundle and vertical flat plates. In the concentric tubes the solution flowing through the inner wall of the inner tube or in the annular section, through the outer wall of the inner tube and the fluid that removes heat flows countercurrent through the annular section or inside the pipe, respectively. For the inner tube, the solution is distributed in falling film on the inner wall of the tube while the vapor fills the internal space of the tube. The fluid flow removes heat by the annular section (Fig. 4a). In the horizontal tube bank, the solution falls along the outer surface of the tube forming a falling film of solution and vapor fills the entire internal space of the heat exchanger shell.