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Pressure drop and heat transfer characteristics of a titanium brazed plate-fin heat exchanger with offset strip fins

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HIGHLIGHTS

- ► We analyzed a titanium brazed plate heat exchanger with offset strip-fins.
- ► Experiments were conducted using water and 10–30 wt% ethylene glycol solutions.
- ► An empirical correlation for the single-phase convection coefficients was determined.
- ► The results were validated against experimental data and other correlations.

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ABSTRACT

This paper is concerned with the experimental analysis of a titanium brazed plate-fin heat exchanger with offset strip fins in liquid–liquid heat transfer processes. An experimental program is conducted by using firstly water on both sides of the heat exchanger and secondly 10–30 wt% ethylene glycol aqueous solutions as working fluids. The pressure drop and heat transfer characteristics are experimentally determined. The Wilson plot method is applied to the reduction of the experimental heat transfer data. An empirical correlation to determine the single-phase convection heat transfer coefficients as a function of the Reynolds number is obtained. The results are validated against experimental data and other correlations found in open literature. In the paper, the experimental setup and procedure are described, the reduction data processes detailed, and the experimental results presented and discussed.

1. Introduction

Plate heat exchangers (PHEs) are commonly used in many applications such as food processing, heating or cooling in industrial processes and refrigeration or air conditioning plants, due to their effectiveness, flexibility, compactness and competitive cost when compared with other types of heat exchangers. Nowadays, brazed plate heat exchangers (BPHEs) are well-established components in liquid–liquid heat transfer processes, as well as condensers or evaporators in refrigeration, air conditioning, and heat pump compact machines. Commercially available BPHEs are commonly made of corrugated stainless steel plates, which are vacuum brazed together using either copper or nickel alloys as brazing materials. The brazing process eliminates the need for sealing gaskets and makes the handling of higher pressures and temperatures easier than the traditional gasketed PHEs. Ayub (2003) [1] and Khan et al. (2010) [2] present detailed reviews of available heat transfer correlations for single-phase flows on corrugated and wash board PHEs. Depending on the application, BPHEs are also made using other plate and brazing materials, such as, aluminum, titanium, etc, and various types of augmented heat transfer surfaces such as wavy fins, louvered fins, or offset strip fins. Ismail et al. (2010) [3] present a review on the research and developments of compact offset and wavy plate-fin heat exchangers.

Heat exchangers made of titanium are required in applications with corrosion problems, such as marine facilities on shore and onboard, desalination, chemical and power plants. The use of titanium also allows a significant reduction in the weight of the heat exchanger for the same heat transfer area as the specific weight of titanium is around 55% lower than the specific weight of stainless steel. Therefore, titanium BPHEs constitute a viable option in applications where corrosion or lightweight become crucial issues.

Offset strip fins (OSFs) have been widely used for industries that require lightweight high-performance heat exchangers (Teruel

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Nomenclature

A	area (m^2)
BPFHE	brazed plate-fin heat exchanger
BPHE	brazed plate heat exchanger
C	constant
Cp	specific heat (kJ kg^{-1} K)
Dh	hydraulic diameter (m)
e	thickness (m)
F	correction factor
G	mass flux (kg m^{-2} s^{-1})
h	heat transfer coefficient (W m^{-2} K^{-1})
hf	fin height (m)
j	Colburn *j*-Factor
k	thermal conductivity (W m^{-1} K^{-1})
L	strip length (m)
OSF	offset strip fin
PHE	plate heat exchanger
Pr	Prandtl number
q	heat transfer rate (kW)
R	thermal resistance (K W^{-1})
Re	Reynolds number
s	transverse spacing (m)
St	Stanton number
t	fin thickness (m)
T	temperature (K)
ΔT	temperature difference (K)
U	overall heat transfer coefficient (W m^{-2} K^{-1})

Subscripts

c	cold
h	hot
i	inlet
f	fouling
LMTD	logarithmic mean temperature difference
o	outlet
ov	overall
w	wall

Superscript

n	exponent of reduced velocity or Reynolds number

et al., 2009 [4]). The thermal enhancement provided by the OSFs is based on repeated growth and wake destruction of boundary layers. The laminar boundary layer being developed on the short strip length is followed by its dissipation in the wake region between strips (1992) [5]. However, it is worth pointing out that these types of fins also increase the pressure drop within the heat exchanger. Therefore, heat transfer enhancement and pressure drop increase should be considered carefully for each application. Due to the complex flow structures in OSFs compact heat exchangers, the pressure drop and heat transfer correlations available in open literature are based on experimental data. Usually, these empirical correlations estimate the friction factor (*f*) and the *j* Colburn modulus as a function of the Reynolds number.

On the basis of these correlations new researches have been carried out to optimize the design of this kind of heat exchangers by using numerical methods, such as genetic algorithm or CFD simulations [6–8]. Mishra et al. (2009) [6] developed a model in order to optimize a cross flow heat exchanger depending on the design variables employing the correlations proposed by Joshi and Webb (1987) [9] for *j* and *f*. A similar work focused on obtain an optimal solution between the total heat transfer rate and the economical costs was presented by Najafi et al. (2011) [7]. Other researches such as Ben Saad et al. (2011) [8] employ the published correlations to validate their own results.

Interesting reviews of this research are presented by Ismail et al. (2010) [3], Shah and Webb (1983) [10] and Manglik and Bergles (1995) [11]. A detailed analysis of these research findings clearly shows that many researchers studied the use of OSFs in plate and fin heat exchangers with air as heat transfer fluid on the fins side meanwhile there are very few works dealing with other fluids. Reviews also point out that there is significant variation in the predictions provided by different correlations.

As indicated above, while the most generalized application of enhanced surfaces with OSFs is for gases, there is a trend toward using them also with liquids [12,13]. Despite this, only a few works have been found in open literature regarding with OSFs to enhance heat transfer with liquids, as pointed out Ismail et al. (2010) [3]. The use of OSFs in BPHEs constitutes an interesting alternative to improve the performance of this type of heat exchangers, which are commonly applied in liquid–liquid heat transfer processes. Moreover, it is also worth mentioning that OSFs are easily implemented in the manufacturing process of brazed plate-fin heat exchangers (BPFHEs). The plates and OSFs are packed and pressed all together and then passed to brazing oven. The brazing process ensures an excellent contact between the OSFs and plates. Consequently, in BPFHEs, from the view point of the heat transfer performance, the effectiveness of fins should be accounted.

Ambiguous information is found in literature with regard to the use of correlations obtained with gases in liquid applications. Ismail et al. (2010) [3] reported that the correlations obtained for gases do not predict well the data for liquids. However, Webb (1992) [5] and Mart (1990) [14] pointed out that, if the Prandtl number dependency is known, the correlations obtained for gases may be applied to liquids. Clearly, there is a need for further research in this respect to develop new correlations for liquid medium applications.

The Wilson plot method and its subsequent modifications constitute a suitable technique to determine the convection coefficients in a large variety of convective heat transfer processes. The advantage of this method is due to avoiding the need to measure the surface temperature of the wall separating both fluids. This is generally a difficult task, because the surface temperature varies from point to point, and the flow pattern can be altered by the presence of the temperature sensors. Moreover, in the case of BPHEs this complication increases because the heat transfer surface is not accessible. Fernández-Seara et al. (2007) [15] has published a review of the Wilson plot method and its modifications for a many convective heat transfer problems. The original technique and subsequent modifications have been employed by many researchers to develop Nusselt number correlations for BPHEs. Muley and Manglik (1999) [16] applied a modification of the original method in order to obtain the heat transfer coefficients in PHE with chevron plates with single-phase water flows. Other authors use this method to analyze the phase change processes, both vaporization and condensation, in different kinds of PHEs. In this case the Wilson plot technique is used to obtain the heat transfer coefficients in the single-phase fluid side and later to calculate the coefficients of convection in the phase change. Hsieh and Lin (2002) [17] and Kuo et al. (2005) [18] analyzed, respectively, the vaporization and the condensation of R410A in plate heat exchangers with a corrugated sinusoidal shape of a chevron angle of 60°. Longo et al. (2004) [19] applied it to obtain the heat transfer coefficients during vaporization and condensation processes of R22 inside