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Thermo-hydraulic behavior of ice slurry in an offset strip-fin plate heat exchanger

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ABSTRACT

Ice slurry is a promising alternative to conventional single-phase coolants in indirect refrigeration systems. In this paper, an experimental analysis of an offset strip-fin heat exchanger operating with ice slurry as working fluid is presented. The pressure drop and thermal performance have been determined. In order to obtain the partial thermal resistance in the ice slurry side an empirical correlation for the secondary fluid side was determined by applying the Wilson plot method in a set of tests performed previously. An empirical correlation in terms of the Colburn j-factor to describe the thermal behavior of the heat exchanger with ice slurry was obtained. On the other hand, the direct pressure drop measurements operating with different flow rates and ice fractions are shown and compared with values obtained with single-phase fluids. Pressure drop instabilities have been observed for flow rates lower than the nominal value provided by the manufacturer.

Comportement thermo-hydraulique d'un coulis de glace dans un échangeur de chaleur à plaques à ailettes non alignées

Mots clés : Coulis de glace ; Ailettes non alignées ; Echangeur de chaleur à plaques ; Systèmes de refroidissement indirect

1. Introduction

Ice slurry is a promising technology whose main advantage is the high heat transportation capacity due to the latent heat of ice crystals. Therefore, ice slurry can provide the same cooling load with much lower volume flow rates or the cooling load for the same refrigerant charge can be increased, offering significant savings in pumping cost and equipment size. Besides advantages regarding cooling capacity, in moderate concentrations ice slurry can be easily pumped, transported and stored without needing to change pumping equipments, distribution networks or accumulation tanks.

The outstanding features of ice slurry are bringing about an increasing interest in this technology, which is being successfully employed in many applications both in direct as indirect systems. Most of the direct applications are related to processing and preservation of food products such as fish,

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Nomenclature

A	area (m^2)
BPHE	brazed plate heat exchangers
PHE	plate heat exchangers
Dh	hydraulic diameter (m)
e	wall thickness (m)
G	mass flux (kg m^{-2} s^{-1})
h	heat transfer coefficient (W m^{-2} K^{-1})
hf	fin height (m)
i	specific enthalpy (kJ kg^{-1})
j	Colburn j-factor
k	thermal conductivity (W m^{-1} K^{-1})
l	strip length (m)
m	mass flow rate (kg s^{-1})
OSF	Offset strip fin
Pr	Prandtl number
$\dot{Q}$	heat transfer rate (kW)
Re	Reynolds number
s	transverse spacing (m)
St	Stanton number
t	fin thickness (m)
ΔT	temperature difference (K)
U	overall heat transfer coefficient (W m^{-2} K^{-1})

Symbols

ρ	mass density (kg m^{-3})
μ	dynamic viscosity (kg m^{-1} s^{-1})
φ	Ice mass fraction

Subscripts

eff	effective
eg	ethylene glycol
i	inlet
ic	ice
is	ice slurry
so	solution
LMTD	logarithmic mean temperature difference
o	outlet

dairy, etc. Other direct applications such as in medicine, pigging, firefighting, etc, are being considered. In indirect applications, ice slurry is being employed as a secondary fluid in air conditioning systems, commercial refrigeration and industrial production processes. Moreover, it is necessary to point out that indirect cooling systems are spreading out due to regulations for the use of synthetic refrigerants and the possibilities that these systems provide for thermal energy storage. Within indirect applications, the high heat transportation capacity of ice slurry and its low operating temperatures make it an excellent alternative to conventional single-phase coolants. In indirect refrigeration systems with ice slurry heat exchangers are necessary. To date, several works have been published regarding the behavior of ice slurry in different kinds of heat exchangers, such as plate heat exchangers (Bellas et al., 2002, Frei and Boyman, 2003, Nørgaard et al., 2005a, Nørgaard, 2005 b and Shire et al., 2009) fan coils (Illán and Viedma, 2009, Fernández-Seara et al., 2010), helical coils (Thongwik et al., 2008 and Haruki and Horibe, 2013) or shell and tube exchangers (Renaud-Boivin et al., 2012).

On the other hand, brazed plate heat exchangers (BPHE) are used in many industrial applications due to their high efficiency, compactness, flexibility and competitive cost. In order to increase heat transfer enhanced extended surfaces geometries, such as the offset strip- fins (OSFs), are used in plate-and-fin heat exchangers. The thermal enhancement provided by the OSFs is based on repeated growth and wake destruction of boundary layers. A laminar boundary layer is developed on the short strip length followed by its dissipation in the wake region between strips (Webb, 1992). However, it is worth pointing out that this type of fins also increases the pressure drop within the heat exchanger. Therefore, both, the heat transfer enhancement and the pressure drop increase. Even though the most generalized application of OSFs is for gases, there is a trend toward using them also with liquids.

Commercially available BPHE are commonly made of corrugated stainless steel plates, which are vacuum brazed together using either cooper or nickel alloys as brazing materials. In applications in which corrosion becomes an issue, such as marine facilities on shore and onboard, desalination, chemical and power plants, titanium constitutes an interesting option, especially when lightness is required (Fernández-Seara et al., 2009). Titanium allows a significant reduction of the heat exchanger weight for the same heat transfer area due to the specific weight of titanium is around 55% lower than the specific weight of stainless steel.

Regarding applications of brazed plate heat exchangers with ice slurry pointed out that they are often employed in indirect systems as intermediate heat exchanger to exchanging heat between ice slurry and another liquid.

High pressure drop and partial or total blockages caused by the size of the channels are the main challenges of using ice slurry in this type of heat exchangers. Until now, several works published demonstrated that plate heat exchangers (PHE) can be employed with ice slurry. Bellas et al. (2002), Frei and Boyman (2003), Nørgaard et al. (2005a) and Nørgaard (2005b) presented works about the thermal and the hydraulic behavior of plate heat exchangers operating with ice slurry, where the general behavior is described. In Frei and Boyman (2003) and Nørgaard et al. (2005a), the presence of overheating of the carrier fluid is pointed out. In Nørgaard (2005b) empirical correlations to define this behavior are published for three different models of plate heat exchangers. In 2009, Shire published a new work focused on the pressure drop in a plate heat exchanger with ice slurry with high ice concentrations (up to 60%).

However, up to now, no data were found in literature about the behavior with ice slurry in heat exchangers with OSFs. Several researches about the offset fin geometry have been performed, but most of then are focused on the behavior of the offset strip fins with air as working fluid, and only a few works have been found in which liquids had been employed (Ismail et al., 2010).

This paper describes the experimental analysis of the pressure drop and thermal performance of a prototype of offset strip-fin heat exchanger with ice slurry as coolant. The ice slurry