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Theoretical analysis of the thermal performance of a plate heat exchanger at various chevron angles using lithium bromide solution with nanofluid

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ABSTRACT

Nanofluids technology has been rapidly developing over the last two decades. In this paper, the performance of a lithium bromide (LiBr) solution with and without nanoparticles in plate heat exchanger (PHE) for various chevron angles and mass flow rates was investigated. As a result, the heat transfer rate and the overall heat transfer coefficient in 60°/60° PHE is over 100% higher than that of 30°/30° PHE, and the effectiveness of the PHE in 60°/60° PHE is about 70% higher than that of 30°/30° PHE. By using nanoparticle in the working fluid, the heat transfer performance can increase significantly. The heat transfer rate of 3 vol.% nanofluids increased about 3–8% compare to that of LiBr solution for all chevron PHEs. Besides, the 60°/60° PHE using 3 vol.% nanofluids produced the largest heat transfer rate and heat exchange effectiveness under given operating conditions.

Analyse théorique de la performance thermique d'un échangeur de chaleur à plaques sous divers angles de chevrons et utilisant une solution au bromure de lithium avec un nano-fluide

Mots clés : Nanofluide ; Echangeur de chaleur à plaques et chevrons ; Transfert de chaleur ; Efficacité

1. Introduction

Since the invention of the plate heat exchanger (PHE) in 1921 for use in the dairy industry, it has been widely used in various fields. It consists of a set of thin, usually metal plates and a frame to support the plates. The working fluid flows through the gap between two adjacent plates. The heat transfer surface can be easily changed by adding or removing plates, and the heat transfer capacity can be adjusted within a certain

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Nomenclature

A	area, m^2
C_p	heat capacity, $kJ\ kg^{-1}\ K$
b	corrugation depth, mm
c	concentration, %
h	heat transfer coefficient, $kW\ m^{-2}\ {}^{\circ}C$
k	conductivity, $kW\ m^{-1}\ K$
Nu	Nusselt number
Re	Reynolds number
PHE	plate heat exchanger
Pr	Prandtl number
Q	heat transfer rate, kW
ΔT	temperature difference, °C
U	overall heat transfer coefficient, $kW\ m^{-2}\ {}^{\circ}C$
T	temperature, °C
C^*	heat capacity rate ratio
t	thickness, mm
M	mass flow rate, $kg\ h^{-1}$

Greek symbols

μ	viscosity
υ	volume fraction
ρ	density, $kg\ m^{-3}$
β	chevron angle
λ	corrugation pitch, mm
ε	effectiveness

Subscripts

nf	nanofluids
bf	basic fluid
p	nanoparticle
h	hot-fluid side
c	cold-fluid side
m	metal plate
i	inlet
o	outlet
min	minimum
max	maximum

range. With increasing demands for energy savings, the PHE now plays an increasingly important role in industry. A high efficiency PHE can substantially reduce energy waste.

There are several types of PHEs, such as chevron, herringbone, and wash board. Among these, the chevron PHE is the most widely used. Normally, a chevron plate can provide relatively high turbulence, enabling effective heat transfer. Heat transfer coefficients produced by a chevron PHE can be equal to values for tubes in which Reynolds numbers are five times higher according to Troupe et al. (1960). For this reason, much research on chevron PHEs with different chevron angles has been conducted.

Okada et al. (1972) studied the effects of the chevron angle on the Nusselt number and pressure drop at angles of 30°, 45°, 60°, and 75°. Chisholm and Wanniarachchi (1992) studied a chevron plate with a chevron angle ranging from 30° to 80°, and they correlated the Nusselt number with the different chevron angles. Khan et al. (2010) conducted a study using water as the working fluid and obtained experimental heat transfer data for single-phase flow configurations in a commercial PHE at symmetric angles of 30°/30°, 60°/60°, and mixed 30°/60° chevron angle plates. Their results showed that the chevron angle had a large effect on the heat transfer and that an angle of 60°/60° produced the best heat transfer performance. Jeong et al. (2011) investigated heat transfer performance of PHE and they found that heat transfer and pressure drop performance increased with increasing Reynolds number. Cui and Oh (2014) investigated performance of plate heat exchanger made of different materials. Generally, changing the plate structure is one way to improve the heat transfer rate of a heat exchanger. However, it is difficult to develop a new type of PHE by changing the shape of the plate. Thus, researchers all over the world are attempting to find other ways to improve the heat exchange rate. Some of the references are summarized in Table 1.

Although exactly how nanofluids influence to heat exchange is not known, there have been major developments in nanofluids technology during the past two decades (Yu et al., 2007). Most scientists believe that nanofluids can raise the heat transfer rate. A nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. Modern technology now allows the fabrication of materials at the nanometer scale and has dramatically reduced the fabrication costs of such materials. Nanoparticles are a class of materials with unique physical and chemical properties compared to those of larger particles of the same material.

Table 1 – Previous studies for plate heat exchangers.

Reference	β	Re	Pr	Nu
Okada et al. (1972)	30	400–15,000		$0.1528Re^{0.66}Pr^{0.4}$
	45			$0.2414Re^{0.64}Pr^{0.4}$
	60			$0.3174Re^{0.65}Pr^{0.4}$
	75			$0.4632Re^{0.62}Pr^{0.4}$
Chisholm and Wanniarachchi (1992)	30–80	1000–40,000	5.0	$0.72Re^{0.59}\varphi^{0.41}(\beta/30)^{0.66}Pr^{0.4}$
Khan et al. (2010)	30	400–2500		$0.1368Re^{0.7424}(\mu/\mu_w)^{0.14}Pr^{0.35}$
	30/60 (mix)			$0.1437Re^{0.7810}(\mu/\mu_w)^{0.14}Pr^{0.35}$
	60			$0.1449Re^{0.8414}(\mu/\mu_w)^{0.14}Pr^{0.35}$
Kwon et al. (2009)	30	80–350		$1.078Re^{0.403}Pr^{0.3333}$
	30/60 (mix)			$8.537Re^{0.259}Pr^{0.3333}$
	60			$5.194Re^{0.387}Pr^{0.3333}$