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A comprehensive review on single phase heat transfer enhancement techniques in heat exchanger applications

Tabish Alam, Man-Hoe Kim*

School of Mechanical Engineering, Kyungpook National University, Daegu 41566, South Korea

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ABSTRACT

The objective of this paper is to review the different techniques, which have been used to enhance the heat transfer rate in heat exchanger devices such as solar air heater, cooling blades of turbine and so on using single phase heat transfer fluids. The results of recent published articles with the development of new technologies such as Electrohydrodynamic (EHD) and Magnetohydrodynamics (MHD) are also included. Enhancement of heat transfer in heat exchanger can achieved by means of several techniques. These techniques are grouped into the active and passive method. In the active methods, system need some external power, however, passive method utilize surface modification either on heated surface or insertion of swirl devices in the flow field. Active methods are very complex because of external power supply, although these methods have great potential and can control thermally. Passive methods include artificial roughness, extended surface, winglets, insertion of swirl devices in the flow which alters the flow pattern causes to disturb the thermal boundary layer, and consequently high heat transfer. Passive methods are dominant over active methods because its can easily employed in existing heat exchangers. In this paper, an effort has been made to categorize the active and passive methods and review the various heat transfer techniques applied in heat exchangers. Important results have been listed for ready reference. It has been concluded that either active or passive methods have been employed alone. Based on literature, a combined method have also been recommended which include both active and passive methods.

1. Introduction

Over the last few decade, usage of energy has increased due to increase in population, industrialization, urbanization; therefore researchers have been engaged to develop the energy saving strategies as well as new sources of energy. Conventionally, energy are produced by means of fossils fuels such as coal, petroleum, natural gases and nuclear etc. These fuels are exhaustible in nature and has adverse effect on the environment. Although, researchers have tried to minimize the effect of emission of these fossil fuels on environment. For examples, emission of NO_X from diesel engine [1,2] and CO_2 from power plant [3–5] have been restricted or minimize into environment.

In order to minimize energy consumption, compact and efficient thermal system are also being designed and developed. Heat exchangers is the one of the most usable thermal system, which are being used in domestic, industrial and commercial purposes. Some examples of heat exchanger include condensation and evaporation in refrigeration, cooling in power plant, radiator in cars, processing of chemical, solar air/water heater, waste heat recovery, cogeneration, steam generation and pharmaceutical industries. Thermal control, energy and material saving in heat exchanger depend on the performance of heat exchanger, which can be achieved by enhancing the heat transfer rate.

Need of high heat transfer in heat exchangers has promoted to develop the various techniques, which enhanced the convective heat transfer by reducing the thermal resistance at the heated surface. Generally, enhanced heat transfer rate is accompanied with increase in pressure drop, leading to high pumping power requirement. Researchers have been trying to develop such techniques, which enhance the heat transfer rate at a minimum possible pressure drop. These techniques include the forced flow of fluid such as air, water, mineral oil, ethylene glycol and other nanofluids on the heated surface. The heated surface may be smooth, rough, stationery or moving, which depend on the applications. Mainly, heat transfer enhancement methods are classified as active and passive method. In the active method, some external power input needs to enhance the heat transfer rate. The external power may be either given to heated surface or given to fluids, which depends on the system requirement. Active methods are complicated because analysis of flow structure is not easily

* Corresponding author.
E-mail addresses: tabish.iitr@gmail.com (T. Alam), manhoe.kim@knu.ac.kr (M.-H. Kim).

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Nomenclature

A	surface Area of heated Plate, m^2
b	obstacles width, mm
D or D_h	hydraulic diameter of duct, mm
d	Diameter/width, mm
e	rib height, mm
f	Frequency, Hz
g	groove position or gap, mm
G	mass flux, kg/s m^2
G_d	gap distance, mm
H	duct height, mm
I	Insolation, W/m^2
L	long way length of mesh or Length of test section, mm
L_v	length of single V-rib, mm
m	mass flow rate, kg/s
p	pitch, mm
P'	staggered rib position from gap in V-rib, mm
s	half width of absorber plate, mm
s'	gap position from leading edge of V-rib, mm
S	short way length of mesh or length of discrete rib, mm
t	Thickness, mm
T_o	air outlet temperature, K
U_l	overall heat loss coefficient, W/m^2 K
v	velocity, m/s
w	width of V, mm
W	width of duct, mm

Dimensionless parameters

A_h/A_w	porosity area ratio
AR	aspect ratio
BR	blockage ratio
d/x or G_d/L_v	relative gap position
d/D	relative rib print diameter
f	friction factor of roughened duct
f_s	friction factor of smooth duct
f/f_s	friction factor enhancement
F_R	heat removal factor
d/w	relative gap position or nozzle diameter ratio or hole diameter ratio or wing cord ratio
D/w	Ratio of cylinder diameter to nozzle width
e^+	roughness Reynolds number
e/D or e/D_h	relative roughness height
F_o	heat removal factor associated with air outlet temperature
g/e	relative gap
g/P	relative groove position
g/H	Groove wing distance to channel height ratio
L/e	relative long way length of mesh
L/w	relative jet impingement distance
Nu	Nusselt number of roughened duct
Nu_s	Nusselt number of smooth duct
Nu/Nus	Nusselt number enhancement factor
p/e	relative roughness pitch
p/P	relative staggered rib pitch
p'/p	relative staggered rib position
PR	Pitch ratio
Re	Reynolds number
Re_j	Jet Reynolds number
Re_r	Rotational Reynolds number
r/e	relative staggered rib size
St	Stanton number
s'/s	relative gap position
S/e	relative short way length mesh
w/e	staggered rib length to rib height ratio
W/H	duct aspect ratio
w/W	depth ratio
W/w	relative rib width
y/w	twist ratio

Greek symbols

φ	chamfer angle, degree
ϕ	concentration
Θ	angle location
ψ	circularity
η	thermohydraulic performance parameter
η_{th}	thermal efficiency
μ	dynamic viscosity, N.s/m^2
ρ	density, kg/m^3
α	Angle/incidence of attack or arc angle, degree
β	open area ratio
$(\alpha\iota)_e$	absorptance-transmittance product

accessible due to external effect. Passive methods do not need any external power and usually utilize the modified surfaces and/or insertion of elements (turbulence promoters) in the flow. This methods alter the flow treatment which causes to convective heat transfer coefficient to increase. Turbulence promoters create turbulence in the flow, which help to eliminate the thermal boundary layer and promote to fluid mixing, leading to high heat transfer rate. Different turbulence promoters in the form of artificial roughness [6,7], ribs [8,9], baffles [10,11], rib-groove [12,13], blocks [14,15], fins [16–18], obstacles [19–21], turbulators [22,23] and use of swirl devices such as cans [24], conical ring [25,26], coiled wires [27,28], twisted tapes [25,29], vortex rings [30,31] and winglets [32,33] have been investigated. In this paper, an attempt has been made to summarize the various techniques that deals the applications of active and passive methods in heat exchangers. The important finding have been emphasized to arrive the proposed method.

2. Overview of active and passive methods

As discussed earlier, active method require external source of energy to augment the heat transfer. Some thermal systems, operate at very high temperature or exposed to excessive heat, cause to affect their operational life and functionality. Failure and degradation of the system before specified life span can be dangerous in safety points of view. To ensure reliability, performance and life, component of the system must be cooled by removing excess heat from system hot spots, and/or must be utilized or rejected to heat sink. In some cases, supply of external energy is very difficult to manage in the system. Advantages of these methods is to control the flow modification as per the need of system, such as ferrofluid is best controlled by magnetic field. Other examples of active methods are included vibrating of heat transfer surface, pulsating flow, application of electric field etc. Active method requires extra effort toward the development and design of compact and efficient heat exchanger.

Passive method does not require any external energy supply to augment the heat transfer, however, it extract small amount of energy from system itself to increase the fluid turbulence This methods are very popular in industries due to its simple design, less expansive and reliability. Surface modification and/or insertion of turbulators lead to increase the turbulence in the flow and consequently high heat transfer rate. Heat transfer can also be enhanced in this method to increase the heat transfer area using extended heat surface i.e. fins. Fins are not