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Research paper

Heat transfer enhancement in a triangular duct using compound nanofluids and turbulators

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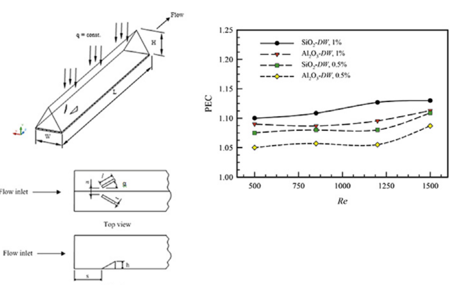
HIGHLIGHTS

- Numerical and experimental study is carried out for comparison.
- Nanofluids and vortex generators are used to improve thermal performance of triangular duct.
- Heat transfer is greatly increased by using both nanofluids and vortex generator.
- High reduction in the heated wall temperature is obtained using nanofluid and vortex generator.
- Performance evaluation criterion is higher than 1.

GRAPHICAL ABSTRACT



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ABSTRACT

Numerical and experimental investigation is carried out to study the laminar heat transfer and fluid flow characteristics in an equilateral triangular duct using combined vortex generator and nanofluids. Two different types of nanoparticles “namely Al_2O_3 and SiO_2” suspended in distilled water with two particles concentrations are successfully prepared and experimentally tested. Both numerical and experimental results show a good enhancement in heat transfer by using vortex generator with base fluid. A significant heat transfer enhancement is observed by using compound vortex generators and nanofluids accomplished with a moderate increase in the pressure drop. High gradient in wall temperatures is monitored when the water is replaced by nanofluid particularly at higher volume fraction. A small deviation has been seen between the present numerical and experimental results.

1. Introduction

Non-circular ducts in the plate-fin heat exchangers have been widely used in last few decades, because they enlarge the compactness of the exchangers. Triangular ducts are extensively used in such applications as blades and vans of gas turbines, heat exchangers, and solar collectors. Among other channels shapes, equilateral triangular ducts are preferred because of their low pressure drop, low fabrication costs, easy construction, and higher mechanical strength. In addition, these ducts provide higher heat transfer rate compared to other triangular channels shapes [1,2]. In order to optimize the performance of heat exchanger, the heat transfer must be increased with as small as possible increase in the pressure drop. The need for non-circular ducts (such as triangular ducts), which have low pressure drop and low heat transfer rate [3],

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Nomenclature

A	area, m^2
a	distance between the leading tips of vortex generator, m
c_p	specific heat capacity, J/kg K
d	diameter, m
D_h	hydraulic diameter, mm, $D_h = 4A/P$
DW	delta wing
DW	distilled water
DWP	delta-winglet pair
f	friction factor
H	height of the duct, m
h	convection heat transfer coefficient, W/m^2 K
h	height of vortex generator, m
h	hour
I	current, A
k	thermal conductivity, W/m K
L	duct length, m
l	length of vortex generator, m
LVG	longitudinal vortex generator
M	molecular weight, kg/mol
$\dot{m}$	mass flow rate, kg/s
N	Avogadro number, l/mol
Nu	Nusselt number
p	perimeter, m
PEC	performance evaluation criteria
Pr	Prandtl number
ΔP	pressure difference, Pa
Q	heat transfer rate, W
q	heat flux, W/m^2
Re	Reynolds number
RW	rectangular wing
RWP	rectangular-winglet pair
s	distance from the leading edge of duct and VG, m
T	temperature, K
t	thickness of the vortex generator, m
u	velocity, m/s
V	voltage, v
VG	vortex generator
W	width of the duct, m
W	weight, g
x, y, z	coordinate, m

Greek symbols

α	attack angle, degree
β	function of liquid volume
κ	Boltzmann constant, J/K
μ	dynamic viscosity, Pa s
ρ	density, kg/m^3
θ	dimensionless temperature
ϕ	volume fraction

Subscripts

avg	average
bf	base fluid
b_{in}	inlet bulk
b_{out}	outlet bulk
c	cross-section
eff	effective
m	mean
nf	nanofluid
p	particle
w	water

motivates the researchers to improve the thermal performance of these types of ducts. Because of the increase in the demand of heat removal from the thermal systems, the recent development in the micro- and nano-technology nowadays offers a new class of working fluid for heat transfer having higher thermal conductivities called nanofluid. Nanofluids are expected one of the promising heat transfer fluids in the future by dispersing nano-size metallic or non-metallic particles in the base fluids to increase the thermal conductivity of fluid and therefore thermal performance of the thermal system.

One of many different methods used to enhance the heat transfer rate in the thermal systems is by using longitudinal vortex generators (VGs). Vortex generators are small protrusions used to generate secondary flow or vortices by swirl the fluid flow. Among different types of turbulators, delta-winglet pair vortex generator is more effective [4]. Fig. 1 shows the main types of vortex generators.

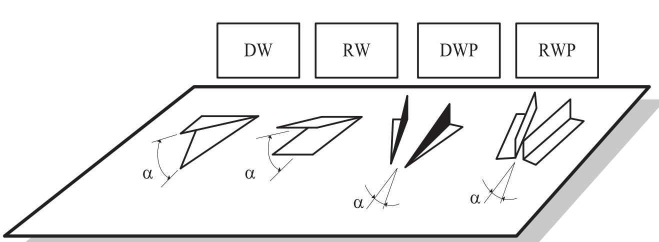

Fig. 1. Schematic diagram of vortex generators; DW: delta-wing, RW: rectangular wing, DWP: delta-winglet pair, and RWP: rectangular-winglet pair.

Munish et al. [5,6] stated that when rectangular wing (RW) is used in a plate-fin heat exchanger with triangular fins as insert to enhance the heat transfer, the price of increase in pressure drop must be paid. The pumping power increases with the increase of the attack angle of VG. Promvonge et al. [7] found that the larger attack angle leads to higher heat transfer rate and flow loss than the lower angles. Althaher et al. [8] indicated that the *Nu* number and friction factor are relatively proportional to the size, number, and the inclination angle of the delta-winglet pair (DWP) of VG. The Nusselt number (*Nu*) increases and the friction factor decreases as the Reynolds number (*Re*) increases. The *Nu* number was significantly affected by the geometry of the VG while the friction factor was slightly changed. Ahmed et al. [9] referred that the heat transfer rate was increased by using nanofluids and it was slightly affected by the type of nanofluids. The Nu_{avg} number increased 50.0% using SiO_2–EG (6 vol.%) nanofluid without any significant increase in the friction coefficient when different types of nanofluids were used. The *Nu* number increased relatively with *Re* number.

Gong et al. [10] reported that the size and position of curved rectangular VG applied on tube-fin heat exchanger played an important role in the heat transfer enhancement. They observed that local Nusselt number on the fin surface contacting with the wake region increased. Zhou and Feng [11] monitored that curved winglet VGs provided better thermohydraulic performance of rectangular channel than corresponding plain winglet VGs under both flow conditions; laminar and turbulent flow. In addition, the smaller face area of VG with relatively smaller hole diameter provided better thermal performance. Li et al. [12] enhanced the air side heat transfer of fin-and-tube heat exchanger by using 12