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Mixed convection heat transfer of nanofluids over backward facing step having a slotted baffle

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ABSTRACT

Mixed convection heat transfer over a 2-D backward facing step with an inclined slotted baffle by using nanofluids is numerically investigated. Continuity, momentum and energy equations were solved by using Finite Volume Method with SIMPLE algorithm to link the pressure and velocity fields. Different Reynolds numbers from 50 to 400 were applied. In addition, the downstream wall of the step from $10 \leqslant X \leqslant 15$ was subjected to a uniform heat flux of 10,000 W/m^2 while the upper wall and the baffle are kept insulated. Five different geometries (without baffle, with a vertical solid baffle, with a solid inclined baffle, with two inclined slotted baffle) were compared to find the best for heat transfer enhancement. Different nanoparticles such as Al_2O_3, CuO, ZnO and SiO_2 with different volume fractions from 0% to 4% and different nanoparticle diameter from 20 to 50 nm were considered with water as a base fluid to explore the best nanofluid for heat transfer enhancement. It is clearly shown that nanofluids with more nanofluid volume fraction and small nanoparticle diameter affect the heat transfer considerably. Results clearly illustrated that SiO_2 with 4% volume fraction and 20 nm nanoparticle diameter shows the best performance for heat transfer enhancement in compared with other nanoparticles. It is also found that the inclined baffle has the maximum average Nusselt number along the heated wall with high pressure drop and skin friction coefficient. However, by increasing Reynolds number, the inclined slotted baffle at $D = 0.5$ had an appropriate average Nusselt number and minimal changes of pressure drop and skin friction which can be considered as the appropriate geometry.

1. Introduction

Mixed convection heat transfer over a backward facing step had been a subject of interest in many research studies. Scientists always are passionate about heat transfer due to its vast application in industry. Hence, there are always encouragements for researchers to obtain new methods for heat transfer augmentation. It was late 1950's when backward facing step is introduced as an appropriate geometry to amplify the heat transfer rate due to flow separation and reattachment phenomena that caused by the abrupt expansion. Studies on internal separated flow have been conducted, numerically and experimentally, in the past decades by different regimes such as laminar, transient and turbulent flows to obtain better understanding of different aspects and reveal more advantages of backward facing step geometry in vertical, inclined and horizontal cases and applying various boundary conditions and different ribs, grooves and baffles [1,2].

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Nomenclature

C_f	skin friction coefficient
C_p	specific heat capacity at constant pressure (J/kg.K)
d	distance between backward facing step and the baffle (m)
D	dimensionless distance between backward facing step and the baffle (d/h_c)
d_p	nanoparticles diameter (nm)
d_f	equivalent diameter of a base fluid molecule
ER	expansion ratio (h_s/h_c)
h	average heat transfer coefficient (W/m^2.K)
h_b	height of the baffle (m)
h_c	channel height (m)
h_s	step height (m)
h_t	baffle's height (m)
k	thermal conductivity (W/m.K)
M	molecular weight (g/mol)
N	Avogadro number (1/mol)
w_b	baffle width (m)
L	length of the heated section (m)
Nu	Nusselt number
q''_s	heat flux (W/m^2)
Re	Reynolds number
R_{np}	nanoparticle radius (nm)
T	temperature (K)
u	velocity component in x-direction (m/s)
u_e	mean inlet velocity (m/s)
U	dimensionless velocity component in x-direction, u/u_e
v	velocity component in y-direction (m/s)
V	dimensionless velocity component in y-direction, v/u_e
X	dimensionless streamwise coordinate, x/h_c

Greek symbols

α_f	thermal diffusion of fluid (Ns/m^2)
β	fraction of the liquid volume which travels with a particle
θ	dimensionless temperature
K	Boltzmann constant
μ	dynamic viscosity (Ns/m^2)
ν_f	kinematic viscosity of fluid (m^2/s)
ρ	density (kg/m^3)
φ	nanoparticles volume fraction
$\emptyset_b$	inclination of the baffle
$\emptyset_t$	inclination of the slot

Subscript

e	inlet condition
eff	effective
f	fluid
nf	nanofluid
np	nanoparticle
s	surface
w	wall

An investigation was conducted by Goldstein et al. [3] on laminar subsonic flow in a horizontal channel showed the inconstancy of the reattachment point in turbulent flow in one hand, and illustrated its dependency on Reynolds number and boundary layer thickness on the other hand. Abu-Mulawah [4] reviewed the results of flow and heat transfer of single-phase laminar mixed convection flow over different orientations for both backward and forward facing steps. In 1980th, couple of experimental and numerical studies was conducted by Aung et al. [5] and Win et al. [6] on fluid flow behavior. They found that the Nusselt number independency of Reynolds number in the laminar air flow. They also illustrated the Nusselt number distribution along the heated wall and observed that the reattachment point has the maximum Nusselt number. Another study on mixed convection turbulent flow over a backward facing step was conducted by