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Convective heat transfer and fluid flow study over a step using nanofluids: A review

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ABSTRACT

Research in convective heat transfer on internal separated flows has been extensively conducted in the past decades. This review summarizes numerous researches on two topics. The first section focuses on studying the fluid flow and heat transfer behavior of different types of single-phase fluid flows over backward facing step (BFS) at different orientations. The second section concentrates on everything related to nanofluids; its preparation, properties, behavior, applications, and many others. The purpose of this article is to get a clear view and detailed summary of the influence of several parameters such as the geometrical specifications, boundary conditions, type of fluids, and inclination angle on the hydrodynamic and thermal characteristics using (BFS). The reattachment length and maximum Nusselt number are the main target of such research where correlation equations were developed and reported in experimental and numerical studies. The heat transfer enhancement of nanofluids along with the nanofluids preparation technique, types and shapes of nanoparticles, base fluids and additives, transport mechanisms, and stability of the suspension are also discussed.

Contents

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1. Introduction

The phenomena of flow separation and subsequent reattachment which occur due to a sudden expansion in the flow passages such as backward facing steps have been recognized as important industrial situations. This complex flow structure present in heating or cooling applications such as cooling electronic equipments, cooling turbines blades, combustion chambers, chemical processes, cooling of nuclear reactors, wide angle diffusers, high performance heat exchangers, energy systems equipment, and flow in valves. In many instances separation of flow is undesirable and leads to unwanted pressure drops and energy losses which require additional fan or pumping power to overcome them. However, in other circumstances flow separation may be encouraged, such as in burner flame stabilization use for turbulence promotion leading to enhanced mixing or heat and mass transfer rates.

The problem of flow over backward facing step has been extensively investigated, both experimentally and numerically. However, case studies such as injection flow, ribs geometry, double step ducts, and onset inlet flow, are not considered in the present review. The current review will only consider the studies of the case of steady-state convective flow and heat transfer over single backward facing steps.

A large number of experimental and numerical studies focus on flow and heat transfer behavior of convective flow over backward facing step geometry have been reported. These vast results and information have dealt with different conditions, parameters, geometry dimensions, and instrumentation, which indeed to undefined solid base for comparison purposes to indicate more accurate methodology for solving the case studies.

The dispersion of these results were attracted the attention of many researchers to unify the information to a general criteria. In 1992 and 1993, the Aerospace Heat Transfer Committee (K-12) of the Heat Transfer Division of the ASME held a technical session for benchmark heat transfer problems during the Winter Annual Meeting to solve numerically laminar mixed convection flow over two-dimensional horizontal and vertical backward facing step, respectively [1–3]. Moreover, due to the importance of the separation and reattachment phenomenon Abu-Mulaweh in 2003 [4] reviewed the results of flow and heat transfer of single-phase laminar mixed convection flow over different orientations of both backward and forward facing steps for several previous work. Most of the studies in this literature declared that only one large primary recirculation region develops downstream of the backward-facing step, while in some cases a secondary recirculation may develop between the downstream stepped wall and the step or at the top wall of the duct due to increase in step height and inlet velocity.

The purpose of this paper is threefold. The primary purpose is to review the available results of the flow and heat transfer presented in previously published data for single backward facing step. The results of massive number of different parameters affect the fluid flow and heat transfer characteristics are summarized and presented with a large number of correlation equations to predict the peaks of the flow and heat transfer in the recirculation regions. The second purpose is to understand the characteristics and functions of nanofluids, to expect their effects and heat transfer enhancement in such geometries. The third purpose is to open a gate for new researches and propose suggestions that could lead to improve the ability to predict separation and reattachment phenomenon

Nomenclature

AR	aspect ratio (W/s)
C_p	specific heat (kJ/kg K)
ER	expansion ratio (*H/h*)
f	elliptic relaxation function
Gr	Grashof number ($g\beta\Delta Ts^3/\nu^2$)
g	gravitational acceleration
H	total channel height (m)
h	inlet channel height (m)
k	thermal conductivity (W/m K)
k	turbulent kinetic energy (m^2/s^2)
L	total length of the channel (m)
Nu	local Nusselt number (hL/k)
Nu_{max}	local Nusselt number (hL/k)
P	pressure (Pa)
q	heat flux (W/m^2)
Re	Reynolds number ($\rho U_0 h/\mu$)
Ri	Richardson number
s	step height (m)
T	temperature (K)
U_0	bulk velocity at the inlet (m/s)
u	velocity component × direction (m/s)
v	velocity component *y* direction (m/s)
w	velocity component *z* direction (m/s)
$x_{u,w}$-lines	$[(du/dy)_{z=const}\|_{y=0}]$
x, *y*, *z*	Coordinate directions
X_i, X_e	upstream, downstream lengths (m)
X_r, X_0, X_n	peak points

Greek symbols

β	thermal expansion coefficient (1/*T*)
ρ	density (kg/m^3)
μ	dynamic viscosity (N m/s)
φ	nanoparticles volume fraction
Δ	amount of difference
ϕ	inclination angle
ν	kinematic viscosity (m^2/s)
ϖ	dimensionless oscillation frequency
ε	turbulent dissipation rate (m^2/s^3)
ξ	buoyancy parameter ($Gr_s/Re_s{}^2$)
ζ	v^{-2}/k

Subscripts

0	inlet
w	wall