International Communications in Heat and Mass Transfer 76 (2016) 237–244

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Heat transfer and fluid flow over microscale backward and forward facing step: A review☆

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ARTICLE INFO

Available online 24 May 2016

ABSTRACT

Research on convective heat transfer in the microscale backward-facing step (MBFS) and microscale forward-facing step (MFFS) has been extensively conducted in the past decade. This review summarizes numerous researches on the three topics; the first section focuses on studying the effect of the geometry on the fluid flow and heat transfer behavior. The second and the third sections concentrate on the effect of the inclination angle and the flow regime on the fluid flow and heat transfer enhancement. 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, type of fluids and boundary conditions. The enhancement in the Nusselt number is the main target of such research where correlation equations were developed in numerical and experimental studies are reported.

Contents

1. Introduction

The flow separation phenomenon and subsequent reattachment due to a sudden expansion or compression in the flow passages, such as backward-facing and forward-facing steps, play a substantial role in the design of a wide variety of engineering applications where cooling or heating is required. The applications of heat transfer appear in such, combustion chambers, environmental control systems, cooling systems for electronic equipment, chimerical process and energy system equipment, high performance heat exchangers, cooling passages in turbine blades, and flow in valves. In many of engineering applications, the separation of flow is undesirable due to unwanted pressure drops

☆ Communicated by W.J. Minkowycz.

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http://dx.doi.org/10.1016/j.icheatmasstransfer.2016.05.022
0735-1933/

and energy losses which require additional pumping power to overcome them. However, in another application, the flow separation and the reattachment region may be encouraged to enhanced heat and mass transfer rates. Because of this fact, the laminar and turbulent flow over backward-facing and forward-facing step geometries in mixed, natural, and forced convection has been investigated rather extensively, both experimentally and numerically. However, case studies such as ribs geometry, injection flow, and onset inlet flow are not considered in the present review.

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

The dispersion of these results hauls the attention of many researchers to unify the information to general criteria. Furthermore, the Aerospace Heat Transfer Committee (K-12) of the Heat Transfer Division of the ASME held a technical session at the 1993 ASME Winter Annual Meeting for a benchmark heat transfer problem [1,2]. In addition, due to the importance of separation and reattachment phenomenon, Abu-Mulaweh, [3] reviewed the results of the flow and heat transfer of single-phase laminar mixed convection flow over different orientations of both backward and forward facing steps for several previous works. While, [4] reviewed the results of effect many parameters on the flow characteristics and heat transfer of single-phase fluid flow over backward facing step.

The objective of this chapter is to present a comprehensive review of the flow and heat transfer results of recent studies of single-phase natural, forced, and mixed convection flow over backward-facing and forward-facing steps. The second purpose is summarized and presented the results of the effects of many parameters on the fluid flow and heat transfer characteristics such as, local heat transfer rate and reattachment lengths, the effects of buoyancy force (assisting and opposing), step height, inclination angle, Prandtl number, Reynolds number, and temperature difference between the heated wall and the free stream on these parameters. The third purpose of this review is to understand the function and characteristics of nanofluids, to expect their effects and heat transfer enhancement in such geometries. The review starts with an extensive review on the flow and heat transfer over backward and forward facing step channels. After that, a comprehensive review for nanofluids and its characteristics was described. At the end, the review concentrates on the flow and heat transfer over a backward and forward facing step using nanofluids.

2. Flow geometry

The scope of this review is to summarize the heat transfer convection flow over backward and forward facing-steps. Fig. 1 presents the configuration of backward and forward facing-step. Both uniform wall temperature (UWT) and uniform heat flux (UHF) were considered.

2.1. Backward facing-step

In the last decades, the convective heat transfer and fluid flow over a backward facing step have been widely investigated, both numerically and experimentally. In the late of 1950s, the first attempt was presented for studying the separation and reattachment flow over a backward-facing step. The revolution of technology development and the improvement of the numerical codes lead to increase the number of new research in such problem and facilitate the complex study of three-dimensional flow in the separation and reattachment zone. The mixed, forced, and natural flow over backward facing-step was investigated for different geometrical parameters, boundary conditions and fluids properties.

The numerical simulation of [5] on mixed convective flow over three dimensional horizontals backward facing step heated from below. They found that when the Richardson number (Ri) increased the recirculation zone was shortened due to the presence of strong buoyancy forces and higher velocity components in vicinity of heated wall. The average Nusselt number distribution at the entrance of backward-facing step channel had a high value and monotonically decreased. The location of maximum spanwise average Nusselt number shifted upstream with

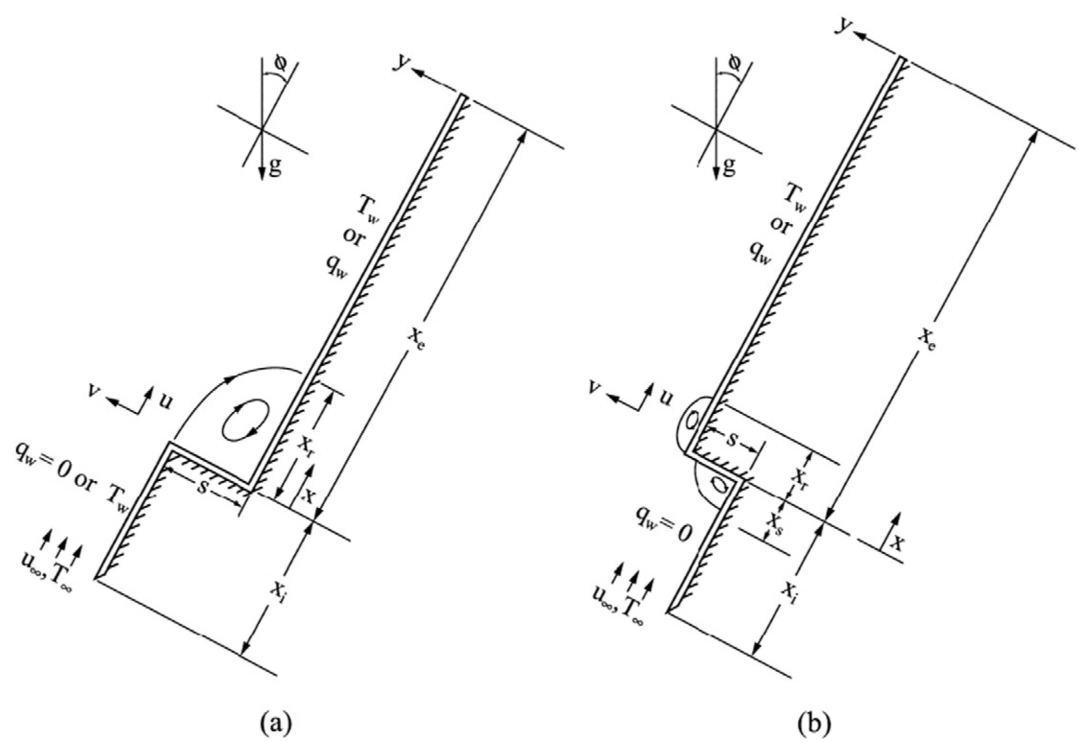

Fig. 1. Configuration of the step geometries: (a) backward-facing step, (b) forward-facing step [3].