International Communications in Heat and Mass Transfer 77 (2016) 9–14

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Effect of laminar separation flow and nanofluids on heat transfer augmentation with passive techniques: A review☆

Hussein Togun

Biomedical Engineering Department, University of Thi-Qar, 64001 Nassiriya, Iraq

A R T I C L E I N F O

Available online 13 July 2016

Keywords:
Nanofluids, sudden expansion
Backward facing step
Forward facing step
Ribbed channel
Laminar flow

A B S T R A C T

Heat transfer in flow channels can be improved by using passive techniques such as ribs on wall and change cross section area where these modifications have practical engineering application for thermal power plant, refrigerators, and radiators. Effects of separation flow and nanofluids on thermal performance for laminar range presented experimentally and numerically in this review. The augmentations of heat transfer with fluid and nanofluid flow through sudden expansion, over backward and forward facing step, and rib channels have been concerned. The experimental results showed good agreement with numerical results and indicated the effects of separation flow and nanoparticles on augmentation of heat transfer rate. The results showed increase in Nusselt number with increase of Reynolds number, step height, and number of ribs. It was detected that by increasing the nanoparticle volume concentrations of nanofluids, improves the heat transfer coefficient. Also different nanoparticles used in the literature investigations are based on thermal conductivity where enhancement of heat transfer rate was obtained significantly.

Contents

1. Introduction

The demand of energy is increasing day by day, but at the same time resources of energy are decreasing due to continuous extraction. In addition to this the growing environmental pollution is putting pressure on companies to become more energy efficient and reduce emissions. In thermal energy transportation, huge energy is lost due to lack of efficient heat exchanging equipment which use inefficient materials. Now researchers are more involved in exploration of better heat exchanging liquid where Nanofluids are getting importance as heat exchanging liquid against conventional liquid.

Flow separation occurs when the velocity at the wall is zero or negative and an inflection point exists in the velocity profile, and a positive or adverse pressure gradient occurs in the direction of flow. Corners, sharp turns and high angles of attack all represent sharply decelerating flow situations where the loss in energy in the boundary layer ends up leading to separation. Here we see how the boundary layer flow is unable to follow the turn in the sharp corner (which would require

☆ Communicated by W.J. Minkowycz.
E-mail address: htokan_2004@yahoo.com.

http://dx.doi.org/10.1016/j.icheatmasstransfer.2016.07.009
0735-1933/

a very rapid acceleration), causing separation at the edge and recirculation in the aft region of the backward facing step [1]. The laminar flow through an axisymmetric sudden expansion, over backward and forward facing step, ribs channel is a created separation flow. Reattachment flow appeared after the separation flow and these flow phenomena are addressed in several experimental and numerical studies [2–12]. This phenomenon has received attention of researchers for a long time because of its fundamental as well as practical interest in numerous equipment such as in heat exchangers, combustors, nuclear reactor cooling channels [13], power plant [14], in the wide angle diffusers, and the airfoils with large angle of attack and with sudden increases in area in channels [15].

The purpose of this review paper is to present results of experimental and numerical studies of heat transfer enhancement in separated region by using nanofluid laminar flow through different configurations.

2. Experimental studies

2.1. Sudden expansion

Macango and Hung [16] are the pioneer of laminar fluid flow study through the sudden expansion. They have report presented results for Reynolds number range ≤ 200 in one to two axisymmetric expansion. Durst et al. [17] have experimentally studied flow over a plane symmetric sudden expansion by using laser-anemometry to measure velocity profiles. The range of downstream flow is 3:1 symmetric enlargement in a duct as aspect ratio of 9.2:1 downstream of the enlargement. The results of velocity indicated to be significantly dependent on Reynolds number, and strongly three dimensional even well away from the passage corners expected at the lowest measurable velocities. The measurements at a Reynolds number of 56 indicated that the separation regions behind each step were of equal length. Symmetric velocity profiles existed from the expansion to a fully developed parabolic profile for downstream, although there were substantial three dimensional effects in the vicinity of the separation regions. The velocity profiles were in good agreement with those obtained by solving the two-dimensional momentum equation. At a Reynolds number 114, the two separation regions were of different lengths, leading to asymmetric velocity profiles and at Reynolds number 252, a third separation zone was found on one wall, downstream of the smaller of the two separation zones adjacent to the steps. Goharzadeh and Rodgers [18] performed an experimental study of laminar water flow in a confined annular channel through sudden expansion. The particle image velocimetry (PIV) and refractive index matching (RIM) were used to measure velocity and length of separation. The presented results showed increased length of separation for increase of Reynolds number as Fig. (1, 2, 3). Moreover, they obtained a good agreement with numerical result reported by Nag and Datta [19].

Xin et al. [20] have performed computational investigation of heat transfer and laminar supercritical CO2 flow through the sudden expansion of horizontal duct. Finite Volume method with different heat flux and Reynolds number was used to solve continuity, momentum, and energy equations. The calculation results revealed the increase of separation length with increase heat flux and also Nusselt number increase with Reynolds number and heat flux.

From the literature, the study of laminar of Nanofluid flow in sudden expansion is very limited and appears only from David et al. [21] where numerical study on laminar Al_2O_3, Ag, Cu, SiO_2, and CuO nanofluid flow in sudden expansion. They used the same method used by Kanna and Das [2006] for solving sudden expansion flow and backward facing flow with Reynolds number from 30 to 150 and volume fraction 0.1, 0.2, 0.5. The result obtained was a decrease in reattachment length of about 1.3% in comparison with Eiyad Abu-Nada [22] as shown in Fig. 4; also they obtained good agreement with Al-Aswadi et al. [23].

2.2. Forward and backward facing step

Armaly et al. [24] have experimental and theoretical investigation of study flow over backward facing and effect of Reynolds number on reattachment length. The experimental test depended on laser Doppler measurement, the range of Reynolds number varied from 70 to 8000 and aspect ratio 1:36. The obtained results found agreement with numerical results and it leads to increase of reattachment length with increase of Reynolds number. Subsequent model particle phase with Eulerian–Lagrangian used to study laminar flows over backward facing step with stream of hot particle presented by Barton [25]. Effect heat transfer and thermal characteristic on recirculation regions was noticed and streamlines in the separation region were 10 times smaller than the streamlines in the free flow. With current development, the lengths of separation and reattachment on lower and upper of duct measured by using hot wire probe with expansion ratio 1.17 and 2 and Re below 3000 were as reported by Lee and Mateescu [26]. The experimental and numerical results showed agreement with previous investigation for separation and reattachment length. To get more information about separation phenomena Stüer et al. [27] used particle tracking velocimetry to study laminar separation flow on forward facing step. The experimental results obtained increase distance between the breakthroughs in span at decreased Reynolds number and they also noticed that the transverse direction of separation was slowcompared with short time scale over. Armaly et al. [28] used two components of laser Doppler velocimeter for study flows on backward facing step where the range of Reynolds number varied from 98.5 to 525 and expansion ratio of 2.02. The measurement data found that increase of Reynolds number leads to increase of size recirculation regions and the maximum locations of streamwise velocity line component (u) is zero at the stepped wall. Velazquez et al. [29] have experimental study of augmentation of heat transfer for laminar flow over a backward facing step. They employed pulsating flow and the measurements showed that the maximum time average of Nusselt number at Re = 100 was 55% higher than steady case and this increment represented augmentation of heat transfer.

2.3. Ribs channel

Han et al. [30] have experimentally studied the effect shape of rib, pitch to height ratio, and angle of attack on heat transfer and friction through parallel plate where the range of Reynolds number varied from 3000 to 30,000. They observed at staggered rib that the results were similar compared with symmetrical rib and they also obtained large improvement of heat transfer at ribs having 45 degree angle arrangement.

Olsson and Sundén [31] carried out an experimental study of heat transfer and pressure drop for flow in rib rectangular channel by using smoke wire visualization at Re = 1100 and laser Doppler velocimtery (LDV) at Re = 3000. The feature of ribs which was employed in their experimental studies consists of cross V-ribs, parallel V ribs, multiple V-ribs, cross ribs and parallel ribs. The results obtained revealed that the parallel V-rib channel having the highest positions was mainly an efficient one compared with other cases of ribs as shown Figs. 5, 6.

Xiufang and Bengt [32] have experimental pressure drop and heat transfer in rib roughened rectangular channel. The aspect ratio used varied from 1 to 8 and three configurations of ribs applied in their investigation that included V-ribs pointing upstream, V-ribs pointing downstream, and inclined parallel ribs. They showed that the highest Nusselt number occurred at V-ribs downstream compared with smooth channel, V-upstream ribs, and inclined parallel ribs as shown Fig. 7.

Nonino and Gomini [33] presented an investigation on a study of three dimensional convective heat transfer and laminar flow through rib channel with angled rib and transverse rib. Heat transfer and pressure drop in ribs channel with different Reynolds number were the objective in their study where they noticed increase in average Nusselt