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Review of forced convection nanofluids through corrugated facing step

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ABSTRACT

This paper presented the recent development of heat transfer enhancement through facing step and corrugated channels. Numerical simulation findings of the convective heat transfer with and without nanofluids have been investigated. The experimental trials to augment heat transfer in the facing step and corrugated channels by using conventional fluids and nanofluids are reported. Both of the laminar and turbulent flows through facing step and corrugated channels are introduced. There were good agreements among numerical and experimental studies to augment heat transfer. The significant applications of the engineering field have led many investigators to use nanofluid in the heat exchanger for heat transfer augmentation. New design of the corrugated facing step channel to enhance heat transfer is being proposed. The utilization of nanofluids will be useful in the new channel to enhance the heat transfer numerically and experimentally. The heat transfer enhancement was estimated up to 60% when using nanofluid in the facing step channel. Regression equations can correlate relationships among the responses and the input parameters. It is needed to compare the dimensions of the new channels that includes height of step, height of corrugated and shape of corrugated that might give an optimum heat transfer enhancement with a slight friction factor.

1. Introduction

The sudden compression or expansion in the channels flow is very important design in many practical applications for cooling or heating systems [1]. The forward-facing and backward-facing steps are significant applications in these types of flow as shown in Fig. 1.

A number of heat transfer industrial applications through facing step channel have been included in energy systems equipment, electronic cooling systems, chemical processes, combustion chambers, turbine blades cooling, environmental control systems and high performance heat exchangers. Particularly, the drop in pressure and heat transfer enhancement in the reattaching flow area and inside the reverse flow area was great. For example, the low pressure drop and the high heat transfer augmentation obtained near the wall channel region whereas the low rate of heat transfer gain at the corner where the sudden change occurs starts in flow region.

On the other hand, the corrugated channels shown in Fig. 2 have been used in a wide range of practical applications to enhance heat transfer. The augmentation of heat transfer in these channels is dependent on bulk fluid mixing and re-initiation of the thermal boundary layer [2].

Through the author's knowledge, investigations concern on nanofluid flow over facing step and corrugated channels were still not entirely understood. The main objective of this review is to summarize the recent studies of heat transfer enhancement through facing step and corrugated channels. In addition, this review will provide a proposed new type of flow in corrugated facing step channels for future work.

2. Heat transfer through facing step geometry

There is one separated region in the flow geometry of backward-facing step, which is developed by the step downstream. Likewise, the flow geometry of forward-facing step as well as the flow field that more complicated and one or two separated regions can develop to one upstream and the other downstream from the step, which depends on the ratio of the approaching flow of thick boundary layer to the forward-facing step height at the step.

Flow over a backward-facing step generates recirculation zones and forms vortices due to the separation flow obtained from the adverse pressure gradients in the fluid flow [3]. The phenomena of flow separation are found in different applications such as heat exchangers,

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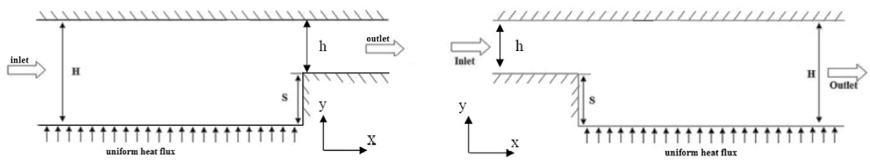
Nomenclature

f	the friction factor -
k	the thermal conductivity [W/m.°C]
Nu	Nusselt Number -
P	Pressure [N/m^2]
Pr	Prandtl Number
Re	Reynolds Number
U	Velocity [m/s]
CFD	computational fluid dynamics
FVM	finite volume method
E	expansion ratio
A	aspect ratio

Subscripts

f	liquid phases
p	solid particle
nf	nanofluid
h	Hydraulic



(a) Forward (b) Backward

Fig. 1. Facing Step Channel [1].

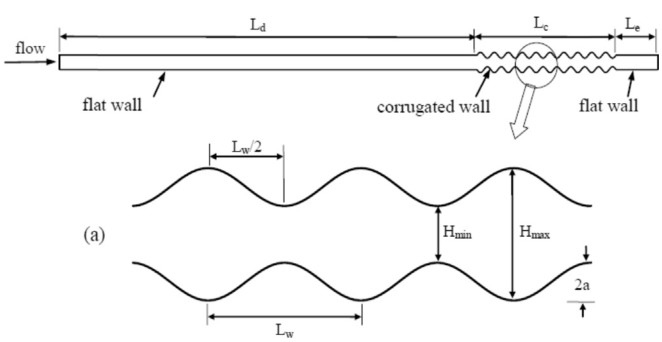


Fig. 2. Corrugated channels [2].

nuclear reactors, power plants, cooling devices, etc. In the past decades, a number of works have been performed on this phenomena and its effect on heat transfer rate [4]. The heat transfer and flow characteristics of the conventional fluids such as air and water through the facing step channels have been studied by many researchers [5,6].

Hattori and Nagano [7] have studied boundary layer turbulent flow through a forward facing step. The separate regions have occurred in the step and in front of the forward facing step flow.

Sparrow and Chuck [8] performed a study of heat transfer and fluid flow through a backward facing step numerically. They implemented a numerical finite difference for studying the airflow phenomenon over a two-dimensional channel that was heated at constant temperature at the bottom wall from the foot of the step to the end of the channel. The low values of Nusselt number at the step were observed furthermore, it advances regularly and achieve an optimum heat transfer augmentation near the wall. Beyond the optimum point, Nusselt number decreases regularly with fully developed value. This behavior reflects the re-attachment, re-development and separation by the flow experience.

Chiang et al. [9] conducted a topological study of a 3D backward facing step channel to improve the visualization of oil flow field. The size of the roof recirculation zone was observed to be dependent on Reynolds number. Saldana et al. [10] reported the numerical results of simulating airflow through a forward facing step horizontal channel under three different Reynolds values. The expansion ratio (E =2) and the aspect ratio (A =4) of rectangular forward-facing step channel have been considered. In addition, a recirculation area was developed next to upstream and the bottom step wall. The separation of flow occurs early with increasing of Reynolds number. The flow through a facing step has simulated numerically by Saldana et al. [11]. The results showed that the separation flow occurs with the increasing of Reynolds number at earlier positions in the direction of the main flow.

In the last decade, many studies of the three-dimensional flow over backward facing step have been carried out experimentally and numerically [12–16]. An experimental and numerical study was performed by Tylli et al. [12] to find the effects of sidewall for 3D flow of water through a backward facing step. The numerical simulation was carried out for laminar flow (Re > 700). It was observed that the three-dimensional CFD analysis has agreed with the experimental data obtained at Re =650. Moreover, the three-dimensional flow and the wall-jet intensity have been increased with the increasing of Reynolds number, and decreased under transitional flow. Available literature for laminar and turbulent situations have been extensively studied both theoretically and experimentally about the flow through a forward facing step by Saldana et al. [10], and Hattori and Nagano [7].

3. Heat transfer through facing step with baffles

A baffle insertion in a cooling system is one of the heat transfer augmentation methods, like ribs, jet impingement. This application was used in many engineering applications as electronic cooling devices, internal cooling systems of the blades of gas turbine, thermal regenerators, turbomachinery machines and shell/tube heat exchangers [22]. The heat transfer through facing step baffle channel shown in Fig. 3 has been adopted by Heshmati et al. [17].

Berner et al. [18] has performed an experimental study of flow velocity distributions through segmented baffles. The turbulent heat transfer and flow characteristics through the periodic cell among segmented baffles staggered in straight channels have been studied experimentally by Habib et al. [19]. The previous researches have utilized the solid segmented baffles. Dutta and Dutta [20] conducted an experimental study on perforated baffles that appeared in better heat transfer enhancement with perforations as compared to the solid baffles.

A number of studies were carried out numerically to capture more

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