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Thermal Nanofluids flow in Corrugated Facing Step - A Review

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Abstract

In this paper, the studies of thermal fluid flow in corrugated and facing step channels by using conventional fluids and nanofluids are summarized. The numerical and experimental results of heat transfer augmentation appeared good agreement. Results of many researchers showed significant applications of both corrugated channels and facing step to enhance heat transfer. The new channel of the corrugated facing step to improve the heat transfer and flow characteristic is a plan of the author. The utilizing of nanofluids will be useful in the new channel to augment thermal fluid flow. Correlation equations between the input and output parameters will adopt in future work.

Keywords: *Nanofluids, Corrugated, Facing step, Nusselt number, Friction factor.*

1. Introduction

The heat exchangers design is required to enhance thermal energy saving. The way to augment the thermal heat exchangers performance is to find efficient heat transfer surfaces that do not induce much pressure loss. The Using of corrugated shape is a suitable method to increase the thermal performance and provide higher compactness. The corrugated channels shown in Fig.1 were used in a wide range of industrials' applications to augment heat transfer such as chemical applications, cooling systems, gas turbine, heat exchangers and control systems.

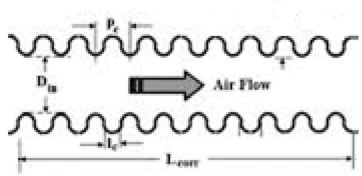

Fig. 1. corrugated channels [1].

The facing step channels are significant design in many practical applications for cooling or heating systems due to the suddenly compression or expansion flow [2]. The facing step shown in Fig.2 has many practical applications included electronic cooling systems, chemical processes, energy systems equipment, combustion chambers, high performance heat exchangers turbine blades cooling and environmental control systems. There are always encouragements for researchers to obtain new methods for heat transfer enhancement. 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 were 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 [2, 3].

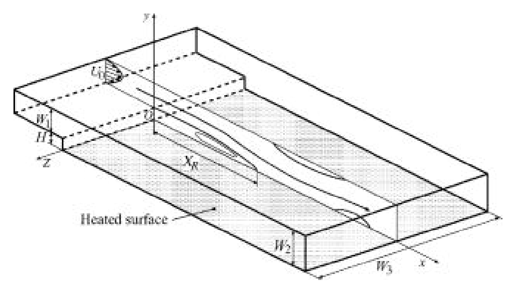

Fig.2. Facing Step Channel [2].

This review is summarized the recent studies of heat transfer enhancement through corrugated and facing step channels. In addition, it will give a significant plan to adopt a new type of flow in corrugated facing step channels for future work.

2. Corrugated Channels

Numbers of experimental studies of the thermal energy performance with conventional fluid in corrugated channels at laminar flow condition were carried out in the past [4-5]. The heat transfer characteristics and pressure drop in the V corrugated channel under constant heat flux were studied by Naphon [6]. Results showed that the corrugated surface has a significant effect on the heat transfer augmentation and friction factor. Mulaweh et al. [7] performed an experimental study of turbulent mixed convection flow through backward facing step. Results showed that the temperature gradient decreased at the downstream heated wall by increasing the velocity. Rush et al. [8] conducted the heat transfer and flow characteristics under sinusoidal wavy laminar flows

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through channel experimentally. The experimental results indicated that the geometry of the channel and Reynolds number have effected directly to the location of the mixing onset. The heat transfer has significantly increased with onset of macroscopic mixing. The convective heat transfer through corrugated channels under turbulent flow condition have been carried out by number of researchers [9]. Oyakawa et al. [10] studied the influence of channel height on the heat transfer enhancement and pressure drop in a sinusoidal-wavy channel experimentally. Results showed that the optimal performance of the wavy channel could be achieved when the ratio of wavelength to channel height was two. Elshafei et al. [11] studied the convective heat transfer and flow characteristics of air flow in corrugated channels under constant surface temperature. Results indicated that the influence of channel spacing variations on heat transfer and friction factor was dependent than the phase shift variation, especially at high Reynolds number.

Several investigations have been studied on the convective heat transfer in nanofluids [12]. Rostami [13] numerically investigated on the convective heat transfer of nanofluid flow in a sinusoidal-wavy channel under constant heat flux. The continuity, momentum and energy governing equations, in a curvilinear coordinate system, were discretized using the finite volume approach and then solved using SIMPLE algorithm. Numerical results were obtained for Reynolds numbers range of 100−250 and nanoparticle volume fraction range of 0-10%. Esmaeili et al. [14] focused on the laminar flow of Al_2O_3/W nanofluid in sinusoidal wavy channel. In this study, the boundary condition was applied a constant heat flux on the channel walls. The governing equations were solved using finite volume method. Results showed that the nanoparticles addition to the basefluid may significantly increase the heat transfer enhancement but the wall shear stress also increased.

Ozbolat and Sahin [15] were investigated on the heat transfer enhancement of Al_2O_3-water nanofluid in wavy channel with eight waves. The wavelength and the amplitude of the wavy channel were 28 mm and 3.5 mm, respectively. The results showed that the enhancement in the heat transfer increased with the increasing in Reynolds number and nanoparticles volume fraction. The heat transfer and flow analysis in anode side of direct methanol fuel cells (DMFCs) have been numerically studied by Heidary et al [16]. To enhance the heat exchange between bottom cold wall and core flow, bottom wall of fluid delivery channel was considered as corrugated boundary instead of straight (flat) one. Four different shapes of corrugated boundary have been considered: rectangular, trapezoidal, triangular and wavy (sinusoidal) shape. Results showed that corrugated channel with trapezoidal, triangular and wavy shape enhances the heat exchange up to 90%. Samples of isothermals and streamlines results showed in Fig.3.

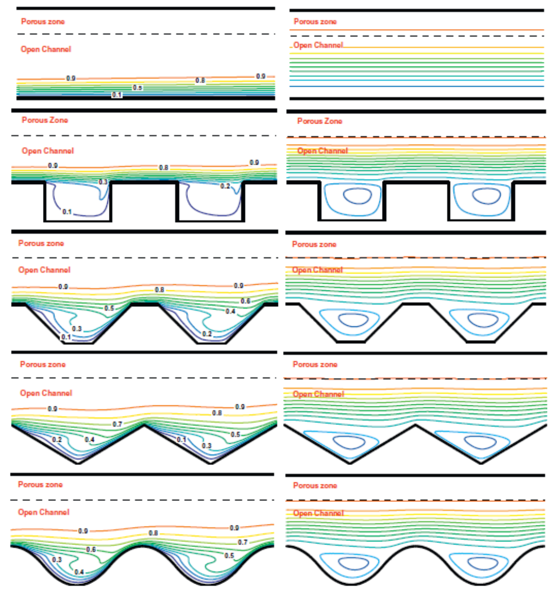

Fig.3. Isothermal and streamline contours [16].

An experimental study on the forced convective flow of different nanofluids through a corrugated channel was performed by Aliabadi et al. [17] at the constant wall temperature condition. Effects of different factors including nanoparticles weight fraction (0.1–0.4%), type of nanoparticles (Cu, SiO_2, TiO_2, ZnO, Fe_2O_3, Al_2O_3, and CuO), and basefluid material (water–ethylene glycol mixture) were examined. Geometrical parameters of the complicated channels have noticeable effects on their thermal–hydraulic performance [18].

The corrugated channel has studied experimentally by Aliabadi et al. [19]. The turbulent flow of Al_2O_3-water nanofluid inside the corrugated channel particularly with sinusoidal waves has been considered. Results of Nusselt number, friction factor, and performance evaluation criterion were reported to illustrate the effects of different geometrical parameters on heat transfer and flow characteristics of the sinusoidal-corrugated channel.

3. Facing Step

There is one separated region in the flow geometry of backward-facing step, which develops of 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 depended to the ratio of the approaching flow of thickness boundary layer to the forward-facing step height at the step.

Numerical simulation of a turbulent forced convection flow over a 2D backward facing step was investigated by Chen et al. [20]. It was observed that the increasing of the step height not only expanded the primary and secondary recirculation area but also caused a rapid augmentation for temperature and turbulent kinetic energy. Heshmati [21] numerically investigated a mixed convection heat transfer over a two dimensional backward facing step. The different geometries (with and without baffle) were compared and different nanofluids such as Al_2O_3, CuO, ZnO and SiO_2. Results clearly illustrated that SiO_2 with 4% volume fraction and 20 nm nanoparticle diameters showed the best performance for heat transfer enhancement as compared with other nanoparticles. Sample of results shown in Fig.4 appeared the comparison between facing step with and without baffles for both of Streamlines and isotherms of different geometries.

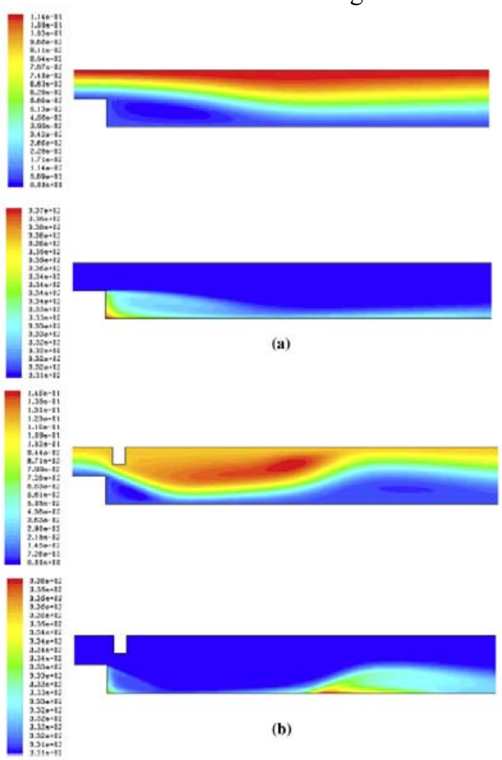

Fig.4. Streamlines (top) and isotherms (bottom) for different geometries, (a) without baffle and (b) with baffle [21].

The velocity of for separated airflow under laminar three-dimensional inherently with a backward facing-step has measured by Armaly et al. [22]. Saldana et al. [23] was reported numerical results for 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 has been considered. In addition, a recirculation area was developed near to upstream and the bottom step wall. The separation of flow occurs early with increasing of Reynolds number.

An experimental and numerical studies conducted by Tylli et al. [24] to investigate the effects of sidewall for 3D flow of water through a backward facing step. The numerical simulation carried out for laminar flow (Re>700). It was observed that the three-dimensional CFD analysis have agreed to the experimental data obtained at Re = 650. Moreover, the three-dimensional flow and the wall-jet intensity have increased with increasing of Reynolds number under laminar flow, and decreased under transitional flow. Biswas et al. [25] studied the laminar fluid flow behavior over a three dimensional backward-facing step with various expansion ratios. The study revealed that the formation of wall jets at the sidewall within the separating shear layer, formed by the span wise of the velocity moves towards the symmetry channel plane.

Kherbeet et al. [26] presented a numerical investigation of the nanofluid effect of laminar flow on a mixed convection heat transfer over 2D microscale backward-facing step. The nanoparticle size was in the range of 25 nm 6 dp 6 70 nm. Four types of nanoparticles were utilized: Al_2O_3, CuO, SiO_2 and ZnO, with a volume fraction of the range 1–4%. The results revealed that there was no recirculation region observed behind the step for all the mentioned nanofluids. The fluids with SiO_2 nanoparticles showed to have the highest Nusselt number. In addition, the results showed Nusselt number increases with the increment of the volume fraction of the nanoparticles in the base fluid. Bao and Lin [27] used the DSMC method to study the transition regime in the microscale backward-facing step. They found that at Knudsen number = 0.136, the streamwise velocity was always positive which indicated that there was no reversed flow existing after the step. The adverse pressure gradient behind the step was too small to stagnate the flow. Furthermore, the mass flow rate increases with the increase of pressure ratio and the relation is not linear as in traditional flow. However, it was found that the gradient increases with the pressure ratio.

4. SUMMARY

This review reported that a large quantity of publications that dedicated to study the thermal performance through facing steps. The effect of several parameters to the heat transfer enhancement such as geometry, boundary conditions, and types of fluids were presented and discussed. The way to contribute an accurate numerical data for convective heat transfer flow through facing steps with baffle has been presented. The articles that included the flow and heat transfer characteristics through corrugated channels with and without nanofluids have been reported. Both numerical and experimental studies of nanofluid preparation, thermal properties and application of nanofluids have been discussed. It should be said, there is no study has focused to convective heat transfer by nanofluid through corrugated facing step. The author will focus on the convective heat transfer by nanofluid through corrugated facing step experimentally.

5. CONCLUSIONS

The heat transfer has augmented by using nanofluids in the facing step channels for cooling system. The comparison between smooth and corrugated channels has been carried out and proved that the corrugated channels has significant heat transfer enhancement. Both numerical and experimental studies for laminar and turbulent flow has been reported and concluded the heat transfer enhancement in the corrugated channels. The using of nanofluids in the corrugated channels has augmented the heat transfer with slightly pressure drop. The enhancement of heat transfer potential of the basefluids in the corrugated facing step channels will offer an opportunity for engineers to develop highly compact and effective heat transfer equipment for many industrial applications. The benefit of utilizing of nanofluids in the new channels will use in practical applications. Future work is very important for expecting a plan of research and any work that will be proposed.

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