HEAT TRANSFER ENHANCEMENT IN A RECTANGULAR DUCT BY USING WINGLET AND NANOFLUIDS

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ABSTRACT

The vortex generators induce streamwise longitudinal vortices. These vortices disrupt the growth of the thermal boundary layer and serves to bring about heat transfer enhancement between the fluid and the fin surfaces. The geometrical configuration considered in this study is representative of a channel with winglets spread over three rows each row 13 a pair of winglets.

In this study, three dimensional turbulent flow of different nanofluids flow inside a rectangular duct with the existence of vortex generator winglets at different angle are (10º, 20º and 30º) is numerically investigated. The effects of type of the nanoparticles, and Reynolds number on the heat transfer coefficient and pressure drop of nanofluids are examined. Reynolds numbers (10000, 20000, 30000, 40000 and 50000). A constant surface temperature is assumed to be the thermal condition for the upper and lower heated walls. In the present work, three nanofluids are examined which are Al_2O_3, CuO and SiO_2 suspended in the base fluid of water with nanoparticles concentration ranged ϕ = 4% and the nanoparticles diameter, dp is (30 nm). The validity of the code is tested by comparing the results for a three-dimensional experimental the published results with numerical results. The results are in good agreement with the published results.

It is observed from the results that the heat transfer increases with the increase in the angle of attack and Reynolds number. the result reporting showed that the case of channel with winglet at angle 30˚ presented highest heat transfer rate. Where that, the case of channel with winglet at angle 20˚ presented, the Nu values are lower than the winglet with angle 30˚. Also, the case of channel with winglet at angle 10˚ and smooth channel presented, the Nu values are apparently lower than the winglet with angle 30˚.

ABSTRACT

This study also reports the heat transfer enhancement by nanofluid in channel flow. Thus, showed that the case of channel with SiO_2+H_2O nanofluid presented highest heat transfer rate. Where that, the case of channel with Al_2O_3+H_2O nanofluid presented, the Nu values are lower than the SiO_2+H_2O nanofluid. Also, the case of channel with CuO+H_2O nanofluid presented, the Nu values are apparently lower than the SiO_2+H_2O nanofluid. It is observed that there is no change in the friction coefficient when the type of the nanofluid is changed.

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LIST OF ABBREVIATION AND SYMBOLS

D_h	hydraulic diameter (m)
d_f	fluid particle diameter (m)
d_p	nanoparticle diameter (m)
C_f	skin friction coefficient
C_p	specific heat capacity (kJ/kg.K)
μ_{eff}	Effective dynamic viscosity
ρ_{eff}	Effective mass density (kg/m^3)
cp_{eff}	Effective specific heat (kJ/kg.K)
ρ_f	The mass densities of the based fluid (kg/m^3)
ρ_{nf}	The mass densities of solid nanoparticles (kg/m^3)
ρc_p	The heat capacities (kg/m^3)
f	friction factor
H	height of the channel (m)
h	convective heat transfer coefficient (W/m^2.K)
K	thermal conductivity (W/m K)
L	length of the channel (m)
LVG	longitudinal vortex generator
M	molecular weight (kg/mol)
ṁ	mass flow rate (kg/s)
N	Avogadro number (N = 6.02214179 × 10^23 mol.1)
Nu	Nusselt number (Nu = h.D_h/k)
P	pressure (pa)
Pr	Prandtl number (l.C_p/k)
R_e	Reynolds number (Re = u.D_h/m)
CuO	Copper Oxide
SiO_2	Silicon Dioxide
Al_2O_3	Aluminium Oxide
RWP	rectangular winglet pair
S	length of the vortex generator (m)
T	temperature (K)

u,v	velocity components (m/s)
FVM	Finite Volume Method
CFD	Computational Fluid Dynamics
VG	vortex generator
X	axial length along the duct (m)
x,y	2D Cartesian coordinates (m)

Greek symbols

α	attack angle of vortex generator
β	thermal expansion coefficient (1/K)
ϕ	volume fraction
μ	dynamic viscosity (kg/m.s)
υ	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
τ	wall shear stress (pa)

Subscripts

Avg	average
α	entry
eff	effective
b_f	base fluid
f	fluid
in	inlet
h	hot
o	initial
m	mean
out	outlet
p	particle
w	wall
x	local

CHAPTER 1

INTRODUCTION

1.1 Introduction

Forced convection heat transfer in a channel had been a subject of interest in many research studies over the past decades. The subject of heat transfer enhancement has significant interest to develop the compact heat exchangers in order to obtain a high efficiency, low cost, light weight, and size as small as possible. Therefore, energy cost and environmental considerations are going on to encourage attempts to invent better performance over the existing designs. Stream wise vortices can be generated using small flow manipulators or protrusions such as wings and winglets configurations. Single-pair, single row, or two dimensional array of vortex generators (VG) can be punched, mounted, attached or embedded in the boundary layer of flow channel as in figure 1.2. (VG) generate longitudinal and transverse vortices, while longitudinal vortices are more efficient for heat transfer enhancement than transverse vortices. A dramatic augmentation in thermal performance of the thermal system can be achieved, but the pressure drop penalty is existed [1,2] in this area have been carried out, but very few attempts of numerical investigation have been made so far due to complexity of flow pattern and computational limitations. In this work, an attempt is made to predict numerically the details of both the velocity and temperature fields responsible for heat transfer enhancement.

In view of earth's depleting fossil fuel reserves, researchers are stimulated to develop renewable energy available on earth. In much renewable energy, solar energy is an epochal alternative as an unlimited source of energy which can fulfill the need of our daily life. The most dexterous way to utilize solar energy is to transform it into thermal energy by using a solar air heater [3,4]. The solar air heater is simple and less sophisticated in nature due to its simple design and low cost. The thermal efficiency of solar air heater is considered to every low because of high thermal resistance or low heat transfer capability between absorber plate and flowing air in the duct. Figure 1.1 show different types of tabulators. Various enhancement techniques are employed to make the solar air heater efficient. Enhancement techniques essentially reduce the thermal resistance in a conventional solar air heater by promoting higher convective heat transfer coefficient with or without an increase in surface area. A number of techniques have been investigated and are available for enhancing the heat transfer rate in solar air heaters. Many investigators used fins, artificial roughness, and corrugated absorber plate to reduce the thermal resistance. Tabulators in the form of delta winglet, vortex generator, obstacles and perforated baffles/ribs/blocks.

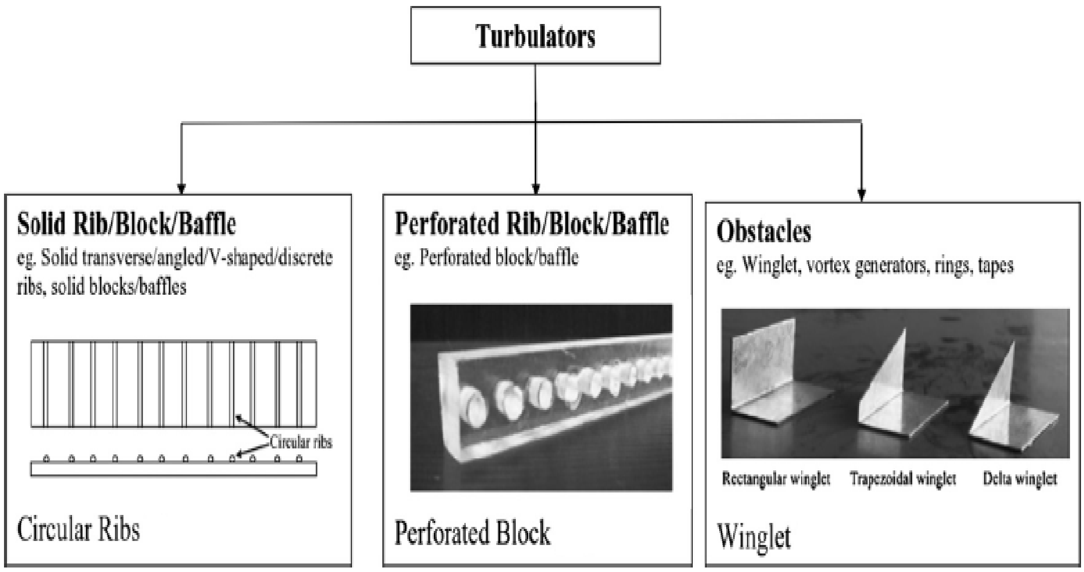

Figure 1.1 different types of Turbulators[9].

The synthesis of the nanofluids is the first key to enhance the thermal conductivity (k) of nanofluids. The convenient of nanofluid does not mean a simple liquid–solid mixture. Nano- fluids are produced by dispersing nanometer-sized solid particles into base-liquid such as water, ethylene glycol (EG), oil, etc. The nanotechnology opens wide opportunities to produce nanometer scale particle with different shapes. Figure 1.3 shows Nanofluid (Water+CuO). Recently, numerous researchers have studied the effect of enhancement of heat transfer on the performance of the heat exchanger by the inserts experimentally, theoretically and numerically. An experimental study was used in order to prove the numerical result in the real life, but experimental study is expensive than the other types of studies. Most of the previous studies preferred the numerical study based on the computational simulation. In terms of cost and time, the numerical method provided a more suitable and accurate results compared to the other methods of studies.

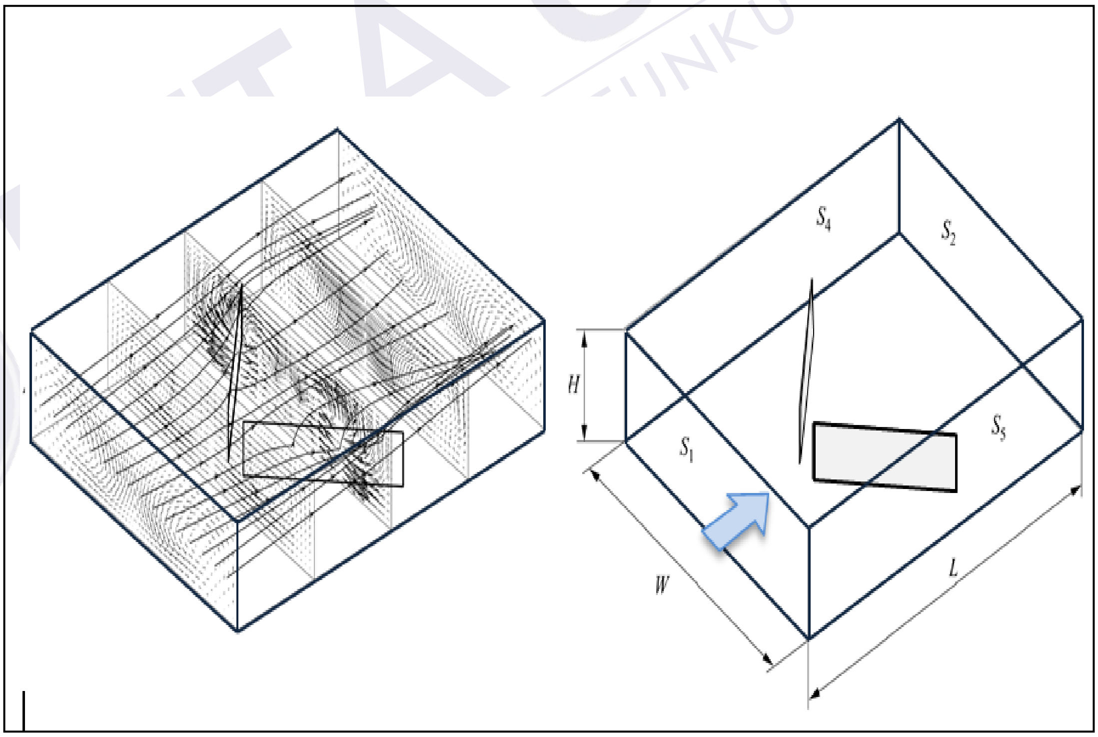

Figure 1.2. Winglets vortex generator[9].

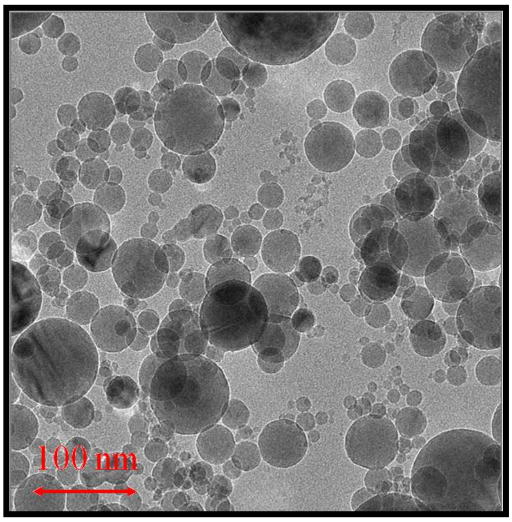

Figure1.3. Nanofluid[34].

1.2 Problem Statement

Rectangle channel is widely used in such fields as heat exchangers, automobile industries, power systems, solar water heater, solar air heater, heating and air conditioning, chemical engineering, electronic chip cooling and aerospace, etc. This subject has received considerable attention to get high efficiency, low cost, small size, and light weight. For the vehicle industries, an additional benefit can be considered such as a small size of the radiator tends to get a small frontal area of the vehicle which in turn leads to diminishing the drag force and subsequently minimizes the fuel consumption. Several engineering applications had held an enormous attention to improve heat transfer performance of the heat exchangers. The traditional heat exchangers are generally improved by serving enhancement techniques with concentration on many types of surface augmentation. The augmentation of heat transfer can be done by disrupting the boundary layer growth, increasing the turbulence intensity, and generating secondary flows.

In the past years, many techniques were utilized to improve the thermophysical properties of fluids by increasing its thermal conductivity. One of these techniques include adding the high thermal conductivity metal nanoparticles (gold, copper, aluminum, silver) etc. to the base fluid. This resulting in increasing the thermal conductivity of mixtures and provided new fluids which called nanofluids, such as, alumina (Al_2O_3), copper oxide (CuO), silicon dioxide (SiO_2), zinc oxide (ZnO) and etc. [5,6]. Nanofluids are prepared by dispersing less than 100 nanometer-sized particles in a base fluid such as water, ethylene glycol, oil and other conventional heat transfer fluids and these types of fluids have high thermal conductivity. There are many reasons lead us to use nanofluids as working fluids.

- Conventional heat transfer fluids have inherently poor thermal conductivity compared to solids.
- Conventional fluids that contain mm- or mm-sized particles do not work with the emerging "miniaturized" technologies because they can clog the tiny channels of these devices.
- Modern nanotechnology provides opportunities to produce nanoparticles.
- Argonne National Lab (Dr. Choi's team) developed the novel concept of nanofluids.
- Nanofluids are a new class of advanced heat-transfer fluids engineered by dispersing nanoparticles smaller than 100 nm (nanometer) in diameter in conventional heat transfer fluids.

Due to the advantages of utilization the nanofluids as working fluids, the effects of nanofluids on the heat transfer rate are investigated in the present study. The heat transfer enhancement resulting from the diffrent type of nanofluids with pure water, the nano-particles diameter, dp is (30 nm) and volume fractions (concentration) ϕ of nanoparticles are used in this study (4%) The Reynolds numbers used in this study are ranged from 10,000 to 50,000.

1.3 Application of the study

As evident from the diversity of application of heat exchangers areas, the study of flow and heat transfer in channel is very important for the technology of today and the future in order to develop and produce high efficiency, small size heat exchangers. Heat exchangers are mostly used devices in many areas of the industries. Hence, the using of high performance heat exchangers is very important for saving energy. But there is limited research related to the high performance thermal system of double pipe heat exchangers by using CFD models. Heat transfer enhancement has significant meanings for environmental problems. The heat transfer coefficient, friction factor and the value of performance evaluation criterion (PEC) in heat exchanger depend on different geometrical parameters of winglet which are investigated in the past studies. The winglet in channel with different geometrical configurations are widely used to enhance the heat transfer rate in many engineering applications, for example, heat recovery processes, air conditioning and refrigeration systems, internal cooling of gas turbine blades, chemical reactors, thermal regenerators, gas-cooled reactors, food and dairy processes, boilers and heat recovery systems.

On the other hand, the utilization of nanofluids is increasing in a wide variety of applications like microelectronics, transportation, lighting, utilization of solar energy for power generation and Micro-electromechanical systems (MEMS). The nanofluids technology can also help to develop better oils and lubrications. Recent nanofluid technology involves using the nanoparticles in the lubricants in order to enhance the thermophysical properties of the lubricants such as load-carrying capacity and anti-wear and friction-reducing properties between moving mechanical components [7]. Furthermore, the nanoparticles are engineered to have larger relative surface areas, less particle momentum, high mobility, and better suspension stability than micron-sized particles and importantly increase the thermal conductivity of the mixture. This makes the nanofluids a promising working medium as coolants, lubricants, hydraulic fluids and metal cutting fluids. Furthermore, negligible pressure drop and mechanical abrasion makes researchers subscribe to nanofluids for the development of the next generation miniaturized heat exchangers [8].

1.4 The Objectives of study

This study is conducted to investigate numerically the utilization of winglet in duct under turbulent flow of nanofluids as shown in figure 1.4. The objectives of the present study are:

1. To study the effects of geometrical parameters of winglet on the thermal and flow fields. The slant angle ($\alpha = 10°, 20°, 30°$) .
2. To examine the effects of (SiO_2, Al_2O_3, CuO) Nanofluids on the thermal and flow fields.
3. To analyze the effect of different Reynolds numbers Re in the range of (10000, 20000, 30000, 40000 and 50000) on the thermal and flow fields.

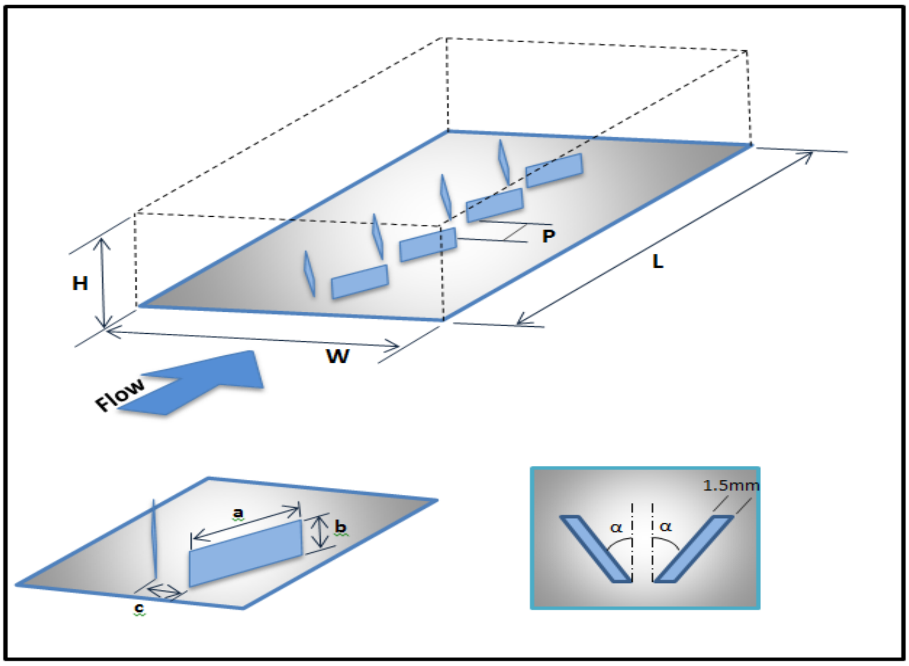

Figure1-4. A duct with winglets.

1.5 Scope of study

Scope of this research is numerical studies of enhance heat transfer in channel with winglets and nanofluid. This work can be summarized as follows:

1. This numerically study 3D using ANSYS software.

2. The study model, rectangular duct with winglets fixed on upper and lower from surfaces Duct.

3. Use different type of nanofluid (water+SiO_2), (water + Al_2O_3) and (water + CuO) as fluid the coolant, the concentration nanoparticles, (4%) and the diameter of all nanoparticles, dp is (30 nm).

4. The using difference Reynolds numbers (10000, 20000, 30000, 40000 and 50000).

5. The using difference winglets angles are (α=10^{o}, 20^{o} and 30^{o}).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Enhanced convective heat transfer in heat exchanger by passive techniques has been a subject of interest for scientists and researchers in the past decades. Numerical and experimental studies have been reported in order to increase the amount of heat transferred by these techniques. Literature reviews on passive techniques of heat transfer augmentation focuses on different types of winglet in different application. The needs to reduce the cost, dimensions and save energy for heat exchanger have stimulated the search for various techniques of heat transfer enhancement. Present work is carried out using one of the passive heat transfer augmentation techniques which is winglet. Different types of inserts have been evaluated and examined by various investigators in order to enhance the heat transfer rates in duct. Figure 2.1 display different types of longitudinal vortex generators.

The thermo hydraulic performance of an insert is determined with reference to its ability to enhance the heat transfer coefficient with a minimum increase in friction factor. Heat exchanger channel with winglets inserts have been used for many years as reliable means for heat transfer enhancement and fouling mitigation in petroleum refineries and chemical plants.

In this chapter, the literature reviews are classified into:

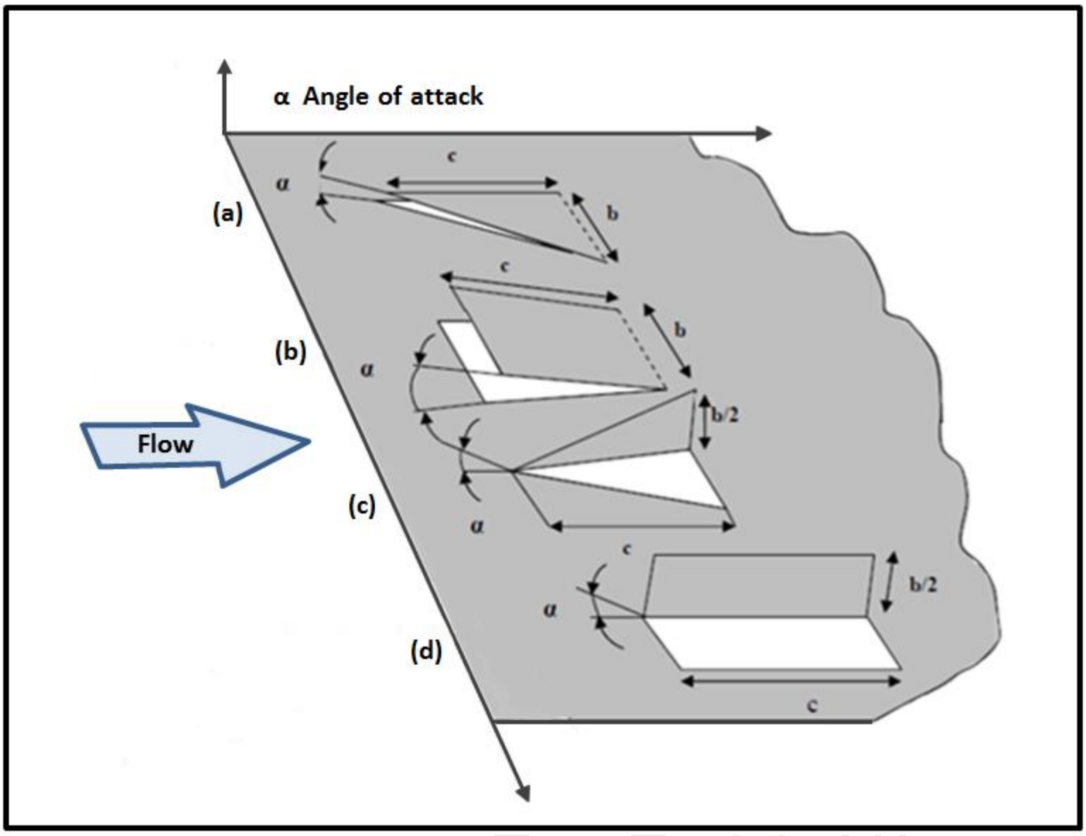

Figure 2.1. Longitudinal vortex generators types; (a) delta wing, (b) rectangular wing, (c) delta winglet pair and (d) rectangular winglet pair [9].

2.2 Applications of winglet vortex generator

There are different types of winglets were used in many application such as the solar heater water, heat exchanger and refrigeration system. Experiments on enhancement of heat transfer in a tube with using winglets have been widely reported.

Ahmed et al. Studied the effect of vortex generator in a triangular duct on heat transfer enhancement of laminar nanofluids flow. Two dimensional laminar flow of different nanofluids flow inside a triangular duct with the existence of vortex generator was investigated numerically. The governing equations of mass, momentum and energy were solved using the finite volume method (FVM). The effects of type of the nanoparticles, particle concentrations, and Reynolds number on the heat transfer coefficient and pressure drop of nanofluids were examined.

Reynolds numbers were ranged from 100 to 800. A constant surface temperature was assumed to be the thermal condition for the upper and lower heated walls. Three nanofluids were examined which were Al_2O_3, CuO and SiO_2 suspended in the base fluid of ethylene glycol (EG) with nanoparticles concentrations ranged from 1 to 6%. From the results it was clearly found that the result the average Nusselt number increased with increasing Reynolds number. The Nusselt number was remarkably increased by using nanofluids. It was observed that the Nusselt number is slightly affected by the type of nanofluid. The nanofluid of CuO –EG gave the best heat transfer performance compared to other nanofluids. It was clearly also noted that there was no change in friction coefficient when different types of nanofluids were used [10].

2.2.1 Winglets in Circular tube

Eiamsa-ard and Promvonge. Studied experimentally the heat transfer and friction behaviors of turbulent tube flow through a straight tape with double-sided delta wings (T-W). They used the T-W formed on the tape as vortex generators for enhancing the heat transfer coefficient by breakdown of thermal boundary layer and by mixing of fluid flow in tubes. The T-W characteristics were (1) T-W with forward/backward-wing arrangement, (2) T-W with alternate axis (T-WA), (3) three wing-width ratios and (4) wing-pitch ratios. The experimental result showed that the using of the T-W, led to increase the Nusselt number (Nu) and friction factor were, respectively, up to 165% and 14.8 times of the plain tube and the maximum thermal performance factor was 1.19. It was also obvious that the T-W with forward-wing gave higher heat transfer rate than one with backward-wing around 7%. It was also found that the heat transfer rate and friction factor obtained from the T-WA was higher than that from the T-W [11].

2.2.2 Winglets in channel or duct

Zhao et al, studied numerically the heat transfer and erosion characteristics to improve heat transfer performance and reduce erosion of economizers in coal-fired power plants for the single H-type finned oval tube with enhanced heat transfer structures including bleeding dimples, longitudinal vortex generators (LVGs), and compound dimple-(LVG).

From the results, it can be noted that the oval tube with compound LVG-dimple enquired the highest heat transfer performance while the oval tube with LVG worked most efficiently in the anti-wear performance. Then based on the H-type finned oval tube, the LVG structure on the first row of tubes together with hemisphere protrusions design, while the compound LVG-dimple on the rest tubes were also simulated. The optimized H-type finned oval tube bank heat exchanger was demonstrated of high performance on both heat transfer and anti-wear [12].

Hatami et al, studied experimentally the use of a vortex generator heat exchanger to recover exergy from the exhaust of an OM314 diesel engine. Twenty vortex generators with 30_ angle of attack were tested to increase the heat recovery as well as the low back pressure in the exhaust. The experiments were prepared for five engine loads (0, 20, 40, 60 and 80% of full load), two exhaust gases amount (50 and 100%) and four water mass flow rate (50, 40, 30 and 20 g/s).

The results showed that the engine was a stationary engine and worked in 1500 rpm, a three way valve were mounted before HEX. Increasing the engine load was led to increase heat transfer and exhaust gases amount due to higher gases temperature in the higher engine loads. The minimum heat recovery was occurred in lower water mass flow rate around 20 g/s. It can be seen that that larger amount of exhaust gases could improved the exergy recovery due to its ability to transfer more heat to the water. pressure drops higher than 5-10 kPa for the engine made a destructive effect on the engine performance due to produced back pressure, the HEX had acceptable pressure drops without effect on the engine performance. Variations of total irreversibility's versus engine loads and water mass flow rate were presented and in all cases, irreversibility increased by increasing the engine loads [13].

Wang et al, examined the air side performance of the fin-and-tube heat exchangers having semi dimple vortex generator or plain fin geometry. Eight samples were made and tested with the corresponding fin pitch (Fp) being 1.6 mm and 2.0 mm and the number of tube row (N) were 1 and 2. The inlet air flow direction was also being examined upon the proposed semi-dimple (VG).

From the results, it can be noticed that the heat transfer performance of the proposed semi-dimple VG with N = 1 at a smaller fin pitch of 1.6 mm was slightly higher than that of plain fin geometry. For N = 1 with a larger fin pitch of 2.0 mm, the semi-dimple (VG) was about 10% higher than that of plain fin geometry. The difference in heat transfer performance amid (VG) and plain fin geometry became more pronounced with N = 2 and was especially evident when Fp =2.0 mm due to mixing contribution. Both geometries showed a dependence on fin pitch at N =1 but the effect was almost negligible when N was increased to 2. The inlet air flow direction casts negligible influence on the heat transfer performance of semi-dimple (VG). Moreover, the friction factors for the opposite air flow operation was lower than that of normal operation, especially in low Reynolds number region [14].

Shi et al, studied numerically the heat transfer enhancement of channel via vortex-induced vibration. Thermal diffusion was considered as a barrier for enhancing the heat transfer rate of air-cooled heat sinks, a passive method using vortex-induced vibration (VIV) was introduced to disrupt the thermal boundary layer and increasing the heat transfer rate. Four different channels were studied: a clean channel, a channel with a stationary cylinder, a channel with a stationary cylinder and plate, and a channel with a stationary cylinder and a flexible plate. These channels were analyzed in terms of the vortex dynamics, disruption of the thermal boundary layer, local and average Nusselt numbers, and pressure loss. A cylinder with a flexible plate was placed in a clean channel; the vortex shedding due to the cylinder rising the vibration of the plate downstream. The consequent flow-structure-interaction (FSI) stiffens the disruption of the thermal boundary layer by vortex interaction with the walls, and enhanced the mixing process. This novel concept was explained by a two-dimensional modeling study at Re = 204.8, 245.7, 286.7, 327.7, and two inlet temperature profiles. The results showed that the VIV could dramatically increase the average Nusselt (Nu) number, with a maximum improvement of 90.1% over that of a clean channel [15].

Hsiao et al, conducted a numerical study on the heat transfer enhancement technique based on longitudinal vortex generators (LVGs) for large-scale heat exchangers. Motivated by the success of the LVGs, a micro mixers based on the T-shaped channel with rectangular winglet pairs (RWPs) mounted on the bottom of the main channel was investigated. The RWPs remained with an angle of attack to the main flow direction and generate longitudinal vortices to enhance fluid mixing. The effects of geometrical parameters on the performance of micromixers with micro-scale LVGs were investigated by numerical simulations and the Taguchi method. A comparison between the numerical simulations and experimental results was examined. From the results it can be cleared that the mixing efficiency of the micromixer with divergent RWPs was greater than that of the micromixer without RWPs for convection-dominant cases as well as diffusion-dominant cases. A static Taguchi analysis showed that the relative effectiveness of the geometrical parameters was ranked as: asymmetry index ,angle of attack ,winglet height and winglet spacing. A best parameter group on the parameter selected range had been gotten based on the relative influence of the geometric parameters [16].

Cheraghi et al, investigated numerically the heat-transfer enhancement in a uniformly heated slot mini-channel due to vortices shed from an adiabatic circular cylinder. The effects of gap spacing between the cylinder and bottom wall on wall heat transfer and pressure drop were systemically studied. Numerical simulations were performed at Re=100, $0.1 \leq Pr \leq 10$ and a blockage ratio of D/H=1/3. From the Results, it can be seen that the thermally developing flow region showed heat transfer augmentation compared to the plane channel. It was noticed that the maximum heat transfer improvement from channel walls was got when the hurdle was placed in the middle of the duct. Displacement of circular cylinder towards the bottom wall led to the suppression of the vortex shedding, the establishment of a steady flow and a reduction of both wall heat transfer and pressure drop. Performance analysis indicated that the proposed heat transfer enhancement mechanism was beneficial for low-Prandtl-number fluids [17].

Xia et al, studied numerically A three-dimensional DDF-MRT-LBE (double distribution function multi-relaxation-time lattice Boltzmann equation) in order to study the flow and heat transfer in dimple heat exchangers. Results were obtained for periodically fully-developed laminar flow in parallel-plate channels with spherical dimples symmetrically opposing onto both walls. Both the heat transfer and flow resistance were discussed. Furthermore, to enhance the heat transfer with low pressure penalty, a small crescent-shape protrusion was added as a LVG (longitudinal vortex generator). And a grooved LVG was developed to reduce the drop loss caused by the crescent-shape protrusion. The streamline contours, isotherms, Nusselt numbers and friction coefficients at various Reynolds numbers were presented. The results showed that the thermal performance of the LVG cases was higher than that of the dimple cases with similar flow characteristics. Moreover, from the viewpoint of energy saving, LVG cases perform was better than the dimple cases [18].

Bali and Sarac, examined experimentally the heat transfer and pressure drop characteristics of a decaying swirl flow in a horizontal pipe. The decaying swirl flow was produced by the insertion of vortex generators with propeller-type geometry, a kind of passive heat enhancement tools. Two different cases were comparatively investigated one propeller case and two-propeller case. In the one-propeller case, the first propeller was placed at the entrance of the flow. In the two-propeller case, the second was placed at a specific distance where the swirl effect generated by the first propeller was decayed. The effects of the joint angle about the core of the insert device and the number of the joint vanes attached circumferentially to the device on heat transfer and pressure drop were investigated for both cases. Reynolds numbers rate was between 5000 and 30,000. The results of experiment work showed that the usage of a second vortex generator at a position where the effect of the first one diminishes enhanced heat transfer significantly. While, for the four joint vanes with the15°-joint angle at Re= 5000, Nu had dramatically increase and reach to 190.1% for Case B according the smooth pipe comparing to case a when the increase was only 93.83% [19].

Gholami et al, studied numerically the heat transfer enhancement and pressure loss penalty for fin-and-tube compact heat exchangers with the wavy-up and wavy-down rectangular winglets as special forms of winglet. The rectangular winglets were used with a particular wavy form for the purpose of enhancement of air side heat transfer performance of fin-and-tube compact heat exchangers. The effect of Reynolds numbers from 400 to 800 and angle of attack of 30° of wavy rectangular winglets were also investigated. The effects of using the wavy rectangular winglet, conventional rectangular winglet configuration and without winglet as baseline configuration, on the heat transfer characteristics and flow structure were analyzed in detail for the inline tube arrangements.

The numerical results showed that the wavy rectangular winglet can significantly enhanced the heat transfer behavior of the fin-and-tube compact heat exchangers with a moderate pressure loss penalty. The wavy winglet cases had huge effect on the heat transfer performance, this increment was more important for the case of the wavy-up rectangular winglet configuration [20].

Chen et al, studied experimentally the frictional pressure drop and heat transfer performance of de-ionized water flowing through rectangular micro channels having longitudinal vortex generators (LVGs). The experimental investigation was conducted under three-sided constant wall temperature boundary condition for the Reynolds numbers rat from 350 to 1500 for LVGs with different number of pairs and dimensions. The aspect ratios of rectangular micro channels were 0.25 and 0.0667, and the corresponding hydraulic diameters were 160 lm and 187.5 lm, respectively. The heights of associated LVGs were 1/4H, 3/4H and H, respectively, where H was the height of microchannel.

The experiment results showed that the heat transfer performance was enhanced by 12.3–73.8% and 3.4–45.4% for microchannels with aspect ratios of 0.0667 and 0.25, respectively, while the pressure losses were increased by 40.3–158.6% and 6.5–47.7%, respectively; and the overall heat transfer performances of some specific micro channels were more than 1 in our study. With the help of LVGs, the critical Reynolds numbers were lower than1000, which were smaller than the generally accepted value of 2300 for regular channel flow [21].

Caliskan et al, investigated experimentally the heat transfer in a channel with new winglet-type vortex generators. Both new punched triangular vortex generators (PTVGs) and punched rectangular vortex generators (PRVGs) were developed. Both the triangular and rectangular vortex generators were directly punched from the longitudinal winglet at attack angles of 15, 45 and 75 respectively. Measurements were carried out for a rectangular channel of an aspect ratio of AR = 2, for a winglet transverse pitch (S) to a longitudinal winglet height (e) ratio of S/e = 0.59, and a winglet height (e) to a channel height (H) ratio of e/H = 0.6. The parameters included the location of the punched vortex generator on the longitudinal winglet, the geometric shapes of the punched vortex generators, and the attached angle of punched vortex generators. The Reynolds numbers considered for the channel flow case ranged from 3288 to 37,817.

The heat transfer results were obtained using the infrared thermal imaging technique. The heat transfer results of the vortex generators were compared with those of a smooth plate. The best heat transfer performance was obtained with the PTVGs. The presence of the vortex generators produced higher heat transfer coefficients than the smooth plate surfaces. Correlations were developed for the averaged Nusselt number for the PTVGs and PRVGs. Results revealed that a 23–55% increase in heat transfer due to the use of vortex generators. The vortex generators showed a high increase in heat transfer coefficient for channel flows [22].

Li et al, investigated numerically the heat transfer and pressure performance of a plain fin with radiantly arranged winglets around each tube in fin-and-tube heat transfer surface. A radiantly arranged LVGs enhanced fin-and-tube structure was studied to enhance air side heat transfer. The arrangement of LVGs was totally different from existing publications. There were 12 winglets around each tube. The attack angles were 50, 50, 50, 50, 70 and 110 respectively. Heat transfer and pressure drop performance were compared with other three structures: an arc-shaped wavy fin-and-tube surface, a common-flow down LVGs enhanced fin-and-tube surface and a plain plate fin-and-tube surface.

The results revealed that the 12 winglets form five local passages which can guide the moving fluid from the main flow to the tube wall, leading to some impinging effect or reducing the wake region behind the tube. It was noticed that the proposed radiantly arranged LVGs enhanced fin -and- tube surface was the best. The field synergy principle was adopted to analyze the four structures and it was found that the domain averaged synergy angle of the proposed radiantly arranged LVGs enhanced structure was significantly less than that of other three cases. From the final results it was clearly seen that the proposed structure of five tubes could replace the wavy structure of six tubes [23].

Akcayoglu. Studied experimentally the flow structure in horizontal equilateral triangular ducts with double rows of half delta-wing type vortex generators. Each duct consisted of double rows of half delta wing pairs arranged either in common flow up or common flow-down configurations. Reynolds numbers were varied from 1000 to 8000. The secondary flow field differences generated by two different vortex generator configurations were examined in detail. The secondary flow was found stronger behind the second vortex generator pair than behind the first pair but becomes weaker far from the second pair in the case of Duct1 [24].

Chompookham et al. Investigated experimentally the heat transfer augmentation in a wedge-ribbed channel using winglet vortex generators. They studied the effect of combined wedge ribs and winglet type vortex generators (WVGs) on heat transfer and friction loss behaviors for turbulent airflow through a constant heat flux channel. In order to create a reverse flow in the channel, two types of wedge (right-triangle) ribs were used: wedge ribs pointing downstream and pointing upstream. The arrangements of both rib types placed inside the opposite channel walls were in-line and staggered arrays. The Reynolds numbers were ranging from 5000 to 22,000.From the result, the combined ribs and the WVGs showed that the significant increase in heat transfer rate and friction loss over the smooth channel. The Nusselt number and friction factor values obtained from combined the ribs and the WVGs were found higher than those from the ribs/ WVGs alone [25].

Colleoni et al. Examined numerically the effect of winglet vortex generators combined with rib lets for wall/fluid heat exchange on the thermal performance of fluid in heat exchanger. Industrial heat exchangers such as solar receivers often have asymmetrical heating. The forced internal convective heat transfer and friction loss behaviors were studied for turbulent flows promoted by a combination of delta winglet vortex generators (DWVG) and rib lets. The use of such a combination of devices maximizes the efficiency of the channel heat exchanger. The efficiency is characterized by two criteria: one based on the turbulent kinetic energy and another one based on the Nusselt number and the friction coefficient. The comparison of those two criteria allows separating the heat transfer intensification due to turbulence and exchange surface enhancement. Several heights of DWVGs and various sizes and shapes of downstream rib lets were simulated using a Reynolds Averaged Naviere Stokes (RANS) approach. From the results, it was clearly found that the bigger and thinner rib lets provided the best thermal performance [26].

Ferrouillat et al. Presented Numerical simulations of vortex generators with advanced turbulence models. They studied the turbulent flow, heat transfer and the mixing ability of compact heat-exchanger geometries. Steady RANS and unsteady large eddy simulation turbulence models, time averaged results were obtained. For the two vortex generators considered here, the computations with a refined mesh gave satisfactory results: the underlying physical phenomena were described and the main geometrical parameters and their effect on turbulence were identified. The results showed that delta winglet pairs (DWP) was more efficient than Rectangular winglet pairs (RWP) in terms of compactness criterion. Heat transfer and mixing efficiencies were optimum when distances between VG rows were around 7–10 times the channel heights. Different numerical models were tested and LES models were validated for a wide range of Reynolds numbers and angles of attack [27].

Kotcioglu et al. Investigated experimentally the effect of winglets in a rectangular duct with plate-fins heat exchanger. This study presented the determination of optimum values of the design parameters in a heat exchanger with a rectangular duct. The experimental investigation for the established heat exchanger involves short rectangular fins attached in 8x8 arrays to a surface having various inclination angles. The effects of the six design parameters such as the ratio of the duct channel width to height, the ratio of the winglets length to the duct channel length, inclination angles of winglets, Reynolds number, flow velocity and pressure drop are investigated. From the results of flow visualization, the mixing effect of secondary flows was found in the intermediate region between wing cascades. This was due to the pressure and velocity differences across the passage between the converging and diverging pairs of fins. The heat transfer was high around the fin rows for diverging and converging fin patterns. The heat transfer in the region between fins in the span wise direction is also enhanced due to lateral mixing and secondary flow. The inclination angle of fins has a great influence on the heat transfer enhancement. The maximum enhancement in the heat transfer was found with the inclination angle of 20° [28].

Min et al. Analyzed numerically the effects of novel longitudinal vortex generators on turbulent flow and heat transfer in a channel. A novel combined longitudinal vortex generator (LVG), comprising a rectangular wing mounted with an accessory rectangular wing. The influences of six main parameters of the combined rectangular winglet pair (CRWP) on heat transfer enhancement and fluid flow resistance characteristics in a rectangular channel were examined. The parameters include the location of accessory wing on the main wing and geometric sizes of the accessory wing. The Reynolds number was varied from 2000 to 16,000. The numerical results showed that the pressure drop decreases at large value of the distance of accessory wing from the channel bottom. In comparison with Rectangular winglet pair RWP, the CRWP generates vortices with larger area and lower core. Furthermore, the accessory wings generated vortices that swirl downward the channel bottom and disturb the boundary layer growth more effectively. Hence the heat transfer was enhanced [29].

Promvonge et al. Investigated experimentally the effect of longitudinal vortex generators on heat transfer enhancement in a triangular ribbed channel. They studied the Effects of combined ribs and winglet type vortex generators (WVGs) on forced convection heat transfer and friction loss behaviors for turbulent airflow through a constant heat flux channel. The cross-section of the ribs placed inside the opposite channel walls to create a reverse flow was an isosceles triangle shape. Two rib arrangements, namely, in-line and staggered arrays, were introduced. The Reynolds numbers based on the inlet hydraulic diameter of the channel was varied from 5000 to 22,000. The experimental results showed a significant effect of the presence of the rib turbulator and the WVGs on the heat transfer rate and friction loss over the smooth wall channel. The values of Nusselt number and friction factor for utilizing both the rib and the WVGs were found to be considerably higher than those for using the rib or the WVGs alone. The larger the attack angle value led to higher heat transfer and friction loss than the lower one. In common with the WVGs, the in-line rib yields the highest increase in both the Nusselt number and the friction factor but the rib with staggered array shows better thermal performance than the others [30].

Promvonge et al. Studied experimentally the effects of combined ribs and delta-winglet type vortex generators (DWs) on forced convection heat transfer and friction loss behaviors for turbulent airflow through a solar air heater channel. Measurements were carried out in the rectangular channel of aspect ratio, AR=10 and height, H=30 mm. The flow rate was presented in the form of Reynolds numbers based on the inlet hydraulic diameter of the channel ranging from 5000 to 22,000.

The cross-section shape of the rib placed on the absorber plate to create a reverse-flow was an isosceles triangle with a single rib height, E/H=0.2 and rib pitch, Pl/H=1.33. Ten pairs of the DW with its height, B/H=0.4; transverse pitch, Pt/H=1 and three attack angles (α) of 60°, 45° and 30° were introduced and mounted on the lower plate entrance of the tested channel to generated longitudinal vortex flows. The experimental results showed that the Nusselt number and friction factor values for combined rib and delta-winglet (DW) were found to be much higher than those for the rib/DW alone. The larger attack angle of the delta-winglet (DW) led to higher heat transfer and friction loss than the lower one. In common with the rib, the delta-winglet (DW) pointing upstream (PU-DW) was found to give higher heat transfer rate and friction loss than the DW pointing downstream (PD-DW) at a similar operating condition [31].

Zhou et al. Carried out experimental investigations of thermal and flow characteristics of curved trapezoidal winglet type vortex generators. The performance of a pair of new vortex generators e curved trapezoidal winglet (CTW) had been experimentally investigated and compared with traditional vortex generators e rectangular winglet, trapezoidal winglet and delta winglet using different dimensionless factors. The results showed that delta winglet pair was the best in laminar and transitional flow region, while curved trapezoidal winglet pair (CTWP) had the best thermo hydraulic performance in fully turbulent region due to the streamlined configuration and then the low pressure drop, which indicates the advantages of using this kind of vortex generators for heat transfer enhancement. Double rows of CTWP did not show better thermo -hydraulic performance due to the larger pressure drop and the spacing between the two rows of CTWP should also be optimized [32].

2.2.3 Swirl Flow Devices Insert

Eiamsa-ard and Promvonge. Studied experimentally the influence of helical tapes inserted in tube on the heat transfer enhancement. The range of Reynolds number (Re) of flow air in the tube was between (2300 and 8800).The experimental studied showed that the effect of the full-length helical tape insert with and without centered-rod. It was noted that the tube fitted with the tape provided higher heat transfer rate than the plain tube. The Nusselt number increased about 165% with used full-length helical tape insert because the swirl and pressure gradient in the radial direction. The experimental results showed that the full-length helical tape with rod provided higher heat transfer rate than that without rod. The average heat transfer rate with used the tape and rod was found 5-10% better than that for the tape without rod. It was noted that the mean Nusselt number increased in heat exchanger was about 145% to 165% with and without rod, respectively. It was observed that pressure drop in full- length helical tape insert decreased at low values of Reynolds number (Re) and increased at high values of Reynolds number (Re). It was clearly noted that the used small value of space ratio(s) gave a higher heat transfer rate than that large value of space ratio (s). It was found that the large pressure drop occurred from the full-length helical tape insert [33].

Suresh et al. Studied experimentally a comparison of thermal performance of helical screw tape inserts in laminar flow of Al_2O_3/water and CuO/water Nanofluids through a straight circular duct with constant heat flux boundary condition. They studied the effect of insertion of helical screw tape inserts on pressure drop. It was noted that the average increased of pressure drop due to the addition of alumina and copper oxide nanoparticles were 3.12% and 4.21%, respectively without inserts. But the average of pressure drop was increased very high with the insertion of helical screw tape inserts in the test section. The average values of friction factors of Al_2O_3/water nanofluids for the inserts with twist ratios 1.78, 2.44 and 3 were found to be 18.0, 14.09 and 12.33 times the friction factor in the case of plain tube in laminar flow with water as the fluid. It was clearly noted that the used of the helical screw-tape inserts gave a very high friction factor than plain tube for both Al_2O_3/water and CuO/water Nanofluids .It was also found the friction factor increased with decreased in twist ratio. It was noted that the thermal performance factor at a peclet number the increased with decreased twist ratio. The greater enhancement when used CuO/water Nanofluids compared to Al_2O_3/water nanofluids. The insertion of helical screw tape inserts caused very high enhancement in the laminar flow of both Nanofluids [34].

Ameel et al. Examined numerically the Interaction effects between parameters in a vortex generator and louvered fin compact heat exchanger. The louver angle and the angle of attack of the vortex generator were impacted on the performance of the design. The fin geometry was enhanced by performing numerical simulations for different values. A full factorial analysis was done to resolve all interaction effects. It was shown that there were important interactions between the aspect ratio of the VG, the height of the VG and the louver angle. The friction factor and the VG-1 performance evaluation criterion (PEC) were mapped. From the result it was found that the fin pitch was by far the most important parameter. Varying the louver angle, VG aspect ratio, the VG height ratio or the VG angle of attack results in a change of the VG-1 PEC of between 0% and 3.5%, was depending on the interaction with other parameters [35].

Xuehong et al. Conducted a Numerical simulation of heat transfer and fluid flow characteristics of composite fin. The composite fin was presented based on the advantage of longitudinal vortex generator and slit fin, respectively. The performance of air-side heat transfer and fluid flow were investigated. The Reynolds number was ranging from 304 to 2130. Stepwise approximation method was applied on the mesh generation for the irregular domains of delta winglets and slit fins. The mechanism for augmenting heat transfer was also analyzed based on the local fluid field, field synergy principle and entransy dissipation principle.

The results showed that some eddies were developed behind the X-shaped slit and delta winglet, which produced some disruptions to fluid flow and enhanced heat transfer; compared with plain fin and slit fin, it was found that the composite fin had better heat transfer performance. The results of numerical simulation revealed that composite fin can improved the synergy of temperature gradient and velocity fields, and its equivalent thermal resistance was smaller and its irreversibility of heat transfer was lower [36].

Guo et al. Investigated numerically the laminar forced convective heat transfer for getting the best heat transfer performance with the least flow resistance increase. The variation calculus method was employed and numerical solutions of the equations for a convective heat transfer process were studied. The heat transfer and flow resistance characteristics of laminar flows in tubes with four-reverse-vortex-generator (FRVG) inserts, four-homodromous-vortex generator (FHVG) inserts, or a twisted tape insert were numerically studied. The calculated transverse secondary flow in the tube with the FRVG inserts approximately followed the optimized flow pattern and the tube was thus found to have the best thermo-hydraulic performance, validating the proposed convective heat transfer enhancement method [37].

Wuu Perng et al. Studied numerically the heat transfer augmentation and vortex-induced vibration in a block-heated channel. The finite element method was used to solve the general Darcy-Brinkman-Forchheimer model and energy equation for the heat transfer increase and vortex-induced vibration from the square vortex generator wrapped by a porous sheath in the block-heated channel. The heat transfer increase and vortex-induced vibration were investigated by varying Darcy number, porosity, porous sheath thickness, and Reynolds number.

As a result, it was clearly noticed that when Reynolds number and porous sheath thickness was increased, the heat transfer augmentation and vortex-induced vibration was increased too. Nevertheless, the porosity had minor impact on the heat transfer augmentation and vortex-induced vibration. As Darcy number equals 10^{-4} a small vortex-generator wrapped with a porous sheath of EP/w = 0.125 best increasing in heat transfer from the heated-block surfaces with a reduction of 53.94% in vortex-induced vibration [38].

Aliabadi et al. Examined experimentally a comparative evaluation of seven common configurations of channels used in plate-fin heat exchangers. All the channels, including plain, perforated, offset strip, louvered, wavy, vortex-generator, and pin, were tested. Water was the working fluid and Reynolds number was ranging from 480 - 3770. Three mostly used energy-based performance evaluation criteria were employed for evaluating the performance of the channels and selecting the best plate-fin channel.

From The results it was found that the vortex-generator channel showed an important improvement in the heat transfer coefficient and a proper reduction in the heat exchanger surface area. The results also showed that the wavy channel displayed the best performance at low Reynolds numbers [39].

Tamna et al. Studied experimentally and numerically the heat transfer augmentation in a solar air heater channel fitted with multiple V-baffle vortex

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