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Augmentation of Convective Heat Transfer through various practices: A Review

[1] Kushal Saxena, [2]Vikrant Mishra, [3]Y.S. Rajpoot, [4]Desh Deepak

[1][2][3][4] Department of Mechanical Engg., Rajkiya Engineering College, Mainpuri, UP, India
[1] saxenakushal05@gmail.com

Abstract— In case of various heat transfer applications, there is a necessity for proper utilization of energy sources. In the previous decades, various practices have been taken into consideration for the enhancement of heat transfer. We can categorize these practices in three types – active, passive and compound practices. All or any individual of these techniques have been applied in many heat exchanger application such as in thermal power plants, automobile sector, process industries, air-conditioning apparatus and chemical industries. This paper is an overview of several methods for the augmentation of heat transfer process and parameters. In most of the methods, the work was focused on increasing the surface area of the heat exchanger or on increasing turbulence using some inserts within the heat exchanger. The later part of this manuscript also depicts heat transfer augmentation using Nano-fluids.

Index Terms— Heat Transfer Enhancement, Heat Exchanger, Turbulence, Inserts

I. INTRODUCTION

Heat transfer enhancement techniques symbolize the various methods used to improve the performance of heat transfer in the system. These methods are of wide importance in the arena of thermal and fluid engineering. Various industries working in the sector of heating ventilation and air conditioning (HVAC), automobiles, thermal power plants are continuously striving to develop solutions to enhance the performance of heat transfer of the systems. All the equipment used in the daily world either in the research laboratories or process industries are increasing the amount of heat which must be transferred in order to save the components from metallurgical and other different point of views. The present work is based on compiling reviews of different experimental as well as computational work performed for the amplification of heat transfer performances.

Heat exchangers are extensively used in various engineering and industrial applications. Heat exchanger design is an important aspect to attain a desired rate of heat transfer. In recent years, three types of heat transfer augmentation techniques have been proposed – passive, active and compound techniques. There is a need of external power input which is not easy to supply in several application in case of active techniques. Also active techniques for heat transfer enhancement have not shown better potential due to complex design of heat exchanger.

In case of passive techniques, any external power input is not required apart from moving the fluid through heat exchanger. Various types of inserts are provided in the heat exchangers to offer more heat transfer area. Some of those inserts are helical/twisted tapes [1, 2], coiled wires [3–5], ribs/fins/baffles [6–8], and winglets [9, 10].In Compound techniques of heat transfer enhancement, two or more techniques are employed simultaneously noting that they offer a more value of heat transfer coefficient than any of the techniques acting alone [11, 12].

In the following sections, passive techniques of heat transfer augmentation are reviewed. Various inserts are employed inside the heat exchanger to make it effective.

II. HEAT TRANSFER AUGMENTATION USING INSERTS/FINS

Govindani P. Sanjay et al. presented an experimental work to investigate the consequences of turbulence in the process of heat transfer. In the analysis a new type of insert (Rotor strand) was used to generate turbulence in the flow of water as a fluid. The thermal hydraulic performance parameters were evaluated to analyze the new type of insert. Mean value of Nusselt number and friction factor were calculated based on the thermal fluid analysis of the system. Experiments were led in a smooth pipe as well as a pipe with the rotor strand and the results were compared to analyze the performance. Results concluded that the rate of heat transfer as well as friction factor got increased for the pipe with new type of insert as compared to the smooth wall [13].

Jamra Sunil et al. performed an experimental investigation to analyze the performance of rectangular inserts in the process of heat transfer amplification. In the analysis experiments were led in a double pipe heat exchanger with hot water and air as working fluids. Various parameter including friction factor and Nusselt number were evaluated. The results obtained for rectangular inserts were compared with the smooth pipe and it was revealed that the heat transfer coefficient increases about 0.9-1.9 times whereas friction factor increases by 0.7-1.7 times from the smooth pipe [14].

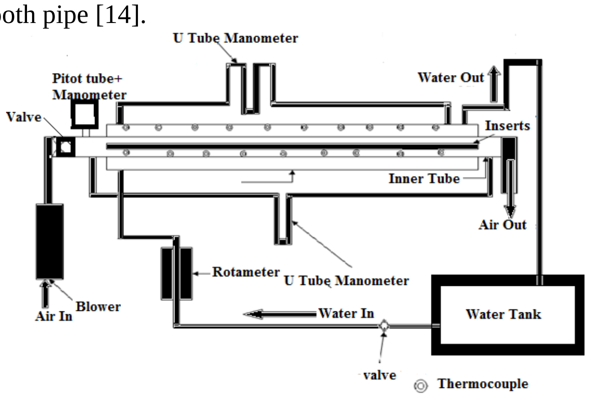


Fig. 1. Experimental set up [14]

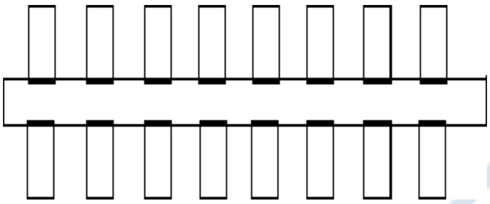


Fig. 2. Rectangular Inserts [14]

Sawarkar A. Pawan et al. carried out a research to examine the effect of turbulence in the convective heat transfer. A cylindrical test section was employed with water as the working-fluid. Twisted tape insertions were provided to enhance the heat transfer performance. Plain twisted tape and twisted tape with semicircular cuts were employed in the test and results of Nusselt number and friction factors were compared. The Reynolds number (Re) was altered according to the flow conditions. The results of the research revealed the augmentation of the thermal hydraulic performance due to increased values of the parameters. The various type of inserts lead to thinning of boundary and increased turbulence and mixing in the flow which leads to increased heat transfer in the test section [15].

Manwatkar Shubhangi et al. accomplished an experimental and statistical study to examine the effect of V – nozzle turbulators on the thermal hydraulic performance. Experiments were performed in a copper-made tube section fitted with the V – nozzle turbulators with air as the working fluid. The results obtained for Nusselt number and friction factors were equated with those of the plain smooth tube. The investigation revealed that a major increase of 107% was attained in the heat transfer rate due to V – nozzle turbulators as compared to the plain smooth test section [16].

Sivakumar K et al. completed a computational study of heat transfer enhancement using twisted tape insertions of different twist ratios in a circular tube using water as the working substances. Experimental analysis of enhancement of heat transfer including parameters such as heat transfer coefficients, Nusselt number and friction characteristics were carried out in case of circular pipebuilt-in with twisted tape insertions. A major increment was found as compared to a plain smooth tube due to swirling flow action and turbulence created due to the insertions [17].

Kailash Pramod Ojha et al. performed experiments for heat exchangers with and without fins, involving hot and cold fluids, different flow rates of hot and cold water. Various thermal hydraulic performance parameters including Nusselt number, pressure drop, friction factor etc. were evaluated. Fins were welded over the tubes with the help of gas welding. Several fins were applied over the tube at certain distances. The results of the experimental investigation concluded that an increase in heat transfer performance takes place due to the fins because of turbulence created in the flow. The Nusselt number, heat transfer coefficients and friction factors were found to be increased with the Reynolds number [18].

Patil S. Avinash et al. performed an experimental analysis in case of a divergent duct with extended surfaces such as bumps, ribs, and fins etc. to analyze the heat transfer performance. Computational analysis was also performed along with the experimental observation. Different contours of temperature distribution were plotted for increasing Reynolds number through CFD. The experimental as well as computational analysis depicted that the heat transfer coefficient increased by 25% to 35% in case of divergent duct with extended internal surfaces such as bumps, fins and ribs etc. due to increased mixing and turbulence created by the bumps. The observations were compared for a divergent channel with extended surfaces were compared with the divergent channel without extended surfaces which explains the advantage of heat transfer enhancement due to increased mixing and turbulence created in the fluid flow over the heated channel [19].

Ahire V. Durgesh et al. investigated the heat transfer performance in a circular pipe using conical inserts of two different materials copper and aluminum. Reynolds number was varied from 6700 to 13000. The heat transfer performance of the copper and aluminum inserts were compared for 30 mm pitch, 3 mm thick and 50 mm pitch, 4 mm thick. In case of aluminum, 50 mm pitch and 4 mm thickness Nusselt number was higher than 30 mm pitch and 3 mm thickness. In the case of copper 30 mm pitch and 3 mm thickness Nusselt number was higher than 50 mm pitch and 4 mm thickness. The Nusselt number was found to be higher for copper so it was considered to be optimum [20].

Ghodake R. Ganesh et al. experimentally analyzed the thermal hydraulic performance of turbulent flow in a tube fitted with screw tape. A twisted tape was used in a heated tube with a centrifugal blower attached for the forced convection heat transfer. In this work, observations were made on a plain tube as well as test section with different inserts. The thermo fluid properties were calculated and analyzed. The experimental values of Nusselt number were found approximately similar to the theoretical results. Different dimensions screw tape inserts were compared for the convective heat transfer enhancement and one with d = 3 mm was found to be the optimum [21].

Manideep R.V.K. et al. did a mathematical analysis to study the effect of corrugations in a plain circular double pipe heat exchanger. In the double pipe heat exchanger the inner pipe was twisted for corrugation through which the hot water flows whereas the cold water flows through the outside normal circular pipe. Numerical analysis was performed with the ANSYS package and results concluded to increase the convective heat transfer in the heat exchangers corrugation must be implemented as it increase the swirling flow and turbulence in the system [22].

Joshi A. Paresh et al. analyzed the effect of wavy twisted tape inserts in enhancing the heat transfer enhancement as compared to the plain smooth tube. Two different materials wavy twisted type inserts with different widths and different pitches were analyzed. The values of Nusselt number and friction factor were calculated to compare the thermal hydraulic performance and the values depicted an improvement in the heat transfer process due to the geometry of the passive technique used. The geometry induced swirling and secondary flow in the tube which produced turbulence mixing between the hot test section and the airflow to increase the contact surface area for increasing the heat transfer. The outcomes of the experimental work were found to be in good agreement with the computational work carried out using ANSYS software [23].

Patil V.S. et al. discussed the effect of swirl flow on heat transfer performance parameters inside a circular tube double pipe heat exchanger equipped with various designs of inserts and compared the performance with the plain tube. Two different pipes of PVC and copper were used in the analysis. Hot water was supplied in the PVC whereas cold water was supplied in the copper tube. Three different inserts wire type, screw type and a combination of them were used in the copper tube. The Nusselt number was determined with variation of Reynolds number in the flow. The experimental results concluded that Nusselt number increases as the Reynolds number increases for the pipe with inserts as compared to the plain pipe. The inserts with combination of coil and screw type inserts contribution was optimum to augment the heat transfer due to secondary turbulent and swirl flow created in the pipe [24].

S. Bhattacharyya et al. implemented numerical investigation of heat transfer parameters such as turbulence intensity, Nusselt number, Performance evaluation criterion and friction factor of turbulent flow in a circular channel fitted with twisted tape insertions. The numerical investigation depicted that the rate of heat transfer can be efficiently augmented using small twist ratio (= 18.0) and larger entrance angle (α = 180°). But flow resistance increases in such case due to increase in turbulence intensity [25].The outline of the channel and entrance angle is shown in the figure 3(a) and 3(b).

A.M. Abed et al. presented numerical analysis of enhancement of heat transfer rate through a horizontal tube with two types of inserts of twisted tapes. First is of V-cut type and other is Plain Twisted tape (P-TT). The simulation was done by means of the Realizable κ–ε (RKE) model. The simulation results were executed for a range of the twisted ratios 4 to 6, Reynolds number value from 4000 to 9000 and heat flux from 5000 to 10000 W/m². The results depicted that V-cut twisted tape is more effective for heat transfer augmentation in comparison of P-TT even with different values of twisted ratios (TR = 4 & TR = 6). The maximum value of thermal performance factor was found for V-cut twisted tape at Reynolds number of 9000 and twisted ratio of 4 [26].

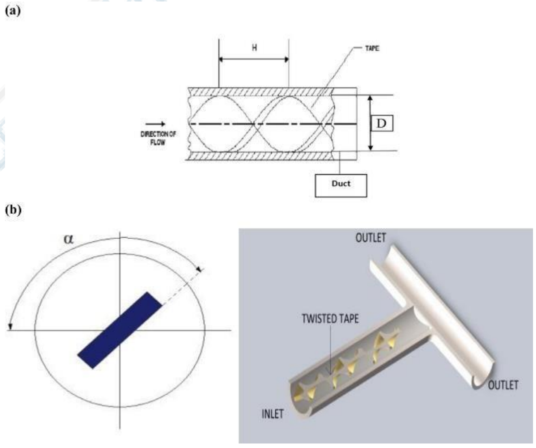
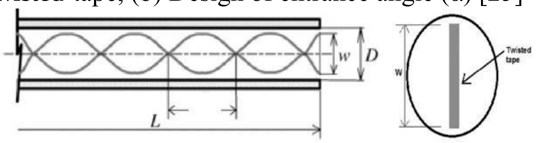


Fig. 3 (a) Outline of the circular channel comprising a twisted-tape, (b) Design of entrance angle (α) [25]



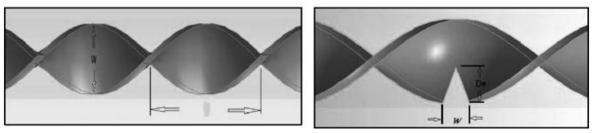


Fig. 4 (a) Geometry of flow domain (b) Typical twisted-tape (c) V-cut twisted-tape [26]

Tusar Mehedi et al. performed a numerical study with the help of ANSYS Fluent software package to explore the effects of inserts twisted ratio on the thermal performance in compare to the plain tube. For that geometry was prepared with two twist ratios 3.46 and 7.6. Air was considered to be the working cooling fluid with the Reynolds number ranging from 3600 – 22000. A constant heat flux was applied over the test section. Average Nusselt number was evaluated and results were validated using the Gneilski and Petukhob standards. It was concluded through the study that heat transfer characteristics got enhanced with the help of twisted tape inserts with an increase in friction factor. Nusselt number enhanced by 20 – 62% for twist ratio of 3.46 whereas twist ratio of 7.6 leads to an increase in 10 – 30%. Similarly friction factor also got increased 185 – 245% for twist ratio of 3.46 whereas twist ratio of 7.6 leads to an increase in 128 – 183%. [27]

Masoud Outokesh et al. with the help of ANSYS Fluent performed a numerical study to evaluate the thermal performance enhancement using curved profile as a turbulence generator. Pitch, height and curvature of the curved profile twisted tape were selected as the geometrical parameters to be varied for studying its effect on the heat transfer enhancement. Turbulence is generated in the flow by varying the velocity as per the Reynolds number ranging 2500 – 20000. A very fine mesh was generated to study the effects of the number of grid on the results. Height of the curvature was varied in 5 – 7 mm, pitch ratio in 1.5 – 15 and length in 1.5 – 5 mm. Curvature with height of 7 mm demonstrated an increase of 35% in the thermal performance than 5 mm which showed 30% increase in it. The highest thermal performance was evaluated at pitch ratio of 5 with Reynolds number 10000. The maximum thermal performance was studied at length 5 mm and minimum occurred at 1.5 mm [28].

Menni Younes et al. performed a theoretical literature survey to determine the enhancement of transfer of heat through heated channels with air as working fluid with the help of obstructions in the path of flow. In the study the working of various researchers have been compiled and presented. To study the effect of heat transfer the

parameter of interest is heat transfer coefficient and every work leads to an increase its value. Different types of passive techniques have been referred in the literature such as transverse/longitudinal baffles, fins and fins. These techniques have been deployed in the design of various heat exchangers to improve its thermal performance. Rate of heat transfer have been increased flat plate solar air dryers, collectors etc. and many other industrial applications. The various configurations of obstructions used included different orientations such as inclined, orthogonal, inclined perforated structures etc. All the compiled literature presented a study of numerical as well as experimental procedures to find out the effect of obstructions in the increment of heat transfer rate by variation of geometry, orientations, perforations etc [29].

Promvonge Pongjet et al. performed an experimental work on a solar air heater duct equipped with turbulence actuators V ribs with holes punched and V grooves with chamfer on it. Air has been used as the working fluid which flowed down the test section. Reynolds number varied in the range of 5300 – 23000. Three configurations of rib pitches (1, 1.5 and 2) with angles of 00, 450 and – 450 was employed. Nusselt number and friction factors were the parameters of interest in the study. The maximum rate of heat transfer increment occurred at the combination of V rib and V groove with chamfered on it at pitch of 1 and angle 450. Nusselt number and friction factors got increased up to 6.52 and 38.67 times for pitch 1.5 and angle 450 with configurations of combination of V ribs and chamfered V groove [30].

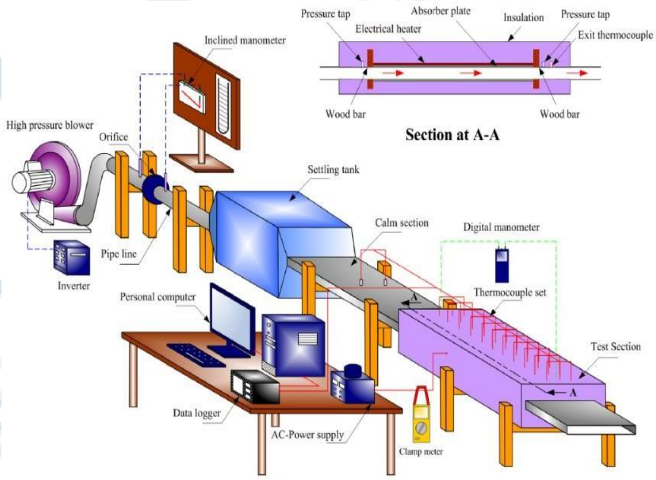


Fig. 5. Layout of the experimental set up [31]

Bhattacharyya Suvanjan et al. focussed his study to find out the heat transfer enhancement by performing experiments in a corrugated tube equipped with inserts. Air was used as the working fluid. The flow was varied as per the Reynolds number 10000 – 50000. Spring tape inserts are used for various pitches and spring ratios. Nusselt number and friction factors the two parameters of interest were found to be increased with reduction in pitches and spring ratio. Pitch of 0.7 and spring ratio of 3 provide highest thermo hydraulic performance [31].

Salman D. Sami compared the rate of heat transfer in case of a ribbed tube with nanofluid with the help of ANSYS Fluent simulation software. Four varieties of nanoparticles of Al_2O_3, CuO, SiO_2 and ZnO with volume ratios of 1% - 4% were used. Nanoparticles were varied in sizes of 30 nm, 40 nm, 50 nm and 60 nm. Reynolds number was varied in the range of 10000 – 30000. Rectangular, triangular and trapezoidal configurations were selected for the ribbed structures. The simulated results concluded that SiO2 with volume ratio of 4%, particle diameter size 30 nm, triangular ribbed configuration at Reynolds number 30000 provided the highest value of Nusselt number [32].

III. RECENT WORK RELATED TO HEAT TRANSFER AUGMENTATION USING NANOFLUIDS

Ajeel K. Raheem et al. performed an experimental study to investigate the effect of corrugated channels in case of heat transfer enhancement. As the past literature survey indicates that using passive techniques such as inserts, fins and corrugation in the surface leads to an increase in heat transfer which has led to development of more consistent heat exchangers. In the work experiments have been performed using Nano-fluid formed by SiO2 nanoparticles in water as the base fluid. Three different channels namely (a.) smooth, (b.) corrugated channels were heated. Corrugated channels included semicircular and trapezoidal configurations. The experimental set up comprised of cooling division, heated test section, different thermocouples, flow regulators, heater, pressure devices, pump and nanofluid tank. Turbulent conditions were maintained in the Reynolds number ranging from 10000 – 30000. SiO2 nanoparticles in two volume proportions of 1% and 2% were suspended in water. Convective heat transfer performance parameters were evaluated with the help of date accumulated through the performed

experiments. The experimental data were then compared with the numerical techniques using the finite volume method. In the numerical study a 3D geometry was made through the Solid Works and then was analyzed for the convective heat transfer parameters using the ANSYS – Fluent software. Average Nusselt number have been evaluated and compared for the experimental and numerical study. A good agreement has been found between the experimental and numerical results. The study concluded that the use of SiO2 – water Nano-fluid has a better impact on heat transfer than the base fluid. Through use of corrugations instead of straight plane channels secondary flow vortices can be induced which can improve the rate of heat transfer to a higher extent. However the corrugated surface may also leads to an undesirable increase in pressure drop [33].

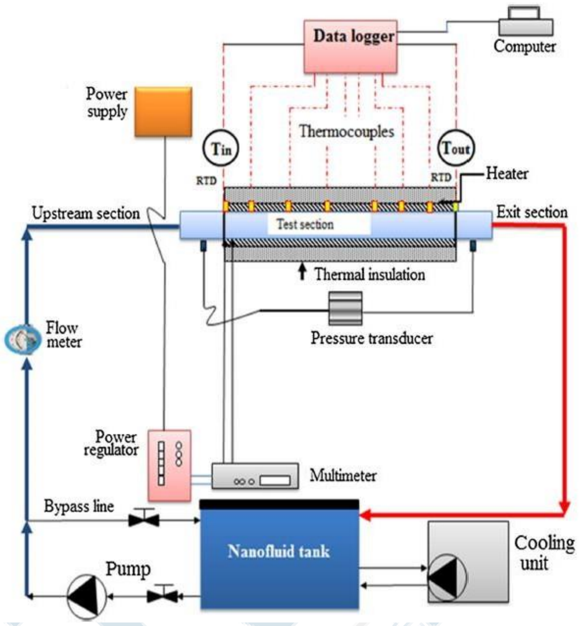


Fig. 6. Layout of the experimental set up [33]

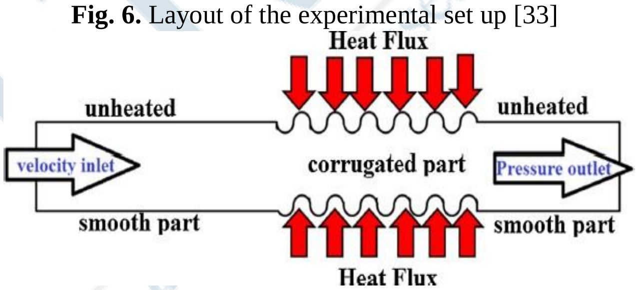


Fig. 7. Geometry and Boundary Conditions [33]

Hussein M Adnan et al. performed computational analysis for evaluating the turbulent convective heat transfer augmentation in a heated tube employing TiO2-water nanofluid. Reynolds number was speckled in the range 10000 to 100000 for creating the turbulence in a horizontal tube with a heated flux of 5000 W/m^2. Concentrations (0.25%, 0.5%, 0.75% and 1%) were employed for TiO2-water as working fluids. The values of Nusselt number and friction factor were calculated for this range of Reynolds number mentioned above. Computational analysis results revealed the fact that the Nusselt number and friction factor upturns with the increase of volume fractions in the Nano-fluid [34].

Thakur Amit et al. performed a computational analysis using Ansys Fluent to predict the thermal hydraulic performance of a circular wavy shaped groove surface tube employing Alumina-water as a nanofluid. Results of convective heat transfer parameters such as Nusselt number, pressure drop etc. were evaluated on the basis of computational analysis. Geometry of the analysis was created using CATIA. The thermal and hydraulic properties of Alumina-water were used for the evaluation of the parameters. The Reynolds number was wide-ranging from 3980 to 119425 for the turbulence in the flow. An increase of 55% to 93% in the convective heat transfer was predicted by the results of Nusselt number. The enhancement was possible due to enhanced mixing, reverse flow and turbulence created by the wavy grooved surface in the flow. Enhanced pressure drop was also noticeable in the work. The nanofluid worked to increase the thermal conductivity of the fluid which also consequences to the increase of heat transfer rate with the walls [35].

Choi and Lee examined the confinement effect on the boiling regime in case of a two-phase closed thermosyphon. In this work, the critical heat flux has been augmented by 14.3% when cellulose Nanofiber fluid was used as the working fluid in place of de-ionized water [36].

Heidarshenas et al. compared the heat transfer coefficient in a micro-channel heat sink of cylindrical shape using two different type of working fluids: (i) Al2O3Nanofluids, (ii) Hybrid Nanofluid made up of ionic liquid [BMIM] PF6 combined with alumina (Al2O3) nanoparticles. The results depicted that the hybrid nanofluid gave better results as coolant in comparison with Al2O3nanofluid. The value of Nusselt number was found greater for the particles size of 20 nm and 50 nm in case of hybrid nanofluid [37].

Firlianda et al. conducted the experiments to augment convective heat transfer in a shell & tube mini-heat exchanger. In this work, the nanofluid was synthesized by the addition of MnFe2O4 nanoparticles into the base fluid of ethylene glycol. The LMTD method was incorporated for the heat transfer analysis and dimensionless numbers Re, Pr and Nu were improved with the inclusion of MnFe2O4 nanoparticles. The optimum value of the heat transfer was attained at MnFe2O4concentration of 0.075% [38].

Saeed and Kim conducted an experimental analysis along with the numerical simulation in single and two- phase model to augment the heat transfer characteristics. In this work, the distilled water coolant in the heat sink was replaced by nanofluidAl2O3-H2O. The results were analyzed and compared for the different channel configuration of heat sink and for the different coolant i.e. nanofluid and distilled water. It was depicted that the use of nanofluid as coolant in place of distilled water is a viable option to enhance the convective heat transfer coefficient [39].

Returi et al. employed various working fluids to compare the heat transfer characteristics in a spiral plate heat exchanger. In this work, the three types of working medium were employed i.e. water, nanofluid (Al2O3-H2O, TiO2-H2O and CuO-H2O) and hybrid nanofluid (Al2O3+TiO2/H2O, Al2O3+CuO/H2O). The results demonstrated that the heat transfer can be enhanced around 16%-27% when hybrid nanofluid were used as the working medium for the heat exchanger in comparison with water as the working medium [40].

IV. CONCLUSIONS

It can be resolved from the various researches on heat transfer enhancement that passive techniques are much significant as these do not require any external means or power input. The rate of heat transfer can be enhanced by using inserts or extended surfaces. The twisted types of inserts are found to be the most suitable inserts in the design of heat exchanger. These twisted type inserts not only enhance the rate of heat transfer but also reduces friction factor. Effective heat transfer area and turbulence in flow also increases which helps in obtaining higher rate of heat transfer. These passive techniques have easy installation and removal process in comparison of active techniques and also have low cost due to simple manufacturing process. So these methods of heat transfer enhancement can be broadly used in industrial applications.

Besides using inserts, heat transfer enhancement can also be done using nanofluid. Recently, many researchers' focused on using nanoparticles in case of flow through heat exchanger. The Reynolds number of flow increases due to use of nanofluid. The value Nusselt number of nanofluid is calculated in terms of Reynolds and Prandtl numbers. An increase in the value of Nusselt number results in the increase in heat transfer coefficient. Also the usage of hybrid nanofluid is recommended for the augmentation of convective heat transfer characteristics. The future research must focus on experimental and numerical analysis of heat transfer augmentation with the use of hybrid nanofluid and uncertainly analysis can be performed to evaluate the uncertainly associated with the various parameters of heat transfer process.

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