

Comparative Study of Thermal Criteria and Fluid-Flow Criteria in Micro and Mini Channel Design Constrains with or without Insert Made of Aluminum Material

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Abstract

Through experimental and simulation results, a comparison between mini and micro channels with inserts or without inserts is conducted; in this case, water is the only working fluid used for present experimentation. In order to research the fluid flow and micro channel features, the results of fluid flowing inside the mini channel and micro channel with insert or without insert separately were admitted. Experiments were performed for various operating and design parameters under counter-flow conditions, with hot water moving into a concentric tube with a 30 mm diameter at 0.00078 kg/sec flow rate. The fluid is moving separately through mini channels with a 2 mm diameter and micro channels with lower than 1 mm dia. at a varying flow rate 0.00015 kg/sec to 0.0062 kg/sec. The working temperatures for hot water and cold fluid were 323 K and 303K, respectively. According to the results, the suggested design of the micro channel with insert performed better than a conventional mini channel, micro channel without insert and mini channel with inserts due to the better thermal conductivity of the aluminum material, effective diameter (1mm) to length ratio of micro channel in which heat exchanges with

minimum volume ratio and the additional exposed area made possible by the rectangular shape of the insert, whereas micro channel with micro insert having rectangular shape showing best results as compared with the other designs of channel due to the rich heat passage and effective pressure drop and temperature. Experimentation and simulation results are coming in positive direction, it is directly observed from the error percentage i.e. 2.41% to 4.29%.

1. Introduction

Due to intense competition, businesses nowadays use cutting-edge equipment and processes to produce a wide range of products that are more productive and help society as a whole. Automation is crucial for modernizing work culture in a productive way [1, 2]. In order to create the best, most responsive, and most dependable products for society and consumers, various industries are using various scientific concepts and emerging technologies to manufacture digitalized electronic products, medical equipment, automotive and aviation products, and research equipment, among other things. The main issue facing the industries in this area is the heat trap and blockage in digital items, which shortens product lifespan. A fresh answer to this problem statement is being found in several sectors, including this one. The product's design is heavily influenced by environmental factors, material choices that are practical and affordable, and geometrical design constraints. For constructing the ideal heat convey equipment to extend the life and dependability of digital products, material conductivity and the area of the heat convey unit are important game changers in the geometrical realm, which is why researchers continue to be drawn to micro channels [3, 4, 5, 6]. Nanofluid has an exceptional chemical, thermo, physical attribute [7, 8].

In order to improve the performance and efficiency of various solar equipment and exchangers in various situations, for varying Re number ranges, many researchers focused on analyzing the behavior of various fluids such as air, water, D₂O, ethylene-glycol, and its mixture with Al₂O₃, TiO₂, ZnO, BeO, CuO, MWCNT, and SWCNT. According to the findings, increasing fluid thermal conductivity will have an impact on performance because it will increase Nu number [9]. Numerous researchers use different factors for analysis for creating effective exchangers, sun heaters, space heaters, cyclone separator [10], etc. Some common factors were selected during analysis like diverse shape and orientation of tube, perforation, absorber plate (AP) such as helical or spiral shape tube, simple tubes, a variety of tubes with diverse inserts or without inserts, pipe bend [11] and roughness like m, w, z shape, c, s shape, sine wave shape, hollow conical ring tapered shape etc. [12, 13, 14, 15], in diverse exchangers like shell-tube, concentric-tube, sun heater, space heater or regenerator, LED [16, 17, 18, 19]. After determining the size, form, and feasibility of the AP, tube. Researchers focused on examining the impact of AP placement and perforation location in various inserts [15, 16] and with various fluids [8, 16, 17, 20]. Researchers further investigate the effect of materials like Clay, dried clay, nylon 6, and other materials etc. that are categorized as sensitive materials beneath packed beds linked to thermal storage [20, 21, 22, 23, 24, 25]. Numerous studies have looked for analysing the impact of heat convey and flow attributes of nanofluids in spiral tubes [19] filled with a variety of fluids, including water [13, 14, 16, 17], and fluid [7, 8], including this such study is also helpful to predict the performance of IC engines with or without heat convey unit of like radiators, exchangers using bio lubricant, bio oil etc. [26, 27, 28]. The results of heat transfer and the thermal characteristics of C.T.T. and C.O.T.T. aqua with base fluid were examined in few studies. The values of Nu, f, and Re diverge by 7200 and 32400, respectively, when the twist ratio falls. When Re is enlarged, the Nu factor produces better results. C.T.T. amplifies heat transmission more effectively than C.O.T.T. [29].

The research presents the findings of studies on the effects of viscosity range, specific heat, and thermal conductivity in a double pipe exchanger with a variety of nanofluids (NF). The results were produced by using a two-step process through MAT lab code to produce N.D.G. NF with a water basis. It was discovered that the twin pipe exchanger's performance improved because of a 15.86% expansion of the heat convey parameters occurring at 0.6 weight percent NF in comparison to water [30]. The effects of thermal convey and f between TiO₂ and Al₂O₃ in turbulent situation at various operating temperatures were examined through analysis. Water and ethylene glycol (EG) 60:40 (W.E.G.) were combined to create the fluids, which were then manufactured using a two-step technique and dilution process at working temperatures of 30, 50, and 70 OC. Temperature had an impact on Al₂O₃, and an increase in thermal conductivity and viscosity was produced. For 0.1 mass at 50 and 70 OC, TiO₂ free of temperature has about the same heat transfer coefficient value, with an increase of 24%. At a temperature of 30 OC, Al₂O₃ outperformed TiO₂ [31].

Experimentally noticed the outcomes of a thermal convey based on nanofluid in a curl tube where screw pitches, rotation angle was taken as the exploring parameters, an improvement were shown for low screw pitch with 450 angle [32]. Heat transport analysis on shell spiral-coiled exchanger was assessed. Physical quality was assessed using numerical and experimental techniques. 42 cases and 15 trials were gathered. The operating fluid used was water, and the temperature affects how it behaves. The results show an increased pitch size. The number

of mussels increases on the shell side by 0.8%, or 50%. The Nusselt number decreases by 34.1% and 28.3%, respectively, when height and diameter increase [33]. Analyze numerically how construction factors affect the heat movement, flow, and stress properties in a spiral exchanger with tube bundles using the thermal interaction of liquid-solid technique. According to the findings, the flow pattern from the shell to the tube shifts from transverse to oblique, and the total heat convey coefficient first rises before falling as the angle decreases [34]. Some researchers investigate the impact of thermo-hydraulic attribute in spirally wrapped exchanger having successive shell. The outcome demonstrates that the only significant dimensionless parameter that has no effect on the flow properties is the tube numbers in the higher layer [35]. This experiment's goal is to evaluate the viability of diverse exchanger like corrugated mini-duct geometries [36], sextant helical baffle [37], cooled by water. It takes varying geometries for analysis, on comparing all sinusoidal show better performance in corrugated mini-duct exchanger [36]. After reading through a number of prior studies on various approaches used to solve the heat convey problem [3, 4, 5, 6, 38], the CFD fluent module was employed in the current study to validate the work using experimentation values through the Viscous- Realizable (k-epsilon) model.

The findings were not limited to but reported that higher number of fins have always shown better performance than arrangements having lower number of fins. Moreover, few literatures suggest composite materials can yield better heat transfer [39-43].

The literature review on the distillate yield of stills suggests that the inclination of the wick and materials used for the wick are the factors that influence the distillate yield. However, limited study has been conducted on the effect of the tilted wick inner part of the watershed. This creates a research gap in understanding the impact of the wick's tilt angle on the distillation process. Exploring the influence of the wick's inclination within the watershed is a crucial factor for several reasons. The tilt angle can affect the flow dynamic of heat transfer within the still. The combined effect of the low-cost jute wick material and its inclination has not been extensively studied. So, to fill this gap a low-cost jute fiber was used as a wick material inner part of the watershed to enhance the distillate yield of the solar still. Literature [44-51] calculates efficiency, energy and exergy and performance of the thermal based system. Recently industries are adapting automation technique [1] during manufacturing reliable products for market, which increases the quality and quantity both and including these industries prime focus is to manufacture automated products also for the society or customers so that it provides easiness to their work culture, work habits and life such as mobile solutions [2], software's, automatic gadgets or devices etc. Thermal, solar, space, automobile industries facing challenges in renewable energy area where energy constancy is the major concern, many researchers worked on specific design and develop high efficient and effective air heaters [12-16] which utilized solar energy more during day for diverse applications and some literature presented the importance of roughness shapes, and demonstrate the positive effects of roughness shape, utilized over absorber plate [12-16, 52, 53]. Some researchers work on efficiency improvement of exchangers through spiral tube and roughness usages [8, 17, 19, 58], some focused on micro channels with diverse effect of fluid [3-6, 54-57] and fins [18], some performed work on cyclone separator and pipe bend effect for thermal industrial applications [10-11].

Including all above research some researchers analyzed the effects of diverse thermal storage material for long term energy storage [20-24]. While doing such type of research, several researchers adopt diverse methodologies for solving their problem statement for that past literature plays an important role for adoption of methodology [26-28, 38, 52-58].

2. Materials & Methodology

Based on previous literature, design constraints, economic viability of material, selection of material and working fluid for channels takes place [11]. The details of its properties are mentioned in Table 1.

Table 1 Properties of processing material

Fluid and Material	Thermal Conductivity 'K' (W/m.k)	Specific Heat 'Cp' (J/kg.k)	Density 'ρ' (kg/m ³)
Aluminium	40	880	3700
Water	29	544	5600

2.1 Fabrication of Test Set-Up and Experimental Procedure

Mini & Micro channel has a common set up for experimentation. It consists of one middle plate for holding channel, two heating plates placed over middle both side and channel. The dimensions of the test set up contain length is 28 cm, width 12 cm and thickness 2 cm. Rubber plate are placed between the middle plate and heating unit for preventing leakage. Separate grooves for channel and concentric tube are provided in the middle plate for inlet and outlet supply of water. Channels are made of diverse dimensions. Mini channels are made of 10.4 cm long, 1 cm wide, 0.3 cm height, and 1 mm in diameter whereas micro channels are made of length 10.4 cm long, 1 cm

wide, 0.3 cm height, and 2 mm in diameter. Thermocouples are fixed over channel separately; special grooves are provided for their placement in middle plate. 3 heaters are used to heat up the water, 2 heaters are placed inside the heating plate on both the side and 1 is placed separately at hot water supply tank. The test setup is packed with the help of nuts and bolts. 8 thermocouples are attached at the outer surface of channel rest 4 thermocouple are fixed at inlet & outlet of hot & cold supply. All thermocouples are attached with data loggers for recording surface temperature, inlet & outlet temperature of hot & cold water. Water is supplied through 2 peristaltic pumps. One is connected at the inlet section of channel and other is attached with inlet section of concentric tube separately. The outlet section of channel is connected to chiller tank for maintaining it at room temperature. Temperature controller and contractor relate to all 3 heaters to maintain the desired temperature. 2 mass flow meters and 4 Pressure gauges are connected to setup for measuring flow rate and pressure drop during experimentation as shown in fig 1 and 2. Installing the appropriate channel is the initial step in initiating an experiment. Before testing the channel's behaviour, a steady state phenomenon must be developed. Start the third heater inside the hot water supply tank for 15 minutes to reach steady state, then turn on the other two heaters on the heating plate. Start the first peristaltic pump, which is connected to the hot water supply tank and supplies the water to the concentric tube to maintain the temperature, at the correct flow rate at the same time. Start the experimentation once steady state has been reached. Turn on the second pump, which is attached to the cold-water tank, at the required flow rate, and feed the channel with water for 30 minutes. Then, take the readings of the channel surface temperature, the cold and hot water entry and outlet temperatures from the data logger. In order to calculate pressure, drop and other characteristics, note down the pressure readings independently from the pressure gauges that were mounted in the setup. Repeat the procedure for the subsequent set of experiments with various working settings.

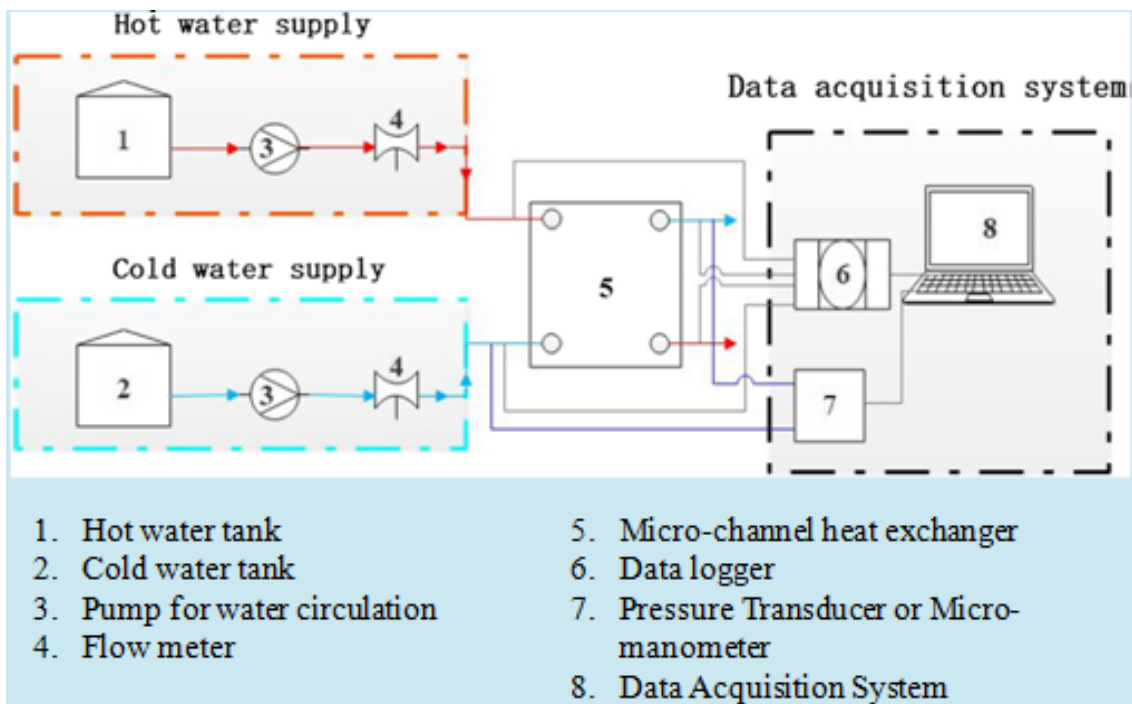


Fig. 1 Line diagram of experimental setup

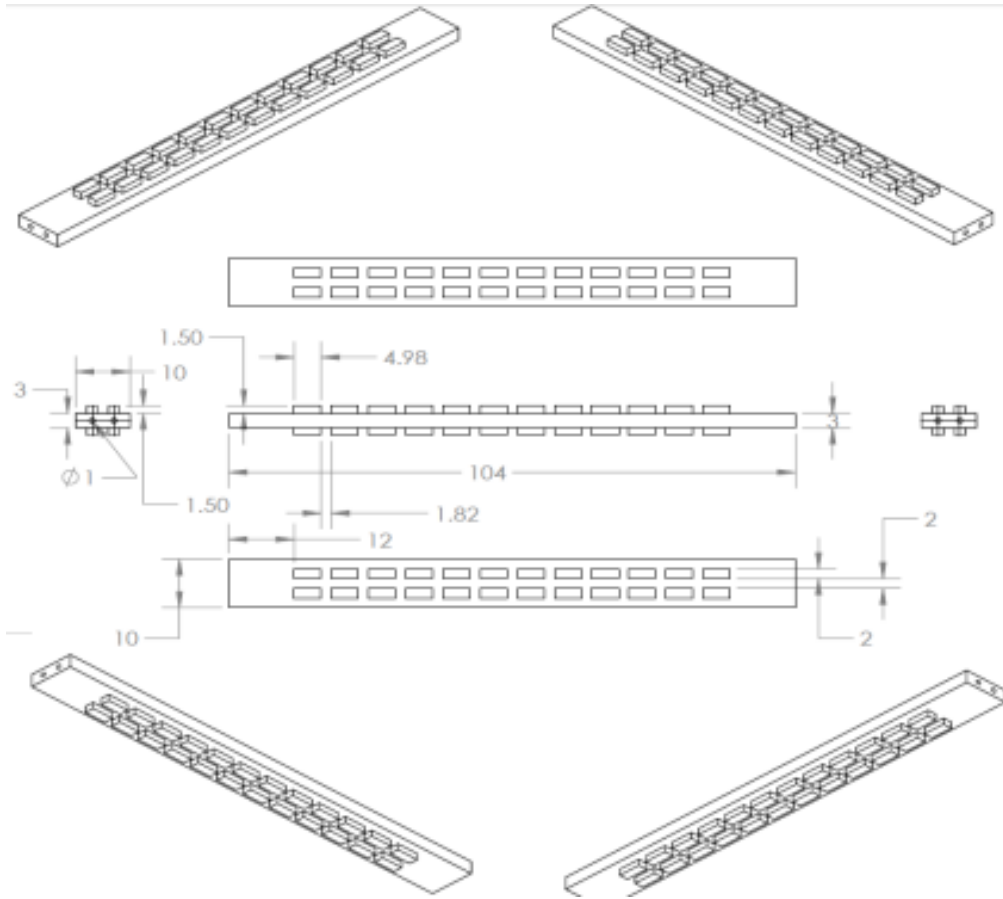


Fig. 2 Computational geometry of micro channel with inserts

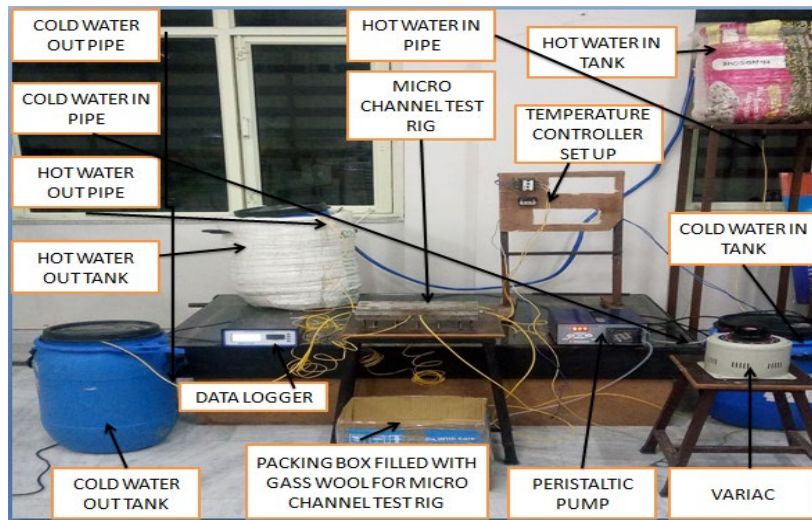


Fig. 3 Photographic experimental view of setup

2.2 Data Reduction

The experiment's results were obtained by using a data reduction approach, and equations were used to calculate the fluid-flow characteristics which are as follows:

$$Q_{ds} = \frac{Volume}{t} \quad \text{where } Q_{ds} = Area \times V \tag{1}$$

$$m_{rf} = \rho_f \cdot A \cdot V_f \tag{2}$$

$$\begin{aligned} Q_{hf} &= m_{hf} \cdot C_{phf} (T_{in} - t_{out}) \\ &= Q_{cf} = m_{cf} \cdot C_{pcf} (T_{out} - t_{in}) \end{aligned} \quad (3)$$

Here, m_{hf} and m_{cf} flowrate (hot water) & (cold water), $T_{h.in}$ = temperature of inlet (hot water), $T_{h.out}$ = temperature of outlet (hot water), $t_{c.in}$ = temperature of inlet (cold water) and $t_{c.out}$ = temperature of outlet (cold water). As per L.M.T.D. method, the governing equation for determining heat rate and coefficient are mentioned below:

$$\begin{aligned} Q_r &= h.A.\Delta T \\ \text{where } \Delta T &= (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2), \\ \Delta T_1 &= (T_{out} - t_{in}), \Delta T_2 = (T_{in} - t_{out}) \end{aligned} \quad (4)$$

$$U = \frac{1}{\left(\frac{1}{h_i} + \frac{1}{h_o}\right)} \quad (5)$$

Following equations are utilized to ascertain fluid-flow performance attributes, which are mentioned below:

$$Nu = \frac{h.D}{k} = 0.023\Re^{0.8} Pr^{0.4} \quad \text{where } \Re = \frac{\rho.A.D}{\mu} \quad (6)$$

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho.v^2}{2}\right)} \quad (7)$$

Following equation and procedures are used to calculate the thermal-performance attributes in accordance with the governing equation:

$$\varepsilon = \frac{Q_{actual}}{Q_{max}} \quad (8)$$

$$NTU = \frac{U.A_s}{Q_{max}} \quad (9)$$

$$\text{where } C_{min} = m.C_{cp} \text{ and } NTU_{counter} = \frac{1}{c-1} \ln\left(\frac{\varepsilon-1}{\varepsilon_c-1}\right) \quad (10)$$

$$\eta_{pf} = \frac{\left(\frac{Nu}{Nu_s}\right)}{\frac{f^{0.33}}{f_s^{0.33}}} \quad (11)$$

$$Nu_s = 0.023\Re^{0.8} Pr^{0.4} \quad (12)$$

$$f_s = 0.316\Re^{-0.25} \quad (13)$$

3. Results & Discussion

3.1 Effect of Design Constrains of Diverse Channels Over Nu & f Flow Parameters:

Fig. 4, 5 show that the fluid-flow and thermal attributes of mini channel (Min. C) perform better than that of the micro channel (Mic. C). Additionally, micro inserts (MI) have a crucial approach in improving performance of flow. Min. C with MI is performing better than other channel designs of channels based on various design constraints,

because of higher size of Min. C, MI area over all surface area increases. It is a crucial factor for enhancing the flow parameters. In Fig. 4, 5 the fluid-flow attributes of water was also showing better flow performance for laminar and turbulent situation due to design constraints, here Nu factor & f factor varied 11.18-41.69 and 0.00591-0.000391 (modeling value), 10.70-40.65 and 0.0065-0.000401 (test value) under laminar situation whereas, 56.23-70.70 and 0.000309-0.000268 (modeling value), 55.77-69.03 and 0.000316-0.000271 (test value) under turbulent situation. Tested value and software modeling results are favorable, as can be seen from the error percentage, which ranges from 2.41% to 4.29%.

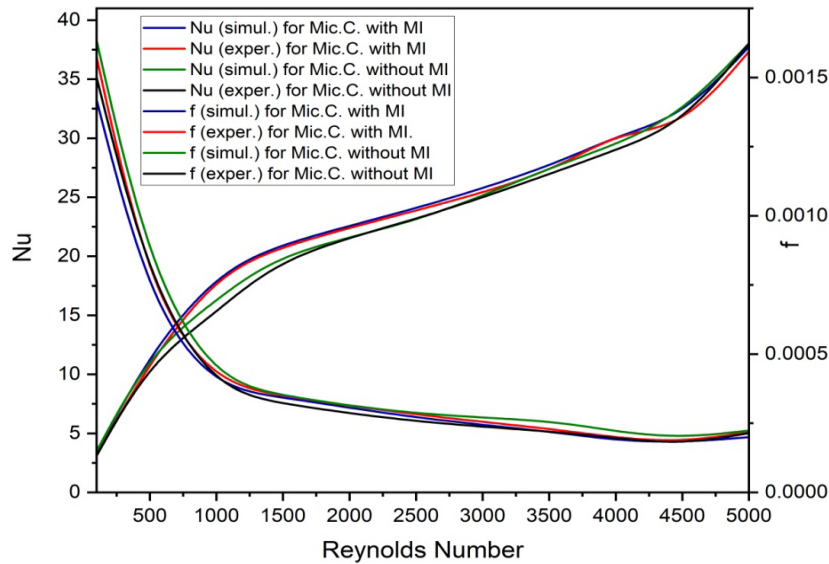


Fig. 4 Representing variation b/w Nu and f with Re for diverse design constrains of micro channel

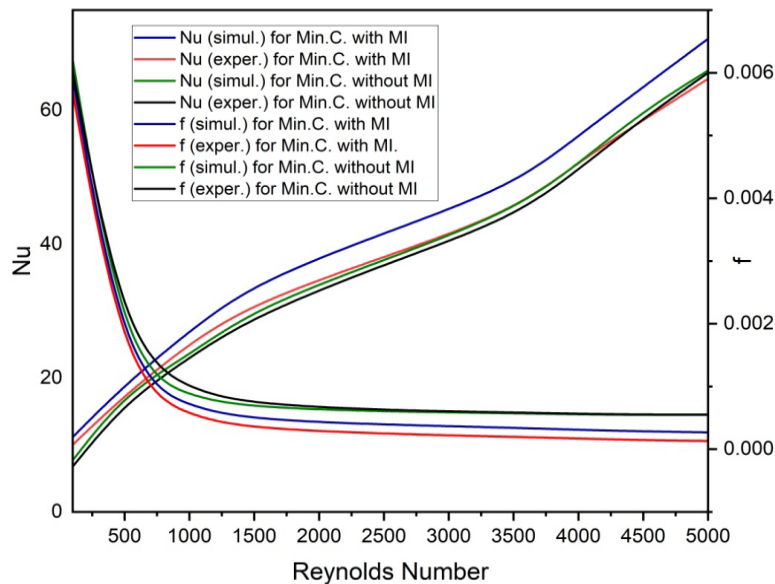


Fig. 5 Representing variation b/w Nu and f with Re for diverse design constrains of mini channel

3.2 Effect of Design Constrains of Diverse Channels Over Nu/Nus & f/fs Flow Parameters

Figures 6 and 7 [35] illustrate the decrement and increment in Nu, f/fs & f, Nu/Nus modeling and test values during the experiment because of the positioning of MI, which caused severe turbulence in the test setup of the channel. Nu/Nus and f/fs is a fractional tested value of proposed geometry to smooth tube geometry without insert for both cases. It is clearly shown from the figure that the proposed geometry with insert performs better than smooth tube geometry without inserts in laminar region compared with turbulent region. From Fig. 6, 7 it is evident that Nu/Nus factor & f/fs factor are coming 0.298-0.101 and 0.0230-0.0305 (modelling value), 0.286-

0.0988 and 0.0254-0.0313 (test value) under laminar situation where as, 0.0988-0.0987 and 0.0361-0.0419 (modelling value) 0.0980-0.0964 and 0.0369-0.0423 (test value) under turbulent situation.

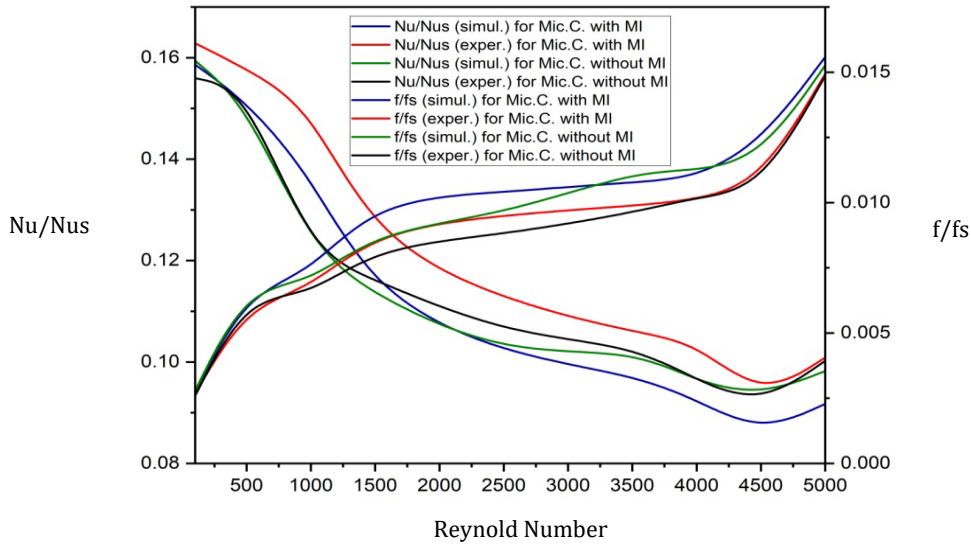


Fig. 6 Representing variation b/w Nu/Nus and f/fs with Re for diverse design constrains of micro channel

3.3 Effect of Design Constrains of Diverse Channels Over Q & ε Thermal Parameters

The relationship between Q, effectiveness with Re is depicted in Fig. 8 and 9. Because of the suggested fluid and channel material, set up have strong thermal conductivity. It is observed that only Q is increasing gradually, because of higher flow rate and convective coefficient. But the other parameters such as ε which also reflects the thermal behaviour like Q of the suggested fluid and shape & material of channel are decreasing quickly because of thermal difference. When evaluating every aspect of all possible geometries. It is shown that a Min. C with MI behaves optimally and performs better than others for Q parameter because of large size of channel which lead to higher surface area, whereas for ε Mic. C. with MI behaves better, because effective thermal difference has occurred by Mic. C. The best results for Q, effectiveness with Re ranged from 40.87-125.85, 0.99-0.372 (modelling values) and 38.18-124.39, 0.941-0.337 (test values) under laminar conditions, whereas 143.39-155.75, 0.296-0.268 (modelling values) and 145.03-154.70, 0.269-0.204 (test values) under turbulent situation

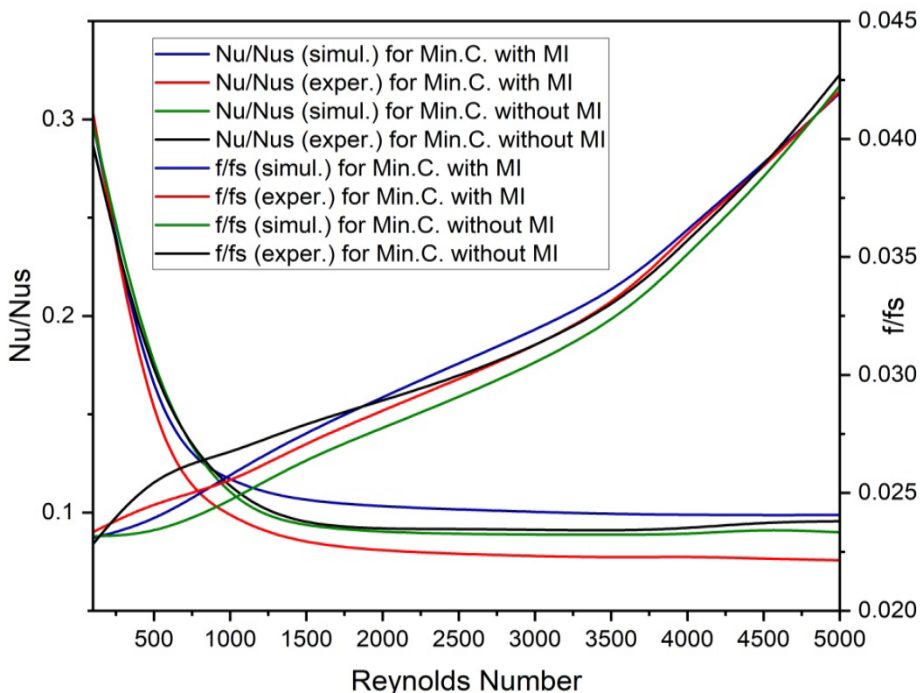


Fig. 7 Representing variation b/w Nu/Nus and f/fs with Re for diverse design constrains of mini channel

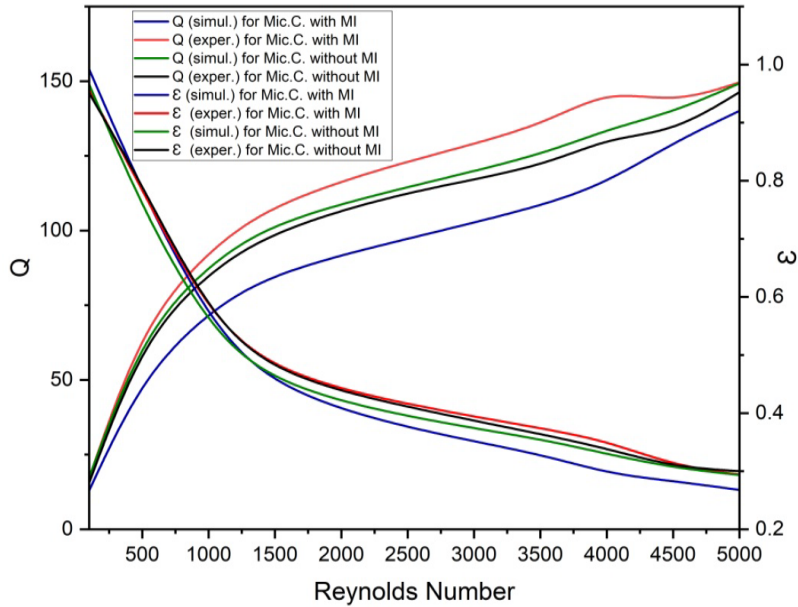


Fig. 8 Representing variation b/w ϵ and Q with Re for diverse design constrains of micro channel

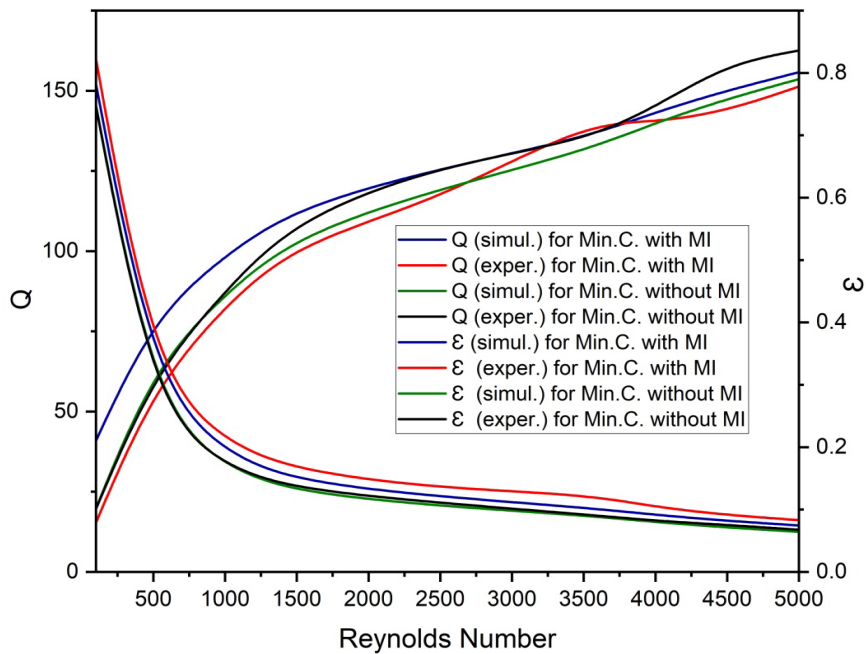


Fig. 9 Representing variation b/w ϵ and Q with Re for diverse design constrains of mini channel

3.4 Effect of Design Constrains of Diverse Channels Over NTU Flow Parameters

Fig. 10 and 11 illustrate the relationship of NTU with Re , here NTU depicts the thermal transfer capability of channel per unit flow rate which is generally influenced by thermal difference. NTU is decreasing with an enhancement of Re because of several factors such as suggested fluid and channel material have strong thermal conductivity, size & shape of channels, extra area gained through MI involvement. It is observed that value of proposed parameter is coming better for Mic. C. with MI, because Mic. C. attains lower volume flow rate per unit length as compared to Min. C., which is not possible in Min. C. and other designs. The best results for NTU with Re ranged from 5.75-0.491(modelling values) and 3.28-0.431(test values) under laminar conditions, whereas from 0.360-0.317 (modelling values) and 0.320-0.231 (test values) under turbulent situation.

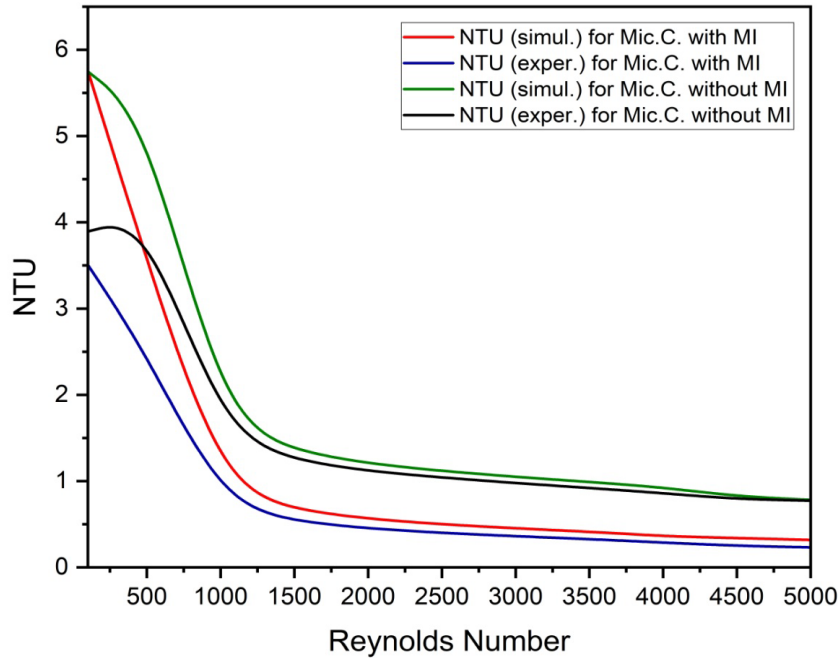


Fig. 10 Representing variation b/w NTU and Re for diverse design constrains of micro channel

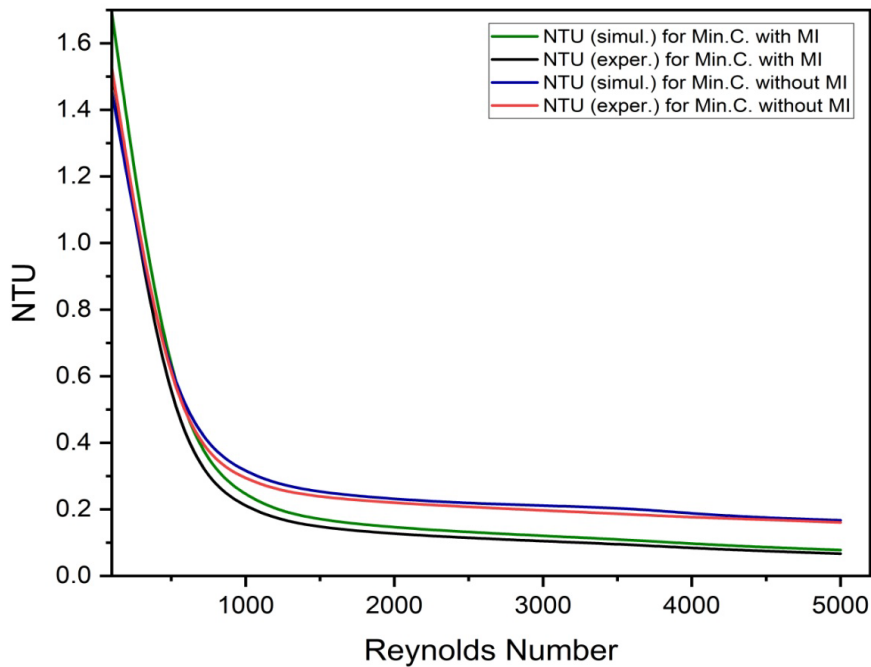


Fig. 11 Representing variation b/w NTU and Re for diverse design constrains of mini channel

3.5 Effect of Design Constrains of Diverse Channels Over TPF Performance Parameters

Fig. 12 and 13 illustrate the relationship of TPF with Re, here TPF depicts the performance rate of channel. It is generally influenced by the ratio of dimensionless number (Nu) of proposed design of channel and smooth channel to the ratio of dimensionless number (f) of proposed design of channel and smooth channel. Because of various factors like suggested fluid and channel material have strong thermal conductivity, size & shape of channels, extra area gained through MI involvement, roughness of channels, TPF is decreasing with an enhancement of Re. Fig. 12 and 13 demonstrates an acceptable range of thermal performance, which has been attained best in the laminar zone when compared to the turbulent region. Meanwhile, Mic. C has the highest potential for thermal transfer when compared to Min. C in terms of performance attributes, because Mic. C has minimum roughness, which leads to lower friction rate inside the channel, it increases the TPF as demonstrated in Fig. 12, and 13. The best results for TPF with Re ranged from 1.11-0.46 (modelling values) and 0.97-0.44 (test values) under laminar conditions, whereas from 0.41-0.36 (modelling values) and 0.40-0.34 (test values) under turbulent situation.

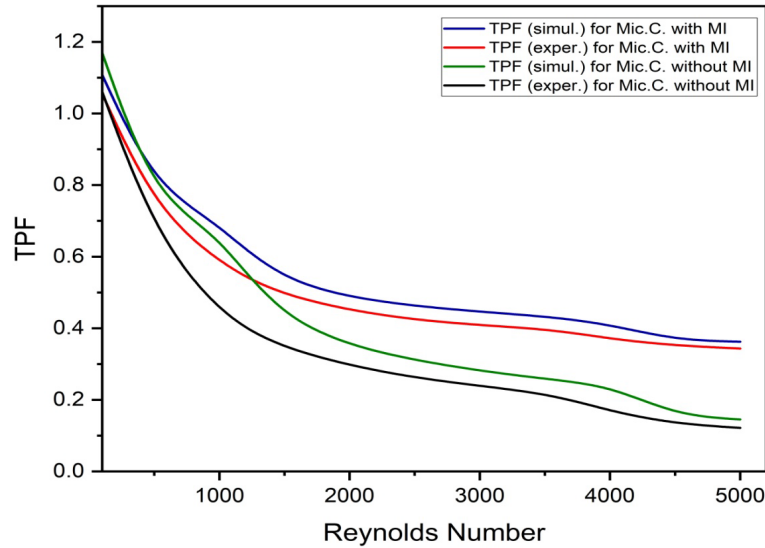


Fig. 12 Representing variation b/w TPF and Re for diverse design constrains of micro channel

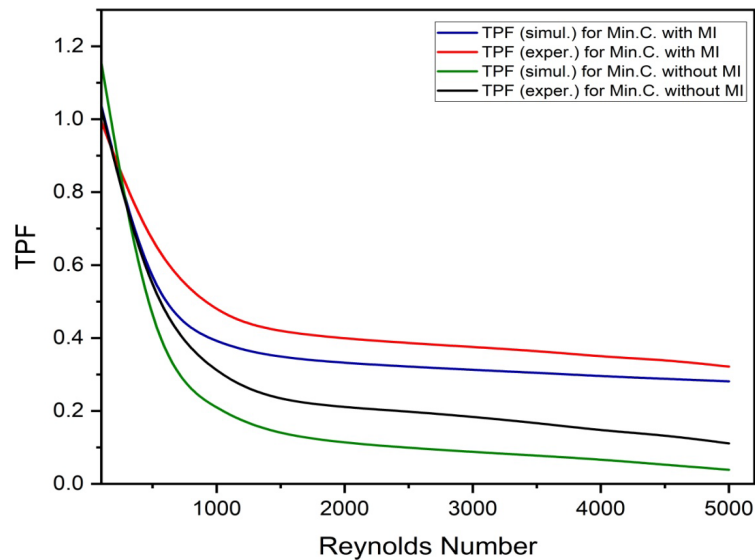


Fig. 13 Representing variation b/w TPF and Re for diverse design constrains of mini channel

4. Conclusion

When comparing micro and mini channels with insert profiles to those without insert profiles, the Min. C. with MI exhibits finer results in terms of fluid-flow criteria, thermal criteria, while Mic. C. with MI exhibits good results for performance criteria and heat movement criteria. It occurs for several reasons which are as follows:

- i. Increased material thermal conductivity and exposed area made possible by MI design. In contrast, the results of the geometrical profile also acknowledge that the Min. C. acts better than the Mic. C. in terms of fluid-flow and thermal parameters.
- ii. The ruling factor is that the Mic. C. hole (diameter) size is smaller, less than 1 mm, than the Min. C. hole diameter, which is 2 mm, because of smaller diameter of hole, effective diameter (1mm) and volume to length ratio in Mic. C. has been achieved which impacts positively more in heat exchange with minimum volume ratio of fluid. Thus, it increases heat dissipation, which was already achieved in the Mic. C. channel at a lower level of flow rate. The results of Mic. C. are too close compared to Min. C.
- iii. The reason which attracts the usage of Mic. C. more compared to Min. C. is the better thermal performance attribute of the channel. It is only achieved in Mic. C. not in Min. C. because of the lower size of Mic. C. It has minimum roughness, which leads to lower friction rate inside the channel, thus it reduces the hydraulic load and increases the TPF of channel.

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Conflict of Interest

Author declares that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Shivasheesh Kaushik, Satyendra Singh, **data collection:** Vikas Singh Mahar, Raja Kumar, Samriddhi Vashisth, Shubham Singh Karki, **analysis and interpretation of results:** Shivasheesh Kaushik, Jagdish Singh Mehta, Prabhakar Bhandari, **draft manuscript preparation:** Ayushman Srivastav, Nikhil Kanoji, **critical review of the article:** Amit Kumar, Desh Bandhu Singh. All authors reviewed the results and approved the final version of the manuscript.

References

- [1] Shivasheesh Kaushik, Rahul Pandey & Abhilash Singh (2023) Industrial Automation System and its effect on position of laborers and their consciousness, Journal for Re Attach Therapy and Developmental Diversities, 6 (2s), 159–163.
- [2] Shivasheesh Kaushik, Abhilash Singh & Ganesh Kumar,(2022) A Comprehensive Study on the Utilization of the Energy Using Mobile Solutions, Res Militaris (resmilitaris.net), 12 (5), 1487–1497.
- [3] Shivasheesh Kaushik, Vipin Uniyal, Subhan Ali, Nikhil Kanojia, Ajay Kumar Verma, Sumit Joshi, Mahesh Makhloga, Pankaj Singh Pargai, Saurabh Kumar Sharma, Raja Kumar & Siddharth Pal (2023) Comparative analysis of fluid flow in mini channel with nano fluids and base fluid, Materials Today: Proceedings, <https://doi.org/10.1016/j.matpr.2023.05.363>
- [4] Shivasheesh Kaushik, Subhan Ali, Nikhil Kanojia, Vipin Uniyal, Ajay Kumar Verma, Sohit Panwar, Shrish Uniyal, Subhanesh Goswami, Sushobhit Kindo, Debajit Som & Nitish Kumar Yadav (2023) Experimental and CFD analysis of fluid flow in rectangular strip based micro channel with nano fluid, Materials Today: Proceedings, <https://doi.org/10.1016/j.matpr.2023.05.647>
- [5] Shivasheesh Kaushik, Ajay Kumar Verma, Satyendra Singh, Nikhil Kanojia, Sohit Panwar, Sushobhit Kindo, Shrish Uniyal, Subhanesh Goswami, Debajit Som & Nitish Kumar Yadav (2023) Comparative Analysis of Fluid Flow Attributes in Rectangular Shape Micro Channel having External Rectangular Inserts with Hybrid $Al_2O_3+ZnO+H_2O$ Nano Fluid and (H_2O) Base Fluid, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 10, Issue 02, 851-862.
- [6] Shivasheesh Kaushik, Vipin Uniyal, Ajay Kumar Verma, Abhishek Kumar Jha, Sumit Joshi, Mahesh Makhloga, Pankaj Singh Pargai, Saurabh Kumar Sharma, Raja Kumar & Siddharth Pal (2023) Comparative Experimental and CFD Analysis of Fluid Flow Attributes in Mini Channel with Hybrid $CuO+ZnO+H_2O$ Nano Fluid and (H_2O) Base Fluid, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 10, Issue 01, 182-195.
- [7] Wisut Chamsa-ard, Sridevi Brundavanam, Chun Che Fung, Derek Fawcett & Gerrard Poinern (2017) Nanofluid Types, Their Synthesis, Properties and Incorporation in Direct Solar Thermal Collectors: A Review, Nano materials (MPDI), vol. 7, 1-131; doi:10.3390/nano7060131.
- [8] Shivasheesh Kaushik, Satyendra Singh & Kuldeep Panwar (2021) Comparative analysis of thermal and fluid flow behaviour of diverse fluid using Al_2O_3 , ZnO , CuO nano materials in concentric spiral tube heat exchanger, Materials Today: Proceedings, Volume 46, Part 15, 6625-6630.
- [9] Nishant Kumar, Shriram S. Sonawane & Shirish H. Sonawane (2018) Experimental study of thermal conductivity, heat transfer and friction factor of Al_2O_3 based nanofluid, International Communications in Heat and Mass Transfer 90, 1–10.
- [10] Vinay Sati, Shivasheesh Kaushik, Dr. Rahul Kshetri, Dr. Kuldeep Panwar & Rahul Pandey (2020) Comparison of a Classical Cyclone Separator and Protruding Surface Cyclone Separator using CFD Softwar, IOP Conf, in: Series: Materials Science and Engineering 802, doi:10.1088/1757-899X/802/1/012008
- [11] Vinay Sati, Shivasheesh Kaushik, Satyendra Singh, Rahul Kshetri & Rahul Pandey (2019) Reduction of Losses in 90 Degree Pipe Bends by Varying Design Parameters using CFD Software, International Journal of Engineering and Advanced Technology 8, 78–87.
- [12] Vipin Uniyal, Sanjeev Kumar Joshi, Shivasheesh Kaushik, & Nikhil Kanojia (2021) CFD Investigation of Transfer of the Heat and Turbulent Flow in Circular Copper Tube with Perforated Conical Rings of Aluminium Material, Materials Today: Proceeding, Vol. 46, Part 15, 6719-6725.

- [13] Ayushman Shrivastav, Shivasheesh Kaushik, Kuldeep Rawat, Abhishek Ghildyal, Vijay Singh Bisht, Kamal Rawat & Prabhakar Bhandari (2022) Influence of M shaped, Wedge shaped and Reverse Wedge shaped Turbulators in Solar Air Heater, *Neuro Quantology*, Vol. 20, 2308-2312.
- [14] Ayushman Shrivastav, Shivasheesh Kaushik, Kuldeep Rawat, Jaya Bohra, Vijay Singh Bisht, Prabhakar Bhandari & Kamal Rawat (2022) Exergy Analysis of Solar Air Heater roughened with Z-Shaped Baffles , *Neuro Quantology*, Vol. 20, 2313-2317.
- [15] Shivasheesh Kaushik, Kuldeep Panwar & Samridhhi Vashisth (2023) Investigating the Thermionic Effect of Broken Perforated Curved Ribs on Solar Preheater through CFD Simulation, *Res Militaris* (resmilitaris.net), vol.13, n°2, 1508-1524.
- [16] Shivasheesh Kaushik, Satyendra Singh (2019) Analysis on Heat Transmission and Fluid Flow Attributes in Solar Air Accumulator Passage with Diverse Faux Jaggedness Silhouettes on Absorber Panel, *International Journal of Engineering and Advanced Technology* 8, 32–41.
- [17] Shivasheesh Kaushik, Satyendra Singh, Nikhil Kanojia, Kuldeep Rawat & Kuldeep Panwar (2020) Comparative Study for Thermal and Fluid Flow Peculiarities in Cascading Spiral Inner Tube Heat Exchanger with or without Diverse Inserts over Spiral Tube, *IOP Conf*, in: Series: Materials Science and Engineering 802, <https://doi.org/10.1088/1757-899X/802/1/012009>.
- [18] Shivasheesh Kaushik, Satyendra Singh, Nikhil Kanojia, Rakshit Naudiyal, Rahul Kshetri, Ashwarya Raj Paul, Ritu Kumari, Alok Kumar & Shambhu Kumar (2021) Effect of introducing varying number of fins over LED light bulb on thermal behaviour, *Materials Today: Proceeding*, Vol. 46, Part 19, 9794-9799.
- [19] Shivasheesh Kaushik, Satyendra Singh & Kuldeep Panwar (2022) Experimental Study of Fluid Flow Properties in Spiral Tube Heat Exchanger with varying Insert Shape over Spiral Tube Profile, *Materials Today Elsevier*, D.O.I.: <https://doi.org/10.1016/j.matpr.2022.10.117>
- [20] Nikhil Kanojia, Shivasheesh Kaushik, Kuldeep Panwar, Rahul Kshetri, Vipin Uniyal & Mayank Singh (2021) Experimental investigation of optimum charging and discharging time on packed bed heat regenerator for space heating and solar drying application, *Materials Today: Proceedings*, Volume 46, Part 15, 6712-6718.
- [21] Nikhil Kanojia, Shivasheesh Kaushik, Vipin Uniyal, Kuldeep Panwar, Satyendra Singh, Shubham Singh Karki, Samridhhi Vashisth, Anurag Rawat & Ashish Nayal (2022) Experimental Study of Heat Storage and Heat Elimination in Packed Bed using Nylon 6 Spiral Balls, *Neuro Quantology*, Vol. 20, 2335-2343.
- [22] Nikhil Kanojia, Shivasheesh Kaushik, Subhan Ali, Ashish Joshi, Satyendra Singh, Aman Kumar, Bashishtha Kumar Rewani, Prince Kumar Gupta & Sahwaj Alam, (2022) Review on Sustainable Thermal Energy Storage Technology with Packed Bed Regenerator, *Neuro Quantology*, Vol. 20, 2324-2334.
- [23] Kuldeep Panwar & Shivasheesh Kaushik (2023) Investigation of Thermo-Mechanical Properties of Flue Gases Using CFD in Thermal Regenerator, *Res Militaris* (resmilitaris.net), vol.13, n°2, 1366-1376.
- [24] Nikhil Kanojia, Shivasheesh Kaushik, Mayank Singh & Manish Kumar Sha (2021) A Comprehensive Review on Packed Bed Thermal Energy Storage System, *Lecture Notes in Mechanical Engineering*, Springer Nature Singapore, 165-174, <https://doi.org/10.1007/978-981-16-0942-8>
- [25] Shivasheesh Kaushik, Kuldeep Panwar & Shubham Singh Karki (2023) Comparative Thermal Analysis and Characteristic Optimization of Cram Bed Regenerator for Space Warmth Applications in Mountainous Areas, *Res Militaris* (resmilitaris.net), vol.13, n°2, 1526-1539.
- [26] Shivasheesh Kaushik, Ashish Joshi, Nikhil Kanojia, Subhan Ali, Avinash Guleria, Aman Thakur, Mohit Nayal & Yash Khandsaliya (2022) Comparative Analysis of Physio-Chemical, Performance-E Emission Properties Between Diesel and varying blend of Castor Biodiesel with Iso-Propanol, *Neuro Quantology*, Vol.20, 2272-2285.
- [27] Shivasheesh Kaushik, Subhan Ali, Ashish Joshi, Kuldeep Panwar, Ashish Benwal, Arshad Khan, Divyanshu Kumar & Dheeraj Kumar (2022) Experimental Analysis of Performance and Emission Characteristic between Diesel and Varying Blends of diesel- Isopropanol-Biogas with different CR, *Neuro Quantology*, Vol. 20, 2272-2285.
- [28] Shivasheesh Kaushik, Vinay Sati, Nikhil Kanojia, Kuber Singh Mehra, Himanshu Malkani, Himanshu Pant, Hina Gupta, Abhay Pratap Singh, Aman Kumar, Ashwarya Raj Paul, Ritu Kumari (2021) Bio-Diesel a Substitution for Conventional Diesel Fuel: A Comprehensive Review, *Lecture Notes in Mechanical Engineering*, Springer Nature Singapore, 13-122, <https://doi.org/10.1007/978-981-16-0942-8>
- [29] C. Gnanavel, R. Saravanan & M. Chandrasekaran (2020) Heat transfer augmentation by nano-fluids and Spiral Spring insert in Double Tube Heat Exchanger – A numerical exploration, *Materials Today: Proceedings*, Vol. 21, Part 1, 857-861.
- [30] Marjan Goodarzi, A.Sh. Kherbeet, Masoud Afrand, Emad Sadeghinezhad, Mohammad Mehrali, Peyman Zahedi, Somchai Wongwises & M. Dahari (2016) Investigation of heat transfer performance and friction factor of a counter-flow double-pipe heat exchanger using nitrogen-doped, graphene-based nanofluids, *International Communications in Heat and Mass Transfer*, Vol. 76, 16-23.

- [31] W.H. Azmi, K. Abdul Hamid, N.A. Usri, Rizalman Mamat & M.S. Mohamad., (2016) Heat transfer and friction factor of water and ethylene glycol mixture based TiO₂ and Al₂O₃ nanofluids under turbulent flow, *International Communications in Heat and Mass Transfer*, Vol. 76, 24-32.
- [32] Xinfeng Zhai, Cong Qi, Yuhang Pan, Tao Luo & Lin Liang (2019) Effects of screw pitches and rotation angles on flow and heat transfer characteristics of nanofluids in spiral tubes, *International Journal of Heat and Mass Transfer*, Vol. 130, 989-1003.
- [33] Ashkan Alimoradi & Farzad Veysi (2016) Prediction of heat transfer coefficients of shell and coiled tube heat exchangers using numerical method and experimental validation, *International Journal of Thermal Sciences*. Vol. 107, 196-208.
- [34] Simin Wang, Guanping Jiana, Juan Xiaoa, Jian Wenb Zaoxiao Zhanga & Jiyuan (2018) Fluid-thermal-structural analysis and structural optimization of spiral wound heat exchanger, *International Communications in Heat and Mass Transfer*, Vol. 95, 42-52.
- [35] Ali Mostafazade Abolmaali & Hossein Afshin (2019) Development of Nusselt number and friction factor correlations for the shell side of spiral-wound heat exchangers, *International Journal of Thermal Sciences*, Vol. 139, 105-117.
- [36] Morteza Khoshvaght-Aliabadi & Farnaz Nozan (2016) Water cooled corrugated minichannel heat sink for electronic devices Effect of corrugation shape, *International Communications in Heat and Mass Transfer*, Vol.76, 188-196.
- [37] Xing Cao, Tingting Du, Zhan Liu, Hongyan & Zhai,Zhenya Duan (2019) Experimental and numerical investigation on heat transfer and fluid flow performance of sextant helical baffle heat exchangers, *International Journal of Heat and Mass Transfer*, Vol. 142, 118-437.
- [38] S. Mehra, S. Kaushik, G. Pant, S. Kandwal & A. K. Singh (2023) Finite Element Modeling and Parametric Investigation of Friction Stir Welding (FSW), *Advances in Industrial Machines and Mechanisms, Lecture Notes in Mechanical Engineering*, 251-259, https://doi.org/10.1007/978-981-16-1769-0_23
- [39] Fauzan, A., Ega, H. M., Sigalingging, J. A. & Nugroho, Y. S. (2021) Analysis of Heat Gains from Flat Plate Heater Measured using Multi-Axis Heat Flux Sensors. *Evergreen* 8, 844-849.
- [40] Zingre, K. T., Yang, X. & Wan, M. P. (2015) Performance analysis of cool roof, green roof and thermal insulation on a concrete flat roof in tropical climate. *Evergreen* 2, 34-43.
- [41] Mishra, S., Yadav, A., & Bhardwaj, P. (2023). An Experimental Analysis of Natural Heat Transfer between Rectangular Solid and Perforated Fins Having Different Perforation Characteristics, *EVERGREEN* Vol. 10, Issue 01, 366-371.
- [42] Dwivedi, S. P., Maurya, M. & Chauhan, S. S. (2021) Mechanical, physical and thermal behaviour of SiC and MgO reinforced aluminium based composite material. *Evergreen* 8, 318-327.
- [43] H. S. Shamsuddin, U. Abidin, H. Abd-Zaidan, & N. Mohd-Ghazali (2021) Effect of Wall Resistance on the Total Thermal Resistance of a Stacked Microchannel Heat Sink. *Evergreen* 8 (1), 138-145.
- [44] Gunjo, D. G., Yadav, V. K., & Sinha, D. K. (2022) Performance analysis of latent heat storage systems using CuO nanoparticles. *EVERGREEN*, Vol. 09, Issue 02, 292-299.
- [45] Dhiman, A., & Sachdeva, G. (2022) Energy and Exergy Analysis of a Pressurized Solar Cooking System Based on a Parabolic Dish Collector. *EVERGREEN*, Vol. 09, Issue 04, 1168-1180.
- [46] Ismaeel, A. A., Wahhab, H. A. A., & Naji, Z. H. (2021) Performance evaluation of updraft air tower power plant integrated with double skin solar air heater. *EVERGREEN*, Vol. 08, Issue 02, 296-303.
- [47] Alhamid, M. I., Rainanda, M. A., & Miftah, R. (2021) Effectiveness analysis of ozonation for prevention of corrosion and precipitation of crust in closed system cooling towers. *EVERGREEN*, Vol. 08, Issue 04, 904-909.
- [48] Shallal, B.A., Engin, G., Wahhab, H.A.A. & Ajel, M.G. (2023) Impact of Alumina Nanoparticles Additives on Open -Flow Flat Collector Performance for PV Panel Thermal Control Application. *EVERGREEN*, Vol. 10, issue 02, 870-879.
- [49] Kumar, R., Verma, S. K., Gupta, N. K., & Singh, S. K. (2022) Performance Enhancement of TSAH using Graphene and Graphene/CeO₂ -Black Paint Coating on Absorber: A Comparative Study. *EVERGREEN*, Vol. 9, issue 03, 673-681.
- [50] Saifullah, Z., Chandrashekara & M., Verma, G., (2023) Thermal Analysis of an Evacuated Tube Solar Collector using a One-end Stainless Steel Manifold for Air Heating Applications under Diverse Operational Conditions. *EVERGREEN*, Vol. 10, issue 02, 897-911
- [51] Dhiman, A., & Sachdeva, G (2022) Energy and Exergy Analysis of a Pressurized Solar Cooking System Based on a Parabolic Dish Collector. *EVERGREEN*, Vol. 9, issue 04, 1168-1180.
- [52] N. Olleh, N.A. Husain, H.M. Kamar, N.B. Kamsah, & M. Idrus Alhamid (2021) Outlets Airflow Velocity Enhancement of an Automotive HVAC Duct, *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, Vol. 08, Issue 01, 163-169.

- [53] Aiman.Y, M.Firdaus, M.N. Musa & S. Syahrullail (2021) The ϵ of Jet Impingement Cooling System on Various Flat Plate Surface, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 08, Issue 01, 187-192
- [54] H. S. Shamsuddin, U. Abidin, H. Abd-Zaidan & N. Mohd-Ghazali (2021) Effect of Wall Resistance on the Total Thermal Resistance of a Stacked Microchannel Heat Sink, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 08, Issue 01, 138-145.
- [55] A.S. Pamitran,, S. Novianto, N. Mohd-Ghazali & R.A Koestoer (2020) Flow Pattern of Two-phase Flow Boiling with Heat Transfer and Pressure Drop Using Natural Refrigerant (Propane) in Microchannel, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 07, Issue 04, 544-548.
- [56] A. S. Pamitran, S. Novianto & A. S. Santoso (2020) Intermittent Flow Pattern on Two Phase Flow Boiling with Horizontal Microchannel, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 07, Issue 01, 150-154.
- [57] Hielfarith Suffri Shamsuddin, Lee Wei Tong, Normah Mohd-Ghazali, Patrice Estellé, Thierry Maré & Maziah Mohamad (2021) Nanofluid-Cooled Microchannel Heat Sink with Carbon Nanotube, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 08, Issue 01, 170-176.
- [58] Yanuar, Ibadurrahman, A. S. Pamitran, Gunawan & Sealtial Mau (2020) Experimental Investigation On The Spiral Pipe Performance For Particle-Laden Liquids, EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, Vol. 07, Issue 04, 580-586.