CHAPTER 1

# INTRODUCTION

## BACKGROUND OF STUDY

In today’s scenario, the need to remove heat from heat-exchanging devices, such as heat exchangers, electrical devices, geothermal applications, etc., has become increasingly important in order to improve thermal system performance. Heat dissipation technology has advanced in many fields, including chemical handling, automotive (particularly in radiators and electronic circuit board cooling), aerospace applications, and waste heat recovery systems (Ahammed et al. 2016; Asirvatham et al. 2015; Brusly Solomon et al. 2013). (Zhao et al. 2016) and (Sabatier et al. 2016) A crucial phenomenon with many applications in the process and heat exchanger sectors is the increase of heat transmission with appropriate pressure drop in heat exchanger devices. The main problem in the heat sector is overheating, which can result in system failure and other heat losses, both of which significantly lower system efficiency (Hunt et al. 2017). Effective cooling is therefore a key requirement of the modern industry. A heat exchanger is the primary component needed for cooling since it transfers waste heat from hot to cold fluid. In the view forward, convectional heat transfer increase is crucial for the current thermal systems. Heat exchangers are employed in many applications, such as cooling and enhancing system performance. For instance, heat exchangers such air pre-heaters, condensers, feed water heaters, and super heaters are utilised in thermal power plants. Heat transfer rate and pressure drop across the heat exchanger are the two key factors that matter most in heat exchangers.

The present cooling systems cannot be meet by the traditional methods used, such as finned systems, heat sinks, cooling thermoelectric systems, etc. (Angeline et al. 2018; Godson et al. 2010). It is widely known that an increase in surface area can facilitate enhanced heat exchanges (Manova et al. 2020a; b; Nimmagadda et al. 2019; Tharayil et al. 2016, 2018; Tomy et al. 2016). It is also well known that the temperature differential between the flowing fluid and the surface and the contacting surface area determine the rate of heat transfer. The improvement of heat transfer can be achieved by many ways, namely passive technique, active technique, and their mixtures according to **Bodade Pradip et al. (2013)**.

Figure 1.1 explore the basic passive approach used for heat transfer rate. The surface treatment procedure is used for the basic passive technique. This method has a cheaper operating cost than the active method because it is simpler and doesn't require any extra electricity. This strategy makes use of a variety of surface treatment techniques, including the use of a fins, baffle, and the addition of surface roughness, the modification of pipe/channel geometry, the insertion of tape, etc. This is based on the idea that when flow is restricted for instance, by using baffles, the flow splits and recirculates close to the channel wall, increasing mixing and turbulence, which raises the rate at which heat is transferred. In general, natural convection works best for cooling electronic equipment by using air as the working fluid, which is less expensive because it requires less maintenance and cools down more quickly. However, in some cases, higher heat flux makes natural convection insufficient to cool such systems. As a result, the active approach to heat dissipation is more economical in higher flux scenarios.

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**Figure 1.1** Passive Method of enhancing heat transfer rate (<https://www.frontiersin.org/articles/10.3389/fther.2022.980985/full>)

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Figure 1.2 Active Method of enhancing heat transfer rate

(<https://www.smlease.com/entries/thermal-design/convection-convective-heat-transfer/>, <https://www.simscale.com/blog/active-and-passive-cooling/>)

As demonstrated in Figure 1.3, a combination of passive and active techniques is used. Because it increases heat transfer rate and makes the heat exchanger smaller, this technique is widely employed in all kinds of heat exchanger applications. Consequently, this technique is evident in the present heat exchangers, which are frequently compact and are used to cool small electronic devices such as computers, laptops, micro heat exchangers, and other electronic instruments. Nonetheless, the passive method of improving heat transfer is the only one being worked on in this effort.

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**Figure 1.3** Compound Method of enhancing heat transfer rate

([https://www.quora.com/Why-do-we-use-fins-in-heat-exchangers-What-is-the advantage-of-using-them-over-other-types-of-surfaces-e-g-tubes](https://www.quora.com/Why-do-we-use-fins-in-heat-exchangers-What-is-the%20advantage-of-using-them-over-other-types-of-surfaces-e-g-tubes), [https://en.wikipedia.org/wiki/Shell-and-tube\_heat\_exchanger](https://thermal.ferrotec.com/technology/thermoelectric/thermalRef05))

As the contacting surface area increases, heat transfer can be enhanced, as discussed above. As a result, researchers are paying closer attention to the use of nanofluid with various geometry of inserts in counter flow heat exchanger in order to enhance heat transfer in numerous additional applications. Researchers are becoming more and more interested in a unique area of fluid mechanics and heat transfer called fluid flow and heat transmission via nanofluid. In order to enhance heat transfer, researchers have been closely observing the use of nanofluid in industrial applications as well as automobile and solar applications as well. Nanofluid like cerium oxide nanofluid, titanium oxide nanofluid, graphene oxide nanofluid etc., can be better options to adopt for the enhancement of heat dissipation rate with least pressure drop comparatively other medium like porous media, extended surfaces and baffles. Further, also the heat transfer enhancement can be attained with the combination of nanofluid with various geometry of twisted tape (TT) inserts by varying the pitch length, varying width and depth ratios and varying the twist ratio as well.

## HEAT TRANSFER ENHANCEMENT

The augment of heat dissipation mechanism could be awareness of the authors at least one of the following. The heat transfer enhancement can be achieved by increasing the surface area, disrupting boundary layer thickness, introducing secondary fluxes, encouraging boundary layer separation, encouraging flow attachment or an attachment for increasing the fluids effective thermal conductivity under static conditions, increasing the fluids efficient thermal conductivity under dynamic conditions, delaying the formation of boundary layers; increasing the number of fluid molecules, redistributing heat, increasing the difference between surface areas and fluid temperatures, increasing the fluid flow rate passively and by increasing solid phase thermal conductivity using special nanotechnology fabrication. The mechanisms include fins that heat or cool the fluid and increase the surface area within contact; surface irregularities and fins with high or short fins that actively encourage wall turbulence, and spiral or helical fin geometry and twisted tapes that create swirl flow to create secondary flows.

### Applications of Nanofluid

The application of nanofluid encounter the enhancement of heat transfer in various engineering thermal systems. that include Generally, nanofluid promotes the thermal systems cooling like solar thermal collectors, thermal control elements used in space-crafts, chemical industries, automobile industries (car radiator), textiles, power plants, process industries, refrigeration and air-conditioning and waste heat recovery electronic appliances, mini-channel heat sinks [XX, XX]. The advantage of using nanofluid is to increase the thermal conductivity and convective heat transfer coefficient comparatively to the fluid. In heat exchangers, due the high thermal performance of nanofluid than water, it can have used in various processes of cooling and heating. The nanofluid used in few applications of the thermal systems are as shown in Figure 1.

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| (a) Fin type radiator [XX]. | (b) u-tube bend solar collector [XX]. |
| (C) Nanofluid in the heat pipe [XX]. | (d) Flat plate solar collector |

**Figure 1.4** Nanofluid used for some applications in thermal systems.

## NANOFLUID

The nanofluid are made by dispersion the nanoscale solid particles into base fluid water with low thermal conductivity, including water, ethylene glycol (EG), oils, etc. Because energy prices are rising, control over heat transfer is essential in many energy systems. Recently, some academics have proposed and examined the use of nanofluids technology to manage heat transfer in a process by numerical or experimental methods. The nanofluid can be used to solve engineering issues with chemical reactions, heat exchangers, and cooling electronic equipment. There are two methods to simulating of nanofluids which are known as single phase and two phase. In the first approach, researchers used the standard equations of mass, momentum, and energy and assumed that nanofluid were pure fluids and they determined only the influence of nanofluid properties are evaluated from the experimental method or theoretical method. These researchers claimed that there is a homogenous mixture of nanoparticles since there are no slip velocities between the nanoparticles and fluid molecules and the nanoparticles are in thermal equilibrium. In the second approach, researchers used the assumption that fluid molecules and nanoparticles move at different speeds. As a result, the volume fraction of nanofluid may no longer be consistent, and the concentration of nanoparticles in a combination may vary. Several researchers have utilised a variety of numerical and semi-analytical techniques to simulate heat transfer and nanofluid flow.

Improved performance and compactness of numerous technical equipment, including heat exchangers and electronic devices, are severely limited by the low thermal conductivity of typical heat transfer fluids, such as water, oil, and ethylene glycol mixture. There is great desire to create sophisticated heat transfer fluids with significantly better conductivity in order to overcome this drawback. Suspending tiny solid particles in a fluid is a creative method of increasing the thermal conductivities of the fluid. Slurries can be created by adding many kinds of powders, including metallic, non-metallic, and polymeric particles, to liquids. It is anticipated that fluids containing suspended particles will have higher thermal conductivities than ordinary fluids. A novel type of heat transfer fluid known as a nanofluid is made up of a limited number of evenly and steadily suspended nano-sized particles in a liquid, usually smaller than 100 nm. A tiny amount of soluble nanoparticles dispersed in traditional fluids significantly alters the fluids' thermal conductivity. The nanofluids exhibit a higher potential for raising heat transfer rates when compared to the methods currently in use for improving heat transfer.

### Advantages of nanofluid

The advantages of nanofluid are as follows.

* Higher specific surface area and therefore more heat transfer surface between particles and fluids.
* Higher dispersion stability with predominant Brownian motion of particles.
* Reduced pumping power with better heat transfer intensification.
* Reduced particle clogging as compared to regular slurries, thus promoting system miniaturization.
* Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.
* High thermal conductivity.

### Applications of nanofluids

Nanofluids have exceptional qualities may have allowed to use in a wide range of thermal applications. Nanofluid with various volume concertation are more common and are considered as a better candidate for heat emission in the heat exchanger, electronic industries and more others. Nanofluid are adopted in the following applications.

* Compact heat exchanger
* Electronic cooling
* Automotive applications
* Heat sinks
* Heat pipes
* Chemical industries
* Solar collectors

## TWISTED TAPE INSERTS

Heat exchangers find extensive use in a variety of sectors and engineering applications, including refrigeration, petrochemical and oil industries, heat exchangers, and chemical reactors. From an economic perspective, thermal performance intensification is crucial to the design of heat exchangers. Generally, it is critical to reduce the pumping power in order to increase heat exchanger efficiency. As a result, there can be a large reduction in operational costs. Furthermore, the advantageous is to size reduction of heat exchangers plays a significant role in thermal system design. In many various kinds of heat exchangers, swirl and vortex generators have been widely employed to improve heat transfer performance [9]. Swirl flow generally increases the fluid mixing between the core region and tube walls, which effectively disrupts the thermal boundary layer and raises the heat transfer rate [12]. The advantages of improving thermal performance of heat exchangers, different modified twisted tape (TT) have been developed.

Recently, twisted tape (TT), TT with cuts and holes are more and more popular techniques employed to improve thermal performance of the heat exchangers. The following are the primary physiological explanations behind the enhanced performance of TT inserts: (a) strong swirl flow created by TT, (b) secondary vortex flow formed near the cuts and holes which improves the turbulent intensity of the fluid flow, and (c) better fluid mixing between the tube walls and the core region. The modified TTs with cuts (square-cut, V-cut, etc.) provide superior heat transfer enhancement because the extra vortex flow through the cuts increases the fluids swirl flow and turbulent intensity. Nevertheless, little research has been done on how various cut ratios affect the intensification of thermal performance and the transmission of heat in turbulent flows. This has spurred the current study numerical analysis in an effort to comprehend the flow structure and underlying physical principles of the enhanced heat transfer via heat exchanger tubes with W-cut TT inserts. Additionally, as the majority of earlier research has concentrated on cut ratios smaller than 1, it is imperative to investigate the TTs efficacy at higher cut ratios. The purpose of this current study is to quantitatively explore the effects of turbulent fluid flow through heat exchanger tubes on streamlines, turbulent intensity, velocity fields, heat transfer, friction, and the thermal performance factor due to the W-cut TT inserts with variation in depth ratio and width ratios. Different types of inserts are employed for the enhancement of heat transfer is shown in Figure 1.5.

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**Figure 1.5** Different types of inserts used for the enhancement of heat transfer.

(<https://journals.sagepub.com/doi/full/10.1177/1687814020924893>)

## ORGANIZATION OF THESIS

**Chapter 1** explores the brief introduction about background, heat transfer enhancement, nanofluid, application of nanofluid, advantages of nanofluid and twisted tape inserts for the enhancement of heat transfer.

**Chapter 2** describes the critical literature on the current and previous studies on shell and tube heat exchanger with the use of nanofluids. Also, the literature review is further extended to twisted tape inserts inside the shell and tube counter flow heat exchanger with accommodation of nanofluid. In the view of similar chapter presents the summary of the literature, research gaps, scope and motive of current work and finally the objectives of the work are addressed.

**Chapter 3** gives the complete overview of the problem geometry, modelling of the porous medium, numerical domain and details of the numerical simulations, grid independence study and validation of the numerical results are addressed.

**Chapter 4** provide the details of numerical consideration of local thermal non-equilibrium (LTNE) and Darcy extended Frochheimer (DEF) models for the analysis of forced convection in a horizontal pipe in the presence of discrete and completely (different lengths) filled metal foams. This chapter also provides fluid flow distributions as well as solid-fluid temperature distributions of completely filed porous region of the conduit. Performance factor of discrete and completely filled metal foam is also examined in account of laminar, transition and turbulent flow regimes.

**Chapter 5** explore the numerical investigation of partially filled high porosity metal foam in a conduit/pipe imposed with uniform heat flux. The numerical investigation includes the six different models (numerical domain) with varying metal foam layer thickness from the conduit wall side and from core of the conduit. The fluid flow and temperature distributions are presented between porous and non-porous region of the conduit for various inlet velocity of air. Also, the results of Nusselt number, heat transfer enhancement ratio and thermo-hydrodynamic performance of partially filled foam pipe are plotted and discussed.

**Chapter 6** is a continuation of chapter 5. Optimization study is proposed for the multi-objective optimization trade-off between heat transfer and the pressure drop. The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method is applied for low and high Reynolds number to determine the optimum porous layer thickness for the maximization of heat transfer and minimization of pressure drop. This chapter provides the best configuration (model) of pipe/conduit to determine the location, PPI (Pores Per Inch) and porous layer thickness based on the requirement of thermal designer for weight of heat transfer and friction resistance.

**Chapter 7** highlights an overview of major conclusions of the work as well as a description of the specific contribution made. There is also a special mention of the scope of future work.

CHAPTER 2

# LITERATURE SURVEY

## INTRODUCTION

A heat exchanger system is required for energy utilisation, recovery, and conversion in any commercial, industrial, or residential application. Enhancing the heat exchange mechanism can reduce the total system cost and increase the thermal efficiency of any thermal system. In order to maximise efficiency and guarantee smooth operation, thermal systems utilised in engineering applications must be carefully designed. Numerous techniques can be applied to a broad range of technical applications to increase heat transmission. Heat sinks, phase-change materials, extended fin surfaces, micro-channels, nanofluid, and porous media are a few examples.

One of the most common processes in many engineering applications during the past few decades is the heat transport phenomenon through highly thermally conductive nanofluid and with inserts. Ensuring increased heat dissipation in various engineering applications such as heat exchangers, heat pipes, nuclear cooling, solar collectors, radiators, and heat sinks is the goal of the numerous documented heat management research. More high-performance cooling methods are therefore required to prevent the issues with traditional cooling equipment. There are benefits to using highly thermally conductive nanofluid and twisted tape (TT) inserts to improve heat transmission. Due to its use of twisted tape inserts and more specific area between the solid particles and fluid allow to mix the fluid leads to improve the convection coefficient and ultimately increase the thermal conductivity and therefore more heat transfer rate. Henceforth, with accommodation of nanofluid with TT inserts is one of the most promising method of heat transfer enhancer.

## FULLY FILLED POROUS MEDIUM IN A CONDUIT/CHANNEL

In the previous studies, many researchers have stated the thermal behaviour and effectiveness of fluid flow and heat transfer through forced convection in tube heat exchangers. Abd et al. [2] explored parametric study on performance of shell and tube type of heat exchanger. The study investigated in account the effect of tube length and shell diameter on convection coefficient and pressure loss with varying square and triangular pitches on shell side of the heat exchanger. At higher tube length of 0.61 m leads to augment in convection coefficient by 31.9% and pressure loss by 14.11% for the tube side. Also, with increasing the length of tube on shell side leads to increase in convection coefficient only 2.2% whereas the pressure drop was rise by 21.9%.

Son and Shin [3] performed the study on enhancement of heat transfer through shell and tube heat exchanger by providing spiral baffles fins inside the tube. The spiral baffles fins create more turbulence inside the shell leads to increase in efficiency of the heat exchanger. It is showed that, by introducing spiral baffles fins inside the shell side of the heat exchanger produces vortices in the flow field which leads to augment in heat transfer with considerable increases in the pressure drop.

De et al. [4] carried out numerical investigation on heat dissipation rate of shell and tube heat exchanger. In the study, helical baffles are designed in such way that the angle of helix is varying from 0° to 30°. The results revealed that, convection coefficient improves with increasing the inlet fluid velocity. Also, reported that the pressure drop decreases on shell side compared to straight conventional baffles heat exchanger. However, with increasing the angle of helix up-to 12° the pressure drop increases significantly and it lowers helix angle larger than 12°.

Elias et al. [5] explored the enhancement of heat dissipation rate accommodation of spiral helix angle in shell and tube heat exchanger. The geometry contains the dimensions of 7 tube made of copper with external diameter of 20 mm and 17 mm internal diameter, 600 mm in length and shell internal diameter of 90 mm, 110 mm outer diameter. They reported that, the optimum helix angle is found to 10° for better enhancement of heat transfer.

Swetha et al. [6] examined the experimental investigation on the performance of shell and tube exchanger in account of Al2O3 nanofluid. They reported that by varying the concentration of nanofluid the thermal conductivity of the fluid increases sharply until a certain limit. Henceforth, the use of nanofluid provides the satisfactory results in terms of convection coefficient, overall heat transfer coefficient at the cost of pressure drop.

Surana et al. [7] carried out numerical investigation on augment of heat transfer through shell and tube heat exchanger in consideration of Al2O3 nanofluid. The study concludes that, the overall heat transfer coefficient of the heat exchanger increases with the concentration of nanoparticle upto 1.25% and thereafter it decreases significantly. However, the pressure drop is found to be optimum with concentration of 1% Al2O3 nanofluid. Furthermore, with insertion of unequal baffles and convection coefficient increases and at the cost of pressure drop. (**up to taken from spiral coil inserts heat exchanger- first conference paper)**

(Rabbani et al. 2019) performed the experimental study on the heat dissipation of MgO nanofluid through the tubes partially filled with open-celled porous metal foam. Results reported that, the average convective heat transfer augment to a high as 9% and 15% for tube I and II, respectively, when compared to base fluid water. By utilizing Mgo nanofluid with partly filled with copper foam the heat transfer rate augment drastically with significant increase in the pressure drop.

(Pourfarzad et al. 2021) experimentally studied the effect of silver-water nanofluid concentrations through rectangular channel partially filled with copper foam. The inlet and outlet of the channel are made divergent and convergent sections. Results revealed that, metal foam filled channel could raise the top wall and bottom wall thermal convection coefficient by 1.6 – 3.7 times at highest *Re* number. Further, with use of nanofluid concentrations of 1000 ppm, 2000 ppm and 4000 ppm the heat convection coefficient was improved by 15%, 20% and 26%, respectively comparatively to deionized water.

(Torabi et al. 2016) reported the effect of nanofluid concentration on heat transfer and the entropy generation rate through partially filled porous channel. The nanoparticles concentration has negligible effect on temperature inside the porous insert. However, the concentration of nanoparticles will effect on the temperature flow inside the clear region of the channel. But with addition of 5% of volume concatenation of nanoparticles can enhance *Nu* number up to around 15%. However, the concentration of nanoparticles is almost independent of local entropy generation rate within the solid phase of the porous media. (**up to taken from my ph.D thesis**)

**Several researchers have investigated DPHEs using nanofluids.**

**Dalkılıç et al.** [27] studied the influence of nanoparticles’ (NP) addition to engine coolant oil in a finned DPHE to optimize the parameters such as heat transfer and drop in pressure. The NPs considered for study were Ti, TiO2, Al, Al2O3, Cu, CuO, graphene and multi-walled carbon nanotubes (MWCNT). They reported that with increase in number of fins, there is a rise in pressure drop as well as pumping power, which however, decrease with an increase in the cleanliness factor.

**Aghayari et al.** [28] explored heat transfer characteristics with the use of MWCNT blends and graphene nanofluid in double pipe heat exchanger (DPHEx). The MWCNT blends and graphene owing to their higher thermal conductivity and lower particle cost while Ti and TiO2 demonstrate the reverse trend. γ-Al2O3 nanofluids comprising particle size of ~20 nm and a volume fraction ranging from 0.1 to 0.3% were studied in a DPHEx. It was reported that the heat transfer coefficient as well as Nusselt number increased by 19 to 24%.

**Durga Prasad et al.** [29] analyzed the heat transfer characteristics of a U-tube heat exchanger fitted with helical tapes using Al2O3-water nanofluids (0.01-0.03% concentration by volume). The helical tapes of different pitch to diameter (p/d) ratios were used. They observed that the Nusselt number enhancement was 32.91% at p/d=5 and 0.03% by volume of nanofluid in comparison to water while the friction factor was 1.38 times higher at same conditions.

**Zheng et al.** [30] carried out experimental investigations on Al2O3/water nanofluids in a double pipe heat exchanger. They concluded that Nusselt number has enhanced with the enhanced nanoparticle volume concentration and Reynolds number but reduced with the reduction in temperature at the cold inlet.

**Han et al.** [31] also carried out similar work and produced similar results. Twisted tapes are the most promising passive techniques to create the turbulence in the heat exchangers and can potentially enhance the heat transfer rate.

**Krishna Varma et al.** [33] investigated Fe3O4/water nanofluids on a heat exchanger inserted with the inserts of varying cut radius twisted tapes. The Nusselt number enhancement of 32% with 1.21 times higher friction factor was observed using nanofluid when compared to the base fluid.

**Krishna Varma et al.** [34] used RSM method to optimize the parameters in a DPHE equipped with twisted tapes. They found that for maximum heat transfer and minimum friction factor, the optimum values of mass flow rate, radius of cut and angle of cut are 0.05 kg/s, 5.464 mm and 450 respectively.

**Krishna Varma et al.** [35] carried out CFD analysis on a return pipe heat exchanger fitted with perforated twisted tapes with an angle of 450. Their results demonstrate an enhancement of 55% in heat transfer using twisted tapes when compared to that plain tube.

**Sundar et al**. [36] have presented an experimental work related to MwCNT-Fe3O4 hybrid nanofluids. They reported that the Nusselt number has enhanced by 31% and friction factor has enhanced by 1.18 times greater than the base fluid. They also have proposed correlations for Nusselt number and friction factor. TiO2-water based nanofluids were studied by

**He et al.** [37] in a DPHE with nanofluid flowing through a vertical pipe in an upward direction. It was found that heat transfer coefficient increased with an increase in nanoparticle concentration at a given Reynolds number while the pressure drop with the nanofluid is close to the base fluid. Cerium oxide nanofluids have been considered in some applications such as heat pipes and solar energy applications.

**Kumar Gupta et al.** [38] considered CeO2/water nanofluids to evaluate numerically the heat pipe’s thermal performance. The volumes of the nanofluids used were 0.5, 1 and 1.5% by and the heat fluxes used were 10, 15 and 20 kW/m2. When compared with the base fluid, use of nanofluids resulted in a reduction in surface wall temperature and thermal resistance.

**Sreeremya et al.** [39] produced Ceria oil based nanofluids using single pot method. These nanofluids showed an enhancement in thermal conductivity of 14.6% compared to the base fluid.

**Sharafeldin and Gróf** [40] investigated the flat plate solar collector’s thermal performance using CeO2/water nanofluids with the volume fractions being considered as 0.0167, 0.0333 and 0.0666% and mass flux rates 0.015, 0.018 and 0.019 kg/s m2. The maximum rise in collector’s efficiency was 10.74% at a NF volume fraction of 0.0666% and a mass flux rate of 0.019 kg/s m2 when compared to that of water based collector.

**Sharafeldin and Gróf** [41] also considered the evacuated tube collectors (ETC) to evaluate their performance using CeO2/water nanofluids with the volume fractions of 0.015, 0.025 and 0.035%. It can be concluded from their results that there is a rise in temperature difference with an increase in NP concentration in base fluid. The maximum improvement in collector’s performance was 37.30% when compared to that of water collector under similar conditions. ~~In the literature, most of the experimental works carried out are performed to determine the convective heat transfer and flow characteristics of Al~~~~2~~~~O~~~~3~~~~, CuO, TiO~~~~2~~ ~~and MWCNT nanofluids~~**~~.~~ (Up to taken from Reddy first paper material research innovation)**

**Irshad et al. [XX]** (2022-case study in thermal engg.) experimentally investigated on the heat dissipation rate with the accommodation of hybrid nanofluid. The study considers new class of hybrid nanaofluid and which depends on multi-walled carbon nanotube (MWCNT) plus cupric oxide (CuO) nanocomposite produced from the base fluid as Therminol55 (TH55). They reported that, Thermal conductivity of fluid was considerably increased by 128.4% at the highest nanocomposite concentration of 0.08 wt%. Also, at Re = 12500 the highest exergy efficiency was observed to be 47.84% at 0.08 wt% concentration.

**Huang et al. [XX]** (IJHMT-2015) examined experimentally the pressure loss and heat dissipation rate of heat exchanger while the working fluid consider as MWCNT/water and Al2O3/water nanofluid. For a constant Re number, heat dissipation rate seemed to be better. However, marginal enhancement of heat transfer was observed at constant flow Re number. Further, in account of MWCNT/water nanofluids deteriorates the heat transfer rate more rigorous than Al2O3/water nanofluids.

**Zheng et al. [XX]** (2021-Fuel) experimentally performed with the effects of several arrangements magnetic fields on plate heat exchanger performance completely filled with nano-ferrofluids. Results revealed that, the heat transfer advanced by 21.8% with lessens 10% of pumping power with vertical arrangement of magnetic field outside the side walls.

**Ray et al. [XX]** (IJHMT 2014) performed experimental and numerical investigation on performance of nanofluid filled in a compact minichannel plate heat exchanger (PHE). The study reported that, with volumetric concentration of 1%, showed a significant improvement in the performance of nanofluid comparatively with the base fluid.

**Tiwari et al. [XX]** (IJHMT-2015) experimentally investigated the various concentration of nanofluid plate heat exchanger. Results reported that, in account of Al2O3/water, CeO2/water, SiO2/water and TiO2/water nanofluids, the optimal volume concentrations are observed to be 1%, 0.75%, 1.25% and 0.75% respectively, at constant flow rate of 3 lpm. However, enhancements in the heat transfer rate are observed to be about 26.3%, 35.9%, 13.9%, and 24.1% respectively, compared to the base fluid.

**Lin et al. [XX]** (IJMHT-2016) numerically investigated the characteristics of heat transfer study on water-based ZnO nanofluid under turbulent flow regimes. They reported that, results of friction factor dominates more for nanofluid relatively to base fluid water and it lessens with higher values of Re number. The performance evaluation criteria (PEC) of nanofluids and base fluid are smaller and higher than unity when the flow Re < 10,000 and Re > 10,000, respectively.

**Yurddas [XX]** (IJHMT-2020) studied proposed the optimization of solar collector thermal performance comprising various types of nanofluids. In their study considered different types of nanofluids viz: MWCNT, TiO2, SiO2 and Cu. They reported with 30º inclination angle relatively to tank, Cu-water nanofluid showed better heat transfer enhancement amongst the other nanofluids.

**Murshed et al. [XX]** (IJTS-2005) studied the influence of thermal conductivity enhancement of TiO2—water based nanofluid. The results showed with maximum 5% volume fraction of TiO2/water nanofluid with particle dimension of ∅10 nm × 40 nm and ∅15 nm attains 33% and 30% higher in thermal conductivity comparatively to the base fluid.

**Aliabadi [XX]** (ECM-2014) examined influence of various design parameters of sinusoidal corrugated channel on the heat transfer rate through Al2O3-water nanofluid flows under turbulent regime (i.e., Re = 6000 – 22,000). The channel wave amplitude and channel height have greater influences on friction factor and the Nusselt number, respectively. Also, corrugated channel with nanofluid attains maximum values of Nu number relatively to the base fluid while pressure drop for both water as well as nanofluid showed nearly similar results.

**Esfe et al. [XX]** (Energy-2017) studied the multi-objective optimization of MgO-water nanofluids flow under double pipe tube heat exchanger. Initially, the response surface method (RSM) and secondly, non-dominated sorting genetic algorithm were applied to optimize the cost involved in the process. They reported that, in account of optimization techniques the cost of system has reduced about nearly 38% relatively to best case.

**Darzi et al. [XX]** (ICHMT-2013) experimentally investigated the characteristics of heat transfer of Al2O3/water nanofluid flow in a double pipe tube heat exchanger. The experiment is carried out for various flow Reynolds number ranges from 5000 to 20,000, and different volume concentration of nanoparticles up to 1%. They recorded that, with use of nanoparticle concentration promotes good thermal performance of heat exchanger with lesser penalty of pressure drop.

**Anoop et al. [XX]** (ICHMT-2013) considered three different concentration of silicon dioxide–water (SiO2–water) nanofluid mass particle of 2%, 4%, and 6% are expressed by dispersing 20 nm diameter nanoparticles in distilled water. They reported that, nanofluid considered better enhancement in the convection coefficient than the base fluid. Also, the thermal performance factor is found to be higher for lower values of mass flow rates and while it reduces with increasing mass flow rate of the nanofluid.

**Reddy and Rao [XX]** (ICHMT-2014) performed experimental investigation on double pipe heat exchanger using ethylene glycol water based TiO2 nanofluid. They found that, the friction factor and heat transfer convection coefficient enhanced by 8.73% and 10.73% for the volume concentration of nanofluid of 0.02% relatively to the base fluid.

**Khedkar et al. [XX]** (ICHMT-2014) performed experimental investigation of concentric pipe heat exchanger using TiO2/water based nanofluid. For inner concentric tube is made of copper having length of 1000 mm. The study experimented for different values of heat fluxes. From the study they concluded that, at lower values of heat flux promotes the better efficacy of heat exchanger.

**Goodarzi et al. [XX]** (ICHMT-2015) experimentally examined the heat dissipation rate of corrugated plate heat exchanger with use of Gum Arabic MWCNT (MWCNT–GA), MWCNT with silver (MWCNT–Ag) and functionalized MWCNT with cysteine (FMWCNT–Cys). The nanoparticles weight percentages varied from 0.0% to 1.0% and the Re number ranges from 2500 to 10,000. They reported that, for specific pumping power and the heat extraction through the nanofluid dominates over the base fluid water.

**Zhao et al.** [28] [NHT] adopted Lattice Boltzmann method (LBM) for simulation of porous channel nanofluid heat exchanger. They reported that the LBM method provides the better results than the other methods. Also, at higher Darcy number, thermal performance of heat exchanger and Nusselt number declines on the heated blocks side.

**Zhang et al.** [29] [NHT] reported the characteristics of nanofluid heat transfer underneath magnetic field action depends on molecular dynamics flow sates. The ability of magnetic fields is to improve heat transfer rate in the magnetic nanofluids. In overall, the disorder thermal boundary layer instigated by the applied magnetic fields effect on the mobility of the magnetic nanoparticles which leads to gives magnetic nanofluids their increased capacity for heat transmission.

**Mohmoodi et al.** [30] [TAYLOR AND FRANCIS] studied how the rotating microchannel improved heat transmission and nanofluid flow. A larger total Nusselt number is offered by the Eulerian-Eulerian model (EEM) and Eulerian-Lagrange model (ELM) than by the single phase model (SPM). With increment of the rotating speed from zero to 600 for volume concentration of 5% the maximum heat transfer augmentations of 53.3%, 45.7%, and 41% are obtained for the EEM, ELM, and SPM, respectively. (**Up to taken from NHT first our paper**)

**Properties of nanofluids**

**Aghayari et al. (2014)** [9] explored the effect of addition of solid particles into the medium of heat transfer has been in use for long time, there are certain issues that these millimetre or micrometre sized particles when suspended can lead to some unavoidable problems such as abrasion, clogging, large pressure drop and sedimentation of particles. However, the nanoparticles, unlike suspended large particles, owing to their low concentration and nanometres size, can potentially prevent the sedimentation in the flow and hence the possibility of clogging.

**Menni et al. (2020)** [10] examined the addition of nanoparticles of diameter less than 100 nm can considerably enhance the thermal properties of conventional fluids. Nanofluids on a solid surface possess certain desirable properties such as better spreading, wetting, dispersion, stability and acceptable viscosity.

**Razzaque et al. (2016) [19]** examined the utility and design of metal oxide nanoparticles from the end functionalized polymer ligands. The cerium oxide nanoparticles manufactured from the end functioned polymer ligands. They reported that, cerium oxide at nanoscale will have a combination of cerium in 3+ and 4+ states on the nanoparticle surface. There is an increase in number of 3+ sites on the surface when nanoparticle diameter reduces with the loss of oxygen atoms.

**Henderson et al. (1999)** [20] explored the structure of CeO2 is like a fluorite with an FCC array of cubes that contain eight coordinates Ce4+ and four coordinates O2-. The CeO2 is a primary ingredient in the catalytic applications and reactions as its oxygen vacancies have high mobility and the reversible features of Ce4+/Ce3+is another reason. Moreover, the vacancies in the crystal structure of CeO2 result in strong bonding of adsorb ate molecules than the normal oxide sites and their dissociation is also easy.

**Kumaravelu et al. (2022)** [22] reported that the nanoparticles of CeO2 are more promising as nanomaterials (NM) owing to their superior physico-chemical properties, being inexpensive and non-toxic when compared to that of other metal oxide powders. Moreover, their ease of availability makes them an attractive alternative NM.

**Xu et al. (2014)** [23] determined that the cerium oxide nanoparticles (CeNP) are most promising candidates for engineering and biological applications such as solid-oxide fuel cells, materials for protection against high temperatures, materials for catalytic applications, solar cells and pharmacologically active agents.

**Dhall et al. (2018)** [24] explored wide variety of synthesis methods of cerium oxide nanoparticles (CeNPs). These methods are the solution precipitation, hydrothermal, solvo-thermal, thermal decomposition by ball milling, sol-gel method, spray pyrolysis and thermal hydrolysis methods. They found that the solvo-thermal and thermal decomposition methods are provides the best effective methods to determine the properties of cerium oxide nanoparticles.

**Suresh et al. (2016)** [25] explored the synthesized CeNPs from a powder mixture of cerium nitrate and sodium hydroxide (NaOH) by employing co-precipitation method. They have characterized the NPs using XRD and SEM analyses and prepared nanofluids of water-CeO2 with the volume fractions. It was reported that the thermal conductivity of prepared nanofluids enhanced by 18.10% at a volume fraction of 0.3% in contrast to the base fluid.

**Stalin et al. [26]** investigated the thermo-physical properties of CeO2-water nanofluidsby considering the volume fractions from 0.01-0.3%. They observed that there is an enhancement of thermal conductivity, coefficient of viscosity and coefficient of density by 35.97, 1.76 and 1.56% respectively at a volume fraction of 0.3%. The specific heat of nanofluid decreased by 5% at a volume fraction of 0.3% when compared to that at 0.01%. (**Up to taken from Reddy first Journal**).

**Literature on various type of inserts**

Prasad et al. [25] performed experimental study with use of trapezoidal cut inserts in a HEx tube. The Al2O3 nanofluid is considered as working fluid. They reported that, for 0.03% concentration of nanofluid the FF (friction factor) enhanced by 1.29 times comparatively to base fluid.

Singh and Sarkar [26] conducted the experimental study on hybrid nanofluid with various twist ratio of V-cut inserts in a double tube heat exchanger for the enhancement of heat transfer. They noticed that, FF and Nu increases with increasing depth ratio (DR), decreasing twist ratio (TR) and inlet temperature of nanofluid.

Nakhchi and Esfahani[27] explored the performance of a tube heat exchanger using double V-cut twisted tape inserts. The greatest value of performance factor (PF) was found at twist ratio of 1.8 and width ratio of 3 at Reynolds number 5000. Further, they reported that the augment of heat transfer by 48.0%, 64.3%, 86.0%, and 117.4% at twist ratios of 0.6, 1, 1.4, 1.8, comparatively to conventional twist tape insert.

Aghayari et al. [28] examined experimental and analytical studies of heat transfer enhancement through pipe heat exchanger insertion with twisted tape. The study considered two different nanofluid concentrations are 0.08% and 0.1% by volume and TR of TT changes from 2.5≤y/w ≤5.2. They reported that, with combined effects of TT and nanofluid, heat transfer improved significantly with no major discrepancy in the friction factor.

Ponnada et al. [29] studied the effect of perforated twisted tapes (PTT), perforated twisted tapes with alternate axis (PATT) and steady twisted tapes (TT) with twist ratios (TR) of 3, 4 and 5 under constant heat flux condition. For constant Reynolds number, PTT, PATT and TT attained superior TPF (thermal performance factor) are about 1.43, 1.39 and 1.24 respectively.

Ju et al. [30] numerically examined the performance of HEx encased with multiple semi-TT inserts using Al2O3 nanofluid. It was observed that more swirl flow streams happen with increasing semi TT inserts leads to increase Nu number as well as FF. The maximum PEC was found to be 1.33 at Re = 750 with 3% nanoparticles for the case of four semi-TT inserts.

Kumar et al. [31] explored the analysis of combined effect on performance of HEx tube with TT inserts and SiO2/H2O nanofluid. They reported that, maximum PEC attained to be 1.74 with *WT/DT*, *LT/DT* and nanofluid concentration are 0.8, 1.74 and 1.25% volume, respectively at Re = 11,000.

Nakhchi and Esfahani [32] explored the impact rectangular cut positioned inside the core region as well as near tube wall on HTR and pressure drop with swirl flow effect. The rectangular-cut TT makes it easier for fluid and centrifugal force to mix together close to the wall as a results better improvement in HTR and FF.

Noorbakhsh et al. [33] examined the various types of inserts inside the tube heat exchanger on pressure drop and heat transfer enhancement. The results indicated that CuO/water nanofluid at Re = 5492 has the highest thermal performance, with a 7% improvement above net water. Studied the effect of linearly decreasing/increasing pitch ratio on pressure drop and heat transfer reported detailed in ref. of Ahmad et al. [34].

Arjmandi et al. [35] performed the optimization study on geometric parameters of double pipe heat exchanger with twisted tape inserts and vortex generators. They reported that with combined turbulator and decreasing angle of vortex generators, both friction factor and Nu number increase significantly.

Sundar et al.[36] investigates thermal properties of hybrid nanofluid for the heat exchanger applications. With adoption of hybrid nanofluid with straight strip inserts cause a slighter increase in friction factor. However, 0.2% hybrid nanoparticles in water leads to penalty of fluid friction by 11%.

Eshan et al. [37] reported that nanofluid and twisted tape inserts for twin pipe HEx increase the efficiency and NTU of the heat exchanger. In addition, TPF for hybrid nanofluid in a PT at ϕ = 1.8% and Re = 8320 is nearly 1.068, but that the TPF increased to 1.33 and 1.37, respectively, when PTT (plain twisted tape) and double V-cut TT were inserted with hybrid nanofluid

Fouad et al. [38] explored the thermal performance of tube heat exchanger with twisted tape inserts and hybrid nanofluid is considered as working fluid. They reported that the friction increases with increasing the concertation of hybrid naofluid than the base fluid. Also, they reported that the friction factor and Nu number is even still more increases with use of nanofluid and twisted tape inserts.

Khargotra et al. [39] reported that the fluid is whipped up into a tangle of vortices and eddies by the twisted tape, which improves heat transfer and turbulence. The TBL (thermal boundary layer) at the pipe wall is broken up by the increased turbulence, which improves heat transfer from the fluid to the tube.

Li et al.[40]explored super critical carbon dioxide (SCO2) fluid for the augment of heat transfer in a heat exchanger equipped with TT inserts. They pointed out at higher mass flux and inlet pressure can decrease but at higher wall flux can increase the enhancement.

Sudheer and Madanan [41]observed THP improvement is believed to be primarily caused by the thinning of TBLs by secondary vortices and development of primary vortex the temperature and velocity fields starts re-development in a mini-channel configurations.

Stalin et al. [42] reported that there is no significant performance gain can be made because of the low thermal characteristics of water. Further, the study revealed that the numerous studies using base fluids and nanoparticles mixed in solar collectors that were carried out over the last decades and they noted that the nanofluid have huge potential to increase the efficiency of the thermal systems.