Frontiers in Heat and Mass Transfer (FHMT), 14, 30 (2020)
DOI: 10.5098/hmt.14.30

Global Digital Central
ISSN: 2151-8629

Frontiers in Heat and Mass Transfer

Available at www.ThermalFluidsCentral.org

A REVIEW ON EXERGY ANALYSIS OF NANOFLUID FLOW THROUGH SEVERAL CONDUITS

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ABSTRACT

This article presents an extensive review on exergy analysis of nanofluid flow through heat exchanger channels. The improvement of exergy efficiency of nanofluid flow through heat exchanger are determined by the net impact of the relative variations in the thermophysical properties of the nanoparticle which are sensitive towards numerous parameters including size and shape, material and concentration as well as base fluid thermal properties. Exergy efficiency of nanofluids flowing through heat exchanger is greater as compare to simple conventional fluids. The augmentation of exergy efficiency in the nanofluid flow through heat exchangers can be achieved by breaking laminar sub layer near the heating surface and can be efficiently done by employing obstacle as roughness elements. However, this gain is accomplished at the expense of decrease in pressure drop. Also exergy efficiency found to be augmented with the rise of the volume fraction with reduction in the value of nanoparticle diameter.

Keywords: *Exergy analysis, heat exchanger, nanofluid, heat transfer.*

1. INTRODUCTION

Exergy is defined as the maximum theoretical useful work obtained if a system is brought into thermodynamic equilibrium with the environment by means of processes in which the system interacts only with this environment (Enrico 2007). Such a final state of equilibrium is known as dead state. From another point of view, the exergy can be considered as a measure of the existing disequilibrium between the considered matter and the environment (Querol, et al. 2013). At the dead state, the combined system possesses energy but no exergy (Moran 1994), (McGovern 1990).

The critical role of the exergy analysis in the several engineering systems and processes including fuel cells, latent heat thermal energy storage, heat exchangers and thermal desalination of energy systems as well as identification of their actual and theoretical limits of performance were recognized by different researchers (Singh, et al. 2018) (Shabgard and Faghri 2019). Various researcher has provided the key insights on how the available energy (exergy) is being destroyed during the process and the ways to minimize its destruction through entropy generation minimization approach (Dutta and Biswas 2018), (Jedsadaratanachai and Boonloia 2018).

Nanofluids have the potential to enhance the thermal performance of high heat flux devices, such as in a nuclear reactor. The application of nanofluid can greatly improve the critical heat flux of the coolant so that there is a bottom-line economic benefit while also raising the safety standard of the power plant system. The safety system around the core of the reactor will include nanofluids to increase or decrease heat exchange efficiency through the control system is added to the control: the size, quantity and type of nanoparticles in the heat exchanger (Ahmed, Baig et al. 2019).

Two remarkable properties of nanofluids utilized are, one is the thermo-physical properties of nanofluids, enhancing the heat transfer and another is the application of nanofluids in solar collectors. (Nagarajan, Subramani et al. 2014). The idea behind using nanoparticle within the base (host) fluid is to increase the thermal conductivity of the carrying fluid, which leads to boosting the heat transfer phenomenon through the system. Use of conventional fluids like air and water in PV/T systems limits the amount of heat that can be transferred from the panel. Researchers have tried to eliminate this shortcoming by using nanofluids as a heat transfer carrier with higher thermal conductivities (Ahmad et al. 2020).

1.1 Basic points of exergy

Exergy of a thermodynamic system is the maximum theoretical useful work (shaft work or electrical work) obtainable as the system is brought into complete thermodynamic equilibrium with the thermodynamic environment while the system interacts with this environment only (Tsatsaronis 2007). The concept of exergy is based on the second law of thermodynamics and in practice relies heavily on the use of the thermodynamic property entropy (McGovern 1990). The word exergy was first coined by to determine the fractional portion of heat energy which can be converted into effective work under ideal conditions by the heat source under existing environment conditions. By using the exergy concept, the available quantity of the heat collected can readily be determined by taking into account both the quantity (heat quantity) and the quality (a function of temperature) of the thermal energy (Suzuki 1987).

Exergy is a property of two states, the state of the system and the state of the environment. Its magnitude can be looked upon as a measure of the departure of the state of the system from that of the environment (Kotas 1980). Exergy is not generally conserved but is destroyed. A limiting case is when exergy would be completely destroyed, as would occur if a system were to come into equilibrium with the environment spontaneously with no provision to obtain work (Moran 1994). The exergy concept is mostly used within energy engineering, where you work with energy of varying qualities. However, the field of application can be extended to the totality of energy and material conversions in the society. This yields a uniform description of the use of physical resources and environmental impacts in connection with this use (Wall 1990), (Dincer 2001), (Dincer 2010), (McGovern 1990).

2. PREVIOUS INVESTIGATIONS ON EXERGY ANALYSIS WITH NANOFLUIDS

Nanofluids are the most recent approach in more than a century of work to improve the thermal conductivity of liquids. The low thermal conductivity of conventional heat transfer fluids HTFs is a serious limitation in improving the performance and compactness of engineering equipment (Das et al. 2006).

Specifically, nanofluids are a novel class of nanotechnology-based heat transfer fluids that are engineered by stably suspending a small amount 1 vol % or less of particles, or tubes with lengths on the order of 1–50 nm in traditional HTFs. The concept and the term were proposed by Choi in the early 1990. Common heat transfer fluids such as water, ethylene glycol, and engine oil have limited heat transfer capabilities due to their low heat transfer properties (Li et al. 2018) and (Yimin 2000).

Cooling is one of the most important technical challenges facing many diverse industries, including microelectronics, transportation, solid state lighting, and manufacturing. There is, therefore, an urgent need for new and innovative coolants with improved performance (Manca et al. 2015).

2.1 Exergy analysis of Al_2O_3 based nanofluid flow through conduits

Chen and Ding (2011) examined the problem of forced convection heat transfer in a microchannel heat sink with pure water and water-based nanofluids containing γ- Al_2O_3 nanoparticles by modelling the microchannel as a fluid-saturated porous medium. They discussed effects of the inertial force term on the heat transfer behaviour and the MCHS performance are examined. Fig. 1 represents the schematic of the microchannel heat sink. The temperature distribution of the channel wall is found to be practically insensitive to the inertial effect, while the fluid temperature distribution and the total thermal resistance alter noticeably due to the inclusion of flow inertial force (Chen and Ding 2011).

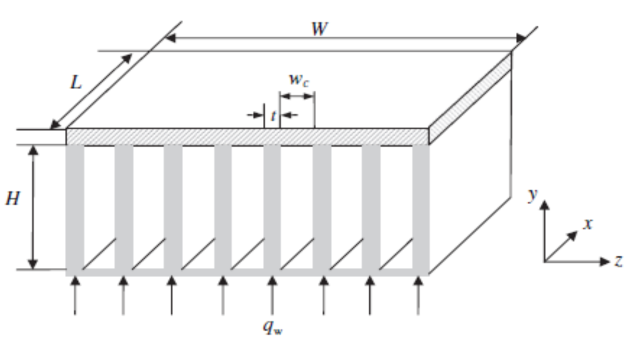

Fig. 1 Schematic of the microchannel heat sink(Chen and Ding 2011)

Hung et al. (2012) investigate mathematical model based on the first law and second law of thermodynamics of water-alumina nanofluids in circular microchannels during steady state. They observed that the rise of entropy generation induced by the rise of nanoparticle volume fraction is attributed to the rise of both the thermal conductivity and viscosity of nanofluid which causes augmentation in the heat transfer and fluid friction irreversibility, respectively. Manca, Nardini et al. (2012) carried out 2-D ribbed channel with square and rectangular ribs, mounted on the principal walls and heated by a uniform heat flux. The fluid was a mixture of water and Al_2O_3 nanoparticles. They observed that the highest Nu values were evaluated for P/e= 8 and 10 for square and rectangular shapes, respectively. Fig. 2 represent the schematic of ribbed height and rib parameters.

Moghaddami, Shahidi et al. (2012) numerically observed the entropy generation of water- Al_2O_3 nanofluid flow through a circular pipe with constant heat flux wall boundary condition in laminar and turbulent regimes. They observed that increasing Re and nanoparticle concentration outcomes in a decrease in heat transfer entropy generation while it rises the friction entropy generation.

Hassan et al. (2013) examined the entropy generation in nanofluids was evaluated using two different models for conductivity and viscosity. For alumina-water (Al_2O_3 -H_2O) nanofluid under laminar flow regime in microchannels, it was observed that the ratio of entropy generation for the nanofluid over the base fluid is greater than unity, and the ratio rises with the rise in solid volume fraction.

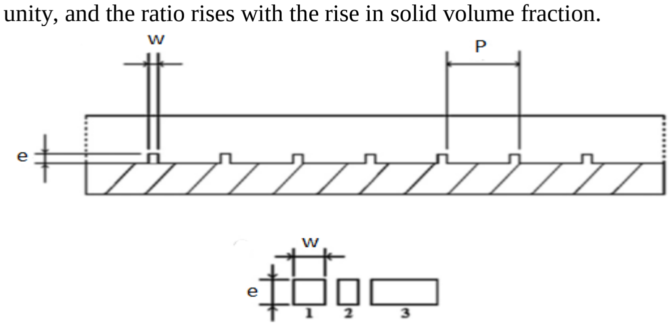

Fig. 2 Schematic of rib channel geometries (Manca, Nardini et al. 2012)

Sohel et al. (2013) analysis the entropy generation of a turbulent flow through the circular microchannel and minichannel heat exchanger is comparatively discussed using two different base fluid and nanofluid at various volume fraction. Entropy generation decreased by the increasing of volume fraction of both type of nanoparticle dispersed in H_2O and EG. The entropy generation rate ratio in microchannel was lower than the unity and it decreased by the increasing of volume fraction. The entropy generation rate increment at much greater rate by the increasing of the diameter of the flow channel for both microchannel and minichannel. Ting et al. (2013) investigate an analytical analysis for the effect of viscous dissipation on the second-law performance of water-alumina nanofluid flow in a circular microchannel subjected to exponentially decaying wall heat flux. The total entropy generation and fluid friction irreversibility in the fluid are overrated when viscous dissipation effect is neglected.

Chen et al. (2014) numerically examined heat transfer performance, viscous dissipation effects and entropy generation behaviour of a fully-developed mixed convection flow of Al_2O_3–water nanofluid within a vertical channel with asymmetric heated walls. In performing the simulations, the velocity and temperature fields within the channel have been solved using the differential transformation method (DTM). The equivalent thermal expansion coefficient of the Al_2O_3 nanofluid is less than that of pure water.

Kianifar et al. (2014) carried out an analytical analysis to analysis the effects of tube roughness, nanoparticle size, and different thermophysical models on the heat transfer and entropy generation in a flat plate solar collector using Al_2O_3 /water nanofluid with volume fraction by 4% and for constant mass flow rates. Nu decreases with increasing the volume fraction while an rise in the size of nanoparticles rises the Nu. The trend of changes in outlet temperature and Nu is exactly opposite, so that the volume fraction and nanoparticle size in which the outlet temperature is maximized can be determined by minimization of the Nu without doing long calculations.

Das et al. (2014) show an experimental result within 1 to 2% between the test data and the predicted values of the heat transfer rate and the overall heat transfer coefficient for water flow in the PHE by the SWEP modelling software. Fig. 3 represents the plate heat exchanger internal view. On the basis of equal pumping power of 0.586W while transferring about 2.5 kW of heat Al_2O_3 nanofluid gave a heat transfer surface area reduction of about 0.86%. Although this area reduction is small, further optimization with different heat transfer, flow rates and different volumetric concentration may yield improved surface area reduction.

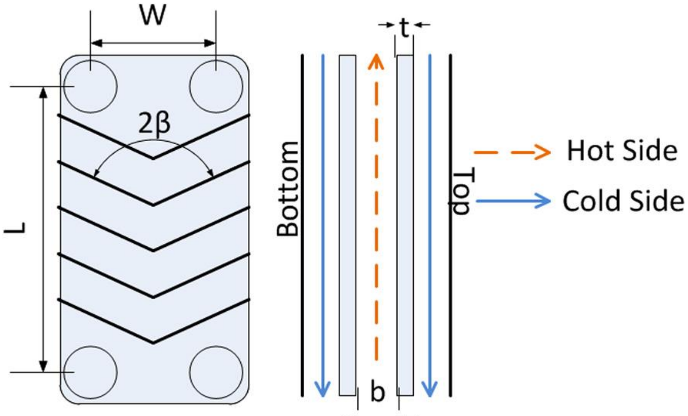

Fig. 3 Plate heat exchanger internal view (Das et al. 2014)

Hajialigol et al. (2015) examined laminar mixed convection and entropy generation in a three-dimensional microchannel filled with Al_2O_3–water nanofluid under a magnetic field. The rise in heat transfer by increasing volume fraction is larger at greater Re. They observed that thermal entropy generation has a major contribution in the total entropy generation compared to frictional and magnetic one. Fig. 4 represent schematic geometry of the physical model.

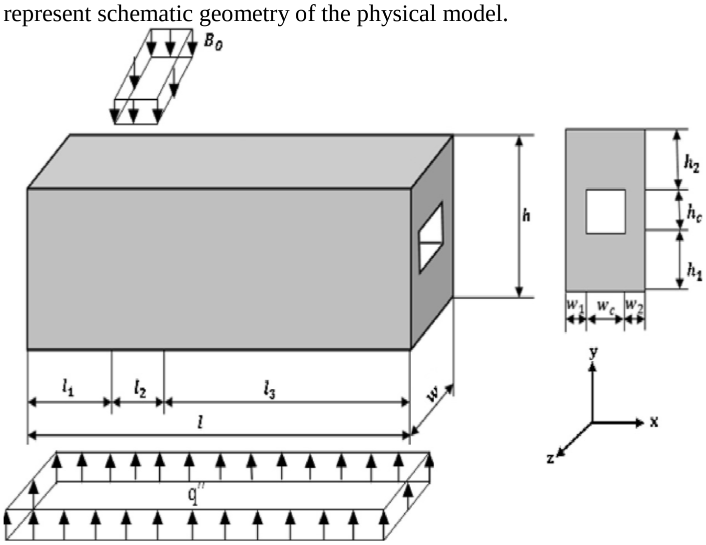

Fig. 4 A schematic geometry of the physical model (Hajialigol et al. 2015)

Shojaeizadeh et al. (2015) investigate the exergy efficiency of a Flat-plate solar collector containing Al_2O_3–water nanofluid as base fluid. Fig. 5 illustrates schematic of the solar collector. The effect of various parameters like mass flow rate of fluid, nanoparticle volume concentration, collector inlet fluid temperature, solar radiation, and ambient, temperature on the collector exergy is examined. They observed that when nanoparticles are presented in the base fluid the maximum collector exergy efficiency is increment about 0.72% and also the corresponding optimized values of mass flow rate and collector inlet fluid temperature are decreased about 67.8% and 1.9% respectively.

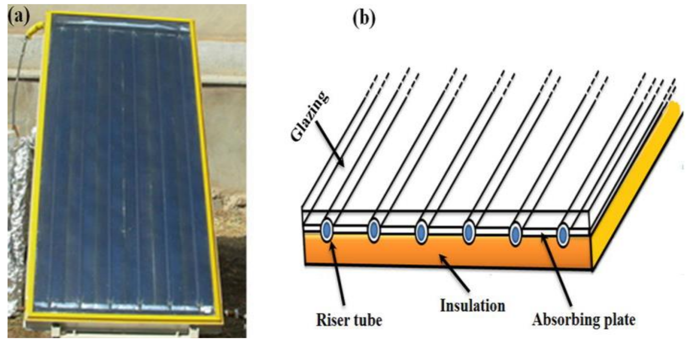

Fig. 5 Schematic of the solar collector (Shojaeizadeh et al. 2015)

Armaghani et al. (2016) analysed the natural convection heat transfer and entropy generation of Alumina- water nanofluid in baffled L-shaped cavity by numerical method.

Khoshvaght-Aliabadi and Sahamiyan (2016) examined Thermal–hydraulic behaviour of a corrugated minichannels heat sink (CMCHS) using the Al_2O_3 /water nanofluid by an experimental approach. Fig. 6 show schematic patterns of CMCHSs and isometric drawing of MCHS. The effects of geometrical parameter (wave-length and wave-amplitude), nanoparticles weight fraction, and mass flow rate are examined. They observed that the Al_2O_3/water nanofluids show a better cooling performance compared to the base fluid.

Said et al. (2016) carried out an experimental research to investigate the thermal performance of a flat plate solar collector using respectively deionized water and water-based Al_2O_3–nanofluid with different sizes as the working liquid. They observed that with smaller size of nanoparticles better stability, thermal conductivity as well as better energy and exergy efficiencies are obtained. Fig. 7 represents the flat plate collector with nanofluids flow inside the tubes by Shojaeizadeh and Veysi (2016). They observed that the optimum exergy efficiency and each of corresponding optimum parameters (mass flow rate of fluid, nanoparticle volume concentration and collector inlet temperature) decrease exponentially with increasing T_a/G_t values (i.e. ambient temperature to solar radiation ratio).

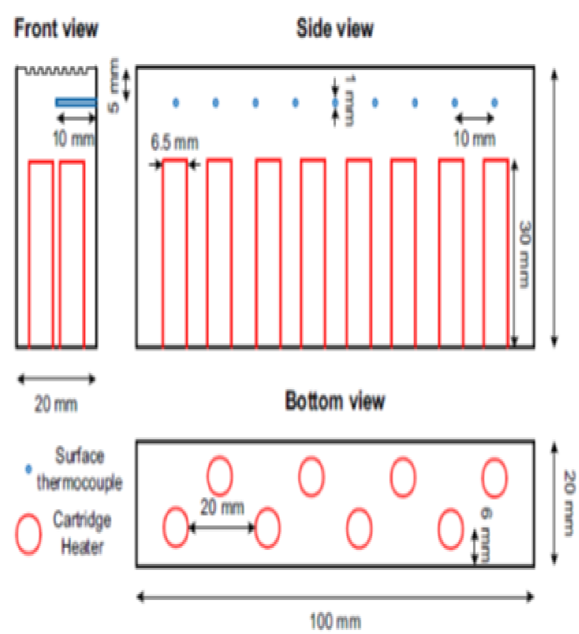

Fig. 6 Schematic patterns of CMCHSs, isometric drawing of MCHS (Khoshvaght-Aliabadi and Sahamiyan 2016)

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DOI: 10.5098/hmt.14.30
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Fig. 7 Pictorial view of solar collector (Shojaeizadeh and Veysi 2016)

Edalatpour and Solano (2017) examined numerically the various parameters of heat transfer in a 30-degree inclined three-dimensional tube-on sheet flat plate solar collector working under conjugated laminar mixed convection. The simulations were performed for water with different concentrations of Al_2O_3 nanoparticles. Nu decreases as the volume fraction of alumina/ water nanofluid rises, whereas when the Re rises, the Nu also rises. Gangadevi et al. (2017) analysis the PV/T system was experimentally examined with water, 1wt% and 2 wt% of Al_2O_3/water nanofluid. The hybrid PV/T system overall performance totally depends on the suspension sustainability of the coolant used. Their outcomes showed that the PV panel temperature increment up to 70 degrees which may cause the reduction of PV panel life. When circulating the 2 wt% Al_2O_3/water nanofluid the temperature of the PV panel decreased into 36 degrees.

Rashidi et al. (2018) used a volume of fluid (VOF) model to investigate the potential of Al_2O_3-water nanofluid to improve the productivity of a single slope solar still. Moreover, an entropy generation analysis was performed to evaluate the system from the point of view of the second law of thermodynamics. They observed that the maximum values of viscous and thermal entropy generations are happened at the regions around the bottom and top surfaces of the solar still. Both types of entropy generation rise by increasing the solid volume fraction of nanoparticles.

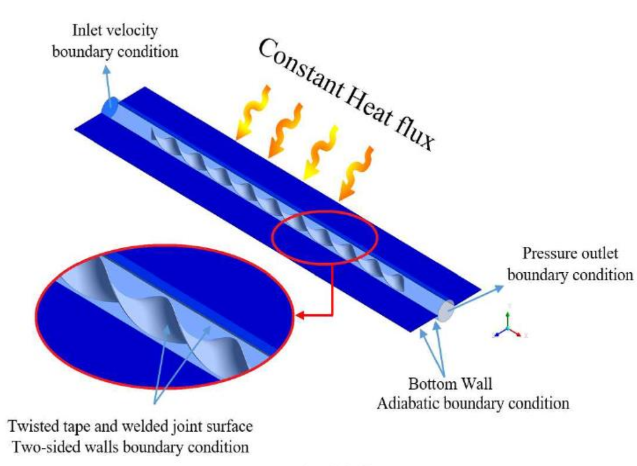

Fig. 8 Schematic view of twisted tape (Farshad and Sheikholeslami 2019)

Arora, Fekadu et al. (2019) focuses on a comparative analysis of nanofluids (i.e. Al_2O_3-water) and water and their effects on performance of Marquise shaped channel flat plate solar collector. The observed outcomes illustrate that their collecting efficiencies are all superior to that of water. The exergy efficiency of the water/Al_2O_3 nanofluid is also greater compared to that of water. Farshad and Sheikholeslami (2019) investigates numerically exergy loss and heat transfer within a solar collector shown in Fig. 8 with insertion of helical tape inside the pipe. Al_2O_3-water nanofluid is selected among other nanofluids which are more common in solar application due to its greater usage and lower price. Also they observed that the adding nanoparticles leads to the exergy loss reduction because of the growth of particles interaction.

Table.1 represents the previous investigation on exergy analysis of Al_2O_3 based nanofluid flow through conduits.

Table 1 Previous investigation on exergy analysis of Al_2O_3 based nanofluid flow through conduits.

Author (s)	*Description*	*Conclusion*
Singh et al. (2010)	Microchannel and conventional channels with laminar and turbulent flow	They observed that after a particular diameter the entropy generation ratio becomes constant or rises very slowly.
Chen and Ding (2011)	Microchannel heat sink	Their investigation showed that the temperature distribution of the channel wall is found to be practically insensitive to the inertial effect, while the fluid temperature distribution and the total thermal resistance alter noticeably due to the inclusion of flow inertial force.
Hung et al. (2012)	Circular microchannels	Incorporating the viscous dissipation effect, both thermal performance and exergetic effectiveness for forced convection of nanofluid in microchannels
Manca et al. (2012)	Ribbed channels	The highest values of overall performance parameters for pitch ratio is 8.0.
Moghaddami et al. (2012)	Turbulent and laminar regimes	It is observed that unlike the laminar regime, the total entropy generation of water-Al_2O_3 nanofluid flow could be more than that of pure water in high Res, restricting the advantage of using water-Al_2O_3 nanofluid.
Hassan et al. (2013)	Micro- and minichannels	The application of alumina-water nanofluids to a minichannel is advantageous.
Sohel et al. (2013)	Circular microchannel and minichannel heat sink	Copper nanoparticle generates much lower entropy than the alumina nanoparticle.
Tiew et al. (2013)	Circular microchannel	Heat transfer irreversibility of nanofluid decreases at small Re, suggesting an ideal operating region to improve the exergetic effectiveness of the flow when the heat transfer irreversibility

DOI: 10.5098/hmt.14.30

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		is the dominant source of entropy generation in the flow.
Chen et al. (2014)	Vertical channels	By contrast, in the regions of the flow field characterized by a greater and more uniform velocity distribution, i.e., the central region of the channel, the total entropy generation rate is dominated by the effects of fluid heat transfer
Mahian et al. (2014)	Solar collector	The effects of roughness in entropy generation are more important when the solar radiation and ambient temperature Decreases
Ray et al. (2014)	Compact minichannel	Copper oxide gave a 4.78% reduction in the volumetric flow rate, and 1.73% reduction in the required pumping power, when compared with the base fluid, which was EG/W.
Hajialigol et al. (2015)	3-D microchannel	The maximum dimensionless horizontal velocity along the center line of the microchannel is affected by varying Hartmann numbers. Maximum horizontal velocity decreases as the Hartmann number rises. In other words, the suppression effect of the magnetic field is emerged only at the central region.
Shojaeizadeh et al. (2015)	Flat-plate solar collector	When nanoparticles are presented in the base fluid the maximum collector exergy efficiency is increment about 0.72% and also the corresponding optimized values of mass flow rate and collector inlet fluid temperature are decreased about 67.8% and 1.9% respectively.
Armaghani et al. (2016)	Baffled L-shaped cavity	Heat transfer decreases via going up towards warm wall. As dimensional ratio grows nanofluid has more effect on Nu increasing.
Khoshvaght and Sahamiyan (2016)	Corrugated minichannels	This high PEC suggests that applying the compound technique examined in this investigation (corrugated minichannels + nanofluid) can be a good choice in practical applications to enhance the heat transfer performance of MCHSs.
Shojaeizadeh and Veysi (2016)	Flat-plate solar collector	It was concluded that each of optimized parameters and the optimum exergy efficiency was of a linear relation with each other.
Edalatpour and Solano (2017)	Tube-on-sheet flat plate solar collectors	Compared to the pure water, heat transfer coefficient proliferates from 10% to 65% as the volume fraction of the Al_2O_3/water nanofluid rises.
Gangadevi et al. (2017)	Hybrid PV/spiral flow thermal collector	The result shows that by using 2 wt% Al_2O_3/water nanofluid the electrical efficiency, thermal efficiency and overall efficiency of the PVT system enhanced by 13%, 45%, and 58% respectively compared with water and 1wt% of Al_2O_3-water nanofluid.
Rashidi et al. (2018)	Single slope solar still	The amounts of the evaporation and condensation heat transfers are improved in the still by adding the Al_2O_3 nanoparticles.
Arora et al. (2019)	Marquise shaped channel solar flat-plate collector	The innovative design of the absorber plate (marquise shaped channel) and use of nanofluids enhances the efficiency of solar flat collector.
Farshad and Sheikholeslami (2019)	Solar collector utilizing twisted tape	Secondary flow intensifies with rise of diameter ratio while exergy loss reduces with it.

2.2 Exergy Analysis of CuO based nanofluids flow through conduits

Chein and Huang (2005) analyzed performances of MCHS using nanofluids as the coolant. Fig. 9 signify Geometric configuration of MCHS. The enhancement is due to the rise in thermal conductivity of coolant and the nanoparticle thermal dispersion effect. The other advantage in using nanofluid as coolant in the MCHS is that there is no extra pressure drop produced since the nanoparticle is small and particle volume fraction is low.

Li and Kleinstreuer (2008) compared two effective thermal conductivity models for nanofluids where the new model, based on Brownian-motion induced micro-mixing, achieved good agreements with the currently available experimental data sets. The thermal performance rises with volume fraction; but the extra pressure drop, or pumping power, will somewhat decrease the beneficial effects. MCHS with nanofluids are expected to be good candidates for the next generation of cooling devices.

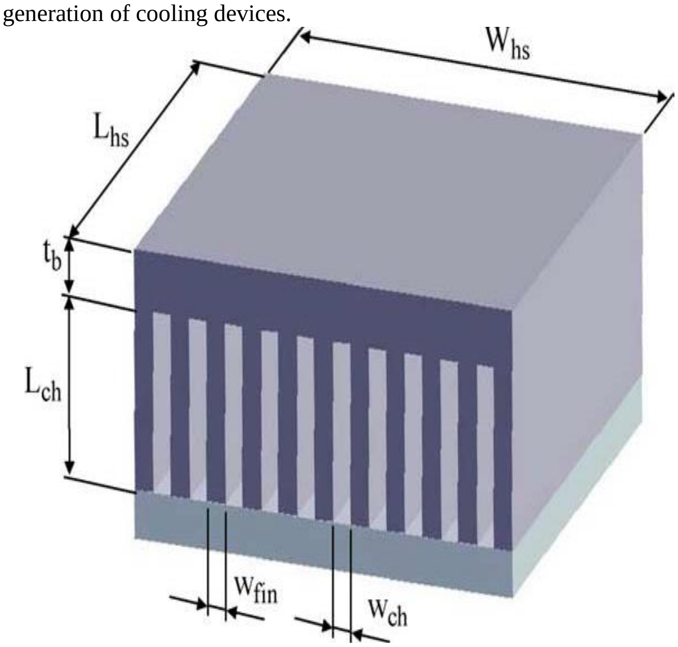

Fig. 9 Geometric configuration of microchannel heat sink (Chein and Huang 2005)

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Jie Li (2010) examined entropy generation in laminar microchannel flow with a computer model, which was validated with benchmark analytical and numerical outcomes. Nanofluids and pure water were selected as potential coolants for three cases of trapezoidal microchannels with the same hydraulic diameter and base angle but different aspect ratios. They observed that the entropy generation decreases with the rise in the fluid inlet temperature, which reduces local temperature gradients.

Khorasanizadeh et al. (2012) analysis Irrespective of the location of the conductive baffle, Nu_m rises by increasing Ra number and φ. For Ra $=10^4$ the conduction is the dominant mechanism of heat transfer and as the baffle moves toward the centre of the cavity the conduction mitigates, thus Nu_m decreases. For Ra $= 10^5$ and Ra$=10^6$ by displacing the baffle toward the centre of the cavity the convection gets stronger and the trend for Nu_m is to rise. The total entropy generation decreases by increasing the Ra for all volume fractions and all positions of conductive baffle.

Khairul et al. (2014) focused on the benefits of using CuO/water nanofluids in a corrugated plate heat exchanger. Analytical outcomes reveal that, CuO/water nanofluids could reduce the exergy destruction by 24%, 16.25% and 8% for 1.5 vol. %, 1.0 vol. % and 0.5 vol. % of nanoparticles, respectively compared to water. Therefore, average 34%, 22% and 12% enhanced exergetic heat transfer effectiveness is found for 1.5 vol. %, 1.0 vol. % and 0.5 vol. % of nanoparticles compare to water. Michael and Iniyan (2015) tested a novel photovoltaic thermal collector were fabricated and its performance using 0.05% volume fraction CuO/water nanofluid. The nanofluid has been proved to rise the thermal efficiency up to 45.76%.

Chamkha et al. (2017) numerically examined effects of the presence of a heat sink and a heat source and their lengths and locations and the entropy generation on mixed convection of a Cu-water nanofluid in a porous media filled in a lid-driven square enclosure with partial slip and subjected to a magnetic field. Increasing the volume fraction of the nanoparticles decreases the convective heat transfer inside the porous cavity for all ranges of the heat sink and the heat source lengths. Abdollahi-Moghaddam et al. (2018) experimentally examined the heat transfer enhancement and pressure drop of CuO/water nanofluid. The experiments were performed in a horizontal tube in which the wall had a constant temperature. The heat transfer coefficient and pressure drop of nanoparticle volume fraction of 0% to 0.7% were measured at various Res. The outcomes showed that heat transfer of nanofluid rises by increasing Re and volume fraction of nanoparticles.

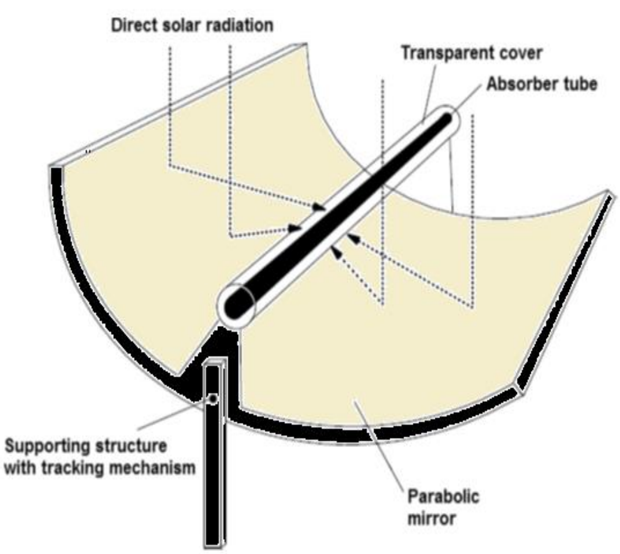

Fig. 10 Parabolic trough collector (Allouhi et al. 2018)

Allouhi et al. (2018) examine the benefits of using nanofluids as working fluids in parabolic trough collectors for medium and high temperature applications. Energy and exergy analyses were carried out based on real fluctuating operating conditions. Fig. 10 illustrate parabolic trough collector. The exergy efficiency varied between 3.05% and 8.5 % for the base fluid case and gets improved more remarkably when nanofluids are employed. The peak exergy efficiency is attained by the CuO based nanofluid and is about 9.05%. Bellos et al. (2018) investigates the dispersion of CuO nanoparticles in Syltherm 800 and in nitrate molten salt for operation in a parabolic trough collector. Moreover, it is found that the maximum exergetic efficiency is achieved for the molten salt case when the inlet temperature is equal to 650 K and then the exergetic efficiency is about 38.4%.
Table.2 represents the previous investigation on exergy analysis of nanofluids flow based through conduits. Table.3 shows the previous investigation on exergy analysis of CuO based nanofluid flow through conduits.

Table 2 Previous investigation on exergy analysis of nanofluids flow based through conduits.

Electrical efficiency of the PV/T collector		
Author (s)	*Nanofluids used*	*Major findings*
Michael and Iniyan (2015)	CuO with glazing	Electrical efficiency is 5.3% at 10:30 max. 5.8% at 12:15 and min. 3.2% at 15:30
	CuO without glazing	Electrical efficiency is 6.4% at 10:00 max. 7.4% at 12:15 and min. 4.8% at 15:30
	Water with glazing	Electrical efficiency is 5% at 10:30 max. 5.9% at 12:15 and min. 3.2% at 15:30
	Water without glazing	Electrical efficiency is 7.8% at 10:30 max. 8.4% at 12:15 and min. 5.2% at 15:30
	Reference PV	Electrical efficiency is 7.9% at 10:30 max. 8.6% at 12:00 and min. 5.1% at 15:30
Thermal efficiency of the PV/T collector		
	Water with glazing	Thermal efficiency is 16% at 10:00 max. 17% at 12:00 and min. 13% at 15:30
	Water without glazing	Thermal efficiency is 14% at 10:00 max. 15% at 12:30 and min. 13% at 15:30
	CuO with glazing	Thermal efficiency is 20% at 10:00 max. 27% at 12:45 and min. 21% at 15:30
	CuO without glazing	Thermal efficiency is 18% at 10:00 max. 23% at 12:45 and min. 18% at 15:30
Overall efficiency of the PV/T collector		
	CuO with glass	Overall efficiency is 31% at 10:00 max. 42% at 12:45 and min. 31% at 15:30
	CuO without glass	Overall efficiency is 35% at 10:00 max. 43% at 12:15 and min. 31% at 15:30
	Water with glass	Overall efficiency is 29% at 10:00 max. 33% at 12:30 and min. 25% at 15:30
	Water without glass	Overall efficiency is 35% at 10:00 max. 37% at 12:00 and min. 30% at 15:30
	Reference PV	Overall efficiency is 20% at 10:00 max. 22% at 12:15 and

DOI: 10.5098/hmt.14.30 ISSN: 2151-8629

		min. 18% at 15:30

Table 3 Previous investigation on exergy analysis of CuO based nanofluid flow through conduits.

Author (s)	*Description*	*Conclusion*
Chein and Huang (2005)	Microchannel heat sink	The advantage in using nanofluid as coolant in the microchannel heat sink is that there is no extra pressure drop produced since the nanoparticle is small and particle volume fraction is low.
Li and Kleinstreuer (2008)	Trapezoidal microchannel	Microchannel heat sinks with nanofluids are expected to be good candidates for the next generation of cooling devices.
Jie and Li (2010)	Trapezoidal microchannels for steady laminar flow	Employing certain nanofluids as coolants may further benefit the minimization of entropy generation in microchannel heat sinks.
Khorasanizadeh et al. (2012)	Cavity with an embedded conductive baffle	Due to enhanced viscose effects with improved convection, the maximum entropy generation occurs when the baffle is at the middle of the bottom wall. The Bejan number rises with increasing Ra number, since heat transfer irreversibility rises while viscose irreversibility decreases.
Khairul et al. (2014)	Corrugated plate heat exchanger	The performance of a heat exchanger can be enhanced by converting the working fluid with nanofluids.
(Michael and Iniyan 2015)	Copper sheet laminated photovoltaic thermal collector	The reduced electrical efficiency using the CuO/water nanofluid, the electrical and thermal efficiencies of the discussed solar photovoltaic/thermal collector can be further improved if the heat exchanger is re-designed for the new nanofluid.
Chamkha et al. (2017)	Lid-driven square porous enclosure with partial slip	Increasing the volume fraction of the nanoparticles decreases the convective heat transfer inside the porous cavity for all ranges of the heat sink and the heat source lengths.
Abdollahi-Moghaddam et al. (2018)	Horizontal tube	Heat transfer of nanofluid rises by increasing Re and volume fraction of nanoparticles.
Bellos et al. (2018)	Parabolic trough collector	The use of Syltherm 800-CuO leads to 0.65% mean thermal enhancement compared to pure Syltherm, while the use of molten salt- CuO leads only to 0.13% mean thermal efficiency enhancement.

2.3 Exergy analysis of TiO_2 based nanofluids flow through conduits:

Leong et al. (2012) carried out an analytical investigation on the entropy generation of a nanofluid flow through a circular tube with a constant wall temperature. Total dimensionless entropy generation is reduced with nanoparticle volume fractions. About 10.8% reduction is observed with an addition of 7% alumina volume fraction compared to base fluid. About 9.7% reduction is observed for 4% titanium dioxide nanofluid. Titanium dioxide nanofluids offer lower total dimensionless entropy generation compared to that of alumina nanofluids.

Mahian et al. (2013) investigate analytical analysis of the second law of thermodynamics to the effect of using TiO_2-water nanofluid (up to 2 vol %) on entropy generation between two rotating cylinders in the presence of magneto hydrodynamic flow. The outcomes for the local entropy generation analysis reveal that entropy generation is highest near the inner cylinder due to the maximum gradients of velocity and temperature. It also was found that the rise in the Hartmann number outcomes in an rise in the average entropy generation number.

Said et al. (2015) found that thermal conductivity improvement is directly related to the volume fraction and enhances up to 6% with 0.3 vol% of TiO_2. Also the energy efficiency increment by 76.6% for 0.1 vol% and 0.5 kg/min, whereas the highest exergy efficiency achieved is 16.9% for 0.1 vol% and 0.5 kg/min, using the nanofluids in comparison to the water. The solar collector efficiency using the TiO_2 nanoparticle has greater energy and exergy efficiencies than water.
Khaleduzzaman et al. (2016) experimentally analysis exergy and entropy generation of TiO_2–water nanofluid for cooling of a water block as an electronic device. The organized TiO_2–water nanofluid was passed through the water block heat sink with the concentrations of 0.10 vol. %. Exergy outlet, exergy gain, and exergy efficiency were found to be greater in the case of nanofluid. However, exergy efficiency and exergy outlet were increment by the rise of flow rate. Besides, the exergy gain was fallen with the rise of flow rate of coolant.

Yazdanifard et al. (2017) analysis a linear parabolic trough CPV/T system shown in Fig**.** 11 Besides, the effects of various geometrical parameters, including concentration ratio, pipe length, and pipe diameter, on the system performance in laminar and turbulent flow regimes were examined. The outcomes showed that with increasing concentration ratio, the PV and outlet temperatures rise in both flow regimes. The total energy efficiency in turbulent flow rises, while the total energy efficiency in laminar flow first rises, and then decreases at a particular concentration ratio.

Qi et al. (2018) experimentally examined and analysed heat transfer and flow behaviour of $TiO_2 - H_2O$ nanofluids in a circular tube with rotating and static built-in twisted tapes by exergy efficiency. $TiO_2 - H_2O$ nanofluids in circular tube with rotating twisted tape shows an excellent enhancement in heat transfer, which can rise the heat transfer by 13.1% at best compared with nanofluids in circular tube with static built-in twisted tape at the same condition. The exergy efficiency of the circular tube with twisted tape is greater than that of circular tube under the same pumping power and pressure drop, while it shows deterioration under the same mass flow rate. Zhao et al. (2019) experimentally examined the flow and heat transfer behaviour of $TiO_2 - H_2O$ nanofluids in CPU heat sink. An exergy efficiency evaluation plot is developed and can guide the working condition and nanoparticle concentration choice.
Table.4 shows the previous investigation on exergy analysis of TiO_2 based nanofluid flow through conduits.

Table 4 Previous investigation on exergy analysis of TiO_2 based nanofluid flow through conduits.

Author (s)	*Description*	*Conclusion*
Leong et al. (2012)	Nanofluid flow in A circular tube	Titanium dioxide nanofluids offer lower total dimensionless entropy generation compared to that of alumina nanofluids.
Mahian et al. (2013)	Two rotating cylinders with magnetohydrodynamic flow	With respect to the second law of thermodynamics, using nanofluids for the flow between two rotating cylinders in the presence of a

DOI: 10.5098/hmt.14.30
ISSN: 2151-8629

		magneto-hydrodynamic field is suggested only at low Brinkman numbers.
Said et al. (2015)	Flat plate solar collector	The solar collector efficiency using the $TiO_2 - H_2O$ nanofluid has greater energy and exergy efficiencies than water.
Khaleduzz et al. (2016)	Water block	Based on exergy (outlet exergy increment 87%) and pressure drop (increment 47.93%) values, 1.5 l/min flow rate of $TiO_2 - H_2O$ nanofluid was found as the optimal flow rate in terms of performance.
Yazdanifar d et al. (2017)	Photovoltaic/thermal system	Employing phase change materials or thermoelectric devices for cooling purpose, and examining different nanofluids such as hybrid nanofluids, or nanofluids contained graphene, nanorods, and nanotubes particles in CPV/T systems are strongly recommended.
Qi et al. (2018)	Rotating twisted tape	$TiO_2 - H_2O$ nanofluids in circular tube with rotating twisted tape shows an excellent enhancement in heat transfer, which can rise the heat transfer by 13.1% at best compared with nanofluids in circular tube with static built-in twisted tape at the same condition.
Zhao et al. (2019)	CPU heat sink with rectangular grooves and cylindrical bugles	For rectangular grooves structure, high exergy efficiency is sensitive to large depth groove (H=2 mm), small Re (Re < 545) and small nanoparticle (ω=0.1%). For cylindrical bulges structure, high exergy efficiency is sensitive to aligned arrangement, small Re (Re < 642).

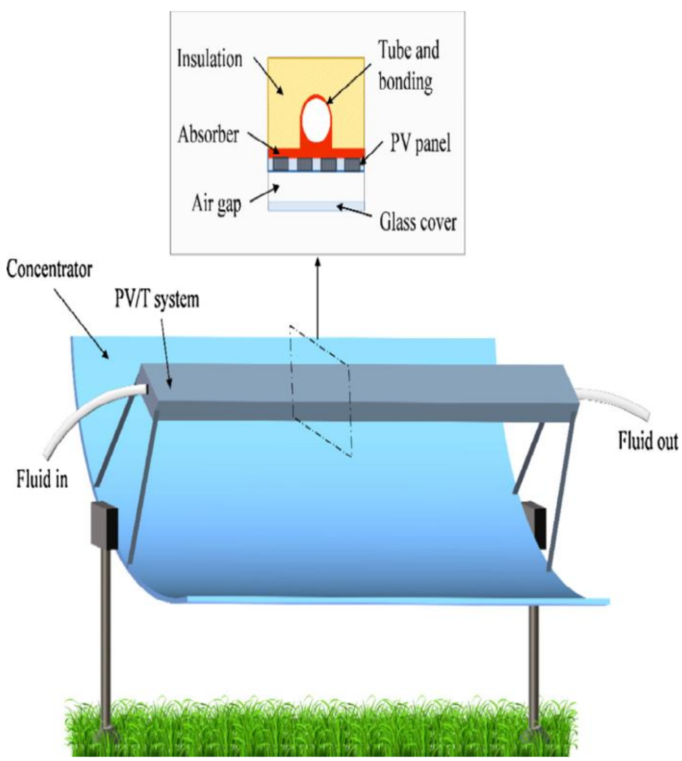

Fig. 11 Linear parabolic trough CPV/T (Yazdanifard et al. 2017)

2.4 Exergy Analysis of ZnO based nanofluids flow through conduits

Kumar et al. (2016) performed experimental work for detailed energetic and exergetic behaviour of PHE for ZnO/water nanofluid at varying particle volume concentrations ranges from 0.5% to 2.0%, at different chevron angles β = $30^0/30^0$, $30^0/60^0$ and $60^0/60^0$ of the plate. Their outcomes showed that when particle volume concentration reaches 1.0 vol. %, performance parameters exhibits optimum response. This optimum concentration corresponds to maximum heat transfer rate for all chevron angles in PHE.

Sardarabadi et al. (2017) analysis designing and fabricating two PVT and PVT/PCM systems, the positive effects of using these collectors as cooling systems for a photovoltaic module and investigate it experimentally. The thermal and electrical outputs of the systems as the critical parameters are compared with each other and with those of a conventional similar photovoltaic module as the reference system. Integrating the fluid-based collector of the PVT system with a PCM medium is considered as a new approach that can improve the system performance. The average thermal energy output of the PCM/water-based collector is increment by 42% in comparison with the case of the water-based collector without a PCM medium. This value is about 48% for the case of PCM/nanofluid based collector in comparison with the case of the nanofluid based collector. From the exergy analysis outcomes, it is found that in the PVT fluid/nanofluid based collector system with the PCM medium, the overall exergy efficiency of the system is increment more than 23%, in comparison with a conventional PV system.

2.5 Previous investigation on exergy analysis of Graphene based nanofluid flow through conduits

Esfahani and Languri (2017) organized graphene oxide in-house and used for nanofluid development and characterization. The graphene oxide was organized by oxidizing purified natural flake graphite via the modified Hummers method. The 0.01 and 0.1 wt. % graphene oxide NFs showed about 9% and 20% greater thermal conductivity compared to DI water at 25^0C, respectively. Different parameters such as effect of NFs concentrations, temperatures and flow rates of exergy destruction was examined experimentally. Comparing the exergy loss of graphene oxide NFs to DI water showed that DI water caused 22% and 109% greater exergy losses when compared to NFs at 0.01 and 0.1 wt. % concentrations in laminar conditions, respectively.

Bahiraei et al. (2018) examined second law behaviour including entropy generation, exergy destruction, and second law efficiency for flow a novel nanofluid containing graphene–silver nanocomposite in a micro heat exchanger. A low exergy destruction happens in the wall due to the small temperature gradient in it. In comparison with the contribution of friction, rise of the Re intensifies the contribution of heat transfer to the exergy destruction, while rise of the concentration decreases it. The second law efficiency reduces by increasing either Re or concentration. Nazari et al. (2018) examined effects of applying graphene oxide nanofluid in thermal performance of a PHP are examined. Graphene oxide nanofluid in four concentrations (0.25 g/lit, 0.5 g/lit, 1 g/lit, and 1.5 g/ lit) were used as working fluid in the PHP. Their outcomes are showed that the increasing concentration worsen thermal performance of the PHP which is attributed to rise in dynamic viscosity of working fluid.

2.6 Exergy Analysis of Hybrid based nanofluid flow through conduits

Ahammed et al. (2016) experimentally examined entropy generation analysis and heat transfer behaviour of alumina, graphene, and hybrid nanofluids in a multiport minichannel heat exchanger coupled with a thermoelectric cooler. Total entropy generation in the minichannel heat exchanger decreases by 31.86% with for graphene–water nanofluid; whereas it is only 19.6% and 6.15% for hybrid and alumina nanofluids respectively. The graphene–water nanofluid makes an enhancement of 88.62% in the convective heat transfer coefficient; whereas it is 63.13% and 31.89% for hybrid and alumina nanofluids respectively.

Bhattad et al. (2018) focused on the energetic and exergetic performance of counter flow plate heat exchanger with corrugation using hybrid nanofluid has been done for the milk chilling application. They observed that the performance index and irreversibility distribution ratio decrease with the nanofluid flow rate due to rise in pressure drop and pumping power. For the examined ranges, a maximum enhancement of 9.4% and 1.6% have been found in the heat transfer coefficient and heat transfer rate, respectively, for the PG based alumina silver hybrid nanofluid in comparison to the base fluid.

Maddah et al. (2018) investigation is concentrated on the advantages of passive techniques utilization in exergy efficiency of a double pipe heat exchanger. Their analysis showed that applying nanofluids and twisted tapes boost up the exergy efficiency in comparison to utilizing conventional water as a heat transfer fluid. Moreover, increasing the nanoparticles volume concentration, uplifting the Re, reduction in twist ratio, all together can significantly raise up the exergy efficiency.

2.6.1 Ag-SiO_2 based nanofluid

Crisostomo et al. (2017) developed a detailed optical and heat losses model which allowed for the estimation of the electric and thermal outputs in addition to the heat loss break-down under different testing conditions used in concentrating PV/T collectors. This theoretical heat losses analysis revealed that by insulating the thermal receiver with a vacuum layer could lead to a reduction of 40% or 50% of the total heat loss.

2.6.2 MgO based nanofluid

Verma et al. (2016) experimentally observed the impact of mass flow rate and particle volume fraction on the efficiency of the collector. The finding reveals that a use of MgO nanofluid rises the efficiency of solar collector in comparison with water as working fluid by 9.34% for 0.75% particle volume fraction. Exergetic efficiency enhanced by 32.23% compare to water.

2.6.3 SWCNTs based nanofluid

Said, Saidur et al. (2014) focuses on analysis of thermal performance of using SWCNTs nanofluids as an absorbing medium in a flat plate solar collector and compared with other oxide based nanofluids. Second law of thermodynamics is used to investigate the performance of a solar collector operated with various nanofluids. Analytical outcomes revealed that SWCNT nanofluid could reduce the entropy generation by 4.34% and enhance the heat transfer coefficient by 15.33% theoretically compared to water as an absorbing fluid. With greater volume fraction of nanoparticles in fluids, greater heat transfer can be achieved.

2.6.4 MWCNT Nanofluid

Fayaz et al. (2018) present both numerically and experimentally performance evaluation and comparison of a PVT system operated by water and MWCNT-water nanofluid. FEM based software COMSOL Multiphysics has performed the numerical simulation. Their analysis showed that MWCNT-water provides significant advantages regarding thermal energy as well as electrical power, which makes the solar systems more efficient and compact.

3. COMPARATIVE ANALYSIS

3.1 Comparison of Al_2O_3 and CuO nanofluids

Ebrahimi et al. (2016) numerically examined heat transfer and single-phase laminar flow structures in a three-dimensional microchannel equipped with longitudinal vortex generators. Water- Al_2O_3 and water-CuO nanofluids with different nanoparticle volume-fractions and sizes were compared to pure-water as working fluids. In addition, nanofluids with greater nanoparticle concentrations although again cost greater pressure drop, result in greater heat transfer enhancement. Khairul et al. (2017) analysed Al_2O_3/DI-water and CuO/DI-water nanofluids with three different nanoparticles weight concentrations. Both the Al_2O_3/DI-water and CuO/DI-water nanofluids showed a noticeable rise in heat transfer coefficient in comparison to the DI-water for all flow regimes (laminar, transitional, and turbulent). Their outcomes showed that the friction factor was decreased as either the Re as well as weight fraction of nanoparticles in the nanofluids increment.

3.2 Comparison of CeO_2/water and ZnO/water nanofluids

Kumar et al. (2017) focused on experimental analysis of using ZnO/water nanofluid over CeO_2/water nanofluid and water in a PHE. The temperatures of hot fluid (water) and cold fluid (water/nanofluids) at inlet are fixed at 50°C and 25°C respectively. Their outcomes showed that the outcomes reveal that, ZnO/water nanofluid could reduce the exergy loss 5.81%, 3.57%, 4.39% and 6.43% for entire range of volume flow rates compared to CeO_2/water nanofluid. Overall performances of ZnO/water nanofluid is better than water and CeO_2/water nanofluid for all operating conditions.

3.3 Comparison of TiO_2 and Al_2O_3 nanofluids

Mahian et al. (2012) applied the Second Law of thermodynamics to analysis the effect of using nanofluids on entropy generation between two concentric rotating cylinders with isoflux boundary conditions. Their outcomes showed that the entropy generation decreases with rises of volume fraction of nanoparticles where the contribution of heat transfer to entropy generation is dominant in the annulus. The outcomes show that TiO_2/water nanofluid is more suitable than Al_2O_3-EG nanofluid to use as the working fluid at low Brinkman numbers. Table. 5 shows the previous investigation on different nanofluids flow through conduits.

Table 5 Previous investigation on different nanofluids flow through conduits.

Author (s)	*Nanofluid*	*Type of channel*	*Conclusion*
Crisostomo et al. (2017)	Ag –SiO_2	Hybrid PV/T collector	The two most concentrated NFs acting as selective absorbing fluids in the experimental set-up could deliver 9% more value than the same PV cell array illuminated with the full concentrated solar spectrum.
Verma et al. (2016)	MgO	Flat plate solar collector	Economically we can make compact collector by reducing surface area about 12.5% when using nanofluid compare to conventional fluid

			water.
Fayaz et al. (2018)	MWCNT Nanofluid	PVT system	Use of MWCNT-water provides significant advantages regarding thermal energy as well as electrical power, which makes the solar systems more efficient and compact.
Bahiraei and Heshmatian (2017)	Novel Biological Nanofluids	Liquid block heat sink	Irreversibility in the whole liquid block decreases by increasing either concentration or Re, which is a positive result based on second law of thermodynamics.
Al-Waeli et al. (2017)	SiC-PCM	Nano based photovoltaic thermal system	The operation of a PV/T system using nano-SiC-PCM and nanofluids improves the thermal and electrical energy and rises the overall energy of the system more than any PV/T system.
Said et al. (2014)	SWCNT Nanofluids	Conventional flat plate solar collector	It has been found that SWCNTs based nanofluids have better thermal properties and this consequently led to improved thermal and exergetic efficiencies compared to the metal oxide nanofluids.
Sardarabadi et al. (2017)	ZnO/ water nanofluid	Photovoltaic thermal systems	The overall exergy efficiency of the system in the PVT fluid/nanofluid based collector system with the PCM medium, is increment more than 23%, in comparison with a conventional PV system.
Kumar et al. (2017)	Comparison of CeO_2-water Zno/water nanofluids	Plate heat exchanger	Overall performances of ZnO/water nanofluid is better than water and CeO_2/water nanofluid for all operating conditions being considered.
Mahian et al. (2012)	Comparison of TiO_2 and Al_2O_3 nanofluids	Co-rotating cylinders	TiO_2/Water nanofluid is more suitable than Al_2O_3 /EG nanofluid to use as the working fluid at low Brinkman numbers.
Ebrahimi et al. (2016), Khairul et al. (2017) and Allouhi et al. (2018)	Comparison of Al_2O_3 and CuO nanofluids	Micro channels, parabolic trough collector	CuO/DI-water nanofluids has the highest energy efficiency and heat transfer coefficient, as well as lowest friction factor and exergy loss. The peak exergy efficiency is attained by the CuO based nanofluid and is about 9.05%.

Fig.12 represents the comparative analysis of entropy generation ratio vs volume fraction with various nanoparticles such as Al_2O_3-EG, $Al_2O_3-H_2O$, $Cu-EG$ and $Cu-H_2O$. It can be observed that the Al_2O_3-EG based nanolfluid flow through conduits is better entropy generation as compared other based nanofluid. Fig.13 signifies the comparative analysis of entropy generation ratio vs Re with various values of volume fraction such as $\phi=0.01$, $\phi=0.02$, $\phi=0.03$ and $\phi=0.04$. The experimental outcomes showed that the value of $\phi=0.01$ is greater entropy generation ratio as compared other values of volume fraction such as $\phi=0.02$, $\phi=0.03$ and $\phi=0.04$.

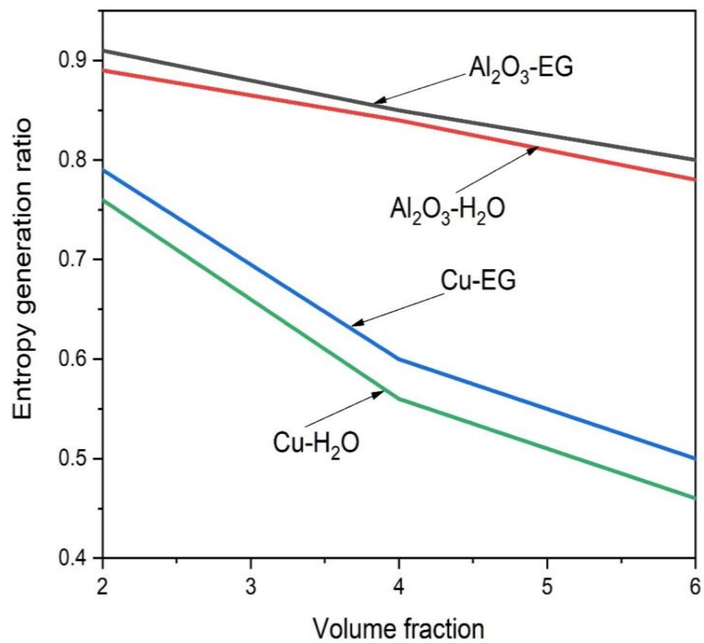

Fig. 12 Comparison entropy generation ratio vs volume fraction with various nanofluids (Sohel et al., 2013)

Fig.14 signifies the comparative analysis of exergetic efficiency vs volume flow rate with various nanofluids such as $ZnO-H_2O$, CeO_2-H_2O and pure water with fixed value of nanoparticle concentration of 0.5%. The experimental outcomes showed that with $ZnO-H_2O$ based nanofluid flow through conduits greater exergetic efficiency as compared other nanofluids and pure water. Fig.15 signifies the comparative analysis of exergy vs Re with various values of volume fraction such as ϕ=0 (Vol%), ϕ=0.01 (Vol%),ϕ=0.03 (Vol%), ϕ=0.3 (Vol%) and ϕ=0.5 (Vol%). The experimental outcomes showed that the value of ϕ=0 (Vol%), is greater value of exergy as compared other values of volume fraction such. Fig.16 signifies the comparative analysis of outlet exergy vs flow rate with TiO_2-H_2O and pure water. The experimental outcomes showed that TiO_2-H_2O based nanofluid flow through conduits is greater value of outlet exergy as compared with pure water.

Frontiers in Heat and Mass Transfer (FHMT), 14, 30 (2020)
DOI: 10.5098/hmt.14.30
Global Digital Central
ISSN: 2151-8629

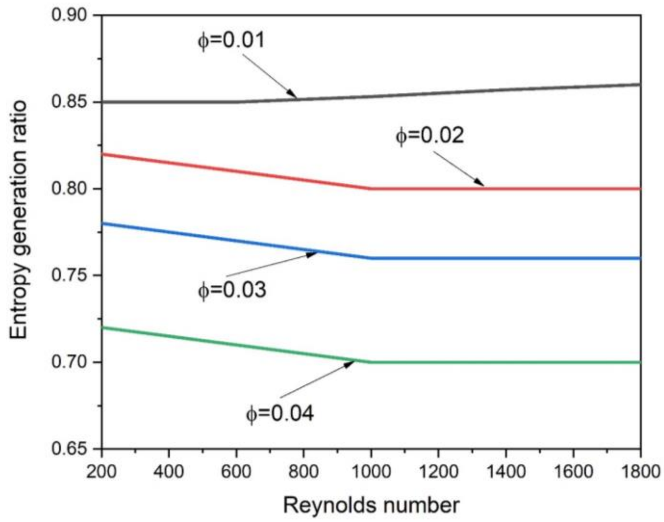

Fig. 13 Comparison entropy generation ratio vs Re with various nanoparticle concentration (Moghaddami et al., 2012)

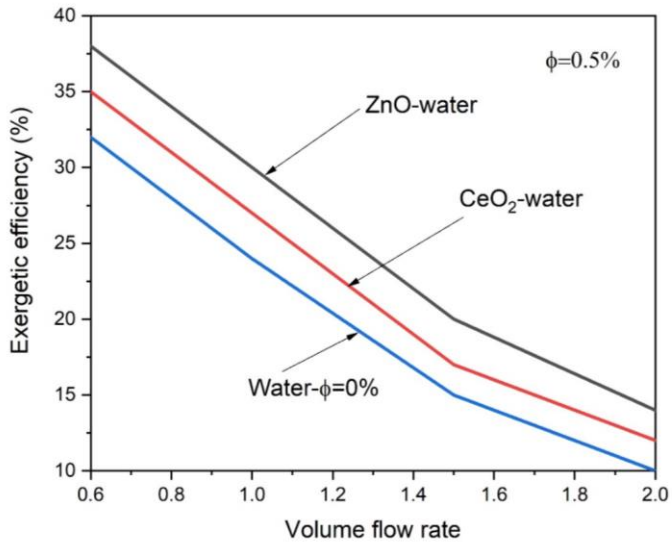

Fig. 14 Comparison exergetic efficiency vs volume flow rate with different nanofluids and pure water (Kumar et al., 2017)

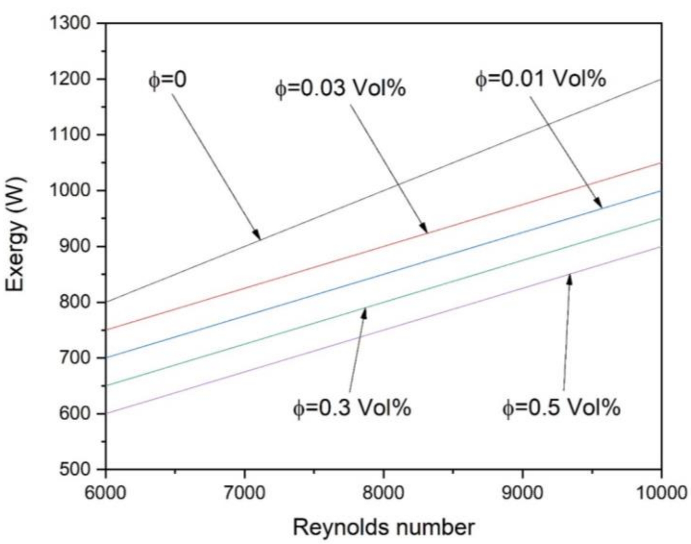

Fig. 15 Comparison exergy vs Re with different nanoparticle concentration (Abdollahi-Moghaddam et al., 2018)

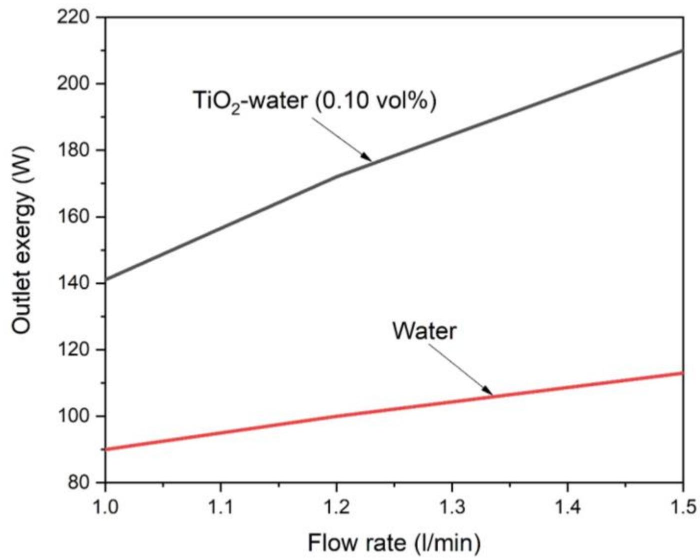

Fig. 16 Comparison outlet exergy vs flow rate with Titanium oxide/water nanofluids with pure water (Khaleduzzaman et al., 2016)

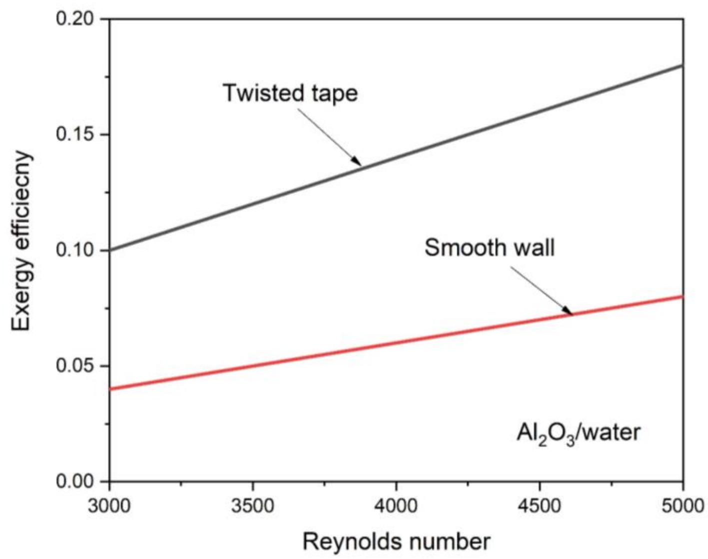

Fig. 17 Comparative analysis exergy efficiency vs Re with twisted tape and smooth wall channel (Source: As per literature review)

Fig.17 represents the comparative analysis of exergy efficiency vs Re with twisted tape inserts and pure water for $Al_2O_3 - H_2O$ based nanofluid through conduits. The experimental outcomes showed that the value of exergy efficiency is greater for twisted tape inserts as compared without twisted tape inserts surface.

4. CONCLUSIONS

In this article a review of exergy analysis of various nanofluids flow through conduits is presented. On the basis of the review of literature and comparative study of exergy analysis with nanofluid flow through conduits, the conclusions can be summarizes as follows:

- The exergetic and heat transfer performance of ZnO/water nanofluid are better than CeO_2/water nanofluid and water whereas TiO_2/Water nanofluid is more suitable than Al_2O_3 /EG nanofluid to use as the working fluid at low Brinkman numbers.
- SWCNTs based nanofluids have better thermal properties and this consequently led to improved thermal and exergetic

efficiencies compared to the metal oxide nanofluids. This, on the other hand, also raised convection heat transfer coefficient compared to the conventional fluids at the same given Re. SWCNT nanofluid could reduce the entropy generation by 4.34% and enhance the heat transfer coefficient by 15.33% theoretically compared to water as an absorbing fluid.

- The rise of entropy generation induced by the rise of nanoparticle volume fraction is attributed to the rise of both the thermal conductivity and viscosity of nanofluid which causes augmentation in the heat transfer and fluid friction irreversibility, respectively. On the other hand, the first-law analysis shows that the heat transfer coefficient decreases with nanoparticle volume fraction largely in the laminar regime of nanofluid flow in microchannel when the viscous dissipation effect is taken into account.
- The optimum Re and the corresponding minimum entropy generation number is found for different examined nanoparticle concentrations revealing that adding nanoparticles to water decreases the optimum Res while it rises the minimum total entropy generation.
- The entropy generation of nanofluids has been more than that of base fluids like water/EG for both laminar as well as turbulent flow at all values of Re.
- The outcomes showed that with increasing concentration ratio, the PV and outlet temperatures rise in both flow regimes. The total energy efficiency in turbulent flow rises, while the total energy efficiency in laminar flow first rises, and then decreases at a particular concentration ratio. The total exergy efficiency rises in laminar flow, whereas in turbulent flow, it initially rises up to an optimum concentration ratio and then decreases.
- Investigation on tube geometries showed that, with increasing pipe length, the PV and outlet water temperatures rise in both laminar and turbulent regimes. The total energy efficiency decreases, but the total exergy efficiency rises in both flow regimes. In addition, increasing the pipe diameter has a negligible effect on energy and exergy efficiencies in the laminar flow, whereas the total energy and exergy efficiencies decrease with increasing pipe diameter in the turbulent regime. Therefore, outcomes of this investigation revealed the importance of optimizing the structural and geometrical parameters to achieve desired system performance based on the flow regime type.
- The outcomes for the surface temperature measurement showed that using a fluid as coolant for the PVT system, can reduce the cell temperature by about 10 degrees. The cell temperature reduction of the PVT fluid/nanofluid coolant system with a PCM medium is more than 16 degrees compared to that of the reference system in the same condition. Also, it is concluded that for the PCM/nanofluid based collector system, the average electrical output is increment by about 13% in comparison with the conventional PV module.
- The entropy generation decreases with rises of volume fraction of nanoparticles where the contribution of heat transfer to entropy generation is dominant in the annulus.

NOMENCLATURE

Re	Reynolds number
Nu	Nusselt number
Al_2O_3	Aluminium oxide
TiO_2	Titanium oxide
CuO	Copper oxide
MgO	Magnesium oxide
ZnO	Zinc oxide

Subscripts

EG	Ethylene glycol
SWCNT	Single-walled carbon nanotubes
MWCNT	Multi- walled carbon nanotubes
PVT's	Photo voltaic thermal system
PCM	Collector-phased change material
NFs	Nanofluids

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