Mono and hybrid nanofluid based heat sink technologies - A review

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Abstract. This paper presents a review of mono and hybrid nanofluid using heat sink technologies, which is the foremost task of new generation technology in cooling electronic devices. Heat generation in a tiny electronic device is the main factor to be prevented to enhance the heat transfer. One prominent remedy for this problem is to adopt mono and hybrid nanofluid based microchannel heat sinks are considered to be the recent trends. In this article, a state-of-the-art review of heat sinks, nanofluids preparation and characterization techniques have been carried out. The study begins with an overview of the heat sink, designing parameters, research work carried out in the last decade using mono nanofluids and hybrid nanofluids followed by the analysis of the research work carried out in the last decade in terms of different geometries of MCHS to examine the diverse factors like pressure drop, heat transfer coefficient, and critical heat flux. Current challenges and opportunities for future research are presented as well.

1. Introduction

Nanofluids are dilute liquid suspensions of nanoparticles in which at least one of its dimensions is smaller than 100 nm, and found to possess improved thermophysical properties which will lead to the progress of the next generation of cooling devices that integrate nanofluids for ultrahigh-heat-flux electronic systems. Nowadays, in many diverse industries, cooling is one of the foremost alarms. Due to the advancement in technology, the manufacturing of electronic systems becomes very compact in size, shape, and weight. So the old technology becomes insufficient to remove heat from these devices. Active heat transfer using a compact system is vital for a modern thermal management system, particularly for cooling application in electronic devices. The step has been taken to improve heat dissipation by using microchannel heat sink technology, which was introduced by Tuckerman and Pease [1] is one of the key solutions for such a problem. A record of the literature shows that there have been several reviews done on MCHS with mono nanofluids. However, the review of MCHS with hybrid nanofluids is rarely available. Consequently, in this article mono and hybrid nanofluids based heat sink including different geometries are considered for analysis and reviewed. Finally, present-day
problems, upcoming developments and the research towards nanofluid based heat sink technology are discussed.

1.1. Heat sink
A heat sink is one of the passive heat exchanger which transfers the heat generated by an electronic or mechanical device to a fluid medium, either by using air or liquid coolant where the heat can be dissipated from the device so that the device can run with a regulated temperature. By using a heat sink, thermal energy can be conducted from higher to a lower temperature fluid medium. It transfers heat via convection, conduction, and radiation using heat sinks in electronic gadgets, since the temperature should be higher than the environment. The surface area of the heat sink which is in contact with the cooling medium neighbouring it should be in such a way that the air should be maximum. The factors that have affected the action of a heat sink are air velocity, choice of things, protrusion design and surface treatment.

1.2. Design Parameters
To provide maximum heat dissipation, the following key factors are to be measured in the heat sink plan which includes thermal resistance, material, fin configuration, fin size and shape, fin efficiency, heat sink attachment method, and thermal interface material as shown in ‘figure 1’. By analysing different heat sink models one can understand that the maximum heat dissipation is done by geometries and parameters.

![Figure 1. Six factors to consider for better design of heat sink.](image)

1.2.1. Thermal Resistance. The heat flow resistance between the die and the coolant fluid is termed as thermal resistance. It includes the thermal boundary resistance and the opposition among the heat sink and the liquid in motion and so on. To model and to analyse the thermal features of devices and heat sinks, the thermal resistance plays a vital role even though the value is an approximation one. By
interconnecting heat sinks through 3D thermal resistances, complex modelling of thermal characteristics can be accomplished.

1.2.2 Material. Design of heat sink is made using conductive resources of heat like Cu and Al alloys, which helps in the dissipation of heat. Copper is an excellent material for heat sink due to its extraordinary property like antimicrobial resistance, corrosion resistance, and thermal conductivity so on, but is more expensive and denser than Al.

1.2.3. Shape, Dimensions, and Position of Fins. Another parameter which greatly impacts on the flow of coolant medium is through the organization of fins on a heat sink. Flow resistance can be reduced by enhancing the configuration so that additional air can drive over a heat sink. The presentation of different fin shapes and figures can be evaluated through modelling.

1.2.4. Fin Efficiency. The fins overall efficiency can be enhanced by decreasing the aspect ratio of the fins, and by consuming a material that has a higher thermal conductivity. As the distance from the base of the heat sink rises, the heat transferred from a fin to the coolant decreases.

1.2.5. Thermal Interface Material. The thermal interface materials are used to overcome the limits of resistance reduction methods. For selecting thermal interface materials for a given thermal application, some parameters like surface gap, electrical resistivity of the material and contact pressure must be considered.

1.2.6. Heat Sink Attachment Methods. Attaching a heat sink to an electronic device has to enhance the thermal performance of a heat sink; hence the selection of the appropriate method should be adopted. Some of the examples are thermal tape, flat spring clips etc.

1.3. Microchannel Heat Sink
The microchannel heat sink (MCHS) was first announced by Tuckerman and Pease[1] to disperse high heat fluxes. Currently, the consequence of fluid runs in micro size applications has eternally increased. The microchannel heat sink (MCHS) can scatter a huge amount of heat from a small area, and its performance can be upgraded using nanofluids as a coolant. However, in the MCHS comparing simple channels and conventional coolants, complex channels due to its surface area are found to be better. In this concern, different configurations were proposed and tested for the MHSs. Microchannel heat sinks feature is mainly useful to electronics cooling, and it is also the best substitute for cooling such small devices. For researchers, the cooling of small devices is a highly challenging chore. In a heat exchanger, a microchannel is one with a small size, which is used to remove heat by using nanofluids and MCHS, which is proved to be the best thermal system due to its high efficiency.

1.4. Nanofluids
To enhance the heat transfer, researchers have shown a nanofluid which is an innovative class of heat transfer fluids that is, a base fluid in which nanoparticles are dispersed and suspended stably. Due to this result, a new field of scientific interest and a new application has appeared. Different shapes of nanoparticles are prepared from pure metal, metal oxides, nitrides, carbides and different types of carbon using a different chemical process. Water, EG, etc., are used as base fluids and it is mixed with NPs in various concentrations to form nanofluids of desired concentration.

1.5. Hybrid nanofluids
To overcome the issues of stability and small thermal conductivity, hybrid nanofluids have been developed. They are the fluids that are formed due to the interruption of nano-sized solid particles of two dissimilar materials. As compared to the base fluids, hybrid nanofluids incorporate similar thermal conductivity, specific heat capacity, and heat transfer coefficients. Development in thermal
characteristics owes to high values of thermal variables of dispersed hybrid nanoparticles. Due to its enhancement of heat transfer, it can shift mono nanofluid in the areas of electronics cooling, automotive cooling so on. The working medium of a heat sink is given in ‘figure 2’.

**Figure 2.** Working medium used in heat sink

1.6. Preparation of Nanofluid

Nanofluid preparation is a critical stage since it decides the stability of the nanofluid. The two methods which are the single-step method and the two-step method of preparing nanofluids are represented in ‘figure 5’. In a single-step method, uniformly dispersed nanoparticles are preparing and dispersed in the fluid concurrently as shown in ‘figure 3’ to reduce the agglomeration of nanoparticles, and also the stability of fluids is increased. The drawback of this method is the remaining reactants are left in the nanofluids due to an incomplete reaction, and cannot create nanofluids in a huge scale; also its price is so high. The proper method to prepare nanofluid which was conveyed by different investigators was elaborated by Haddad et al., 2014 [2].

**Figure 3.** Single-step method

The most broadly used method to prepare nanofluids is a two-step method as shown in ‘figure 4’. Initially, the materials to be prepared as a dry powder by chemical or physical methods. In the second phase, the nanosized powder will be dispersed as shown in figure 5 into a fluid using rigorous
“magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling” as shown in ‘figure 5’. Nanoparticles have an affinity to aggregate due to its property like high surface area and surface activity. Surfactants is another method which is used to enhance the stability of the nanoparticles in fluids, But it fails to be stable at high –temperature applications. The advantage of this method is cost-effective. Sharma and Gupta, 2016[3] had a foremost task in preparing a long term stable nanofluids in their paper. It has been found that maximum researchers implemented a two-step method for the preparation of hybrid nanofluid.

Figure 4. Two-step method.

Figure 5. Methods of nanofluids preparation, Kaggwa and Carson, 2019[4]
1.7. Characterization
For heat transfer augmentation, nanofluids are to be characterized to find the composition, size, and impurities. The characterization of nanofluids can be done from the following methods. SEM, studies the microstructure and morphology of nanoparticles. XRD techniques, help to identify and study the crystal behavior of nanoparticles. To study the surface chemistry of solid particles and solid or liquid particles, FT-IR spectroscopy is done. Size (structural properties), size distribution and agglomeration state of NPs can be studied by DLS and TGA is performed to study the impact of heating and melting on the thermal stabilities of nanoparticles. The zeta potential is openly associated with the stability of nanoparticle dispersion in base fluid[5].

2. Main text
2.1. Review of hybrid nanofluids in Microchannel heat sink using experimental and theoretical method.

PonnusamySelvakumar, 2012 [6] practically studied by using hybrid nanofluid of Al₂O₃-Cu/Water and concluded that the heat removed from the electronic components by using hybrid nanofluid due to less percentage increase in pumping power than the convective heat transfer coefficient.

Nimmagadda and VenkataSubbaiah, 2015 [7] statistically studied the good enhancement in heat transfer by hybrid nanofluids to attain great heat transmit features and becomes a worthy substituting selection with minimum cost, also it offers direction for planning the thermal systems for electronics cooling by using hybrid nanofluids (Al₂O₃ + Ag/Water).

SarbolookzadehHarandi et al., 2016 [8] studied experimentally the improvement of thermal conductivity as 30%, and also they recommended a specific correlation to predict the thermal conductivity by using hybrid nanofluids.

HemmatEsfe et al., 2018 [9] studied the ratio of thermal conductivity of MWCNT-SiO₂ hybrid nanofluid which was augmented to 20.1% more than that of EG, and by increasing the temperature and solid volume fraction, the consideration of nanofluid’s thermal conductivity was also amplified. Furthermore, in the estimation and prediction of thermal conductivity ratio, they have mentioned that the neural network is stronger than the correlation.

Bahiraei and Heshmatian, 2018 [10] simulated arithmetically with two MCHS and hybrid nanofluid containing graphene–silver nanoparticles and found that for entropy generation, heat transfer plays a vital role than friction factor and based on both first and second laws of thermodynamics, nanofluids is the best option to be utilized in electronics cooling.

And also Bahiraei et al., 2019 [11] evaluated numerically with the ability of a hybrid nanofluid in MCHS and found that by increasing the concentration and Reynolds numbers, the average convective heat transfer coefficient increases and also at higher Reynolds number and concentrations, the flow experiences a superior pumping power.

Akhgar and Toghraie, 2018 [12] experimentally found that the results of EG-H₂O/TiO₂–MWCNT hybrid nanofluid, become consistent with laboratory data from the proposed model and showed the maximum thermal conductivity of nanofluid as 38.7% and also achieved good stability.

Asadi, 2018 [13] studied the observation that the various concentrations of MWCNT-ZnO hybrid nanoparticle for the process of selecting a new coolant which possesses greater heat transfer properties and also found that there was an enhancement of convective heat transfer coefficient by 42%.

Al-Rashed et al. 2019 [14] investigated mathematically the performance of MCHS using Carboxymethyl Cellulose (CMC) in CNT/Fe₃O₄ nanoparticles in water and acquired the ratio of maximum heat transfer enhancement to pressure drop ratio.

2.2. Review of work related to the use of mono nanofluids in MCHS by experimental and theoretical work.

Jang and Choi, 2006 [15] did the preliminary numerical work towards the augmentation of the heat transfer of a microchannel with nanofluids. By using the finite difference method the main equations
with the distinct thermophysical stuffs of nanofluids were worked out. They initiate that there was an augmentation of cooling performance of about 10% at fixed pumping power.

Cheing and Chuang, 2009 [16] the prominent researchers who conducted experimental work on microchannel sinks with CuO/water nanofluid used as a coolant in the silicon MCHs. The nanofluid was found to absorb more heat however, particle agglomeration remained unsolved.

Izadi et al., 2009 [17] using a two-phase model and considered a mixture model to study the heat transfer of 1 vol% of Cu nanoparticles in water. The contrast between single and mixture models was made for the first time and exposed that the mixture model approach shares a good understanding with the research consequences of all Reynolds numbers measured, whilst the single-phase model overrated the value of Nusselt numbers.

Mohammed et al., 2010 [18] numerically investigated Al2O3-H2O nanofluid in a rectangular microchannels heat sink and found that there was an increase in cooling under the excessive heat flux conditions of the nanoparticles of good value and also only a slight increase in pressure drop was observed.

Ebrahimi et al., 2010 [19] investigated numerically with MWCNT/water nanofluid and showed the enhancement of thermal conductivity and temperature gradient in MCHS done with the increase in nanolayer thickness.

Lelea, 2011 [20] explained by using Al2O3/water nanofluid through the microchannel heat sink about the conjugate heat transfer by the numerical modelling and fluid movement, and made the analysis on a basis of constant Re at the exposure of different local heat transfer.

Hung, et al., 2012 [21] numerically suggests the noble increase of thermal conductivity using the system Al2O3 water nanofluid-cooled MCHS, under given geometric conditions with the adjustment of volume fraction and pumping power.

Duangthongsuk et al., 2012 [22] investigated experimentally with Al2O3-H2O nanofluid in MCHS and found that by increasing Reynolds number and particle concentrations, there was an augmentation in the transfer of heat by using nanofluids than the base water.

Tokit et al., 2012 [23] studied numerically with an interrupted MHS in the existence of different nanofluids and inferred that the highest thermal augmentation is anticipated for Al2O3, followed by CuO and finally for SiO2.

Noh et al., 2014 [24] investigated numerically using Diamond-H2O in a 3-D microchannel heat sink and found that the heat transfer efficiency of 0.3% was best, compared with other nanofluids and also there was a development of Nusselt number with the increase of Reynolds number.

Rimbault et al., 2014 [25] experimentally investigated CuO nanoparticle-water nanofluid and found a small enhancement in heat transfer with low particle volume fractions with respect to water for nanofluids.

Yang et al., 2014 [26] arithmetically simulated using CuO/water nanofluid in a trapezoidal microchannel heat sink (MCHS) and found that the two-phase model is best for thermal resistance than single-phase model and also there was a slight increase of pressure drop for the laminar flow of nanofluid-cooled MCHS.

Rahimi-Gorji et al., 2015 [27] investigated analytically that the heat transfer of microchannel heat sink (MCHS) by using a nanofluid like (Cu, Al2O3, Ag, TiO2 in water and ethylene glycol as base fluids) and found that there is an increase in the Brownian motion of the particles, by increasing the nanoparticles volume fraction and, also less modification between coolant and wall temperature was obtained.

Pourmehran et al., 2015 [28] investigated analytically to study the problem of heat and fluid flow using nanofluid in MCHS and found thermally that the Cu–water nanofluid is more profitable than Al2O3–water nanofluid and also they originate that thermal resistance, friction factor and Nusselt number are not reactive to an inertial decision.

Narrein et al. 2016 [29] studied by considering pulsating Al2O3/water nanofluid movement in helical MCHS. In a sinusoidal velocity inlet condition, extra blending of movement was presented which expressively developed the heat transmission performance related with steady movement conditions.
Wu et al., 2016 [30] numerically examined the efficiency of Al$_2$O$_3$/H$_2$O nanofluids on refining the complete performance of MCHS. It specifies that Al$_2$O$_3$/H$_2$O nanofluid appears not to be upright select for coolants in MCHS.

Xia et al., 2016 [31] analysed experimentally with Al$_2$O$_3$ and TiO$_2$ nanofluids and concluded that by increasing the particle volume fraction there was an augmentation in the thermal conductivity and also found that the heat transfer performance in fan-shaped microchannel heat sink is more strengthened than rectangular microchannel heat sink.

Abdollahi et al., 2017[32] numerically studied by using different nanofluids like silicon dioxide, aluminium oxide zinc oxide and copper oxide and dispersed in water as a base fluid in an MCHS and found that highest heat transfer rate for SiO$_2$ and also the Nusselt number enhanced by augmenting the volume fraction of nanoparticle as well as by decreasing the diameter of the nanoparticle.

Zargartalebi and Azaiez, 2018 [33] used a two-component model to study the properties of heat removal performance of nanofluids. It is exposed that the presence of nanoparticle plays a significant role in the transfer of heat. Furthermore, it is identified that the impact of nanoparticles on heat transmission depends equally on the pin size and the flow control. Hence, depending on the nanoparticle stuffs, a typical curve is presented, with which, nanoparticles can carefully progress the heat transmission.

Elbadawy and Fayed, 2020 [34] arithmetically examined for single and double stack microchannel at constant heat flux with (Al$_2$O$_3$-H$_2$O) nanofluid and found that at the highest nanoparticles concentration of 5% there was an extreme enhancement of heat transfer as well as amaximumreduction in temperature is achieved by using double-stack microchannel than using single stack microchannel and also due to the significant influence of the nanofluid it was found for a single stack of about 62.5% of volume reduction can be achieved.

Mukesh Kumar and Arun Kumar, 2020[35] studied numerically the heat transfer performance using water and Al$_2$O$_3$/water nanofluids as coolants, in six globular network heat sink for the electronic chip and concluded that Al$_2$O$_3$/water nanofluids are better than water due to the exterior temperature decrement, low power consumption and by the decrement in thermal resistance. Moreover, they found that by using nanofluids, the stability and the Nusselt number increases than water as a coolant.

2.3. Review of Mono nanofluids in different geometries of MCHS by investigational and theoretical work.

2.3.1. Microchannel geometries. Researchers have used different microchannel geometries to carry out the research for different factors like pressure drop, heat transfer coefficient, and critical heat flux by using, zigzag, triangular square, circular, rectangular, trapezoidal and wavy and also used in different fields like laser mirrors, industrial heat exchangers, bioengineering, micro sensors, blades, automotive, and microelectronic cooling etc..[36]. Some of the review related to the geometries of MCHS is reviewed as follows:

Fani et al., 2013 [37] investigated numerically the copper-oxide/water nanofluidsin a trapezoidal microchannel-heat sink (MCHS) and found that there was an increment in the pressure dropof 15% at Re=500and 1% volume concentration, and decrement of heat transfer, and it was also found that more decrement in Nusselt number although the diameter of NP increases and concluded that for the ability of thermal performance, copper-oxide nanofluidis very important.

Kuppusamy et al.2013 [38] numerically investigated the thermal and flow-fields using Al$_2$O$_3$–H$_2$O int he trapezoidal microchannel heat sink and found that the maximum enhancement of heat transfer in the trapezoidal groove, and also the triangular shape would be good, related to rectangular profile MCHS due to a maximum increaseof ‘a’ width and minimum decrease of ‘b’ width within the trapezoidal channel.

Peyghambarzadeh et al., 2014 [39] experimentally investigated and shown that by maximizing the concentration of nanoparticle, make the heat transfer coefficient to be increased, but not by increasing the Reynolds number using water-based copper oxide and aluminium oxide nanofluids in a Cu–Be
alloy heat sink. It also showed that in both conductive and convective heat transfer process, which shows the great importance in heat exchangers and by comparing Al₂O₃ nanofluids, CuO nanoparticle was more efficient since it could be used with less concentration.

Ghale et al., 2015 [40] investigated arithmetically and compared with experimental data about the heat transfer in a ribbed microchannel heat sink using single-phase and multiphase CFD models and concluded by comparing single-phase model, the two-phase model gives better calculations and also they found that in a ribbed microchannel the value of the Nusselt number and friction factor of nanofluids are higher than those of ordinary microchannel.

Sakanova et al., 2015 [41] investigated the performance of the heat transfer of microchannel heat sink (MCHS), with the innovative passage assemblies and effective liquids, and initiate that the improvement of heat transmission of MCHS is expressively developed associating the straight passage MCHS, whereas by nanofluids makes the influence of wavy wall as unnoticeable.

Azizi et al., 2015 [42] investigated experimentally the thermal performance of a cylindrical MCHS of electronic devices, and created that the development of Nusselt number for similar Re, the Nusselt number decreased with the increase of Re in laminar flow regime (Re < 900), and also there was an enhancement for the heat transfer coefficient of 0.3 wt.% however the pressure drop was less than 0.15 bar.

Rajabifar, 2015 [43] investigated experimentally to develop the cooling performance of a 3D conjugated heat transfer model using double-layer microchannel heat sink (MCHS) through nanofluids and found, the enhancement of cooling performance and the drawbacks linked with nanofluids are removed significantly.

Wong and Lee, 2015 [44] verified positively the augmentation of heat transfer in the MCHS with triangular ribs. To find the best design they studied the different parameter effect like width, length and height of the ribs and found 43% of amplification in heat transfer with Reynolds number of 500.

Abubakar et al., 2016 [45] simulated numerically in a 3D rectangular microchannel heat sink with Fe₃O₄–H₂O and found that there was a reduction of temperature of the surfaces due to the presence of nanoparticles, as the particle volume fraction of Fe₃O₄–H₂O increases than pure water due to its higher dynamic viscosity and lower heat capacity.

Azizi et al., 2016 [46] investigated experimentally the convective heat transfer coefficients and friction factor of copper nanofluids in a cylindrical MCHS and found that the thermal resistance decreased by increasing the volume fraction of nanoparticles, and the thermal entrance length for the microchannel heat sink can be obtained from the local heat transfer coefficients. Nusselt number and friction factor also increased due to the existence of nanoparticles.

Ahmed et al., 2016 [47] investigated experimentally using Al₂O₃–H₂O and SiO₂–H₂O nanofluids a novel pioneering project of an aluminium rectangular and triangular double-layered microchannel heat sink (RDLMCHS) and (TDLMCHS), respectively and found a good drop in the wall temperature of 27.4% in TDLMCHS than RDLMCHS and thermal resistance of 16.6% is provided by TDLMCHS which is less than RDLMCHS and also no variation of pressure drop in both designs. Finally improved thermal control for both nanofluids than pure water was found at higher nanoparticle concentration and showed the best performance by the Al₂O₃–H₂O nanofluidat (0.9 vol.%).

Duangthongsuk and Wongwises, 2017 [48] investigated experimentally with SiO₂ nanoparticles and dispersed in deionized water with particle loadings of 0.3, 0.6 and 0.8 vol. % in the continuous zigzag flow channel (CZ-HS) and the single cross-cutting zigzag flow channel (CCZ-HS) and found that the nanofluid-cooled heat sinks gave a good thermal performance, and also thermal performance done by CCZ-HS are superior to CZ-HS, and the value of pressure drop had less effect due to the concentration of particle and cross-cutting of the flow channel.

Arani et al., 2017 [49] investigated in an innovative design using the double-layered microchannel heat sink (MCHS) about the laminar flow type and heat transfer of nanofluid water/CNT (Single-wall) and initiated by increasing the volume fraction of nanoparticles and by decreasing λ, which reduced the ratio of thermal resistance, and also there was an increase in (PEC) factor on the base of the channel in all proportions of λ, by improving nanoparticle volume fraction.
Khodabandeh and Abbassi, 2018 [50] numerically and analytically studied the transfer of heat using Al$_2$O$_3$ nanofluid in a trapezoidal cooling microchannel and found that in a particular volume fraction range, there was a maximum thermal conductivity in a trapezoidal microchannel and also obtained a maximum value of thermal conductivity in the dimensionless condition when there is a constant pressure drop with a suitable side angle of 70°.

Lodhi et al., 2020 [51] investigated experimentally the single-phase fluid flow and heat transfer characteristics of nanofluid in a circular microchannel and achieved the maximum enhancement in local heat transfer coefficient, and also found that the performance evaluation criterion of Al$_2$O$_3$/water nanofluid is superior to unity, and good agreement was established by the proposed relations for friction factor and Nu number using Al$_2$O$_3$/H$_2$O nanofluid.

2.3.2. Images of different geometries of MCHS.

Figure 6. A simple MCHS diagram with its computational domain, Kuppusamy et al., 2013 [38]

Figure 7. Diagram of microchannel heat sink

Figure 8. Sizes of the heat sink
(a) heat sink (b) straight microchannel (c) Wavy Sakanova, A., et al., [41]
3. Discussion
In this Review, after the survey of the heat transfer characteristics and overall cooling performance of a microchannel heat sink by using mono and hybrid nanofluids, the following points are identified and listed. The best performance of heat transfer related to geometry is obtained, if the large surface area is exposed by the coolant in a heat sink with the highest channel heights, lowest fin spacing and fins with circular geometry. By enhancing wave amplitude and decreasing wavelength, the augmentation of heat transfer occurred for wavy channel heat sinks. The higher heat transmission rate has taken place in the staggered arrangement of pin fins on the heat sink than an inline arrangement. Good thermal performance is found by many researchers using water and EG. By increasing the concentration and flow rate of nanofluid, a good heat transfer coefficient was observed. One of the drawbacks found by using nanofluids is the formation of an increased pressure drop. For good heat transfer, the particle size should be small and there should be a good interface with base fluids. Lower heat flux should also be maintained.
Figure 12. Usage of individual nanoparticles

From the ‘figure 12’ it was clear that Al$_2$O$_3$ nanoparticles are most widely used since it is having good stability with base fluid, cheap and easily available.

Figure 13. Usage of Base Fluids

From the ‘figure 13’ the most used base fluid is water, since it is low-priced and has broad application and good thermal conductivity.
4. Present-day challenges and the future of nanofluids

- From the above review it is clear that by using mono nanofluid as a working medium, a large amount of research work has been carried out.
- So far the research which was carried out is based on the types of nanofluid, the concentration of nanoparticles and different geometries so on by using mono nanofluid than hybrid nanofluid.
- In future, considerable research has to be carried out using hybrid nanofluids.
- Even though there is a good augmentation in heat transfer, there are still some obstacles in implementing this in the industrial sector.
- Currently, there is no fixed price for nanoparticles since its cost is so high, and the physical property data differs based on different manufacturers.
- Nanoparticle production cost also high since extra care to be taken while manufacturing, due to harmfulness.
- To improve the overall performance and possible applications, important efforts to be approved out in both theory and experimental part.
- Still, numerous challenges have to be identified to improve the overall performance and possible applications.
- Current research on the microchannel heat sink for an effective cooling system is still massive rolling

5. Conclusions
This paper presented a review which gives the great enhancement of heat transfer in the MCHS by using mono and hybrid nanofluids. Conclusions from the review are as follows: Nanofluids become a favourable heat transfer fluid for this new group. Many advantages have been identified by many researchers in the field of electronic devices cooling. The variable which is used to improve the heat transmission of nanofluids is difficult to control. More augmentation of heat transfer was observed in hybrid nanofluids than mono nanofluids. The revision of the thermal design of the cooling system for an electronic device is needed. The two foremost factors which impede the utilization of nanofluids in MCHS are the stability and production cost. Current studies on the MCHS for a real cooling structure are still huge developing.

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