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A Short Review on Thermal Properties of Nanofluids in Heat Transfer Applications

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ABSTRACT

Due to the increased technology penetration in urban and rural areas, energy consumption has seen an upward trend. To fulfil the energy demand, we must go for optimization of the energy demand in various industrial as well as domestic applications in a heat exchanger device by improving the heat transfer rate by applying various heat transfer enrichment methods such as passive, active, and combined methods. Therefore, numerous techniques have been encouraged to boost heat transfer rate and to reduce the cost and size of equipment especially the heat exchangers like radiators, refrigeration systems etc. In the present work, a short review of various heat transfer augmentation techniques by using different nanofluids of different nanoparticle sizes and concentrations to improve the "heat transfer rate" (Q) and "overall heat transfer coefficient" (U) in a variety of heat exchangers in different industrial applications is carried out. The impact of the concentration of nanofluids on heat transfer rate and heat transfer coefficient is particularly given special importance in this review. Also, the impact of the Reynolds (Re) number and Nusselt (Nu) number on heat transfer rate and frictional factors are presented.

Keywords: Heat transfer rate, Nanofluid, Reynolds Number, Nusselt Number, Frictional Factor.

1. INTRODUCTION

These days shortage of energy is the major problem in the world. Higher the dependency of the fossil fuels increases the demand of the fuels is increasing every day; it may lead to depletion of the conventional energy resources. Because of the depletion of these energy sources owners of industries are making a great effort to utilize the available energy more effectively and efficiently and need to develop effective methods to do the same [1]. In such effective energy utilization techniques use of nanofluid is one of them in the heat transfer augmentation. Nanofluid is a type of fluid that comprises nanometer sized solid material particles in it. Nanofluid was pioneered by Choi has been demonstrated the efficiency of nanoparticles on efficient heat transfer compared to standard fluids. A nanofluid is often produced by dispersing nanomaterials of a size about 100 nm. To prepare nanofluids familiarly, two methods were adopted, are one step method and another one is two-step process. The add-on of the nanoparticles in the base fluid can change the different thermochemical features of base fluid such as thermal conductivity, thermal diffusivity, viscosity and so on. Currently, in engineering applications, different variety of nanoparticles like metallic, non-metallic, and ceramic nanoparticles are used very effectively [2].

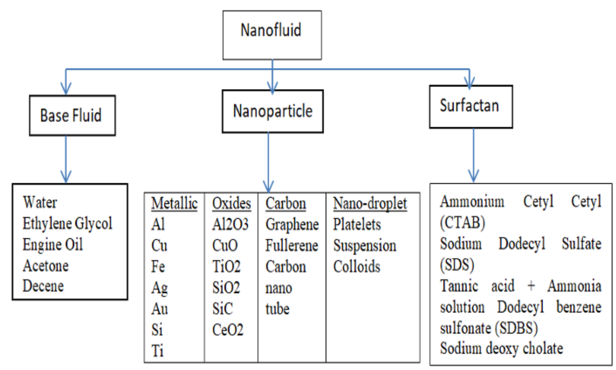

Table :1 Experimental investigations on nanofluids in heat transfer enhancement

Authors	Nanofluid	Concentration	Findings
Ehsanollah Ettefaghi et al. [1]	graphene quantum dots/distil water	100, 200, 500, and 1000 ppm.	Low concentration nanofluid produce better performance and stability. At 100ppm k & h were increased by 5–7% and 1–17% respectively.
Waqas Arshad et al. [3]	Graphene nanoplatelets/water	10% weight concentration	At heat flux of 0.7194×10^5 W/m^2, 0.5995×10^5 W/m^2 and 0.4796×10^5 W/m^2, Convective heat transfer coefficient increased about 13.76%, 15.38% and 21.51%, respectively.
C. Selvam et al. [4]	Graphene-based suspensions / Water-ethylene glycol mixture	0.1% to 0.5%.	External convective coefficient of heat transfer boost up with an increase in air velocity, it is observed to be 104.00% at 0.50 vol%, 62.50g/s of mass flow rate and 5.0 m/s

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			velocity of air when compared to 0.0 vol%.
H.Bonnemann, et al. [5]	copper- and silver-nanocolloids / Korantin	0.10g and 0.12g of Cu and Ag respectively	A low concentration of Ag leads to good stability and leads to more stability about 1 month compared to Cu.
J. A. Eastman et al. [6]	Cupper / ethylene glycol	0.3 vol%	The thermal Conductivity grew by up to 40%
Bhanu Pratap Singh et al. [7]	Al_2O_3/Water	0.1%, 0.5%, 1%	At 1% concentration, 3.6% heat transfer rate increased
S.M. Peyghambarzadeh et al. [8]	Al_2O_3 / water / ethylene glycol	0.1, 0.3, 0.5, 0.7, and 1 vol.%	Observed 40% enhanced in Nusselt number.
Deviredddy Sandhya et al. [9]	ethylene glycol water based TiO_2	0.1%, 0.3% and 0.5%	At 0.50% concentration, noticed 35.0% of heat transfer development compared to base fluid.
Guilherme Azevedo Oliveira et al. [10]	MWCNT / water	3%	At 0.16 wt% concentration at 30°C maximum heat transfer enhancement of 54%
Bin Sun et al. [11]	$A1_2O_3$/water & Cu/water	0.1–0.5%	Copper-water about 01.10–2.00 times and Al_2O_3-water about 01.10–01.60 times heat transfer coefficient increased.
Adnan So¨zen et al [12]	$A1_2O_3$/water	2%	Time consumption for cooling is reduced
Nilesh Purohita et al. [13]	$A1_2O_3$/water	0.5%, 1.5% and 2.5%	Achieve faster cooling rate with nanofluid faster than the without nanofluid
Xiaoke Li et al. [14]	SiC/water/ethylene glycol	0.5 vol.%	Maximum thermal conductivity improvement is 53.81% for 0.50 vol.% nanofluids at temperature of 50 °C.
M. Naraki et al. [15]	CuO/ H_2O	0.40 vol.%	The overall coefficient of heat transfer is enhanced up to 8.0%.
K.Y. Leong et al. [16]	Cu/water	0% to 2%	By adding 2% of copper nanoparticles about 3.8% heat transfer enhancement achieved.
S.M. Peyghambarzadeh et al. [17]	CuO and Fe_2O_3 /water	0.15%, 0.40%, and 0.65 % of volume.	Fe_2O_3 concentration improves the overall coefficient heat transfer is rises compared to CuO nanoparticle concentration.
Hussein S. et al [18]	$A1_2O_3$/ water	0–2%	At 1% nanoparticle concentration, bulk temperature of 80°C and velocity of flow 2 m/s, coefficient of heat transfer is maximum about 78.67% associated to water at the same boundary condition.
K. Goudarzi et al. [19]	Al_2O_3 / EG	0.08%, 0.50% and 1.0%	Thermodynamic performance is boosted up to 5% when contrasted to EG as base fluid.
D.Madhesh et al. [20]	copper-titanium hybrid / water	0.1% to 1.0%.	At 0.70% of a volume concentration of the mixture nanocomposite, the coefficient of heat transfer is found maximum by 48.40%.
Rashmi R. Sahoo et al. [21]	SiC, Ag, Cu, CuO and TiO_2, Al_2O_3/ EG	0% –1.0%	Ag based hybrid nanofluid has a superior thermal property associated to all other nanofluids. Also had greater effectiveness and rate of heat transfer about 5.0% and 8.0% respectively.
Hooman Yarmanda et al. [22]	graphene nanoplatelet -Platinum hybrid nanofluids	0.02 and 0.1%,	The highest Nusselt number is 28.48%, at 0.1 wt% for graphene nano platelet.
Waqas Arshad et al. [23]	TiO_2 / Water	15% weight concentration	It has shown a maximum enhancement of 12.75%
Elham Hosseinirad et al. [24]	MWCNT/water and Al_2O_3/water	0-3 vol.%,	At 1 vol.% Al_2O_3-H_2O nanofluid has the premier overall thermal performance
P.B. Maheshwary et al. [25]	titania/water	0.5-2.5 Wt.%	Compared to base fluid titania based nanofluid give maximum upto 69.43% of thermal conductivity.

2. EXPERIMENTAL STUDIES ON NANOFLUIDS IN HEAT TRANSFER ENHANCEMENT IN VARIOUS ENGINEERING APPLICATIONS

Many researchers conduct experimental work on heat transfer enhancement using nanofluids of various concentrations summary shown in Table 1. Ehsanollah Ettefaghi et al. [1] conducted experimental work by using graphene quantum dot at extremely minimal concentrations comprising 100ppm, 200ppm, 500ppm, and 1000ppm. At 100 ppm they observed the increase of the thermal conductivity and the heat transfer coefficient and by 5.20% and 17.00% respectively. And quantum dots show better performance and better stability. The effect of water-based graphene nanoplatelets nanofluids on hydrodynamic and thermal performance on the integral fin heat sink by Waqas Arshad et al [3], observed maximum convective heat transfer improvement noted as 36.81^0C and 23.91% consistent to Reynolds number 972.00 for the heat flux of $47.96x10^3 W/m^2$, correspondingly at this condition highest pumping power was observed $4x10^{-2}$ W. C. Selvam et al [4] conducted experimental work on automobile radiator cooling by using graphene-based suspension nanoparticles in base fluid water-ethylene glycol combination (70:30 of volume) by varying the rate of mass flow from 12.50 g/s to 62.50 g/s with the concentration of nanofluid 0.10% to 0.50%. Observed coefficient of heat transfer boosted with mass flow rate and found overall coefficient of heat transfer 104 $W/m^{2o}C$ at 35ºC. H. Bonnemann et al [5] conduct experimental work to compare the stability of silver and copper colloid nanoparticles suspension. They claimed that the silver suspensions were steady for nearly 30 days.

Effect of the copper nanoparticles in a ethylene glycol-based nanofluids by J. A. Eastman et al [6], they come to know that thermal conductivity is 40% more in ethylene glycol with copper nanoparticles of concentration 0.30% compared to ethylene glycol. Bhanu Pratap Singh Tomar et al [7] experimentally work conducted to enhance the heat flow in automobile radiators by using Al_2O_3 / Water nanofluid of nanoparticle concentration of 0.10%, 0.50%, 1.0%. From this experimental work, they came to know that heat transfer rate varies linearly with the concentration of nanoparticles with the flow rate ranges from 2.0 to 5.0 LPM. To increase the cooling rate in the radiator by using water-ethylene glycol and Al_2O_3 of variable concentration with a flow rate ranger 2.0 to 6.0 LPM by S.M. Peyghambarzadeh et al [8], they came to know that 40.00% of heat transfer improved compared with the normal base fluid. Devireddy Sandhya et al [9] were done an experimental study to improve the heat transfer rate in automobile radiators using ethylene glycol water based TiO_2 nanofluids of various concentrations. From this experimental study come to know that at a low-level concentration enhanced the rate of heat transfer up to 37.00% in comparison with the normal base fluid. Guilherme Azevedo Oliveira et al [10] experimentally investigated the rate of heat transfer of MWCNT/H_2O nanofluid flowing in car radiator, they conducted experimental work by maintaining a constant flow rate and varying the temperature from 50, 60, 70 and 80ºC. If the nanoparticles concentration increased above 5.0% the heat transfer rate gradually decreased.

On the another side, Bin Sun et al [11] made experimental work to enhance the heat transfer rate in computer CPU by using Cu-water and $A1_2O_3$-H_2O nanofluids with a mass fraction of 0.10–0.50%, with a Reynolds number ranges from 400 to 2000. The results are confirmed that the rate of heat transfer boosted significantly about 1.1 to 2.0 times compared with the normal base fluid. An experimental investigation was carried out on a refrigeration system by Adnan So¨zen et al [12] by using ammonia/water couple with Al_2O_3 as nanoparticles of various concentrations. In this study, they were detected that operation duration of system was diminished due to smaller heat transfer periods. Nilesh Purohit et al [13] experimentally compared the results of the water-cooled gas cooler and alumina-based nanofluid cooler in the refrigeration system. The effect of nanofluid on COP, Reynolds number and pumping power were discussed in detail. Nanofluid gives better performance and expensive experimentation. To increase the cooling rate in automobile radiator by using H_2O/ethylene glycol-based fluid with a proper concentration of SiC nanoparticles by Xiaoke Li et al [14]. They were observed maximum thermal conductivity enrichment was observed to be 53.81% for 0.50 vol.% nanofluids at 50°C. the effect of CuO/water on overall coefficient of heat transfer in the car radiator by M. Naraki et al [15]. From this experimental work came to know that rises overall heat transfer coefficient (U) by 08.0% at the nanoparticle concentration of 0.40 vol.% in compared with water.

In another study by K.Y. Leong et al [16] were conducted experimental work on car radiator cooling systems by using copper nanoparticles and ethylene glycol as the base fluid. It is noted that about 3.80% of heat transfer improvement could be accomplished with the supplement of 2.00% copper grains in the base fluid with Reynolds number of $6x10^3$ and $5x10^3$ for air and coolant respectively. Further studies on car radiator cooling systems using CuO and Fe_2O_3 nanoparticle is included to the water at three intensities 0.150%, 0.400%, and 0.650% of volume with contemplating the best pH for extended permanence by S.M. Peyghambarzadeh et al [17]. Results prove that both nanofluids show a excellent overall coefficient of heat transfer in analogy with water up to 9.0%. Hussein S. Moghaieb et al [18] tested the effect of γ-Al_2O_3/water nanofluid employed in engine cooling. From the result, they came to know that the greatest coefficient of heat transfer is 78.670% which was accomplished at a 1% volume concentration of nanoparticles associated with water. In another work, K. Goudarzi and H. Jamali [19] were investigated the combined effect of Al_2O_3-EG based nanofluids and wire coil inserts in car radiator cooling systems by considering the nanofluids of volume concentrations of 0.080%, 0.500% and 1.000%. From this experiment, they got heat transfer enhancement up to 9% more in the case of nanofluid with wire spiral inserts compared to wire coil inserts alone. Further studies on heat transfer enhancement by using hybrid nanoparticles like copper-titanium hybrid nanocomposite were done by D.Madhesh and S.Kalaiselvam [20]. In this current work, the coefficient of heat transfer was observed highest by 48.40% up to 0.70% volume concentration of a hybride nanocomposite.

Followed by [20] Another important work on heat transfer enhancement using hybrid nanofluids as a coolant in louvred fin in an automotive radiator by Jahar Sarkar and Rashmi R. Sahoo [21]. They used Ag, Cu, SiC, CuO and TiO_2 in 0.0% – 1.0% volume small percentage of Al_2O_3 nanofluid, as a coolant for louvred fin in an automobile radiator. In this experiment, 1.0%

Ag hybrid nanofluid (Ag of 0.50% and Al_2O_3 of 0.50%) yields the greatest effectiveness and rate of heat transfer as good as pumping power. Hooman Yarmand et al [22] were practically investigated the effects on convection heat transfer improvement using graphene platinum /nanoplatelet hybrid nanofluid by varying the Reynold number from 5000 to 17500 and concentration of 0.02% and 0.10%. Nusselt number was 28.48%, the peak load of nano composite (0.10 wt %), with the Reynolds number of $1.75x10^4$. Hafiz Muhammad Ali and Waqas Arshad [23] were experimentally investigated the impact of nanofluid concentration on heat transfer and pressure change in a straight small channel heat sink using titanium oxide nanofluid. In this work, they got while passing through the mini channel, an axial growth of the base temperature is noticed from inlet to outlet of a heat sink. Elham Hosseinirad and Faramarz Hormozi [24] experimentally investigated the impact of MWCNT-H_2O and Al_2O_3-water nanofluids on the thermal accomplishment of different longitudinal pin fins as vortex generators in the miniature channel. From this experimental work, they concluded that the water flow and 1.0 vol.% Al_2O_3-H_2O nanofluid has the ultimate overall accomplishment in the triangular pin fin small channel.in the other side P.B. Maheshwary et al [25] done a comprehensive study on particle size and particle shape on thermal conductivity of Ti/H_2O-based nanofluid. This experiment got a result of cubic shaped (2.50 Wt. %) TiO_2water-based nanofluid showed the greatest thermal conductivity.

Table: 2 Summary of numerical work done on nanofluids for heat transfer application

Authors	Nanofluid	Volume concentration	Findings
M. Elsebay et al. [26]	Al_2O_3/ water and CuO/water	1, 3, 5 and 7%	For Al_2O_3 and CuO coefficient of heat transfer raised up to 45% and 38% respectively. And similarly, a friction factor and the pressure drop increased by 271.0% and 267.0% for Al_2O_3 and 266.0% and 226.0% for CuO respectively.
Adnan M. Hussein et al. [27]	TiO_2/ water	1%, 2%, 3% and 4%	At 1.0% concentration of TiO_2 raise in heat transfer up to 20.0% compared with base fluid.
Gabriela Huminic et al. [28]	MWCNT-Fe_3O_4 / water hybrid nanofluid	0.1% and 0.3%	At low Reynolds number and 0.3% concentration of nanoparticle heat transfer enhance up to 31.0% compared with water.
Vahid Delavari et al. [29]	Al_2O_3/water and Al_2O_3/ethylene glycol	0.1, 0.3, 0.5, 0.7 and 1%	Compared to water-based fluid, the coefficient of surface friction at 1.0% nanofluid concentration is 1.20 times better and 1.80 times for glycol-based fluid.
Minea Alina Adriana [30]	Al_2O_3, TiO_2 and SiO_2 / water	1 to 12%	Convection heat transfer coefficient of hybrid nanoparticles of concentration 4% has given 257% enhancement.
Seyed Hadi Rostamian et al. [31]	CuO-SWCNTs-EG / water	0.02% to 0.75%.	ANN model can accurately forecast the effects of the nanoparticle concentration on thermal conductivity.
Ravikanth S. et al [32]	Al_2O_3, CuO & water	1 to 10%	The average coefficient of heat transfer when compared to base fluid water at 10.0% concentration of Al_2O_3 is 94% and that for CuO at 6% concentration is 89%.

3. NUMERICAL STUDIES ON NANOFLUIDS FOR HEAT TRANSFER APPLICATION

In the latest years many researchers are concentrating more on numerical works compared to experimental works. The experimental methods are costlier than the numerical approaches and the flexibility in numerical methods are more when compared to experimental methods. Numerical research on nanofluids became the choosing approach to express their superior execution to conventional heat transfer fluids. The of the various numerical works are tabulated in Table No. 2.

M. Elsebay et al [26] predict the effect of Al_2O_3 / water as well as CuO/water in automobile radiators by varying the concentration of the nanoparticle from 1% to 7% by varying the Reynolds number 250 to 1750. From this study increase in coefficient of heat transfer achieved 45.0% and 38.0% for aluminium oxide with water and CuO with water, respectively compared to the values of the pure water. The use of TiO_2 nanoparticles in automobile radiator cooling by Adnan M. Hussein et al [27]. They were investigated by taking TiO_2 concentrations of 1.0%, 2.0%, 3.0% and 4.0% by varying a Reynolds number 10000 to 100000 and inlet temperature vary from 60°C to 90°C. from this analysis they came to know that friction factor declines as the Reynolds number raises and increases as the volume intensity increases.at low concentration of TiO_2 enhance up to 20% heat transfer rate compared with water.

In another numerical study Gabriela Huminic and Angel Huminic [28] investigated by taking a very low concentration of MWCNT–Fe_3O_4 with water hybrid nanofluids of 0.10% and 0.30% and Reynolds number of 50 to 1000. From the results of this numerical work, they concluded that at low Reynolds number and less concentration of hybrid nanoparticles give up to 31% enhancement when compared with water. Vahid Delavari, Seyed Hassan Hashemabadi [29] did computational simulation of heat transfer enrichment of Al_2O_3 /H_2O and Al_2O_3/ ethylene glycol nanofluids in a car radiator. From this, they understood that the coefficient of surface friction for 1.0% nanofluid is 1.20 times that of the water-based fluid and 1.80 times that of the ethylene glycol-based fluid. Recently Minea Alina Adriana [30] numerically investigated the effect of Hybrid nanofluids based on SiO_2, Al_2O_3 and TiO_2 by different numerical methods. It was noted all nanofluids thermal characteristics are changing with the adding of nanoparticles and thermal conductivity is improving by 12.0%. In another recent work done by Seyed Hadi Rostamian et al [31] by using an artificial neural network modelling to inspect the thermal conductivity of CuO-SWCNTs hybrid nanofluid versus temperature. in this work, they were compared the numerical work with experimental work by ANN model taking nanoparticle concentration of 0.02% to 0.75%. from this work they can know that the ANN model gives better accurate results when compared to experimental work. Ravikanth S. Vajjha et al [32] were led the numerical investigation on heat transfer and fluid dynamic performance of CuO and Al_2O_3 nanofluids in the flat tubes of a radiator. From this study, they came to know that Results for the average and local friction factor and coefficient of heat transfer enhances with rising particle volumetric concentration of the nanofluids.

4. CONCLUSION AND FUTURE WORKS

A review was done by considering the latest experimental investigations and numerical studies were conducted on the heat transfer enhancement in various engineering applications like radiators, heat exchangers, and refrigeration systems by using different nanofluids of concentration ranges from 0.01% to 15.0%. The use of nanoparticles in base fluids in heat transfer applications collaboratively produces more impact by enriching the thermal properties of base fluids. It has been noticed that the enhanced thermal conductivity and convection heat transfer coefficient of nanofluids are the driving components for enhanced execution in various applications. In general, it is often concluded that heat transfer enhancement is observed by using nanofluids of vary low concentrations like below 1% volume observed better thermal stability and better heat transfer enhancement. And observed very less frictional factor with variable Reynolds number. From this literature, in future works, the researchers could perform experimental works on giving more importance to the stability of nanofluids, pressure drop, frictional factor, sonication time, avoid the coagulation of nanoparticles after continuous use, nanoparticles size, types of base fluid, hybrid nanoparticles, the concentration of nanoparticles and so on at the same time which leads to increase the performance of nanofluids in different engineering applications. considering can carry out the experimental and numerical simulations.

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NOMENCLATURE

k	*Thermal Conductivity*	W/m K
h	*Heat transfer coefficient*	W/m^2K
Re	Reynolds Number	----
Nu	Nusselt Number	---
U	Overall Heat transfer Coefficient	W/m^2K
ff	Friction Factor	---
ANN	Artificial Neural Network	---
CFD	Computational Fluid Dynamics	---
EG	Ethylene Glycol	---
MWCNT	Multi Walled Carbon Nanotubes	---
SWCNTs	Single Walled Carbon Nanotubes	---

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