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A review on thermal conductivity and stability enhancement of nano fluid

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ABSTRACT

This study provides a critical review of thermal conductivity and Nano fluid stability enhancement. The majority of the review is based on numerical and experimental studies of metal oxide nanoparticles in water-based fluids. However, there are difficulties in processing stable Nano fluid and improving heat dissipation. As a result, the resolution of this review is to examine the result of volume fraction, particle size and shape, temperature, as well as material type on the thermal conductivity of Nano fluid. Furthermore, the stability of Nano fluid is examined in this review. The results showed that increasing the concentration and temperature of nanoparticles in a base fluid causes an increase in thermal conductivity. Furthermore, by decreasing the particle size of the Nano fluid, thermal conductivity is increased. Several studies have confirmed that the shape of a nanoparticle influences the thermal conductivity of a Nano fluid. In comparison to other shapes, cubic shape nanoparticles have the peak thermal conductivity. The thermal conductivity of a hybrid Nano fluid is also greater than that of a non-hybrid Nano fluid. Finally, optimizing each parameter and ensuring uniform dispersion of Nano particles increases the stability and thermal conductivity of the Nano fluid. However, volume fraction has the greatest result on stability and thermal conductivity of Nano fluid. According to this survey, volume fraction contributes approximately 60%, particle size contributes approximately 25%, and particle shape contributes approximately 5.4 percent to the thermal conductivity enhancement of Nano fluid.

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1. INTRODUCTION

A nano fluid is a type of nanotechnology that consists of a suspension of high thermal conductivity solid particles in a base fluid. The goal of this process is to achieve higher heat transfer values when associated to the base fluid. Because of the thermophysical properties and heat transfer performance, this is extremely important in modern industry. As a result, it is useful in a variety of fields, including micro electromechanical systems, aerospace applications, coolant in machining, personal computers, several medical applications, heat exchangers, nuclear reactors, and automobile radiator cooling. However, there is a real issue due to the low heat transfer improvement of fluids, which causes materials to become obsolete in a short period of time. Furthermore, the Nano fluid presents a challenge due to its poor stability. To address these issues, many researchers have been working on Nano fluid heat transfer enhancement for many years. For example, in order to improve heat transfer rates, a number of researchers have worked on radiators using a new class of coolants is called as Nano fluid. This study demonstrated a rise in the heat transfer rate of Nano fluid, which resulted in a reduction in radiator size [1-5]. Additionally, these indications to a decline in weight, size, as well as fuel consumption, resulting in a rise in vehicle proficiency. It was addressed the reciprocal relationship between thermal conductivity and Nano fluid stability.

A various studies [6–9] have examined the result of volume fraction, particle shapes and size, and also material type on the heat transfer of Nano fluids using experimental methods involving Nano phase powders and base liquid. This experiment method analysis is limited in its examination of the effects of particle clustering, pressure drop, and suspended particle dispersion. However, Mirlohi et al. [9] include binary fluids as base fluids or used hybrid Nano fluids. As a result, they all attempted to optimize the amount of heat transfer using the parameters. Mohammed et al. [10] has also examined the heat transfer enhancement of Nano fluids in micro tubes with constant heat flux while varying particle size, volume fraction, and material type using finite volume difference and simpler algorithms. He did not address the effect of Nano fluid shape in this study. As a result, researchers should consider the effect of moving particles in the case of clustering particles and suspended particle dispersion. It should also be addressed the effect of geometrical shape and pressure drop.

2. THERMAL CONDUCTIVITY ENHANCEMENT OF NANO FLUID

Heat transmission is one of the most significant components of many consumer and industrial products, according to Habib et al. [11]. Conventional fluids' low thermal conductivity, on the other hand, places a basic limit on heat transport. Researchers have been attempting to raise the essentially low thermal conductivity of fluids by adding nanoparticles into liquids for more than a century.

Nano fluids, according to Godson et al. [12], have a important rise in heat transfer coefficient, liquid thermal conductivity, and viscosity. This is made by combining Nano particles with base fluid at various concentrations, and the result is a raise in thermal conductivity. As a result, thermal conductivity enhancement is affected by particle shape, material type, volume concentration, particle size, and operating temperature. When compared to the high thermal conductivity type of material, the effect of low thermal conductivity material type has a relatively small result on thermal conductivity enhancement of Nano fluid. Thermal conductivity enhancement of Nano fluid using metal particle, for example, is greater than that of metal oxide particle. However, it has its own limitations due to the formation of oxidizing particles during the preparation process. Disregarding the oxidation process through production and later during use is one of the most difficult challenges for metal-particle Nano fluid. As a result, the particle coating technique is used to prevent oxidation.

Putra et al. [13] prepare thermal conductivity of titanium oxide of Nano fluid with temperature as function of volume fraction at various volume fraction and temperature. This demonstrates that thermal conductivity amplified as both volume and temperature fraction increased when associated to the base fluid. The average kinetic energy of particles escalations as the temperature rises. Furthermore, as the volume fraction rises, so does the contacting area. However, as the volume fraction rises, particles aggregate in a specific area. A recent study found that the result of particle aggregation in base fluid is dispersed by the addition of a surfactant (surface active agent). Li and Peterson [14] used experimental and theoretical approaches to examine the thermal conductivity of a Nano fluid. Thermal conductivity rises as the volume fraction, particle size , as well as temperature decrease. According to the authors, thermal conductivity has a nonlinear relationship with temperature, nanoparticle size, and volume fraction. Furthermore, it was demonstrated that the result of particle size variation has the greatest influence on thermal conductivity [14]. Other researchers used experimental and theoretical investigation to investigate the result of Brownian motion, thermophoresis, diffusion-phoresis, and suspended particle dispersion on the thermal conductivity of Nano fluid [9, 12]. The addition of surface active agent's increases particle dispersion in a continuous phase of altered composition. This improves particle kinetic stability without requiring significant storage changes. Thermal conductivity Nanofluid is also affected by the random movement of particles suspended in gas or liquid (Brownian motion). According to particle kinetic theory, this motion is caused by particle collisions with the base fluid and rises with increasing temperature. However, Godson Raja, et al. [12] observed the effect of turbulence intensification. As a result, the researchers claim that increasing uniform dispersion of Nano particles, Brownian motion, and thermophoresis increases thermal conductivity. However, the increase in turbulence has little effect on thermal conductivity.

3. FACTORS AFFECTING THERMAL CONDUCTIVITY ENHANCEMENT OF NANO FLUID

Many factors affect the effective thermal conductivity of Nano fluids, including volume fraction, particle size and shape, operating temperature, Nano base fluid, as well as Nano particle stabilization technique (surfactants) or additives, among others.

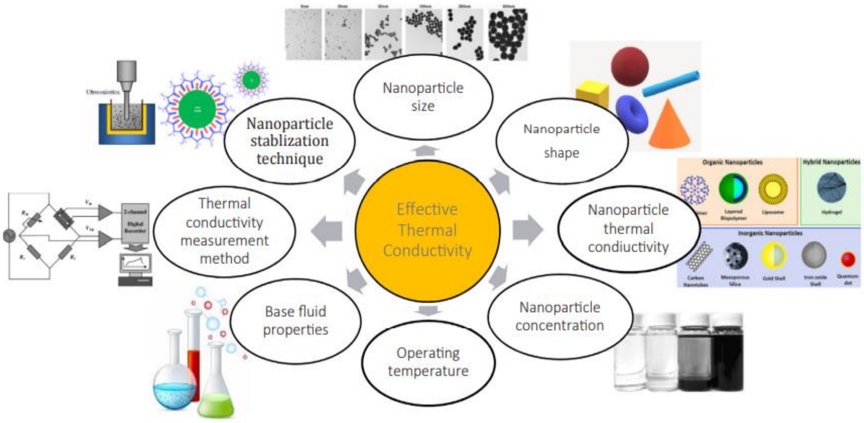

Figure 1. Factors affecting effective thermal conductivity of Nano fluid [15]

From the Figure 1. See that each Nano fluid parameters has influence on the thermal conductivity of Nano fluid.

3.1. Particle Volume Fraction

Syu et al. [16] the result of volume fraction on thermal conductivity was investigated experimentally using deionized water and Al_2O_3 particles of 35 nm diameter. The spray mass flux ranges from 26.433 to 176.433kg/m2, with particle volume fractions of 0 percent, 0.001 percent, 0.025 percent, and 0.05 percent specified. The thermal conductivity of this experiment was measured using a Decagon Pro KD_2 analyzer with a hot-wire measuring probe. The KD_2 analyzer was adjusted before the measurement tests by placing the measuring probe into a calibration liquid container. The suspension stability of Nanofluid was ensured by an ultrasonic bath and a magnetic stirrer. As a result, a low volume fraction of nanofluid (i.e., 0.001 Vol percent) improves spray cooling efficiency significantly. This is due to the fact that the majority of nanoparticles bounce back from the heated surface. In other words, the heat resistance at the fluid-surface contact is lowered since a Nano sorption coating is not produced.

According to Lin et al. [17], the Nano particle interacting with the base fluid tends to aggregate due to Brownian motion and the Vander Waals force. Finally, the particles sink and collect at the bottom of the fluid. However, Syu et al. [16] prepared a good suspension stability using an ultrasonic bath magnetic stirrer.

$$\text{Ø} = \frac{\text{volume of Al2O3}}{volume\ \text{Al2O3}\ +volume\ of\ de\ ionized\ water} \quad [16] \quad \text{..... Eqn. (1)}$$

Where, Ø is volume fraction Spray cooling with a large volume fraction Nano fluids (0.025 percent and 0.05 percent) have a lower concentration than the base fluid. This is because particles with a huge volume fraction are easily deposited. However, at a low volume fraction (0.001 percent), there is an important escalation in heat transfer without the formation of a Nano sorption, resulting in a decrease in thermal resistance. However, Maheshwary [18] observed a red shift as concentration increased in the UV-VIS spectra of TiO_2 –water Nanofluid. This red shift suggests that when concentration rises, agglomeration causes the particle size of scattered TiO_2 to grow. The concentration, particle size, and particle shape can all affect this fluid feature. Probe sonication is another way for altering fluid viscosity by shattering agglomerated particles in addition to these parameters.

The thermal conductivity of Fe at various volume fractions was examined by Wang et al. [19]. As the volume fraction increases, the intensification of heat conductivity increases. This is also higher than the Nano fluid based on copper. Deepak et al. [15] created a model that uses particle size distribution to estimate thermal conductivity. This concentrates on particle clustering, interfacial layer formation, and Brownian motion. Zareh et al. [20] used hybrid Nano particle in water base fluid, which differs from the previous researchers. Likewise, Lee et al. [21] the effect of TiO_2-MWCNTs (70-30)/EG-water hybrid Nano-fluid on thermal conductivity was investigated using a temperature range of 20-60^{o}C and volume fractions of 0.125, 0.5, 0.75, and 1%. He proposed that increasing the size of particle and temperature of nano fluid would improve its efficiency. Particle size variation was more noticeable than temperature fluctuation in positions of thermal viscosity and conductivity. The largest increase in thermal conductivity is 34.3 percent at 60°C and 1% volume fraction. As both the volume fraction and the temperature increase, and also the thermal conductivity increases.

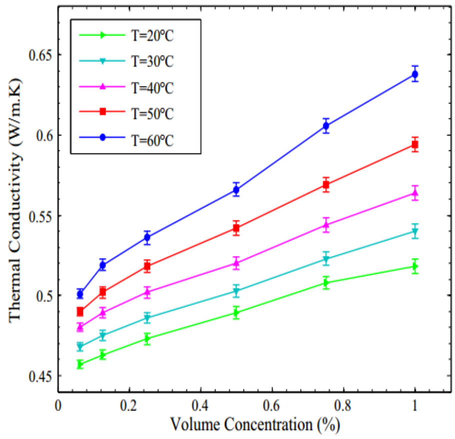

Figure 2. Thermal conductivity of the hybrid Nano fluids against volume concentration at various temperature [20]

According to Figure 2, thermal conductivity rises as the volume fraction rises. Furthermore, the effect of temperature variation is less significant at low volume fractions compared to high volume fractions. Thermal conductivity increases from 0.45-0.65 W/mk as temperature and volume fraction increase from 0.1 percent v_l and 20°c to 1 percent and 60°c.

Toghraie et al. [22] investigated the thermal conductivity of water ethylene glycol/TiO_2- MWCNT Nano fluid by varying the volume fraction from 0.1 to 1 percent and the temperature from 20-50 degrees Celsius. This demonstrated that at higher temperatures and volume fractions, thermal conductivity increases in evaluation to the base fluid. This is due to an raise in particle motion, intensification of clustering, and the formation of a continuous chain between particles. As a result, the heat transfer rate at high volume fraction increases. Even if the temperature remains constant, the effective thermal conductivity increases as the volume fraction increases. However, the power loss due to particle clustering is not considered in this study. With accumulative volume fraction, the nano fluid thermal conductivity increases [23]. This, however, has an unfavorable effect on the thermal conductivity of the Nano fluid. The viscosity increases with the volume fraction, but this necessitates more pumping power. It also significantly increases clustering and particle agglomeration in the Nano fluid.

Table 1. Volume fraction

Reference No.	**Material type**	**temperature**	**Volume fraction**	**Thermal conductivity enhancement**
[16]	Al_2O_3-water Nanofluid	--	0%, 0.001%, 0.05% v_l	For 0.001%, 0.025% and the enhancement becomes 11.5, 5.8 and 2.5% respectively.
[21]	TiO2-MWCNTs (70-30)/EG-water hybrid	20-60°c	0.125, 0.75 and 1% v_l	The maximum enhancement 34.3% at 60°c and 1% volume fraction
[22]	Water ethylene glycol/TiO_2-MWCNT	20-50°c	0.05-1% v_l	Maximum temperature enhancement 38.7% at 50°c and 1% v_l

[23].	Engine oil with ZnO Nano powder	25-55°c	0.125-1.5%v_l	The maximum enhancement is 8.74% at 1.5% v_l and 55°c

As shown in table 1, thermal conductivity increases from 6.5-8.74 percent on average when temperature and volume fraction increase from 20°C and 0.125 percent v_l to 50°C and 1% v_l. However, when the temperature and volume fraction are increased to 1% v_l and 55°C, the thermal conductivity of the hybrid Nano fluid increases on average from 34.3-38.7 percent associated to the base fluid.

3.2. Particle Size

Maheshwary, Handa, and colleagues [18] investigated the consequence of particle size on thermal conductivity of Nano fluid using a unique method of review sonication at various time intervals. XRD analysis absorbs the outcome of probe sonication. The particle size of the dispersion Nano particle will change as the sonication time increases. This method breaks the particle size in a liquid medium and reduces particle size. Furthermore, this method prevents particle sedimentation in the medium, resulting in long-term stability. Viscosity is a fluid property that allows it to withstand shear stress. This fluid property can be changed by varying the concentration, particle shape, and size. Another advantage of probe sonication is that it disperses agglomerated particle regions [28].

Using the steady-state technique, Chand et al. [24] observed the outcome of particle size on thermal conductivity. This study uses Al_2O_3 particles with sizes of 36 nm and 47 nm in distilled water. The experiment is carried out at temperatures ranging from 27-37 degrees Celsius and with volume fractions ranging from 0.5 to 6%. It was discovered that the thermal conductivity of 36 nm nanoparticles was 8% larger than that of 47 nm Al_2O_3 nanoparticles. The contacting surface area of a Nano particle increases as particle size decreases, resulting in increased thermal conductivity.

Hasan et al. [7] explored the outcome of nano fluid particle size on the Nusselt number as well as skin friction factor with varying Reynolds numbers. According to the findings of this study, reducing particle size outcomes in an raise in surface area per unit volume. This is due to Brownian motion velocity and adds another path to the total heat transfer of the fluid. Hung et al. [25] studied the result of particle size on the thermal conductivity of an water/alumina Nano fluid. The Brownian motion produced by random motion of the Nano particle within the bulk liquid was investigated in this study. The constant collision of particles resulted in increased thermal conduction. As a result, Brownian motion of particles is characterized by the Brownian diffusivity coefficient Db, which can be articulated by the Einstein–Stokes equation [19]. As eqn (2).

$$D_b = \frac{K_B \mathrm{T}}{\{3\pi\eta(\mathrm{dp}/109)\}} \quad [19@F]\ldots. \quad \text{Eqn. (2)}$$

Where D_b –Brownian diffusion coefficient
K_B –thermal conductivity
dp –diameter of particle size
T –temperature

According to Equation (2), the Brownian diffusion coefficient is relative to temperature. It does, however, have an inverse relationship with particle diameter. This suggests that the addition of smaller particles with high temperatures causes more collision, resulting in better thermal conduction. As a result, accumulative the temperature and falling the size of the Nano particle optimize heat conductivity. Thermal conductivity of sliver Nano particle fluid decreases as particle size decreases below a critical particle size [26]. This is because the aggregation rate of particles increases with particle size. As a result, as particle size decreases, the surface area over which the heat transfer mechanism among the particles becomes larger, resulting in increased thermal heat conductivity.

Table 2. Particle Size

Reference No.	Temperature (°c)	Particle size (nm)	Enhancement or results
[18]	10-50	31.339, 30.381, 20.657, 16.372nm	Each of them contributes (0.85-1.2), (0.95-1.4), (1-1.5), (1-1.6)W/mk respectively

[24]	27-37	36 and 47nm	Thermal conductivity of 36nm is greater than by 8% of the 47nm
[7]		20-50nm	Thermal conductivity of 20nm is much greater than that of 50nm due to increasing in Brownian motion of particles.

According to table 2, as particle size decreases, thermal conductivity increases due to Brownian motion, creating an additional path for heat transfer. For example, the thermal conductivity of a 36nm nanoparticle is 8% greater than that of a 47nm nanoparticle at the same temperature.

3.3. Particle Shape

The form of the particles affects the Nanofluid's thermal conductivity as well as its stability. The boost in effective thermal conductivities expected by the Hamilton-crosser equation is greatly reduced by interfacial effects proportionate to the total surface area of nanoparticles.

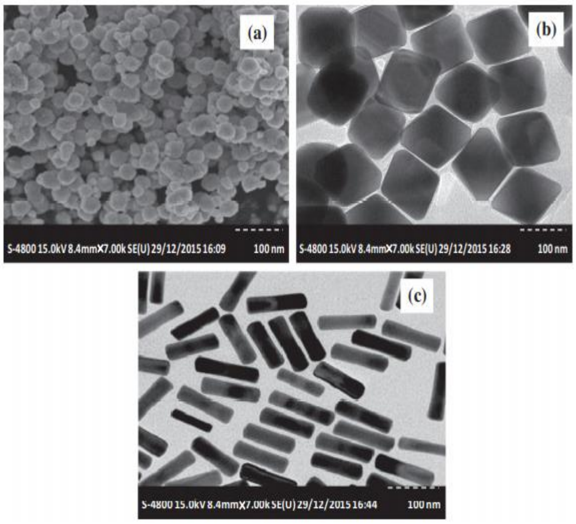

Figure 3. SEM images of TiO_2 nanoparticle a) spherical b) cubical c) rod shapes [18]

Figure 3 indicates the scanning of electron microscopy morphological image of nanoparticle to observe and investigate the shape and distribution in Nanofluid.

Vanaki, Mohammed, et al. [27] investigated various forms such as blades, cylindrical, bricks, platelets, and spherical Nano fluids with varied phase shifts and wavy amplitudes utilising the energy equation and the Navier Stokes equation with the finite volume approach. Researchers concluded from this experiment that the thermal conductivity of platelets > cylindrical > bricks > blades > spherical shapes. The effect of turbulence flow with different phase shifts and wavy amplitudes was also considered in this study. The authors, however, did not address the effect of motion and diffusivity.

Li et al. [28] conducted experimental and theoretical research on spherical and rectangular shapes with varying concentrations of Nano fluid. According to the findings, the thermal conductivity of spherical and rectangular shapes is nearly the same. However, the viscosity of rectangular shapes is 7.7 percent greater than that of spherical shapes. Both of them reported similar findings regarding the particle shape of various Nano fluids such as cubic, spherical, and rod [18, 28]. Despite the fact that they used different base fluids and techniques, the first used 2.5 wt percent TiO_2 water-based Nano fluid and the second used ZnO Nano fluid. According to the experts, when compared to the other shapes, the cubic shape has the highest thermal conductivity. The cubic shape is also said to have a higher viscosity than the rod and spherical shapes. This is because spherical and rod shapes are more difficult to spin than cubic shapes. The viscosity and heat conductivity of Nano particles are significantly affected by their form. Even though the cubical shape has high thermal conductivity, it has limitations for the following reasons [28].

- ❖ Synthesis of cubic shape Nano particle is hard and expensive

- ❖ Have high cogging issue
- ❖ The Stability is less. For this reason, spherical shape is more applicable in different applications.

Routbort et al. (2009) [29] result of shape particle on thermal conductivity of Nano fluids characterized by given (Eq. (3)) [36]

$$\frac{K_{eff}}{K_o} = 1 + (C_k \text{ shape } + C_k \text{ surface})\ldots \qquad \text{Eqn. (3)}$$

Where

$C_{k\text{shape}}$ Thermal conductivity enhancement coefficient function of shape

$C_k$surface Thermal conductivity enhancement coefficient function of surface

K_{eff} is the thermal conductivity of Nano fluid after accumulation of foreign material in base fluid and K_O thermal conductivity of referred base fluid. From Eqn. (2) the ratio of thermal conductivity is function of surface thermal conductivity and shape thermal conductivity.

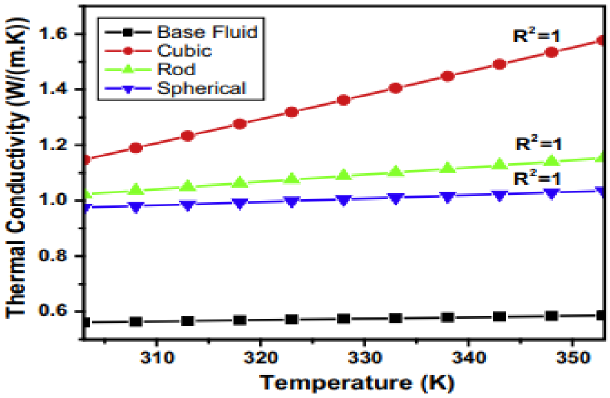

Figure 4. Experimental thermal conductivity TiO_2 water base fluid with the result of Nano particle shape [18]

Figure 4, the thermal conductivity of a cubic shape increases linearly as the temperature rises. However, for the rod and spherical shapes, it slightly increases, whereas for the base fluid, it is nearly constant with temperature. When the temperature increases from 310 degrees Celsius to 350 degrees Celsius, the thermal conductivity of cubic shapes increases by 28.125 percent, rod shapes by 12.5 percent, and spherical shapes by 3.125 percent when linked to the base fluid.

Dewangan et al. [30] used spherical and cylindrical particles to examine the result of particle shape on the thermal conductivity of Nano fluid. At 4.2 vol. percent of water base fluid, this was prepared by 4.2 vol. percent of 26nm average diameter spherical and 4.2 vol. percent of 600 nm cylindrical. According to the outcomes of this experiment, the thermal conductivity enhancement for cylindrical and spherical shapes is 15.8 percent and 22.9 percent, respectively. This is due to the fact that cylindrical shapes have a large heat transport along their length. This is not possible, however, because it produces more viscosity than spherical shapes. As a result, more pumping power is required.

Table 3. Particle shape

Reference No.	**Material type**	**Particle shape**	**Results or enhancement in %**
[27]	SiO_2 displaced in EG	blades, platelets, cylindrical, bricks and spherical	platelets > cylindrical > bricks > blades > spherical shapes

[28]	ZnO Nano fluids	spherical and rod , cubic shapes	Thermal conductivity cubic shape (28.125%) > rod (12.5%) > Spherical shapes (3.125%). However the viscosity of rectangular shape is greater by 7.7% that of spherical shapes. Cubic shape has higher viscosity than of both shapes. 28
[30]	AlO_3 Nano fluids	spherical and cylindrical shapes	Thermal conductivity enhancement for cylindrical and spherical is 15.8%and 22.9% respectively.

According to the table 3, the thermal conductivity of cubic shapes is superior than that of other shapes. Thermal conductivity enhancement of cubic shapes is approximately 28.125 percent on average when associated to base fluid. A cubic shape, on the other hand, has a higher viscosity than a rod or a sphere. This is because spherical and rod shapes are more difficult to spin than cubic shapes. As a result, the applicability of cubic shapes is lower than that of other shapes.

3.4. Effect of Material type

Hasan and colleagues [7] Al_2O_3, SiO_2, CuO, and ZnO nanoparticles were studied with pure water as the base fluid. This study was created with a 0.04 volume fraction and a particle diameter of 20 nm of Nano fluid. According to the findings, the thermal conductivity of SiO_2 is the lowest but still larger than that of the base fluid. Furthermore, for all types of Nano fluids, this study clearly demonstrated that skin coefficient friction decreases with increasing Reynolds number at constant volume fraction and particle size. The skin friction coefficient of SiO_2 is the highest, followed by that of Al_3O_2. Chavda and colleagues [31] It was also discovered that the thermal conductivity of pure metals such as Ag and Cu is larger than that of ceramic oxides such as Al_2O_3, SiO_2, and TiO_2. However, particle aggregation occurs in metals, resulting in low stability. To overcome the low thermal conductivity and stability, a recent study combined more than one nanoparticle in a base fluid to achieve the synergetic effect known as hybrid Nano fluid. The results showed that adding SiO_2 to water has only a 2% increase in thermal conductivity, whereas the hybrids of SiO_2-Cu/water and SiO_2-Cu/EG have up to 11 and 11.5 percent increases in thermal conductivity, respectively [9]. According to the consequences of this experiment, the hybrid Nano fluid has a advanced thermal conductivity enhancement than the non-hybrid Nano fluid.

3.5. Temperature

Mao et al. [23] studied engine oil with ZnO nanoparticles at temperatures ranging from 25 to 55 degrees Celsius and volume fractions ranging from 0.125 to 1.5 percent. In this experiment, the thermal conductivity of the Nano lubricant increases as the temperature rises. As the temperature rises, so does the energy level, average kinetic energy of particles, and vibration of the base Nanofluid. As a result, the bonds between fluid layers weaken. Furthermore, by randomly striking and colliding the surface solid nanoparticle, the random Brownian motion of particles is enhanced. Thermophoresis is a Brownian motion phenomena that influences Nanofluid's thermal conductivity and cooling impact. This phenomena is linked to temperature gradients, and it increases thermal conductivity performance in cooling the engine by transporting Nano particles from a hot to a cold area.

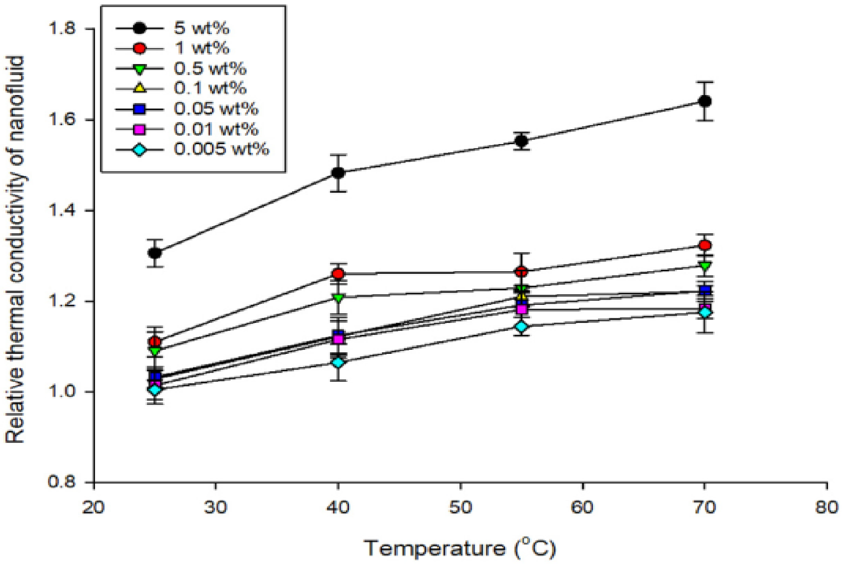

Figure 5. Relative thermal conductivity of Nanofluid versus temperature [23]

According to Figure 5, relative thermal conductivity increases with temperature. However, its rate is higher in the high-volume fraction. Thermal conductivity increases from 1-1.8 W/mk as temperature rises from 20 to 70 degrees Celsius and volume fraction rises from 0.005 to 5% v_l.

Sulgani and Karimipour [32] investigated the thermal conductivity of 10w40 engine oil at different temperatures with the addition of Al_2O_3/Fe_2O_3 nanoparticles. The study's main goal is to examine the result of powder hybrid nanoparticles on thermal conductivity as temperature and mass fraction vary. As a result, as the temperature raises, so does the thermal conductivity of the addition powder hybrid Nano particle. The nanoparticles are distributed using an ultrasonic probe, and the thermal conductivity of the hybrid Nano fluid is measured using a KD2-probe thermal analyzer. At the highest volume and temperature percent, this results in the highest thermal conductivity. In order to obtain an accurate experimental relationship, curve fitting is also functional to the experimental data. As a result, as the temperature rises, so does the average molecular movement of the powder hybrid Nano particle. Heat energy is transferred between Nano fluid layers during this process. As the temperature rises, the thermal conductivity behaviour of the base fluid changes due to the addition of nanoparticles.

4. STABILITY OF NANO FLUID

According to Pourfayaz et al. [33], one of the difficulties in the thermal conductivity of Nanofluid is the poor stability behavior of Nanoparticle fluid. This is due to particle-particle interactions as well as particle-particle interactions with surrounding liquids. This type of personality trait is related to the two opposing forces. One is the Vander Walls' attraction force on the particle, which causes particles to be attracted to one another and form groups or agglomerations of particles. This separates from the base fluid and settles due to gravitational force. The second type of force is repulsion, which causes particles to repel one another due to steric and electrostatic repulsion mechanisms. This study investigated the stability of Nanofluid by employing various methods to reduce aggregation and improve nanoparticle dispersion in base fluid [34]. Long-term stability, including chemical or physical treatment, is hampered as a result. However, it has been reported that as particles are collected and aggregated in base fluid, the thermal conductivity of Nanofluid increases. As a result, during preparation, this issue must be considered in order to strike a balance between thermal conductivity and stability. Other researchers, however, believe that different surfactants can help adjust hydrophobic materials to allow dispersion throughout the solution. As a result, this prevents nanoparticle aggregation, sedimentation, and clogging, thereby increasing thermal conductivity [34, 35]. Even though surfactants improve the stability of Nano fluid, they have no effect on its thermal conductivity [27]. To address this effect, a novel method of modifying SiO_2-coated graphene nanomaterial with water is employed. This method significantly improves graphene's hydrophilicity, as well as its stability and thermal conductivity. As a result, the thermal conductivity of SiO_2-coating is greater than that of surfactants used in the preparation of water-based Nano fluid.

The thermal conductivity of nanoparticles in aqueous solution is considerably increased by their stability, according to Said et al. [36]. This is connected to the electrokinetic features of the material. Nanoparticles having a higher surface charge density, like charged particles, exert larger repulsive forces in a base fluid. The zeta potential, distinct as the potential difference among base fluid and the hybrid nanoparticles, is used to assess nanofluid stability. Stable nano fluids have a zeta potential of 30–40 mV, though zeta potentials of 40–60 mV have good stability. However, because zeta potentials below 30mV have low stability, the nanoparticles agglomerate. The zeta potential values of ternary rGO-Fe_3O_4-TiO_2/EG Nano fluids with concentrations ranging from 0.01 to 0.25 wt percent and temperatures ranging from 25 to 60^oC are investigated experimentally. Carbonyl, carboxyl, hydroxyl, and epoxide functional groups make up GO. The interaction of the functional groups with the solvent improves the stability of Nanofluid. According to the results, the suspension stability of rGO-Fe_3O_4-TiO_2 hybrid Nanofluid is greater than that of rGO Nanofluids. This condition may be caused by Fe_3O_4 and TiO_2 nanoparticles chained and adorned on a surface of condensed grapheme oxide, and this phenomenon is important in preventing the grapheme layers from stacking and overlapping. A variety of factors influence the stability of Nano fluid. Brownian motion, different types of nanoparticles and bases, particle-fluid and particle-particle interactions, and thermophoresis [11]. Thus, the stability of Nano fluid can be improved by employing various techniques are ultrasonic agitation, PH control, surface modification, and surfactant addition. Nanoparticle aggregation and sedimentation are the causes of Nanofluid instability. This condition occurs as a result of particle-to-particle and particle-to-fluid interactions and results in coagulation or aggregation, which can be regarded as the primary source of instability.

Table 4. Summary of the Survey Findings

Tittle/author	Purpose	Methodology	Sample parameters	Key findings	Limitation/ remarks
[8]Heat transfer enhancement of Nano fluid	To know the effect of volume fraction, shapes and material type on HTENF	Using experiment Nano phase powders and base liquid	- Volume fraction - Shapes - Particle size	Thermal conductivity increase from 1.24 to1.78 when the volume fraction ultra-particle increases from 2.5% to 7.5%	The author does not consider diffusion sedimentation and dispersion
[10] Heat transfer enhancement of Nano fluids flow in micro tube with constant heat flux	To investigate the effect particle size, concentration and type of material	finite volume difference with the aid of simpler algorithms	- Particle size varying volume fraction varying - Type of material	The thermal conductivity for Al_2O_3 = 0.31112,CuO = 0.313164, SiO_2 = 0.274434 and ZnO = 0.30544	Even though he addressed many things still does not consider shape of particle
[27] Particle shape effect on the viscosity and thermal conductivity of ZnO Nano fluids	To know effect of particle shape and material type	Experimental	- Particle shape - Material type - Concentration	Thermal conductivity for both rectangular and the spherical nearly the same. But, viscosity of rectangular greater by 7.7% than of that spherical	The researcher should not consider the particle size
[18] comprehensive study of effect of concentration, particle size and particle shape onTC titanium/water based Nano fluid	To analyze the effect of concentration, particle size and shape	Experimental	- Concentration - Particle size - Shape of particle	Concentration 69.23% & Particle size contributes 24.85% & Shape factor contributes 5.54% in enhancement of thermal conductivity	The author also consider the effect Brownian motion

5. TRENDS OF THE RESEARCH AND CHALLENGES

The research trends are focusing on hybrid Nano fluid and critical factors of Nano fluid thermal conductivity. Furthermore, the nanoparticle coating and stability issues are improving current and future studies of Nano fluid.

6. GABS OF THE RESEARCH

- The researchers did not address the reciprocal relation between stability of Nano fluid and thermal conductivity. Since as volume fraction increases the thermal conductivity also increases, but the stability decreases. Thus it should be address.
- Even though, addition of Surfactants is increasing the stability of Nanofluid, authors did not explain the effect of surfactants, since it forms foam.
- Most of the thermal conductivity studies have been accomplished with oxide nanoparticles; authors did not address metallic coating as nanoparticle. Since metallic particles have higher thermal conductivity compared to other particles. However, there are less applicable because of having low stability. Therefore coating mechanism should be considered.
- Most of the researchers investigate the effect of particle shapes of spherical, cylindrical and cubic. Researchers should also consider other shapes.
- The authors should also consider the power and pressure loss during increasing concentration.

7. CONCLUSION

This review provides an in-depth look at the research progress made in the thermal conductivity, heat transfer, and stability properties of Nano fluids. Heat transfer enhancement of Nano fluid has been studied using both experimental and numerical techniques. Many of these studies revealed strong agreement between experimental and numerical consequences. Nano fluids offer a better potential for heat transfer enhancement, according to the conclusions of the review, and are ideally suited for use in actual heat transfer processes. This is a fantastic opportunity to create or improve highly compact and efficient heat transfer equipment. The heat transmission of Nano fluid is said to be much greater than that of the base fluid in many published papers. Finally, this study is summarized as follows:

- The thermal conductivity of Nano fluid increases with increasing the volume concentration. But, as concentration increases the viscosity also increases. This requires high pumping power.
- As temperature increases the thermal conductivity also increases. However, at low volume fraction effect of temperature is insignificant.
- The features of hybrid Nano fluids improve with rising temperature and volume fraction, although some hybrid Nano fluids have volume fraction upper limitations. As volume fraction increases beyond this limit the performance of hybrid Nano fluid becomes deteriorate.
- Particle shape also affects the thermal conductivity of Nanofluid. Thus cubic shape nanoparticle has the peak thermal conductivity associated to other shapes.
- Stability affects the thermophsical properties, as well as the performance of entire thermal system.
- Stability of Nano fluid is affected by suspended nanoparticles and this enhanced by uniform dispersing particles
- Addition of surfactants enhances the stability of Nanofluid. But as increases surfactants it reduces the thermal conductivity whereas the viscosity of Nano fluid increase

8. RECOMMENDATIONS

- Further research inputs are required to grow the exact correlations between the changes in thermal conductivity and stability with variation of the parameters are concentration, particle size and shape, temperature, and material type. Since theses affects the stability and thermophsical property of Nanofluid.
- Additional precise experimental investigations are required to be optimizing with respect to each parameters such as temperature, particle shape, preparation technique and stability.
- Further research should require towards metallic coating as nanoparticle. Since metallic particles have highest thermal conductivity than others.
- Future study of thermal conductivity should be on pure metallic nanoparticle with different concentration and particle shapes to fill the gap of heat transfer. Since pure metallic have 100 times higher than of that of the oxide Nano particle.

- Researchers should address the reciprocal relation between thermal conductivity and stability of Nanofluid as volume fraction increases.

9. DISCLOSURE STATEMENT

Certain products or services identified in the paper to foster understanding does not imply recommendation or endorsement by the current author, nor does it imply that the products or services identified are necessarily the best available for the purpose.

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REFERENCES

[1] H. M. Ali, H. Ali, H. Liaquat, H. T. Bin Maqsood, and M. A. Nadir, "Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids," *Energy (Oxf.)*, vol. 84, pp. 317–324, 2015.

[2] M. M. Elias *et al.*, "Experimental investigation on the thermo-physical properties of Al2O3 nanoparticles suspended in car radiator coolant," *Int. commun. heat mass transf.*, vol. 54, pp. 48–53, 2014.

[3] K. Y. Leong, R. Saidur, S. N. Kazi, and A. H. Mamun, "Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator)," *Appl. Therm. Eng.*, vol. 30, no. 17–18, pp. 2685–2692, 2010.

[4] M. Naraki, S. M. Peyghambarzadeh, S. H. Hashemabadi, and Y. Vermahmoudi, "Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator," *Int. J. Therm. Sci.*, vol. 66, pp. 82–90, 2013.

[5] B. P. S. Tomar and A. J. I. J. O. A. R. I. S. Tripathi, "Experimental study of heat transfer of a car radiator with nano fluid-Al2O3 water mixture as coolant," vol. 2, pp. 830–837, 2015.

[6] A. Hussein, K. Sharma, R. Bakar, and K. J. J. O. M. E. Kadirgama, "Heat transfer enhancement with nanofluids-a review," vol. 4, pp. 452–461, 2013.

[7] H. A. Mohammed, H. A. Hasan, and M. A. Wahid, "Heat transfer enhancement of nanofluids in a double pipe heat exchanger with louvered strip inserts," *Int. commun. heat mass transf.*, vol. 40, pp. 36–46, 2013.

[8] Y. Xuan and Q. Li, "Heat transfer enhancement of nanofluids," *Int. J. Heat Fluid Flow*, vol. 21, no. 1, pp. 58–64, 2000.

[9] M. H. Ahmadi, A. Mirlohi, M. Alhuyi Nazari, and R. Ghasempour, "A review of thermal conductivity of various nanofluids," *J. Mol. Liq.*, vol. 265, pp. 181–188, 2018.

[10] B. H. Salman, H. A. Mohammed, and A. S. Kherbeet, "Heat transfer enhancement of nanofluids flow in microtube with constant heat flux," *Int. commun. heat mass transf.*, vol. 39, no. 8, pp. 1195–1204, 2012.

[11] B. Bakthavatchalam, K. Habib, R. Saidur, B. B. Saha, and K. Irshad, "Comprehensive study on nanofluid and ionanofluid for heat transfer enhancement: A review on current and future perspective," *J. Mol. Liq.*, vol. 305, no. 112787, p. 112787, 2020.

[12] L. Godson, B. Raja, D. Mohan Lal, and S. Wongwises, "Enhancement of heat transfer using nanofluids—An overview," *Renew. Sustain. Energy Rev.*, vol. 14, no. 2, pp. 629–641, 2010.

[13] R. Saleh, N. Putra, R. E. Wibowo, W. N. Septiadi, and S. P. Prakoso, "Titanium dioxide nanofluids for heat transfer applications," *Exp. Therm. Fluid Sci.*, vol. 52, pp. 19–29, 2014.

[14] C. H. Li and G. J. J. O. A. P. Peterson, "The effect of particle size on the effective thermal conductivity of Al 2 O 3-water nanofluids," vol. 101, 2007.

[15] T. Ambreen and M.-H. Kim, "Influence of particle size on the effective thermal conductivity of nanofluids: A critical review," *Appl. Energy*, vol. 264, no. 114684, p. 114684, 2020.

[16] T.-B. Chang, S.-C. Syu, and Y.-K. Yang, "Effects of particle volume fraction on spray heat transfer performance of Al2O3–water nanofluid," *Int. J. Heat Mass Transf.*, vol. 55, no. 4, pp. 1014–1021, 2012.

[17] D. Wen, G. Lin, S. Vafaei, and K. Zhang, "Review of nanofluids for heat transfer applications," *Particuology*, vol. 7, no. 2, pp. 141–150, 2009.

[18] P. B. Maheshwary, C. C. Handa, and K. R. Nemade, "A comprehensive study of effect of concentration, particle size and particle shape on thermal conductivity of titania/water based nanofluid," *Appl. Therm. Eng.*, vol. 119, pp. 79–88, 2017.

[19] I. Nkurikiyimfura, Y. Wang, and Z. Pan, "Heat transfer enhancement by magnetic nanofluids—A review," *Renew. Sustain. Energy Rev.*, vol. 21, pp. 548–561, 2013.

[20] A. Moradi, M. Zareh, M. Afrand, and M. Khayat, “Effects of temperature and volume concentration on thermal conductivity of TiO2-MWCNTs (70-30)/EG-water hybrid nano-fluid,” *Powder Technol.*, vol. 362, pp. 578–585, 2020.

[21] S. W. Lee, S. D. Park, S. Kang, I. C. Bang, and J. H. Kim, “Investigation of viscosity and thermal conductivity of SiC nanofluids for heat transfer applications,” *Int. J. Heat Mass Transf.*, vol. 54, no. 1–3, pp. 433–438, 2011.

[22] A. Akhgar and D. Toghraie, “An experimental study on the stability and thermal conductivity of water-ethylene glycol/TiO2-MWCNTs hybrid nanofluid: Developing a new correlation,” *Powder Technol.*, vol. 338, pp. 806–818, 2018.

[23] L. Yang, M. Mao, J.-N. Huang, and W. Ji, “Enhancing the thermal conductivity of SAE 50 engine oil by adding zinc oxide nano-powder: An experimental study,” *Powder Technol.*, vol. 356, pp. 335–341, 2019.

[24] B. Ravisankar and V. Tara Chand, “Influence of nanoparticle volume fraction, particle size and temperature on thermal conductivity and viscosity of nanofluids- A review,” *Int. J. Automot. Mech. Eng.*, vol. 8, pp. 1316–1338, 2013.

[25] T.-P. Teng, Y.-H. Hung, T.-C. Teng, H.-E. Mo, and H.-G. Hsu, “The effect of alumina/water nanofluid particle size on thermal conductivity,” *Appl. Therm. Eng.*, vol. 30, no. 14–15, pp. 2213–2218, 2010.

[26] P. Warrier and A. Teja, “Effect of particle size on the thermal conductivity of nanofluids containing metallic nanoparticles,” *Nanoscale Res. Lett.*, vol. 6, no. 1, p. 247, 2011.

[27] S. M. Vanaki, H. A. Mohammed, A. Abdollahi, and M. A. Wahid, “Effect of nanoparticle shapes on the heat transfer enhancement in a wavy channel with different phase shifts,” *J. Mol. Liq.*, vol. 196, pp. 32–42, 2014.

[28] J. Jeong, C. Li, Y. Kwon, J. Lee, S. H. Kim, and R. Yun, “Particle shape effect on the viscosity and thermal conductivity of ZnO nanofluids,” *Int. J. Refrig.*, vol. 36, no. 8, pp. 2233–2241, 2013.

[29] E. V. Timofeeva, J. L. Routbort, and D. Singh, “Particle shape effects on thermophysical properties of alumina nanofluids,” *J. Appl. Phys.*, vol. 106, no. 1, p. 014304, 2009.

[30] I. Ganesh Ranakoti, S. Dewangan, S. Kosti, R. J. M. -C. H. Nemade, and M. Transfer, *Heat transfer enhancement by nano fluids*. 2012.

[31] R. K. Bumataria, N. K. Chavda, and H. Panchal, “Current research aspects in mono and hybrid nanofluid based heat pipe technologies,” *Heliyon*, vol. 5, no. 5, p. e01627, 2019.

[32] M. T. Sulgani and A. J. J. O. M. L. Karimipour, “Improve the thermal conductivity of 10w40-engine oil at various temperature by addition of Al2O3/Fe2O3 nanoparticles,” vol. 283, pp. 660–666, 2019.

[33] M. Aramesh, F. Pourfayaz, and A. Kasaeian, “Numerical investigation of the nanofluid effects on the heat extraction process of solar ponds in the transient step,” *Sol. Energy*, vol. 157, pp. 869–879, 2017.

[34] A. Hilo, S. R. Nfawa, M. T. H. Sultan, M. F. A. Hamid, M. N. J. J. O. A. R. I. F. M. Bheekhun, and T. Sciences, “Heat transfer and thermal conductivity enhancement using graphene nanofluid: a review,” vol. 55, pp. 74–87, 2019.

[35] M. Mehrali *et al.*, “Preparation, characterization, viscosity, and thermal conductivity of nitrogen-doped graphene aqueous nanofluids,” *J. Mater. Sci.*, vol. 49, no. 20, pp. 7156–7171, 2014.

[36] N. K. Cakmak, Z. Said, L. S. Sundar, Z. M. Ali, and A. K. Tiwari, “Preparation, characterization, stability, and thermal conductivity of rGO-Fe3O4-TiO2 hybrid nanofluid: An experimental study,” *Powder Technol.*, vol. 372, pp. 235–245, 2020.

[37] M. Zarringhalam, A. Karimipour, and D. Toghraie, “Experimental study of the effect of solid volume fraction and Reynolds number on heat transfer coefficient and pressure drop of CuO–Water nanofluid,” *Exp. Therm. Fluid Sci.*, vol. 76, pp. 342–351, 2016.