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HEAT TRANSFER ENHANCEMENT BY HYBRID NANO FLUIDS: A COMPREHENSIVE REVIEW

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ABSTRACT

The variety of techniques are used to increase the heat transfer rate of a thermal system like inserts, changing the geometry of tubes, etc. but they increases the operational cost of the system. The traditional coolant like EG, Water is used to cool the system. The mono nano fluid shows the improved performance of cooling but as we increased the volume concentrations of nano particles, it increases the chances of clogging as the nano fluid possesses the agglomeration. As their performance is limited so hybrid nano fluid is introduced as a coolant. The exhaustive literature shows that hybrid nano fluids gives very impressive results. In this research article a rigours review is made to identify the effect of hybrid nano fluids on thermal systems. The various factors like stability, ph control, viscosity were studied which affects the performance of hybrid nano fluids. The effect of hybrid nano fluid on the thermo physical properties like thermal conductivity, specific heat, dynamic viscosity was also studied and it’s noted that the hybrid nano fluids were more effective as it improves the performance of system by improving the thermo physical properties of coolants. This paper includes the rigours study of thermo physical properties of hybrid nano fluids.
Keywords; Thermal conductivity, Specific heat, Dynamic Viscosity

I. Introduction

The nano-sized dispersion of nano particles in conventional coolant like water , EG is called nano fluid. The nano particles can be made of metallic or non metallic elements. The materials used for nano particles are metals like gold, copper. metal oxides like aluminium oxide, sulphur dioxide, titanium dioxide, copper oxide, oxide ceramics, metal nitrides, metal carbides, carbon nano tubes, graphite diamond, etc .The base fluid may be water, ethylene glycol, organic liquids, ,refrigerants , oils, bio fluids, etc. The materials used for nano particles should be chemically stable to avoid chemical reactions with base fluid, which affect the thermo physical properties of nano fluid and ultimately reduce its effectiveness. The effectiveness of nano fluids depends on variety of aspects like factors like geometrical shape , size of nano particles , and volume concentration of nano particles , the type of base fluid, and temperature. The applications of nano fluids are in almost every field, like electronics, solar energy, automotive industries, medical fields, heating and cooling of buildings. [12] ,[16] The nano fluid prepared by single elemental nano particles has shown limited effectiveness, so researchers are attracted to multiple elemental nano particles studies. The addition of multiple types of elemental nano particles along with single elemental nano particles improves the effectiveness of nano fluids. In continuation with mono-nano particles fluid, scientists discovered a new type of nano fluid called hybrid nano fluid, which is a composition of multi-element nano particles and base fluid..The effectiveness of nano particles is based on their thermo-physical properties like specific heat, viscosity, and thermal conductivity. The thermal conductivity of nano fluid can be improved by increasing the volume concentration of nano particles in the base fluid. But , it increases the pumping power. The viscosity of mono-nano fluids can be improved by the addition of nano particles by volume, but it results in a pressure drop that is responsible for the creation of clusters that increase hydrodynamic diameter and reduce specific surface area. The increment in viscosity also results in clogging in pipes, which ultimately increases erosion. Although the thermo physical properties depend on a combination of nano particles. The hybrid nano fluid observed to be more stable in comparison with traditional nano fluids. The Table 1 shows the various types of nano particles and there base fluid combinations. Water as a base fluid is preferred by most of researchers as it is readily available and the small volume concentrations nano particles were easily dispersed in it.

Table 1**:** Various types of Nanoparticles and base fluids

Elements Group	**Nano Particles**	**Base fluids**
Metals	Ag	Water, toluene.
	Au	Water, toluene.
	Al	Water, EG, oil , kerosene
	Cu	Water, EG, oil, acetone , EG
Oxides	SiO_2	Water, EG, glycerol, oil , glycerol , EG
	TiO_2	Water, EG, oil, water, EG, bio glycol, water.
	Al_2O_3	Water, EG, oil, water , glycerine
	ZnO	Water, EG, oil.
Non Metals	SWCNT	Water, EG
	DWCNT	Water, EG.
	MWCNT	Water, EG, fullerenes oil.
	Nano Diamond	Water, EG, propylene glycol, midel oil, silicone oil, mineral oil, transformer oil , engine oil
	Graphene	Water, EG
	Graphite	Water, texatherm oil.

II. Literature

2.1 Preparation of Hybrid Nano fluids

The hybrid nano fluid is a combination of multi-elemental nano particles and a base fluid. As it consists of multi-elemental nano particles, several factors are playing a significant role, and these should be taken into account. The effectiveness of nano fluid is increased by the addition of nanoparticles to the base fluid, but it results in an agglomeration problem. Due to agglomeration, the pipes get clogged, which increases the corrosion on solid surfaces. This agglomeration problem is solved by adopting ultra sonication methods.

The hybrid nano fluids can be produced by two methods:

1) Single-Step Method

2) Two-Step Method

1) Single Step Method

In this method, two types of nano particles were synthesized at the same time. The single-step method consists of a variety of techniques like Laser Ablation Process (LBA), Electro Discharge Machining (EBM), and Micro Electrical Discharge Machining (MEDM).The single-step method is not suitable for large-scale production as it is time-consuming and thus it becomes uneconomical. The single-step method is not suitable for large-scale production as it is time-consuming. [76]

2) Two Step Method-

Firstly, nanoparticles synthesized from several physical or chemical processes and base fluids were mixed together at a time. Then surfactant is added, and afterwards ultrasonication is carried out to avoid the clogging. It increases the stability of nano fluids.

The hybrid nano fluids can be prepared with the above methods, and the base fluid may be of different types, like: Water, Ethylene glycol, Water+ethylene glycol , Vegetable oil , PAO oil, Naphthenic mineral oil, SAE oil , Transformer oil, Paraffin oil, , Dia-thermic oil etc. The Table 2 shows the methods opted by researchers for synthesis of hybrid nano particles. Most of researchers choose Ball milling or mechanical milling to synthesise the nano particles as it is easily operational. [77]

Table 2 : Synthesis methods for hybrid Nanoparticles

Ref	Composition of Hybrid Nanoparticles	Base Fluid	Method
Suresh [1]	Al_2O_3-Cu	Water	Thermo chemical
Chen [2]	MWCNT-Fe_3O_4	Water	Ball Miling
Batmunkh [3]	Ag-TiO_2	Water	Mechanical Stirring
Madhesh [4]	Cu-TiO_2	DI Water	Mechanical Milling
Sundar [5]	MWCNT-Fe_3O_4	DI Water	Chemical Co-precipitation.
Nine [6]	Cu-Cu_2O	Water	Wet Ball Milling
Li [7]	CNT-SiO_2 and CNT-Sio_2-Ag	Water	Plasma Treatment
Yarmand [8]	GNP-Ag	Water	Chemical Water Deposition.
Baby [9]	MWCNT-GO	DI Water	Catalytic Chemical Vapour Deposition
Abbasi [10]	Al_2O_3-MWCNT	Water	Solvothermal
Chen [11]	Ag-MWCNT	Water	Ball Milling

2.2 Factors affecting performance of Nano fluid:-

2.2.1 Stability:

The van der Waals and cohesive forces are mainly responsible for the agglomeration of nano fluids. Due to its heat transfer characteristics, the hybrid nano fluid decreases its potential due to its proneness to coagulation. The frictional resistance gets amplified due to the addition of nano particles in the nano fluid, which increases the pressure drop. The thermo physical properties of the hybrid nano fluids were depend on the stability of the hybrid nano fluid. Stability analysis can be done with a variety of methods, like the spectral analysis method and the sedimentation method. Light scattering method, zero potential analysis, centrifugation method the common methods were developed for the sake of simplicity in analysis for reducing agglomeration, like i) Addition of Surfactant. ii) Controlling pH with electrostatic stabilization iii) Ultrasonic Vibration The addition of Surfactant is the most suitable method for increasing the stability of Hybrid nano fluids but it has a limitations of base fluid selections in hybrid nano fluids. The Table 3 shows the Stability period for various hybrid nano particles fluids. The hybrid nano particles were stable up to 10 to 15 days if used in combination of base fluid water [22] and shows significant stability of more than 50 days if solely used with base fluid as water. The stability of hybrid nano fluid can be improved by using sonication as to reduce chances of clogging in pipes. Similarly hybrid nano fluid stability is also dependant on type of base fluid used. The liquids other than water are more viscous since the stability of hybrid nano fluid reduced. [17]

Table 3 : Stability period for various hybrid nano particles fluid

Reference	**Composition of Hybrid Nanoparticles**	**Base Fluid**	**Stability Period**
Mechiri [14]	Cu-Zn	Vegetable oil	03 days
Parsian [18]	Al_2O_3-Cu	EG	03 days
Esfe [16]	Cu-TiO_2	Water and EG	07 days
Asadi [12]	Al_2O_3-MWCNT	Thermic oil	07 days
Shriravi [21]	Carbon black	Water	07 days
Wei [13]	Sic-TiO_2	Diathermic oil	10 days
Esfe [19]	MWCNTs-ZnO	Water and EG	10 days
Qing [15]	SiO_2-graphene	Naphthenic mineral oil	14 days
Hamid [22]	TIO_2-SIO_2	Water and EG	14 days
Yarmand [20]	GNPs-Pt	Water	22 days
Ma [23]	Al_2O_3-CuO	Water	25 days
Ma [23]	Al_2O_3-TiO_2	Water	25 days
Sundar [17]	MWCNT-Fe_2O_3	Water	60 days

2.2.2 pH Control Method:

The hybrid nano fluid persists under strong repulsive forces since its stability depends on its electro kinetic properties. The stability of Hybrid nano fluid can be increased by controlling its pH value. The hybrid nano fluid with water as a base fluid, CNT nano particles , and acid as a surfactant can increase the stability of the water-CNT hybrid nano fluid. For different combinations of nano particles and base fluids, different pH values exits. [79]

2.2.3 Ultrasonic Intensity:

The ultrasonic intensity is very helpful in changing the structure of hybrid nano particles and there characteristics. Due to increment in ultrasonic intensity the shockwave is generated inside the hybrid nano fluid composition which significantly affects the effectiveness of hybrid nano fluid. since by utilising reduce size hybrid nano particles composition in hybrid nano fluid improves the performance of hybrid nano fluid. [78]

2.3 Thermo Physical properties of Hybrid Nano Fluids-

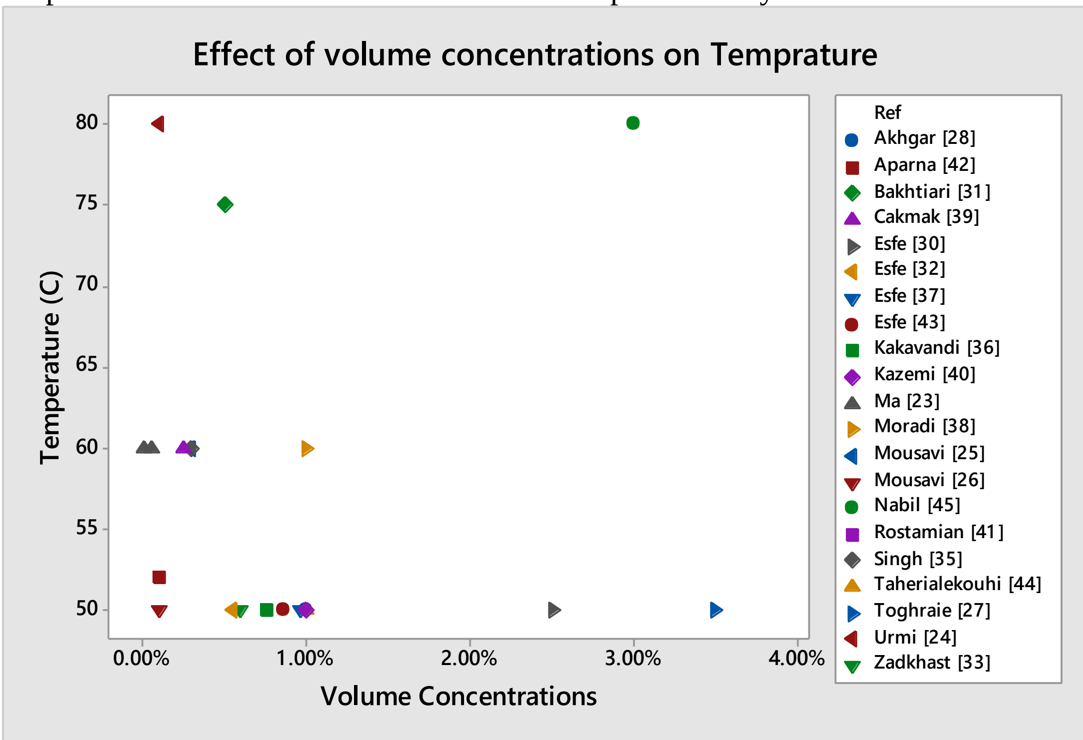
2.3.1 Thermal Conductivity:-

The thermal conductivity is the most important property to identify the heat transfer characteristics of a hybrid nano fluid. The literature shows that, the thermal conductivity of the hybrid nano fluid is dependent on the nano particles combinations .The table 4 shows a comparison of various hybrid nano fluids with volume concentrations and enhancement in temperature and thermal conductivity.

Table 4- Findings of the work on thermal conductivity of hybrid nanofluids

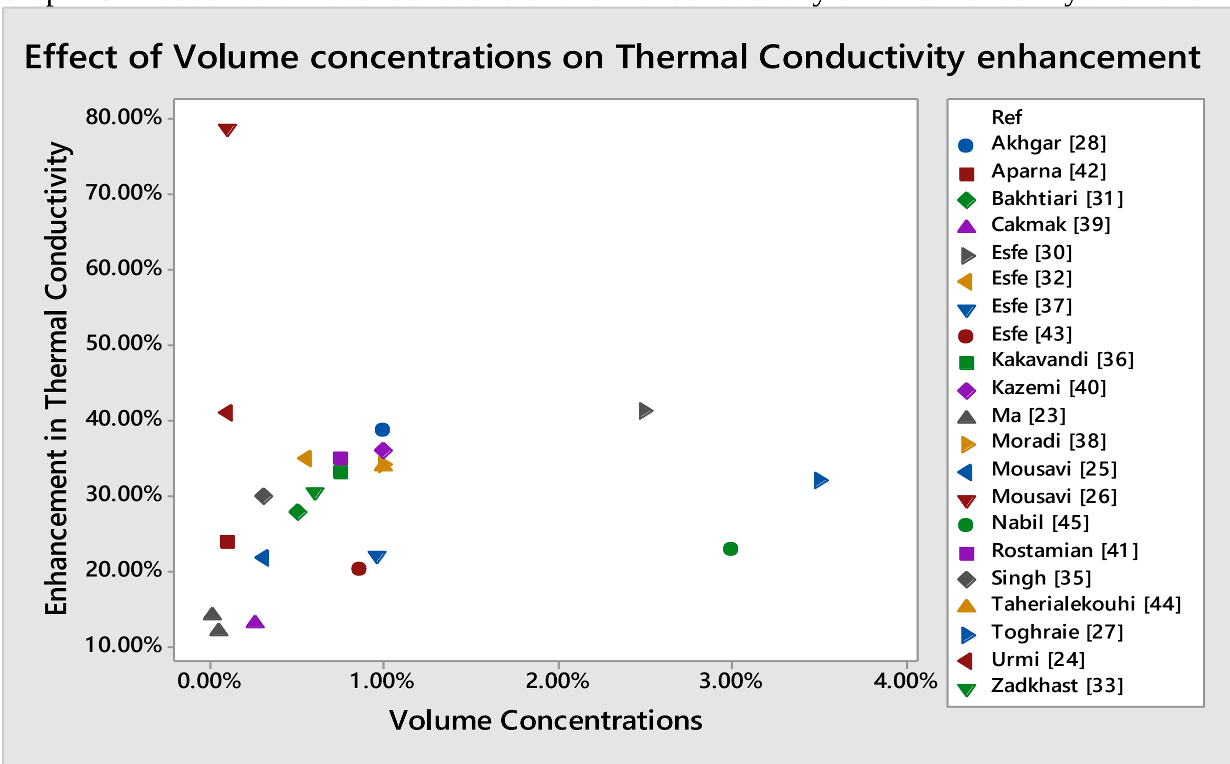
Ref	Hybrid Nanoparticles composition	Base Fluid	Volume Concentration of Hybrid nano particles	Temperature of hybrid Nanofluid	Enhancement in Thermal Conductivity
Ma [23]	Al_2O_3-CuO	Water	0.05%	60	12%
Ma [23]	Al_2O_3-TiO_2	Water	0.01%	60	14%
Urmi [24]	TiO_2-Al_2O_3	Water -EG	0.1%	80	40.86%
Mousavi [25]	MGO-TiO_2	Water	0.3%	60	21.8%
Mousavi [26]	CuO-MgO-TiO_2	Water	0.10%	50	78.6%
Toghraie [27]	ZNO- TiO_2	EG	3.5%	50	32%
Akhgar [28]	TiO_2-MWCNT	Water -EG	1%	50	38.7%
Esfahani [29]	ZnO-Ag	Water	2%	50	TCR-1.25
Esfe [30]	SWCNT-Al_20_3	EG	2.5%	50	41.2%
Bakhtiari [31]	TiO_2-Gr	Water	0.5%	75	27.84%
Esfe [32]	SWCNT-MgO	EG	0.55%	50	35%
Zadkhast [33]	MWCNT-CuO	Water	0.6%	50	30.38%
Esfe [34]	Cu- TiO_2	Water -EG	2%	60	TCR= <1.4
Singh [35]	Go-CuO	Distilled water	0.3%	60	30%
Kakavandi [36]	MWCNT-SiC	Water -EG	0.75%	50	33%
Esfe [37]	MWCNT-MgO	Water -EG	0.96%	50	22%
Moradi [38]	TiO_2-MWCNT	EG-Water	1%	60	34%
Cakmak [39]	rGO-Fe_3O_4-TiO_2	EG	0.25%	60	13%
Kazemi [40]	Graphene-SiO_2	Water	1%	50	36%
Rostamian [41]	CuO-SWCNT	EG-Water	0.75%	50	35%
Aparna [42]	Al_2O_3-Ag	Water	0.1%	52	23.82%
Esfe [43]	MWCNT-SiO_2	EG	0.86%	50	20.1%
Taherialekouhi [44]	GO-Al_2O_3	Water	1%	50	33.9%
Nabil [45]	TiO_2-SiO_2	Water	3%	80	22.8%

Graph 1: Effect of volume concetrations on temprature of hybrid nano fluids.



The graph 1 shows an illustrative effect of volume concentrations on temperature of hybrid nano fluids. The researchers predicted that the temperature of hybrid nano fluid can be increased by addition of Cu based nano particles for a least combination of 0% to 1%.[37] while using non Cu nano particles based hybrid nano fluid shows a average temperature rising up from 50 ^{0}C to 60 ^{0} c which is quite adoptable to use hybrid nano fluids in high temperature applications for volume concentrations from 0% to 2 %. [44]

Graph 2: Effect of volume concetrations on thermal conductivity enhancement of hybrid nano fluids.



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The graph 2 shows the thermal conductivity improvement of hybrid nano fluids on the basis of volume concentrations of hybrid nano particles in base fluid. The graph predicts that hybrid nano fluid shows significant improvement up to 80% for Cu based nano particles for least volume concentrations from 0% to1 % [26] and the avergage thermal conductivity improved by hybrid nano particles other than Cu based hybrid nano particles up to 40% for volume concentrations from 0 % to 3% [44]. [40].

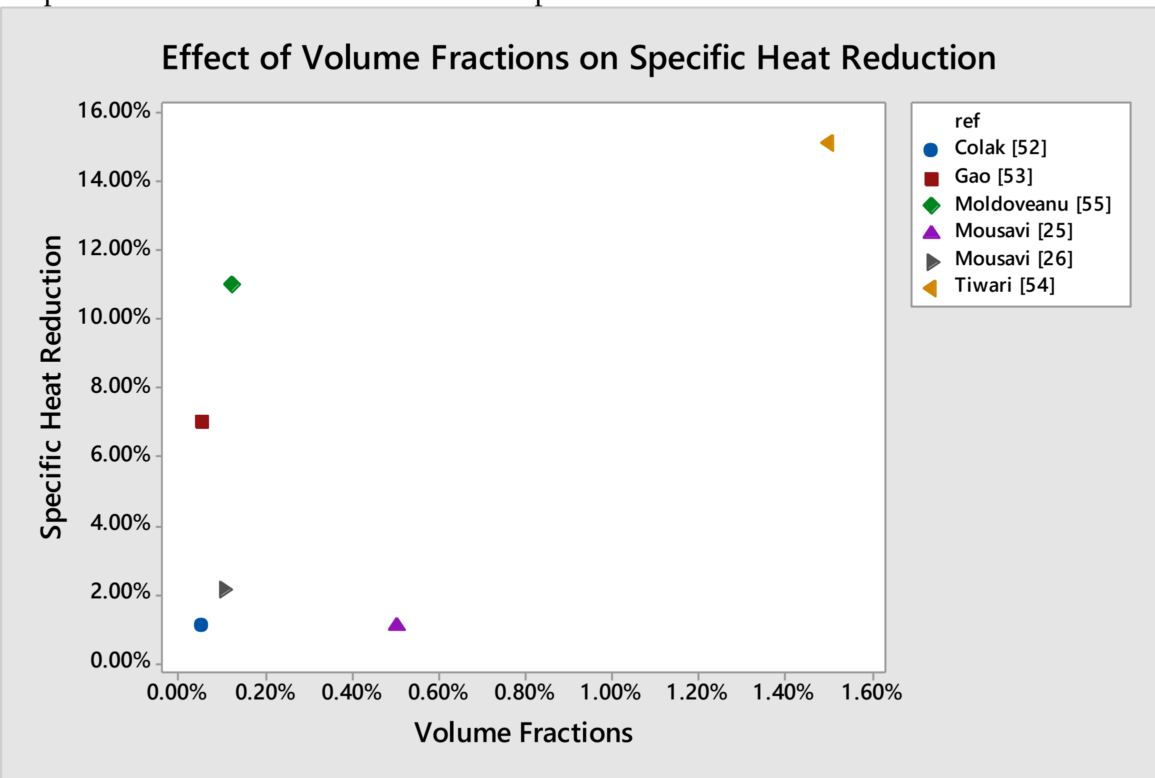
2.3.2 Specific Heat:-

The specific heat of hybrid nano fluids plays an significant role in calculating heat transfer rates. The specific heat reduced by addition of hybrid nano particles volume fractions in base fluid. The least amount of volume concentrations shows better results. The optimum amount of volume fraction of hybrid nano particles needed for specific heat improvement in hybrid nano fluids. The table 5 shows a comparison of specific heat reduction for various hybrid nano fluids.

Table 5- Findings of the work on specific heat of hybrid nano fluids

Ref	**Hybrid Nanoparticles Composition**	**Base Fluid**	**Volume Fractions**	**Specific Heat Reduction**
Colak [52]	Cu-Al2O_3	Water	0.05%	1.08%
Mousavi [25]	MGO-Tio$_2$	Water	0.5%	1.08%
Gao [53]	GO-Al$_2$o$_3$	Water	0.05%	7%
Tiwari [54]	SnO_2-MWCNT	Water	1.50%	15.09%
Mousavi [26]	CuO-MgO-TiO_2	Water	0.10%	2.13%
Moldoveanu [55]	Al_2O_3-TiO_2	Water	0.12%	11%.

Graph 3 : Effect of Volume fractions on Specific heat reduction



The graph 3 shows the effect of volume fractions of specific heat reduction. The graph shows that by increasing the volume fractions of hybrid nano particles in hybrid nano fluid results in reduction of specific heat of hybrid nano fluids .The 15% of the specific heat reduced for Cu based hybrid nano fluids for volume concentrations up to 1.50% [54]. The average reduction in specific heat observed up to 6% for non Cu based hybrid nano particles hybrid nano fluid for volume concentration from 0% to 0.80% [25], [53]

2.3.3 Dynamic Viscosity:

The viscosity of hybrid nano fluid shows a significant increment by addition of hybrid nano particles in hybrid nano fluid. The viscosity of hybrid nano fluids depends on the selection of nano particles, their volumetric concentration, and their temperature. When temperature increases, the intermolecular attraction between nano particles gets weaker, which results in a lower viscosity. With the addition of nano additives, the van der Waals forces increase and large nano clusters get formed, which prevents the oil layer from moving on top of each other since it again increases the viscosity of nano fluid.

The addition of nano particles to base fluids leads to increased shear stress in nano fluids, which results in an increase in the viscosity of the nano fluid. By increasing the hydrodynamic diameter of nano particles, they tend to increase viscosity through adsorption and clustering.

The viscosity of nano particles gets increased by the addition of nano particles by volume, and lowering the volume concentration of nano fluid in base fluid leads to a decrease in the viscosity.

The viscosity of nano particles gets increased by the addition of nano particles by volume, and lowering the volume concentration of nano fluid in base fluid leads to a decrease in the viscosity. The internal resistance between the hybrid nano fluid layers is affected by the addition of nanoparticles in the base fluid. It is increased by the addition of hybrid nano particles volume concentrations in the hybrid nano fluids and decreased by lowering the volume concentration of hybrid nano particles in the base fluid. The table 6 gives the dynamic viscosity for various hybrid nano fluid combinations. The Dynamic viscosity increased by increasing the volume fractions of hybrid nano particles in base fluid. The hybrid nano particles are made up of metals or non metals ss they possesses density and increasing the volume fraction of these denser particles results in increasing the dynamic viscosity of the hybrid nano fluid. The increment in dynamic visocity is not fruitful as due to this, the hybrid nano fluid restricted to flow. Thus, it increases the pumping power and ultimately high volume fractions results in agglomeration of hybrid nano particles in tubes of heat exchanging devises and reduces the effectiveness of thermal systems. [61].

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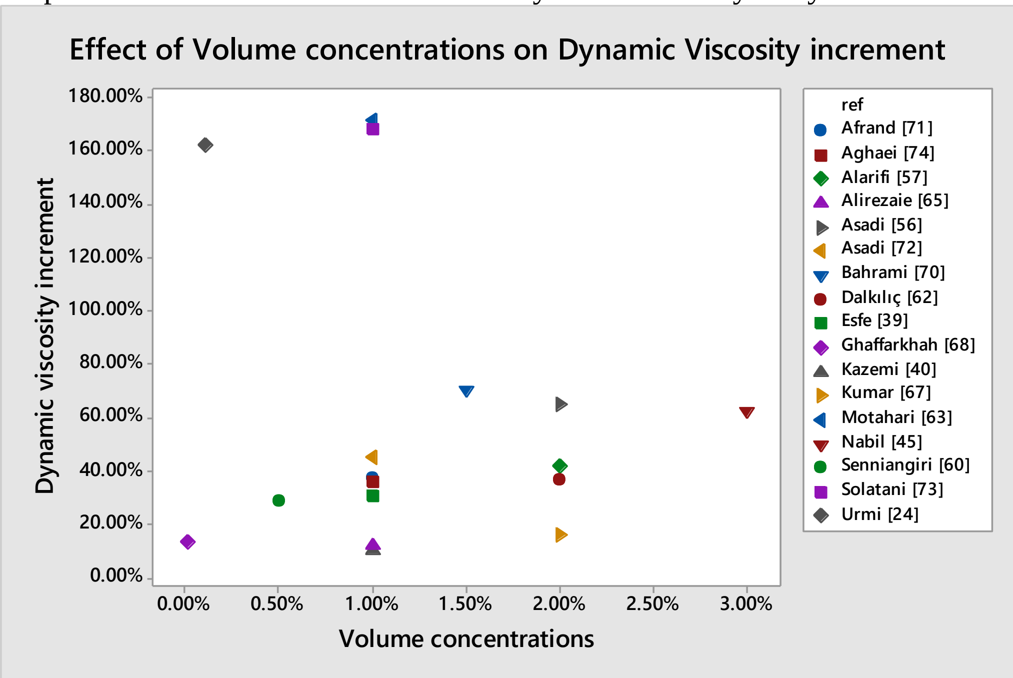
Table 6: Findings of the work on dynamic viscosity of hybrid nano fluids

Ref	Hybrid Nanoparticles Composition	Base fluid	Volume Fraction	Dynamic Viscosity Increment
Asadi [56]	MWCNT-MgO	SAE50 oil	2%	65%
Alarifi [57]	TiO_2-MWCNT	5W50 oil	2%.	42%
Asadi [58]	CuO-TiO_2	Water.	1%	Increase in the DV by increase in the solid fraction
Goodarzi [59]	ZnO-MWCNT	SAE 10W40	0.05%	Up to around 100% increase in the DV was observed.
Senniangiri [60]	Gr-NiO	Coconut oil	0.5%,	28.49%
Esfe [61]	MgO-MWCNT	5W50 oil	1%	Non Newtonian behaviour observed
Dalkılıç [62]	SiO_2-graphite	Water	2%	36.12%
Kazemi [40]	graphene-SiO_2	Water	1%	10%
Ma [23]	Al_2O_3-TiO_2 and Al_2O_3-CuO	Water	0.05% and 0.01%	Increase in the surfactant concentration led to an increase in the DV
Motahari [63]	MWCNT-SiO_2	20W50 oil	1%	171%
Ruhani [64]	ZnO-Ag	Water.	2%	Rel Viscosity =1.75
Alirezaie [65]	MWCNT (COOH Functionalized)- MgO	Engine oil	1%	12%
Urmi [24]	TiO_2-Al_2O_3	Water-EG	0.1%	161.8%
Nadooshan [66]	SiO_2-MWCNT	10W40	1%	DV increased by an increase in the solid fraction.
Kumar [67]	Al_2O_3-CuO	EG-water and PG-water	2%	16.2%
Ghaffarkhah [68]	Different materials	Transformer oil	0.01%	13.618%
Sahoo [69]	Al_2O_3, TiO_2 and SiC	Water	0.1%	Increase in DV by temperature reduction and solid fraction increase.
Bahrami [70]	Fe-CuO	Water-EG	1.5%	70%
Nabil [45]	TiO_2-SiO_2	Water-EG	3%	62.5%
Afrand [71]	SiO_2-MWCNT	SAE40	1%	37.4%.
Asadi [72]	MWCNT-ZnO	Engine oil	1%.	45%
Esfe [39]	MWCNT-SiO_2	SAE40	1%	30.2%
Solatani [73]	MgO-MWCNT	EG	1%	168%
Aghaei [74]	CuO-MWCNT	SAE5W50	1%.	35.52%

The graph 4 shows a illustrative representation of volume concentration effect of dynamic viscosity. The Cu based hybrid nano fluids possesses high amount of increment in dynamic viscosity up to 171% for a volume concentrations up to 1%.[63] Lowering the concentration may reduces the dynamic viscosity but it reduces the thermal conductivity of hybrid nano fluid. Non Cu based hybrid nano particles shows increment in dynamic viscosity up to 161% for a volume concentration of 0.1% when used in combination of base fluid as water and EG. [24] The average increment in dynamic viscosity is 40% for a volume concentration of 0% to 2%.

Graph 4 : Effect of Volume fractions on dynamic viscosity of hybrid nano fluids



III. Conclusion:

The hybrid nano fluids shows improved results in comparison with conventional or traditional nano fluids.. The following conclusions were noted in this exhaustive review study:

1) The agglomeration is the most common problem in nano fluids. This can be avoided by using hybrid nano particles together as they gave lesser dynamic viscosity in comparison with mono nano fluids.

2) Some of the hybrid nano fluids stays stable up to several days and the stability of hybrid nano fluids can also be increased by addition of suitable additives/surfactant in solution.

3) The thermal conductivity can be increased by increasing the temperature but after some steady specific temperature the hybrid nano fluid shows null effect on thermal conductivity improvement.

4) The well dispersed nano particles in hybrid nano fluid shows increment in thermal conductivity for higher temperatures.

5) The specific heat capacity of hybrid nano fluid is increased by volume addition of nano particles concentration.

6)The viscosity of hybrid nano fluids can increased by addition of solid fraction .

7) Most of hybrid nano fluids shows Newtonian behaviour while some of shows non Newtonian due to high solid fractions additions.

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