Hybrid Nano fluid: An Overview on preparation methods, properties, and its application

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Abstract

A novel type of In order to create hybrid nanofluids, two different nanoparticles are added to a conventional heat transfer fluid. Compared to conventional Oil, water, and ethylene glycol are examples of heat transfer fluids. Nano fluids with individual nanoparticles and combined nanofluids may provide superior thermophysical characteristics and heat transfer efficiency. It has been shown that hybrid nanofluid can serve as a substitute for a one nano fluid because it intensifies temperature. Transmission more, particularly in the areas of solar power, electric power, HVAC systems, and automotive applications. In this study, we summarized the most recent improvements in methods for producing hybrid nanofluids, variables influencing equilibrium, and improvement of thermal properties techniques, and hybrid nanofluid applicability. Therefore, for illustrating the potential benefits of hybrid nanofluid in engineering uses, a comprehensive examination of heat transmission and other thermophysical characteristics is required. Besides that, this study highlights challenges associated with hybrid nanofluids and proposes some suggestions to enhance further studies in this field.

Keywords: ***Hybrid nanofluid, Preparation method, Thermophysical properties, Applications***

Introduction

The demand for extremely useful small gadgets with optimum efficiency, proper operation, and a long service life is being driven by current scientific and technological advancements. In order to improve heat exchange systems' temperature regulation scientists and scholars gathered. The investigators were persuaded to introduce a fresh category of liquids, which they later developed and termed "nanofluids," due to Materials' higher capacity to transfer thermal compared to common liquids. (Babar et.al 2019) invention of the nanofluid was suggested as a solution to improve heat transmission over 20 years ago. Solid nanoparticles are dispersed into a base fluid to create nanofluids, which are fluids that are an extension of nanotechnology. The addition of particles millimetres or micrometres in fluids is one potential method to enhance heat transmission. Numerous published studies have documented a notable enhancement in heat transmission when employing nanofluid as opposed to traditional heat transfer fluid. Many factors, including choice of foundation liquid, nanoparticle equilibrium, fluid humidity, density, and dimension, nanoparticle variability, nanoparticle method of production and clarity, nanoparticle shape, dimensions and harmony it results in a balance of the nanofluid combination, have a significant impact on Hybrid nanofluids' improved transfer of heat. Thermal conductivity is the most important metric that significantly improved heat transport out of all of them. Numerous studies have shown that employing nanofluid significantly improves heat conductivity (Sidik et.al 2017).Metal nitrides (aluminium nickel, SiN), metal carbides (silicon carbide), and nonmetals (graphene, graphite, and single and multiwalled carbon nanotubes), oxides (TiO2, Al2O3, SiO2, CuO, and zirconia), and chemically stable metals (iron, copper, gold, and aluminium) comprise nanoparticles found in nanofluids. Conductive fluids like water or ethylene glycol are the basis fluids used. However, the preparation of the nanofluids also uses lubricants, oil, biofluids, and polymeric solutions (Gupta et.al 2018).There are two-step and one-step both methods for making nanofluids. Using a one-step approach, the production of nanoparticles concurrently with their diffusion into a base fluid. There is less particle sedimentation and the nanofluids made using this technique are more stable. Research pertaining to nanofluids frequently employs the two-step technique. Nanoparticles are created using this approach, and they are subsequently released into the base fluid. It is easy to buy commercial nanoparticles or nano powder on the market (Leong et.al 2016).When employed as a heat transfer medium in vast engineering applications, nanofluids outperformed conventional fluids(Sajid et.al 2018).

Hybrid nanofluid (HyNF) is a novel fluid type designed to combine the advantageous properties of many nanoparticles into a single fluid. To achieve good thermophysical and rheological qualities, HyNF involves completely mixing two or more nanoparticles in the base fluid. The base fluid mostly contains a mixture of metal and metal oxide particles. By combining metal and metal oxide nanoparticles, a hybrid nanofluid can achieve the combined benefits of improved chemical stability and inertness as well as excellent thermal conductivity (Muneeshwaran et.al 2021) .There are numerous methods to create hybrid nanoparticles, such as in-situ, mechanical alloying, thermo-chemical, ballmilling, wet chemical, solvo thermal, chemical reduction, chemical vapour deposition, aerosol, and many more (Sajid et.al 2018).The synthesis, characterisation, modelling, convective and boiling heat transfer, and uses of nanofluids have all been the subject of extensive research in recent decades, more the 70 reviewed and articles published shown by Table 1. However a more recent variety of nanofluid is the hybrid nanofluid. That can be made by suspending (i) hybrid (composite) nanoparticles in the base fluid, as well as (ii) one or more different kinds of nanoparticles in the base fluid. A substance that simultaneously combines the chemical and physical characteristics of several materials and offers them in a homogenous phase is called a hybrid material. Amazing physicochemical properties that are absent from the constituent parts are displayed by synthetic hybrid nanomaterials (Jahar et.al 2015). exceptional physicochemical properties that are absent from the constituentparts. This study's primary goal is to provide a thorough analysis of previous research on the preparation, stability, and characteristics of HNFs, as well as their possible uses and difficulties, in order to make it easier for researchers to understand and apply the new technology in hot conditions. Transmission systems to maximise energy efficiency. Researchers can quickly comprehend the benefits of HNFs over traditional ones and the rationale behind their selection by contrasting them.

Table 1: An overview of earlier studies on hybrid nanofluids.

Authors	Base fluid	Types of anaoparticles	
Nine et al.	Distilled water	$Al2O3$-MWCNTs	The hybrid nano fluid's thermal conductivity has improved when compared to pure $Al2O3$/water nano fluids. Spherical nanoparticles in hybrid nanofluids exhibit less improvement than nanoparticles with a cylindrical form.
Ramaprabhu and Baby	water and ethylene glycol to deionise	Ag/HEG	It was found that when temperature and volume fraction increased, thermal conductivity improved. Because distilled water basis hybrid nano fluid has a higher viscosity than ethylene glycol base fluid, it exhibits more enhancement.
Batmunkh and associates	deionize water	Ag/TiO2	Comparing Ag/TiO2 to a nanofluid that contains only TiO2, a notable improvement is shown. When Ag nanoparticles are ground, the particles' aspect ratio in the solution rises.
Jana and Zhong	deionize water	AuNPs, CUNPs, CNTs, CNT-AuNP, and CNTs each.	The individual nanoparticles (CNTs, CuNPs, and AuNPs) in the nanofluid exhibit more enhancement than the hybrid (CNT-CuNP, CNT-AuNP). The hybrids' incompatibility in solution caused the augmentation to decrease.
Botha et al.	oil	Ag, silica, and oil	There was an increase in thermal conductivity as the volume percentage of silver nanoparticles increased.
Chopkar et al.	Water and ethylene glycol to deionise	Al2Cu and Ag2Al	Compared to spherical and cylindrical nanoparticles, plate-like particles function better. Compared to Al2Cu, Ag2Al exhibits more enhancement.
Botha et al.	oil	Ag-silica/oil	It was shown that when the volume proportion of silver nanoparticles increased, so did thermal conductivity.

Chopkar et al.	water and ethylene glycol to deionise	Al2Cu and Ag2Al	The performance of plate-like particles is superior to that of spherical and cylindrical nanoparticles. Ag2Al outperforms Al2Cu in terms of enhancement.

Preparation

As seen in Fig.1and Table 2, the two primary techniques for creating nanoparticles are the two-step and one-step approaches. The nanoparticles have been prepared and are now dispersed throughout the base fluid at the same time in the one-step process. In the one-step method, the creation of the nano fluid can be done either chemically or physically. The physical process consists of vacuum-based submerged arc, laser ablation, pulse wire evaporation, magnetron sputter deposition, Gas condensation in the physical phase and evaporation, and dual plasma synthesis. Chemical reduction, micro emulsion, polyol, and sol-gel procedures are all used in the chemical approach concurrently .The one-step method is frequently used to create metal nanoparticles with high thermal conductivity in order to prevent oxidation, but it is not appropriate for large-scale manufacturing (Muneeshwaran et.al 2021).In contrast, mass production is best served by the two-step process. Nanoparticles are created in the first stage of the two-step process, and in the following steps, they are suspended in the base fluid. Several procedures, including the solvothermal technique, mechanical procedures (such as sintering, grinding, and milling), and chemical vapour deposition can all be used to generate the nanocomposites in the two-step method. A magnetic stirrer and an ultra sonicator can then be used to carry out the dispersion (Muneeshwaran et.al 2021).

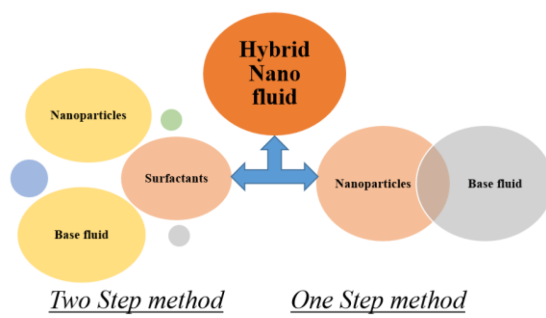

Fig1. Different method of preparation of Hybrid Nano fluid

Table 2: An overview of hybrid nanofluids made using various nanoparticles.

Nanoparticles	Basefluid	Method	References
Al2O3-MWCNT	Thermaloil	Twostep	(Sajid et.al 2018).
SiC-TiO2	Diathermicoil	Twostep	(Sajid et.al 2018).
MWCNT-Fe3O4	Water	Two-step method	(Nabil et.al 2017)

Al2O3/PCM	Water	Two-step method,	(Jahar et.al 2015).
CNT/Fe2O3	Water	Two-step method	(Jahar et.al 2015).
Cu/Cu2O	Water	Two-step method	(Jahar et.al 2015).
MWCNT-ZnO	Engine oil	Two-step method	(Nabil et.al 2017)
Al2O3-MEPCM	Water	Two-step method	(Nabil et.al 2017)
Ag WO_3	Water	One-Step Method	(Singh et.al 2024)
MWCNTs-Ag	Water	One-Step method	(Sajid et.al 2018).
Silver/CNT	Water	One-step method,	(Jahar et.al 2015).
Al2O3-CuO	Water	One-step method,	(Nabil et.al 2017)
Ag-Al2O3	Water	One-step method,	(Nabil et.al 2017)
Ag/Fe	-	One-step method,	(Sidik et.al 2017)
HCNF's	Sodiumdodecyl sulphate	One-step method,	(Sidik et.al 2017)

Stability

A novel fluid type with favourable thermal properties is hybrid nano fluid. One of the key elements that affects its performance is stability. Due to their propensity for coagulation, hybrid nanofluids may lose their capacity to transport heat. Therefore, stability assessment and research cannot be disregarded. The hybrid nanofluids' thermophysical characteristics can be changed by poor stability, which will lead to less effective performance in heat transfer applications. In relation to time, (Sidik et.al 2017) conductivity. Several strategies have been investigated and put into practice to improve the stability and homogeneity of systems based on nanofluids. However, adding surfactants was mentioned as the most economical solution for the issue at hand (Rasheed et.al 2021).

Stability evaluation methods.

To achieve constant thermophysical characteristics, stability is necessary. Researchers have used a variety of assessment techniques to look into the stability of NF. These are a few common methods. Singh Bikram

Sedimentation photograph capturing technique

The photography technique is another name for this approach. It is the simplest method that doesn't call for specific equipment. Particle settlement can be identified by using gravity as a signal. Because the NF needs to be examined for a long time, it takes some time. Beginning with the NF manufacturing process, this technique involves taking photographic photographs at regular intervals. The stability of NFs was ascertained by comparing these photos. The state is said to be steady if there is no sedimentation (Singh et.al 2024).

Zeta potential

The potential differential between the base fluid and the charged hybrid nanoparticles is known as the zeta potential. It shows the intensity of the charged particles in the fluid repulsion. High zeta colloids, whether positive or negative, are stable, while low zeta colloids have a tendency to lump (Sidik et.al 2017). The zeta potential measurement is the procedure used to detect the surface energy around each particle. In practical terms, a higher repelling force and increased stability are indicated by a bigger zeta potential. While colloidal particle suspensions with higher zeta potentials are inherently stable, those with lower zeta potentials are thought to be unstable because they accumulate more quickly. In many instances, zeta potential analysis has been used to quantify the stability of NF (Singh et.al 2024).

Sedimentation

A qualitative visual method called sedimentation analysis evaluates stability loss brought on by particle aggregation by analysing sample photographs taken over a predetermined amount of time the term "zeta potential" refers to the potential difference between the charged hybrid nanoparticles and the base fluid. It displays how strongly the fluid's charged particles are present is the foundation of UV-vis spectroscopy. The dispersion stability is determined by the fact that the remaining suspended particles absorb less light when the agglomerated particles settle (Asim et.al 2022).

Centrifugation method

Centrifugation is much faster than sedimentation when it comes to confirming the stability of the fluids that are produced. Numerous stability studies have employed to visually inspect the HNF sedimentation, use the dispersion analyser centrifuge (Singh et.al 2024).

The hybrid's thermophysical characteristics Nano fluids

In order to assess the effectiveness of thermal systems that use nanofluids, precise knowledge of thermophysical parameters is essential. An important factor influencing thermophysical characteristics is shown in Fig 2 the quantity of nanoparticles introduced to the base fluids. It is believed that the nanoparticles were evenly distributed throughout the base fluids, ignoring the thermophysical characteristics of the nanofluids, whether they were measured experimentally or analytically. The main characteristics of these thermal fluids consist of viscosity, density, specific heat, and thermal conductivity. (Gupta et.al 2018). By taking into account the effects of temperature, particle concentration, base fluid, particle combination, and other elements such as cluster formation, Brownian motion, and dimensions, researchers can better understand the thermal conductivity of hybrid nanofluids. Taking into account these variables allows researchers to produce a more precise and comprehensive model of thermal conductivity.

Thermal conductivity

The temperature of a fluid conductivity directly affects how well it transfers heat, hence using a fluid with a higher thermal conductivity is advantageous to improve this property. NPs can be added to fluids to increase their thermal conductivity. A number of factors, most notably the type, size, shape, and stability of the dispersed NPs, the base fluid selection, temperature, and NP concentration, are crucial in controlling an NF's thermal conductivity (Singh et.al 2024).

Viscosity

The key concept in the study of NFs is viscosity, which has a major impact on the fluid flow's atmospheric pressure loss of circulation. Consequently, the increased viscosity of NFs relative to the original fluid necessitates rigorous research and analysis when using them in routine scenarios the amount of power required for pumping due to frictional effects depends critically on the viscosity of HNFs. In relation to thermal conductivity, the viscosity of HNFs is strongly influenced by temperature, as well as the size, shape, and number of NPs. Viscosity decreases tiny spherical forms, improves with particle percentage, and is affected by temperature variations Singh et.al 2024).

Density

One important aspect of NF is density. Variation in density affects the amount of Re, frictional factors, pressure loss, and Nu. When NPs disperse the density of NFs rises in base fluids. As NPs were added, the density of NF rose, when the fluid's initial volume level increased as well. However, as the variable of temperature increased, the volume level fell. As the nanoparticles' density increases in the initial fluid is below the optimal level, a collection occurs, completely upsetting the NF's stability Different forms of HNF are measured for density using a density meter ,the standard is computed, whereby provides the relevant information. The Reynolds ratio, pumping strength, stability, frictional considerations, and other heat-transferring properties of the HNFs are all significantly influenced by their density. One of the most important thermophysical properties in this sense is this (Singh et.al 2024).

Specific heat

When evaluating a system's hydraulic and thermal performance, specific heat is crucial. Variables like as temperature, material selection, and NP size and shape all affected the specific heat. To make educated judgements for uses where heat storage and transmission are necessary, it is crucial to obtain a thorough understanding of HNFs' specific heat capacity (Singh et.al 2024).

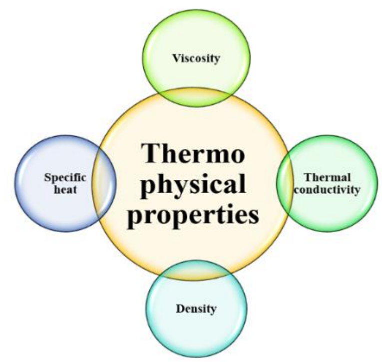

Fig 2. Thermo physical properties of Hybrid nanofluid

Application

HNFs are an innovative family of specially designed fluids that contain attracted significant interest in the domains of energy management, uses in industry, including heat transfer. These new liquids are concentrations of colloids made of NPs mixed with other substances like polymers, surfactants, or other additives. In contrast to conventional either traditional NFs or conduction of heat fluids, the fluid produced by the synergistic combination of these components has improved thermal, rheological, and stability properties (Singh et.al 2024). The use of HNFs in electronics thermal management is a noteworthy creation of tackles the growing problems with heat dissipation in contemporary electronic equipment. The amount of heat produced inside electronic equipment rises with the size and power of its components, which could cause malfunctions or even performance loss. By enhancing the electronics cooling systems' capacity for heat exchange, HNFs present a viable remedy (Singh et.al 2024). It is possible to design HNFs with specific absorption characteristics that correspond to the solar spectrum, enabling more effective solar energy absorption. Higher operating temperatures and increased system efficiency can result from these NFs' ability to maximise the amount of absorbed energy by integrating NPs with specific optical characteristics (Singh et.al 2024).

For every unit volume of material removed, incredibly significant levels of energy are generated .during the grinding process, and all of this energy is transformed into heat. This can result under hot conditions and causing thermal harm to the workpiece, including burns, phase changes, undesired fissures, and residual tensile stresses, reduced fatigue strength, and errors and distortions caused by heat. Recently, an experimental investigation was conducted using when six different silica (SiO2) nanoparticles are combined with palm oil as the MQL base fluidcarbon nanotube (CNT), zirconium dioxide (ZrO2), polycrystalline diamond, aluminium oxide (Al2O3), and molybdenum disulphide (MoS2). The development of nanofluids has led to its application in minimal quantity liquid (MQL) grinding in place of conventional fluid for cuts. In the MQLgrinding process, these nanofluids' superior cooling and lubricating capabilities, along with their sophisticated heat transmission and tribological characteristics, make production viable (Sidik et.al 2017). Heat exchangers transfer heat from hot to cold fluids, and using nanofluids in heat exchangers is a novel idea that has emerged in recent years. In numerous engineering applications shown in Fig 3, including automotive, aerospace, and energy systems, heat exchangers are frequently utilised. Although the system's proper operation depends about the thermal performance of the heat exchanger, its applications are limited by pressure drop and pumping power consumption. Researchers and scientists have investigated how the way heat exchangers work thermally can be greatly enhanced by raising the TC of base fluids. To improve temperature performance of the heat exchanger, several fluids, including hybrid and nanofluids, are added.

A system's performance is directly impacted by new cooling solutions for different devices. Fuel efficiency, pollution, material choices, and engine performance are all directly impacted by the HT. Temperature management, oil cooling, and engine longevity are all aided by the regulation of heat during combustion. Conventional fluids don't perform any better, and advanced fluids must be used in circulation to reduce coil heat loss. For the purpose of improving system performance, the researchers looked into different NPs in base fluids (Jamil et.al 2020).

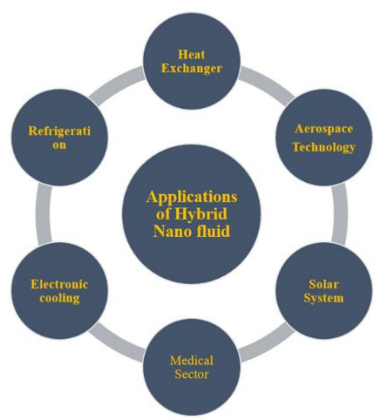

Fig 3. Various application of HyNF in different field

Challenges and future outlook

The thermal performance of nanofluids in a chaotic flow and completely formed regions, the improved pumping power and pressure drop, reduced specific heat, greater viscosity, and sustained stability of nanoparticle dispersion, production process challenges, and the expensive nanofluids are some of the challenges that researchers encounter when using them. The challenges that hybrid nanofluids face are nearly identical. When hybrids consist of two or more distinct kinds of nanofluids, the stability issue is more severe. Surfactants, functionalised groups, pH, and the kind of nanoparticles with hybrid properties. that is incorporated into the basic fluid all have an impact on the stability of nanofluids. However, without using any surfactants, the authors found that the nanocomposites had greater extreme stability (Gupta et.al 2018). Alternatively, the production of hybrid nanoparticles required intricate processes including the aerosol approach polymerisation, Wet chemical, reduction chemical technique and others. Comparatively speaking, this procedure is more difficult, lengthy, and expensive than creating traditional nanofluids. A primary concern for both conventional and hybrid nanofluids is stability. The tendency of nanoparticles to aggregate and the sedimentation of particles increases over time. There are several studies on the stability of conventional nanofluids but there aren't many on the stability of hybrid nanofluids. There isn't a single study that focusses exclusively on the stability of hybrid nanofluids, according to the scientists (Leong et.al 2016) .The stability problems limit the usage of HyNF in commercial settings. Thus, to increase novel synthesis, stability, and processing methods it has to be developed. Standardisation is necessary for mass production and repeatability in addition in order to create novel preparations and synthesis methods. Among the factors that may hinder the application of hybrid nanofluids in various industrial sectors is the complexity of the production process, which would result in higher nanofluid manufacturing costs (Kumar et.al 2018).

Conclusion

The term hybrid or composite nanofluid refers to a novel kind of nanofluid that is produced by impregnating two or more metals, metal oxides, or a mixture of both particles in a base fluid. Compared to a single or mono nanoparticle this hybrid nanofluid is present in the base fluid. Offers a higher improvement in characteristics of thermophysics , particularly in heat conductive properties. Few studies have been conducted, and there are there are very few models describing the properties of fluid nanocomposite that have been published in the literature. The various facets about synthetic nanofluids were reviewed in this research. When in contrast to single-nanofluids and base fluids, hybrid nanofluids were found to typically exhibit superior thermal conductivity and heat transfer capability. “Like mono nanofluids, hybrid nanofluids reduce the effectiveness of transfer of heat as the concentration of nanoparticles exceeds its maximum. Although the one-step method of preparation is more complex, the hybrid nanofluids that are created are more stable than those produced by the two-step procedure. However, because the two-step procedure is easy to follow and can be produced in large quantities, it is frequently employed by previous researchers. Hybrid nanofluid applications have been the subject of much discussion. However, in contrast to single base fluids and nanofluids, HyNF's thermal properties were higher in this investigation. Conclusion The performance of HyNF improves with increasing temperature and NPs volume fraction, but only to a certain extent. More research is required to fully examine this issue, including its stability component. The stability issue is the reason behind the traditional nanofluids' inability to be commercialised. Choosing nanoparticles to create hybrid nanofluids is a difficult procedure, and there aren't many models on the thermal conductivity of these fluids.

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