A REVIEW ON MODERN APPROACH TO PREDICT THE VISCOSITY OF NANOFLUIDS

1 G.ASHOK,2 C.NAGA BHASKAR,3 M.NAVEEN ,4 D.NAGASAI .
1MECHANICAL ENGINEERING DEPARTMENT,
1NRIIT,POTHAVARAPADU,INDIA.
gumpaashok@gmail.com, cnbhaskar@gmail.com, naveenroymattakoyya97@gmail.com

nagasai1532002@gmail.com ,

ABSTRACT:

A nanofluid is a liquid mixture that contains nanoparticles, which are tiny particles with diameters typically ranging from 1 to 100 nanometers that can improve heat transfer. Researchers used machine learning (ML) to predict the behavior of nanofluids. Literature shows that ML algorithms can accurately predict the viscosity. The results demonstrated that ML is a powerful tool for understanding and optimizing nanofluid behavior, which can lead to more efficient heat transfer systems. A nanofluid is a specially engineered liquid mixture that contains nanoparticles, which are extremely small particles with diameters typically in the range of 1 to 100 nanometers. When these nanoparticles are dispersed in conventional base fluids, such as water, ethylene glycol, or oil, they can significantly enhance the thermal properties of the fluid. One of the most important improvements observed in nanofluids is their ability to increase heat transfer efficiency, which makes them highly attractive for applications in cooling systems, electronics, renewable energy, and industrial processes.In recent years, researchers have increasingly turned to machine learning (ML) techniques to better understand and predict the behavior of nanofluids. Traditional experimental methods to determine nanofluid properties, such as viscosity and thermal conductivity, are often time-consuming, costly, and sometimes limited in scope. In contrast, ML algorithms can analyze large datasets, recognize hidden patterns, and make accurate predictions about fluid behavior under different conditions.The results from these studies demonstrate that ML is not only a reliable predictive tool but also a powerful approach for optimization. By leveraging ML, researchers can accelerate the design of next-generation nanofluids, leading to more efficient, cost-effective, and sustainable heat transfer technologies.

KEYWORD*S:*Nanofluids, Machine Learning, Heat Transfer, Thermal Conductivity, Viscosity

I. INTRODUCTION

Nanofluids are a new class of heat transfer fluids formed by dispersing nanoparticles, typically less than 100 nm in size, into conventional base fluids such as water, ethylene glycol, or oil. The incorporation of nanoparticles significantly enhances the thermal properties of the fluid, making nanofluids highly attractive for energy conservation and efficient heat transfer in various industrial applications, including heat exchangers, cooling systems, and renewable energy devices. Among the thermophysical properties of nanofluids, viscosity plays a particularly important role, as it directly affects the flow behavior, pumping power, and overall heat transfer performance. Unlike thermal conductivity, which generally improves with the addition of nanoparticles, viscosity exhibits more complex behavior. Depending on the nanoparticle type, concentration, size, shape, and surface chemistry, the viscosity of nanofluids can either increase or decrease compared to their base fluids. Other external factors such as temperature, pH level, and shear rate further influence this property, making viscosity prediction highly challenging. Conventional empirical correlations and theoretical models are often inadequate for accurately capturing the nonlinear interactions that govern nanofluid viscosity across different systems. This limitation creates significant uncertainty when designing nanofluid-based heat transfer equipment. In recent years, machine learning (ML) and artificial intelligence (AI) techniques have shown promise in addressing this challenge by identifying hidden patterns and developing predictive models based on experimental data. However, despite these advances, no universal correlation exists that can estimate the viscosity of all nanofluids while simultaneously accounting for particle concentration, size, and temperature effects. Therefore, more systematic investigations are required to establish reliable datasets, improve predictive capabilities, and ultimately derive a common empirical equation.

II. LITERATURE REVIEW:

Mohammad M. Rashidi.et al[1]: Hybrid nanofluids offer substantial potential in enhancing thermal performance for energy systems. Experimental and model-based evaluations consistently demonstrate significant improvements in thermal conductivity—up to 50% in some cases. However, viscosity increases with higher nanoparticle concentration, potentially impacting flow characteristics. Specific heat tends to decrease with nanoparticle addition. Among modeling approaches, machine learning—especially ANN—delivers superior prediction accuracy. The study highlights the importance of factors like nanoparticle size, type, sonication, and mixture ratio. For future development, hybrid nanofluids must balance thermal benefits with manageable viscosity and ensure long-term dispersion stability for practical engineering applications.

Sadeq R. Nfawa,.et al[2]: This study successfully shows a new method to improve heat transfer usinghybrid nanofluids. Adding a small amount of MgO nanoparticles to CuO/water nanofluids can make a big difference in how well the fluid transfers heat.The new hybrid fluid, CuO–MgO/water, was tested at various concentrations and temperatures. Results confirmed that both increasing the nanoparticle concentration and raising the temperature improved thermal performance. However, going beyond 1% concentration caused the particles to clump, which reduced efficiency.The best result was at 0.75% concentration and 50°C, offering a great balance between performance and stability. Also, a simple formula was made to help engineers predict thermal performance without needing experiments every time

Farid Soltani.et al[3]: The study successfully applied ANN to predict the thermal conductivity ratio of WO_3–MWCNT hybrid nanofluids in engine oil. The optimal ANN design used 7 neurons and achieved high prediction accuracy. Both ANN and correlation methods worked well, but ANN had lower errors and occasionally perfect predictions. Thermal conductivity increased significantly with higher temperatures and nanoparticle concentrations. ANN modeling offers a fast, cost-effective, and reliable alternative to purely experimental approaches. This method can be extended to other nanofluid types, enabling efficient development of advanced heat transfer fluids for automotive and industrial applications

Abu Raihan Ibna Ali1i.et al[4]: This review outlines the significant potential of nanofluids inheattransfer applications, supported by improved thermophysical properties. However, challenges like stability, cost, and lack of universal models hinder their widespread use. Future research should focus on cost-effective preparation, hybrid nanofluids, and optimal conditions for sonication and surfactant use. Investigating multi-wall carbon nanotubes and formulating accurate property correlations can help bridge existing gaps. Continued development will support nanofluids' commercial use in various thermal systems and engineering applications.

Hamza Babar.et al[5]: Hybrid nanofluids show great potential in enhancing heat transfer due to their improved thermal properties compared to conventional fluids. However, challenges such as limited stability, poor dispersion in two-step methods, and lack of universal predictive models hinder their widespread application. The single-step method offers better stability but is less scalable. Existing models fail to accurately predict properties like viscosity and thermal conductivity for hybrid nanofluids. More research is needed to understand particle behavior, optimize preparation techniques, and improve long-term stability. Addressing these issues will pave the way for efficient use of hybrid nanofluids in real-world thermal systems

Mahdi Ramezanizadeha.et al[6]: This study reviewed machine learning applications for modeling the dynamic viscosity of nanofluids. Key findings include the importance of input variables like temperature, concentration, shear rate, and nanoparticle size. Among the methods, ANN-based models showed superior accuracy due to their complex structure. Some models can generalize across different nanofluids using viscosity ratios or structural properties. Model accuracy is influenced by the ANN's structure (layers, neurons) and activation functions, requiring optimization. Future research should aim to develop generalized models for various nanofluids using diverse datasets, enhancing accuracy by including more influential parameters and improving model flexibility.

Ahmad Moradi.et al[7]: This study shows that using MWCNT–water nanofluids and porous plates in a heat exchanger can greatly improve heat transfer. The best improvement happened when three porous aluminum plates were used. This setup increased the heat transfer efficiency by up to 35%, especially when the nanofluid concentration was low (0.04%).When the flow rate was low (100 L/h), the porous plates had a big effect, but at higher flow rates (300 L/h), their effect was smaller. This means the plates work better when the fluid is moving slowly. Also, if the concentration of nanoparticles is too high, the fluid becomes too thick and flows less easily. This reduces the heat transfer benefit.Using just one plate did not help much, but using three plates made a clear improvement.

Andrey V. Minakov.et al[8]: The study concludes that nanofluids can change from Newtonian to non-Newtonian behavior depending on nanoparticle size, concentration, and material. At low concentrations, they behave like normal fluids, but higher concentrations and smaller particles increase viscosity and alter flow patterns. This effect is significant in drilling and industrial fluids. The findings emphasize the need for further research to better predict and model nanofluid behavior, especially since current theories don't fully explain the changes caused by particle interactions in various fluid systems.

M. Mehrabi.et al[9]: This paper presents a comprehensive review of the thermo-physical properties of hybrid nanofluids and nanolubricants, highlighting their potential in heat transfer applications due to synergistic effects from multiple nanoparticles. While improved thermal conductivity is a key advantage, most studies focus mainly on stability and conductivity, neglecting other important properties like viscosity and specific heat. The review covers preparation methods, instrumentation, and recent developments. Despite their promise, more in-depth research is needed to fully understand and optimize hybrid nanofluids for commercial use.

M.F. Nabili.et al[10]: Hybrid nanofluids and nanolubricants combine the strengths of multiple nanoparticles, delivering higher thermal conductivity and better heat transfer than single-particle systems. They are promising for cooling, lubrication, and renewable energy applications. However, challenges like long-term stability, increased viscosity, and production costs hinder industrial adoption. More research is needed on underexplored properties such as specific heat and density under various conditions. With improved synthesis methods and cost reduction, hybrid nanofluids could become mainstream in high-performance thermal systems, providing efficient and sustainable solutions for industrial and technological heat management.

Kazem Bashirnezhadai.et al[11]: This review highlights that nanofluid viscosity is influenced by multiple factors including particle volume fraction, temperature, size, shape, and base fluid. Experimental data often diverge from theoretical predictions, stressing the need for more comprehensive studies. Developing accurate models requires considering all parameters simultaneously. Understanding these variations is critical for optimizing nanofluid use in real-world systems like heat exchangers. Continued research will help create standardized, reliable viscosity correlations that support the design of more efficient thermal management systems.

Ravi Agarwala.et al[12]: The study successfully demonstrated that Al_2O_3 nanofluids synthesized using the solution combustion method enhance thermal conductivity in both distilled water and ethylene glycol. Particle size increased with combustion temperature, affecting thermal performance. Nanofluids prepared with nanoparticles combusted at 1000 °C showed up to 30–31% improvement in thermal conductivity for 2 vol% concentration. Sensitivity analysis confirmed that concentration has a stronger effect on conductivity than temperature, especially at higher volume fractions. These findings support the potential of Al_2O_3 nanofluids for advanced heat transfer applications. Future studies could explore different nanoparticle types and real-time thermal system integration

M.A. Ariana.et al[13]: The study concludes that ANN is a very strong tool for predicting the thermal conductivity of alumina–water nanofluids. It considers important factors like temperature, nanoparticle diameter, and concentration. Compared to traditional models, the ANN provides the least error and highest accuracy. It avoids the high cost and time of experiments and can be used as a practical design tool. The ANN captured complex nonlinear effects such as the influence of clustering at small sizes. Its superior performance proves that intelligent models are better than equations for nanofluid studies. Hence, ANN models are recommended for engineers and researchers working on advanced heat transfer fluids.

Purna Chandra Mishrai.et al[14]: This review concludes that nanofluid viscosity is influenced by numerous factors, including base fluid type, particle volume fraction, size, shape, temperature, shear rate, pH, surfactants, dispersion techniques, and aggregation behavior. Despite various theoretical models proposed to estimate viscosity, none have shown consistent agreement with experimental results. The discrepancies are attributed to effects like Brownian motion, oversimplified assumptions, and limitations in dispersion quality. There is currently no established optimal nanoparticle size for balancing stability and minimizing aggregation. Moreover, the increase in viscosity leads to higher pumping power, raising concerns for practical applications.

W.H. Azmia.et al[15]: This study shows that both TiO_2 and SiO_2 nanoparticles can significantly improve the heat transfer of water in turbulent flow. The improvement depends strongly on concentration and particle type. TiO_2 works best at lower concentration (1%), giving 26% improvement, while SiO_2 works best at higher concentration (3%), giving 33% improvement. Higher concentrations of TiO_2 reduce performance because viscosity increases faster than thermal conductivity. Friction factor rises with nanoparticle density and concentration, so pressure drop is higher for TiO_2 than SiO_2. These findings help in selecting the right nanofluid and concentration for applications where high heat transfer and acceptable pressure drops are needed.

L.SyamSundara,.et al[16]: This review highlights that the viscosity of nanofluids increases with particle volume concentration and decreases with rising temperature. While several empirical correlations exist to estimate viscosity based on concentration and temperature, few consider particle size and shape, which also significantly influence viscosity. Discrepancies in experimental results arise from differences in particle size, preparation methods, and dispersion stability. Although some nanofluids exhibit Newtonian behavior, others show non-Newtonian characteristics. There is currently no universal empirical or theoretical model to predict nanofluid viscosity accurately. Therefore, further experimental and theoretical studies are essential to develop reliable, generalized correlations for practical applications.

Tony John.et al[17]: This study shows that adding nanoparticles to ethylene glycol improves its heat transfer ability and changes its viscosity. CuO nanofluids provide higher thermal conductivity than TiO_2 nanofluids, making them better for cooling uses. However, both types have viscosity increases that are higher than theoretical predictions, which may affect pumping power in systems. Temperature strongly affects thermal conductivity but has little impact on viscosity. Stability is a concern, especially at higher particle concentrations, as settling occurs within a couple of days without surfactants. For practical use, lower concentrations are preferred to balance performance, stability, and energy requirements. These findings help in selecting nanofluids for industrial cooling and lubrication purposes.

Md. Hashim Farooky.et al[18]: This experiment shows that Al_2O_3 and CuO nanofluids can improve thermal conductivity when mixed in a 50:50 mix of ethylene glycol and water. CuO nanofluid performs better than Al_2O_3 in all conditions. The amount of nanoparticles and temperature plays a major role in improving the performance. Simple formulas were developed to estimate the heat conduction of these fluids. These nanofluids are useful in cold regions for heating systems, cars, and industrial machines. Their ability to carry heat better makes them a good choice for modern thermal systems.

Fakhri Yousefi.et al[19]: In this research, the viscosity of different nanofluids was predicted using a powerful method called diffusional neural networks (DNN). The study included six types of nanofluids, using different nanoparticles and base fluids. Because real experimental data were limited, the researchers added extra "virtual" data based on known trends. They trained the neural network using both real and virtual data to make accurate predictions. The results showed that this AI-based method works better than older mathematical models, which often have high error. The average error for the DNN method was very low (only 3.44%). The model is useful because it does not need a deep understanding of the physics—it only needs data. It also saves time and effort, especially when experimental tests are difficult or expensive

M. Mahbubul.et al[20]: This study concludes that nanofluid viscosity is influenced by several interdependent factors, including temperature, particle size, shape, and volume fraction. Generally, viscosity increases with nanoparticle concentration and decreases with rising temperature. However, inconsistent findings across studies highlight the need for standardized experimental approaches and more versatile predictive models. While base fluids significantly impact viscosity, the effect of nanoparticle material is often minimal. Additionally, discrepancies arise due to agglomeration and inadequate dispersion techniques. The current research on viscosity is insufficient to establish universal trends, especially for newer nanomaterials like graphene. Therefore, further experimental and theoretical investigations are essential for practical application.

Weerapun Duangthongsuk.et al[21]: This study confirms that TiO_2-water nanofluids have improved thermal properties compared to water. Thermal conductivity rises with both nanoparticle concentration and temperature, while viscosity shows the opposite temperature trend but increases with particle loading. Existing theoretical models failed to match the measured data, showing the need for new predictive equations. The proposed correlations provide a better match within the tested temperature and concentration ranges. Differences from other researchers' results highlight the importance of particle preparation, size, and measurement techniques. Overall, TiO_2-water nanofluids show promise for heat transfer applications, but more detailed studies are required to develop standardized models and understand long-term stability.

N. Chandrasekar.et al[22]: The study confirmed that Al_2O_3/water nanofluids improve thermal conductivity, making them suitable for cooling applications. Conductivity rises linearly with concentration, but the gain is moderate compared to the strong increase in viscosity. High viscosity may limit flow efficiency by demanding more pumping power. The fluids behaved as Newtonian, meaning viscosity stayed consistent with shear rate. The new models developed in this work successfully predicted both thermal conductivity and viscosity, avoiding the limitations of traditional Maxwell and Einstein models. These models matched well with experiments, proving their usefulness for engineering design. Future work should focus on reducing viscosity while keeping thermal conductivity high to make nanofluids more practical for industry.

Mauro Lomascolo.et al[23]: This review of nanofluids shows that they are a strong alternative to traditional cooling fluids. By adding nanoparticles to water, oil, or glycol, the heat transfer ability can be significantly improved. Conduction and convection performance both show clear gains, especially at low to medium nanoparticle concentrations. Cylindrical nanoparticles like carbon nanotubes give the best performance, but they increase viscosity and are harder to prepare. In boiling conditions, results are not always positive, but the increase in critical heat flux is very important for safety in high-heat applications.For solar energy, nanofluids can directly absorb sunlight and convert it to heat, making them suitable for advanced solar collectors.With better preparation methods, nanofluids may replace traditional fluids and provide higher efficiency in many engineering fields

Lazarus Godson.et al[24]: Nanofluids offer a promising way to improve heat transfer in many engineering applications. Their unique properties, such as high thermal conductivity and stability at low concentrations, make them suitable for compact and efficient cooling systems. Applications in electronics, automotive, and energy fields are especially attractive. However, challenges like long-term stability, inconsistent boiling performance, and high production costs must be addressed before widespread use. More detailed experiments and reliable theoretical models are needed to predict performance accurately. Overall, nanofluids represent a major advancement in heat transfer technology, with the potential to reduce energy consumption and carbon emissions in future thermal systems.

S. Salman.et al[25]: Hybrid nanofluids are a promising solution to improve heat transfer in BFS and FFS geometries. They combine the advantages of different nanoparticles and provide higher thermal conductivity than single nanofluids. The review found that increased nanoparticle concentration improves the Nusselt number, but also increases viscosity and flow resistance. Step height, Reynolds number, and fluid type strongly influence results. The review concludes that hybrid nanofluids, when optimized, can significantly improve thermal system efficiency. More experimental studies on microscale BFS and FFS are required to validate numerical models. In simple words, hybrid nanofluids can change the way we cool and heat systems, but more work is needed to make them reliable and economical for real-world applications

W.H. Azmi.et al[26]: His review concludes that nanofluids offer significant potential to improve heat transfer in engineering applications. The addition of nanoparticles enhances thermal conductivity beyond what base fluids can achieve, even at low concentrations. However, the accompanying increase in viscosity can sometimes reduce the overall efficiency by raising pumping costs. Temperature is a favorable factor since it improves conductivity and lowers viscosity. The choice of nanoparticle type, size, and concentration plays a major role in performance. Future work should focus on improving stability, reducing viscosity while maintaining high conductivity, and developing universal predictive models. If these challenges are addressed, nanofluids could become key materials in renewable energy systems, electronics cooling, automotive industries, and advanced HVAC systems

Gwon Hyun Ko.et al[27]: This study shows that preparation methods strongly affect CNT nanofluid flow behavior. Both PCNT and TCNT nanofluids act as shear-thinning fluids. PCNT nanofluids, prepared with surfactants, have higher viscosity and lead to larger pressure drops in laminar flow, making them less energy-efficient. TCNT nanofluids, prepared by acid treatment, show lower viscosity and smaller friction penalties. At turbulent flow conditions, both types behave almost like water, meaning they do not significantly increase pumping power. CNT nanofluids also extend the laminar regime to higher flow rates, which can sometimes reduce drag. Overall, acid-treated CNT nanofluids offer better performance for applications, combining improved heat transfer potential with lower flow resistance

S.M.S. Murshed.et al[28]: This work compared TiO2 and SiO2 nanofluids under the same experimental conditions. Both nanofluids improved heat transfer compared to pure water, but the improvement depended strongly on concentration. TiO2 nanofluid gave maximum benefit at 1%, while SiO2 required 3% to reach peak performance. This difference is due to viscosity increase in TiO2, which reduces flow efficiency at higher concentration.The experiments also showed that friction factor increases with density and viscosity of nanoparticles. TiO2 nanofluid created a larger pressure drop than SiO2, meaning higher pumping power would be required in real systems.Therefore, nanofluids can be very useful in cooling technologies, but they must be carefully optimized. Using too high a concentration may lower performance instead of improving it.

Ji-Hwan Lee,et al[29]: This study explored Al_2O_3–water nanofluids with very low particle concentrations. The experiments proved that ultrasonic vibration for about 5 hours gives stable dispersions. The viscosity of nanofluids decreased with higher temperature but increased nonlinearly with concentration, showing particle interactions not explained by Einstein's model. On the other hand, thermal conductivity rose almost linearly with concentration, closely matching theoretical predictions. Even at 0.3% concentration, nanofluids improved heat transfer properties. These findings show that nanofluids can provide better thermal performance with very small amounts of nanoparticles, making them promising for applications in cooling and energy systems. However, the unexpected viscosity behavior requires further experimental and theoretical study.

X.F. Li, D.S. Zhu.et al[30]: This study proved that **Cu–H_2O nanofluids** show higher thermal conductivity compared to pure water, especially when chemical conditions are optimized. Ultrasonication with SDBS surfactant successfully dispersed nanoparticles, reducing particle size and improving stability. The role of **pH was crucial**; higher stability and conductivity occurred at pH 8.5–9.5 due to strong surface charges. Optimal surfactant concentration (0.1 wt%) further enhanced conductivity but excessive surfactant reduced efficiency. Conductivity increased with copper concentration, reaching 10.7% at 0.1 wt%. These results highlight that controlling **pH and surfactant chemistry** is necessary for practical applications in cooling and heat transfer devices. This research provides useful guidelines for designing efficient nanofluids.

Min-Sheng Liu,.et al[31]: This study confirmed that adding CNTs to base fluids such as ethylene glycol and engine oil significantly increases thermal conductivity. A maximum enhancement of 12.4% for EG nanofluids and 30% for oil nanofluids was recorded. The improvement is almost linear with CNT concentration and much greater than enhancements obtained using CuO nanoparticles. CNTs, due to their high conductivity and fiber-like structure, create networks that facilitate heat transfer inside the fluid. The choice of base fluid affects results, with oil-based nanofluids showing higher conductivity ratios. Surfactants like NHS further improved stability and conductivity in oil suspensions.

Nor Azwadi Che Sidik.et al[32]: Hybrid nanofluids are an advanced technology that offers improved thermal properties compared to traditional fluids. By mixing two or more nanoparticles in a base fluid, researchers achieved higher thermal conductivity and better heat transfer efficiency. They are useful in industries such as solar energy, automotive engines, and electronics cooling.The main advantages are enhanced heat transfer, better energy efficiency, and potential to reduce environmental impacts by saving energy.

Qing-Zhong Xue.et al[33]: This study developed a new model for effective thermal conductivity of nanofluids by considering the interface effect between nanoparticles and fluid. Unlike conventional models, it explained the strong and nonlinear enhancement observed in experiments. For carbon nanotube–oil nanofluids, the model predicted up to 160% conductivity increase, while for Al_2O_3–water nanofluids, predictions closely matched measurements. The results show that heat transfer in nanofluids is controlled not only by particle concentration and thermal conductivity but also by the interfacial layer formed between particle and fluid. This model gives better physical understanding and can be used to design high-performance nanofluids for industrial applications in cooling, energy systems, and electronics.

Abdolreza Moghadassi,.et al[34]: This research proves that hybrid nanofluids, such as Al_2O_3–Cu/water, can improve the efficiency of heat transfer in laminar flow through tubes. The study shows that even a very small concentration of nanoparticles (0.1%) can give meaningful improvement. The Nusselt number increased significantly, meaning more heat was carried away from the heated surface. The presence of copper in the hybrid nanofluid gave better performance than Al_2O_3 alone.Although the friction factor increased, this increase was not large enough to cancel out the heat transfer benefits. Further studies are needed to explore higher concentrations, long-term stability, and cost-effectiveness, but the current findings strongly support the potential of hybrid nanofluids as advanced heat transfer fluids.

Xing Zhang.et al[35]: This study proved that nanofluids show improved thermal conductivity and diffusivity mainly due to particle loading and shape. Spherical nanoparticles such as Al_2O_3, TiO_2, and CuO showed moderate enhancements, while CNTs showed much higher improvements because of their large aspect ratio. No unusual or extremely high conductivity was detected, unlike in some earlier studies. The Hamilton–Crosser model accurately predicted results for spherical nanoparticles, and the Yamada–Ota model matched CNT data. Proper dispersion and probe insulation were found essential for reliable experiments. Overall, nanofluids can be used to enhance heat transfer, but their performance follows predictable trends rather than unexplained anomalies.

Dan Huang.et al[36]: This study showed that hybrid nanofluids are effective for improving heat transfer in plate heat exchangers. By mixing Al_2O_3 nanoparticles and MWCNTs, the thermal conductivity and heat transfer coefficient increased compared to water and single nanofluids. The hybrid nanofluid achieved the best performance when both heat transfer and pumping power were considered.The pressure drop for the hybrid nanofluid was slightly higher than water but lower than Al_2O_3 nanofluid. This balance makes it suitable for real applications where energy efficiency is important.Although the observed improvement was small, the results still suggest that hybrid nanofluids are promising for cooling, heating, and other thermal systems. Future work should focus on preparing more stable hybrid nanofluids with better mixing methods to enhance their performance further.

Ehsan Ghomie.et al[37]: This study confirmed that hybrid nanofluids can significantly improve heat transfer in laminar flow conditions. A very small amount of nanoparticles (0.1%) was enough to increase the Nusselt number and enhance heat transfer compared to pure water. Hybrid Al_2O_3–Cu nanofluid performed better than Al_2O_3 nanofluid, showing that the addition of copper nanoparticles provides extra benefits.However, the increase in viscosity also caused higher friction factor and pressure drop, which means more pumping power is required. Despite this, the improvement in heat transfer is useful for practical systems where cooling efficiency is important.In conclusion, Al_2O_3–Cu/water hybrid nanofluids are promising for thermal management applications such as cooling in electronics, automotive, and energy systems. They improve heat transfer by around 5–13% with only a small concentration, making them efficient and practical for industrial use.

S.M.S. Murshed.et al[38]: The study proved that nanofluids have much better thermal conductivity than ordinary liquids, even with a small fraction of nanoparticles. Conductivity rises with both particle loading and temperature. Particle shape, size, and the thin interfacial layer around nanoparticles strongly influence results. The new models developed matched experimental findings better than older classical theories. However, viscosity also increased, which could limit their usefulness in some systems. In conclusion, nanofluids hold strong promise for applications in electronics cooling, automotive engines, and energy systems, but further work is required to reduce viscosity problems while keeping the high thermal conductivity benefits.

Ali Ghadimi.et al[39]: This review showed that nanofluid stability is the key challenge for their use in engineering and science. Nanoparticles tend to agglomerate, which reduces performance. Techniques like ultrasonication, pH adjustment, and surfactants can improve stability, but results vary with particle type and base fluid. Long-term stability is still difficult, especially under flow conditions. The authors suggested that more research is needed to find reliable methods for keeping nanofluids stable in real applications. Achieving stable nanofluids will make them more useful in cooling technologies, energy systems, and industrial processes. Thus, solving stability problems is essential for nanofluids to move from laboratories to practical, large-scale usage.

Xiang-Qi Wang.et al[40]: Nanofluids represent a new class of heat transfer fluids with strong potential in engineering and environmental applications. They show better thermal conductivity and convective heat transfer than pure liquids. However, challenges like nanoparticle agglomeration, higher viscosity, and inconsistent results in boiling and natural convection limit their practical use. Future work should focus on better preparation methods, stable suspensions, and clear theoretical models to explain observed behavior. Applications such as electronics cooling, refrigeration, solar energy, and climate systems will benefit greatly once these problems are solved. In conclusion, nanofluids are promising but need more research to become reliable, efficient, and widely usable cooling agents.

IV.PREPARATION OF NANOFLUIDS: This study, a two-step method was used to prepare the hybrid nanofluid. First, 80% copper oxide (CuO) and 20% magnesium oxide (MgO) nanoparticles were mixed in water at different volume concentrations (0.25% to 1.25%). The mixture was stirred with a magnetic stirrer for 1 hour, then placed in an ultrasonic bath for 7 hours to break any clumps and ensure even distribution. After this, the fluid was observed for stability over several days. A KD2 Pro thermal analyzer was used to measure thermal conductivity at different temperatures (25°C to 50°C). Each test was repeated three times to make sure the results were accurate. This process helped understand how the nanofluid's heat transfer changes with temperature and concentration.

V.CONCLUSION: Hybrid nanofluids hold significant promise for enhancing heat transfer in thermal systems due to their improved thermal conductivity and energy efficiency compared to conventional fluids. Numerous studies confirm that the addition of nanoparticles—especially in hybrid combinations like CuO–MgO, MWCNT–Al_2O_3, or Cu–Al_2O_3—can improve thermal conductivity by up to 50% under optimized conditions. However, this thermal advantage often comes with increased viscosity, which can hinder fluid flow and increase pumping power requirements. Factors such as nanoparticle size, shape, concentration, temperature, and base fluid type greatly influence both thermal conductivity and viscosity, making it essential to strike a balance between heat transfer enhancement and flow behavior.Despite the demonstrated benefits, key challenges remain. Stability issues, particle agglomeration, and inconsistent dispersion—especially in two-step preparation methods—limit performance and repeatability. Existing predictive models, both empirical and theoretical, often fail to generalize across different nanofluid systems due to oversimplified assumptions. Machine learning approaches, particularly artificial neural networks (ANNs), have shown superior accuracy in predicting thermal properties and offer a promising alternative. The field lacks standardized experimental protocols and universally applicable models, leading to discrepancies in data and conclusions. For broader industrial adoption, future research must focus on cost-effective synthesis, long-term stability, and optimized operational conditions.

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