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CFD And Thermal Analysis of Radiator Using Magnesium Oxide And Graphene Nanofluids

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ABSTRACT

The utilization of magnesium oxide and graphene nanofluids in radiator applications offers a range of distinct advantages. Beyond augmenting heat transfer rates, these nanofluids exhibit promise in curbing energy consumption associated with cooling processes. This advantage is attributed to their markedly superior thermal conductivity compared to conventional water-based coolants. Moreover, these nanofluids showcase exceptional resilience to elevated temperatures, maintaining their structural integrity and corrosion resistance, thereby establishing them as suitable candidates for demanding radiator environments. Employing Ansys Fluent software, this research employs Computational Fluid Dynamics (CFD) analysis to systematically evaluate the efficacy of magnesium oxide and graphene nanofluids in the context of radiator systems.

Key words: Computational Fluid Dynamics (CFD), Ansys, nanofluids.

INTRODUCTION

A radiator is a heat exchanger used to transfer thermal energy from one medium to another for the purpose of cooling and heating. The majority of radiators are constructed to function in cars, buildings, and electronics.

A radiator is always a source of heat to its environment, although this may be for either the purpose of heating an environment, or for cooling the fluid or coolant supplied to it, as for automotive engine cooling and HVAC dry cooling towers. Despite the name, most radiators transfer the bulk of their heat via convection instead of thermal radiation.

Radiation and convection

Heat transfer from a radiator occurs by two mechanisms: thermal radiation and convection into flowing air or liquid. Conduction is not normally a major source of heat transfer in radiators. A radiator may even transfer heat by phase change, for example, drying a pair of socks. In practice, the term "radiator" refers to any of a number of devices in which a liquid circulates through exposed pipes (often with fins or other means of increasing surface area). The term "convector" refers to a class of devices in which the source of heat is not directly exposed.

To increase the surface area available for heat exchange with the surroundings, a radiator will have multiple fins, in contact with the tube carrying liquid pumped through the radiator. Air (or other exterior fluid) in contact with the fins carries off heat. If air flow is obstructed by dirt or damage to the fins, that portion of the radiator is ineffective at heat transfer.

Radiators are commonly used to heat buildings on the European continent. In a radiative central heating system, hot water or sometimes steam is generated in a central boiler and circulated by pumps through radiators within the building, where this heat is transferred to the surroundings.

Engine cooling

Radiators are used for cooling internal combustion engines, mainly in automobiles but also in piston-engine aircraft, railway locomotives, motorcycles, stationary generating plants and other places where heat engines are used (watercrafts, having an unlimited supply of a relatively cool water outside, usually use the liquid-liquid heat exchangers instead).

To cool down the heat engine, a coolant is passed through the engine block, where it absorbs heat from the engine. The hot coolant is then fed into the inlet tank of the radiator (located either on the top of the radiator, or along one side), from which it is distributed across the radiator core through tubes to another tank on the opposite end of the radiator. As the coolant passes through the radiator tubes on its way to the opposite tank, it transfers much of its heat to the tubes which, in turn, transfer the heat to the fins that are lodged between each row of tubes. The fins then release the heat to the ambient air. Fins are used to greatly increase the contact surface of the tubes to the air, thus increasing the exchange efficiency. The cooled liquid is fed back to the engine, and the cycle repeats. Normally, the radiator does not reduce the temperature of the coolant back to ambient air temperature, but it is still sufficiently cooled to keep the engine from overheating.

This coolant is usually water-based, with the addition of glycols to prevent freezing and other additives to limit corrosion, erosion and cavitation. However, the coolant may also be an oil. The first engines used thermosiphons to circulate the coolant; today, however, all but the smallest engines use pumps

Up to the 1980s, radiator cores were often made of copper (for fins) and brass (for tubes, headers, and side-plates, while tanks could also be made of brass or of plastic, often a polyamide). Starting in the 1970s, use of aluminium increased, eventually taking over the vast majority of vehicular radiator applications. The main inducements for aluminium are reduced weight and cost.

Since air has a lower heat capacity and density than liquid coolants, a fairly large volume flow rate (relative to the coolant's) must be blown through the radiator core to capture the heat from the coolant. Radiators often have one or more fans that blow air through the radiator. To save fan power consumption in vehicles, radiators are often behind the grille at the front end of a vehicle. Ram air can give a portion or all of the necessary cooling air flow when the coolant temperature remains below the system's designed maximum temperature, and the fan remains disengaged

engine cooling

A typical automotive cooling system comprises:

- a series of galleries cast into the engine block and cylinder head, surrounding the combustion chambers with circulating liquid to carry away heat;
- a radiator, consisting of many small tubes equipped with a honeycomb of fins to dissipate heat rapidly, that receives and cools hot liquid from the engine;
- a water pump, usually of the centrifugal type, to circulate the coolant through the system;
- a thermostat to control temperature by varying the amount of coolant going to the radiator;
- a fan to draw cool air through the radiator.

The combustion process produces a large amount of heat. If heat were allowed to increase unchecked, detonation would occur, and components outside the engine would fail due to excessive temperature. To combat this effect, coolant is circulated through the engine where it absorbs heat. Once the coolant absorbs the heat from the engine it continues its flow to the radiator. The radiator transfers heat from the coolant to the passing air.

Radiators are also used to cool automatic transmission fluids, air conditioner refrigerant, intake air, and sometimes to cool motor oil or power steering fluid. A radiator is typically mounted in a position where it receives airflow from the forward movement of the vehicle, such as behind a front grill. Where engines are mid- or rear-mounted, it is common to mount the radiator behind a front grill to achieve sufficient airflow, even though this requires long coolant pipes. Alternatively, the radiator may draw air from the flow over the top of the vehicle or from a side-mounted grill. For long vehicles, such as buses, side airflow is most common for engine and transmission cooling and top airflow most common for air conditioner cooling.

Engine coolant

Before World War II, engine coolant was usually plain water. Antifreeze was used solely to control freezing, and this was often only done in cold weather. If plain water is left to freeze in the block of an engine the water can expand as it freezes. This effect can cause severe internal engine damage due to the expanding of the ice.

Development in high-performance aircraft engines required improved coolants with higher boiling points, leading to the adoption of glycol or water-glycol mixtures. These led to the adoption of glycols for their antifreeze properties.

Since the development of aluminium alloy or mixed-metal engines, corrosion inhibition has become even more important than antifreeze, and in all regions and seasons.

OBJECTIVE

The objective is to investigate the advantages of utilizing magnesium oxide and graphene nanofluids in radiator applications, emphasizing their potential to enhance heat transfer rates and reduce energy consumption in cooling processes due to their superior thermal conductivity.

Additionally, it underlines their ability to withstand high temperatures, maintain structural integrity, and resist corrosion, making them suitable for demanding radiator environments.

LITERATURE REVIEW

Xie et al[1] reported heat transfer enhancement using nanofluids of Al2O3, ZnO, TiO2 and MgO with a mixture of water and ethylene glycol of 55% and 45% respectively. Al2O3, MgO and ZnO nanofluids showed superior increment in heat transfer compared to TiO2 nanofluids. Peyghambarzadeh et al.[2] tested a car radiator using Al2O3/water based nanofluids. The volumetric concentrations were varied in a range of 0.1-1%. A maximum heat transfer enhancement up to 45% at 1% volumetric concentration was recorded. Naraki, et al.[3] reported experimental results for CuO/water nanofluids tested under laminar flow regime in a car radiator. Volumetric concentration was varied from 0 to 0.4% and inlet temperature was changed from 50 to 80 C. An 8% increase in overall heat transfer coefficient compared with water was reported for 0.4% vol. nanofluids. Hussein et al.[4] tested TiO2 and SiO2 water based nanofluids in a car radiator under laminar flow regime. Volumetric concentration and fluid inlet temperature was changed in a range of 1-2% and 60-80 C. Lee et al.[5] experimentally studied the mixture of ethylene glycol and CuO nanoparticles of 35 nm size at the concentration of 4.0 vol.% and found a 20% increase in thermal conductivity. Yu et al.[6] experimentally investigated that, the thermal conductivity of nanofluid strongly depends on nanoparticle volume concentrations and it increases nonlinearly with the increase of volume concentration and the enhanced thermal conductivity was found to be 26.5% at 5.0vol.% concentration. Nguyen et al [7] experimentally investigated the effect of volume concentrationand temperature on the dynamic viscosity of Al2O3–water nanofluid and found that viscosity of the nanofluid considerably increases with the increase of particle volume concentrations, but it decreases with the increase of temperature. Wang et al.[8] investigated the viscosity of Al2O3–water nanofluid prepared by mechanical blending with particle size of 28nm at 5 vol.% concentration and viscosity increased by 86% compared to the base fluid. They also investigated Al2O3/ethylene glycol nanofluid and found a 40% increase in viscosity. Das et al.[9] also observed that with the increase of particle volume concentration, viscosity of the nanofluid increases. Elias et al.[10] reported findings about thermal conductivity, viscosity, specific heat and density of Al2O3 nanofluids in water and ethylene glycol used as coolant in car radiator. Volume concentration and coolant temperature were kept up to 1% and 50C respectively. Viscosity, thermal conductivity and density of the nanofluids were found to increase whereas specific heat of nanofluid was found to decrease with increasing volumetric concentrations. Masuda et al.[11] studied the thermo physical properties of Al2O3–water, SiO2– water and TiO2–water nanofluids. The transient hot-wire method was used to measure the thermal conductivity of nanofluids. They establish that the thermal conductivity of nanofluids increasing by 32 % at the concentration of 4.3 vol. %. They concluded that temperature did not have any effect on the increase of relative thermal conductivity. Lee et al.[12] conducted an experiment to measure the thermal conductivity of Al2O3 and CuO suspended in water and ethylene glycol. Particle sizes of Al2O3 and CuO were 23.6 nm and 38.4 nm, respectively. Their results indicated that nanofluids had higher thermal conductivity than the base fluid, and it increased with the increasing level of concentration. Wang et al.[13] studied thermal conductivity of Al2O3 and CuO nanofluids with a particle size of 20 nm. Each was suspended in water, vacuum pump oil, engine oil, and ethylene glycol. The steady state method was used to measure thermal conductivity. Their results showed that the thermal conductivity of both nanofluids were higher than that of the base fluids and varying with concentration level. Sundar and Sharma [14] obtained thermal conductivity enhancement of 6.52% with Al2O3 nanofluid, 24.6% with CuO nanofluid at 0.8% volume concentration compared to water. Vahid Delavari et al [15] CFD simulation of heat transfer enhancement of Al2O3/water and Al2O3/ethylene glycol nanofluids in a car radiator. Thirumala Reddy[16] Performance Improvement of an Automobile Radiator using CFD Analysis.

Nano fluid

A Nano fluid is a fluid containing nano meter-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid the nanoparticles used in Nano fluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil.

Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, in grinding, machining and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Knowledge of the rheological behaviour of Nano fluids is found to be critical in deciding their suitability for convective heat transfer applications. Nanofluids also have special acoustical properties and in ultrasonic fields display additional shear-wave reconversion of an incident compressional wave; the effect becomes more pronounced as concentration increases.

In analysis such as computational fluid dynamics (CFD), Nano fluids can be assumed to be single phase fluids; however, almost all new academic papers use a two-phase assumption. Classical theory of single phase fluids can be applied, where physical properties of Nano fluid is taken as a function of properties of both constituents and their concentrations.[10] An alternative approach simulates Nano fluids using a two-component model.

The spreading of a Nano fluid droplet is enhanced by the solid-like ordering structure of nanoparticles assembled near the contact line by diffusion, which gives rise to a structural disjoining pressure in the vicinity of the contact line. However, such enhancement is not observed for small droplets with diameter of nano meter scale, because the wetting time scale is much smaller than the diffusion time scale.

Synthesis

Nanofluids are produced by several techniques:

1. Direct Evaporation (1 step)
2. Gas condensation/dispersion (2 step)
3. Chemical vapor condensation (1 step)
4. Chemical precipitation (1 step)
5. Bio-based (1 step)

6. Analysis process

7. Hybrid Nano fluid properties

8. **- 50% Water (H_2O)**
9. **- 25% Magnesium Oxide (MgO)**
10. **- 25% Silver Nanofluid (Ag)**
11. **Density (ρ):**
12. Assuming a linear mixture rule, the density of the mixture can be estimated as:
13. $\rho_{mixture} = 0.5 * \rho_{H2O} + 0.25 * \rho_{MgO} + 0.25 * \rho_{Ag}$
14. where $\rho_{H2O} \approx 1$ g/cm³, $\rho_{MgO} \approx 3.58$ g/cm³, and $\rho_{Ag} \approx 10.49$ g/cm³ (density of silver nanoparticles).
15. $\rho_{mixture} \approx 4.035$ g/cm³
16. **Specific Heat Capacity (Cp):**
17. Using the mass-weighted average method:
18. $Cp_{mixture} = 0.5 * Cp_{H2O} + 0.25 * Cp_{MgO} + 0.25 * Cp_{Ag}$
19. where $Cp_{H2O} \approx 4.184$ J/g·K, $Cp_{MgO} \approx 0.887$ J/g·K, and $Cp_{Ag} \approx 0.233$ J/g·K (specific heat capacity of silver).
20. Z
21. **Thermal Conductivity (k):**
22. Using the Maxwell-Garnett model for nanofluids:
23. $k_{mixture} = k_{H2O} * (1 + 3 * \varphi * (k_{Ag} / k_{H2O} - 1) / (k_{Ag} / k_{H2O} + 2))$
24. where $k_{H2O} \approx 0.613$ W/m·K, $k_{Ag} \approx 429$ W/m·K (thermal conductivity of silver), and $\varphi = 0.25$ (volume fraction of silver nanoparticles).
25. $k_{mixture} \approx 1.415$ W/m·K
26.
27.
28. **Dynamic Viscosity (μ):**

29. Using the Einstein-Batchelor model for nanofluids:
30. $\mu_{mixture} = \mu_{H2O} * (1 + 2.5 * \varphi)$
31. where $\mu_{H2O} \approx 8.9 \times 10^{-4}$ Pa·s.
32. $\mu_{mixture} \approx 1.122 \times 10^{-3}$ Pa·s
33.
34. - 50% Water (H_2O)
35. - 25% Magnesium Oxide (MgO)
36. - 25% Graphene nanofluid (GNF)
37. 1. Density (ρ):
38. Assuming a linear mixture rule:
39. $\rho_{mixture} = 0.5 * \rho_{H2O} + 0.25 * \rho_{MgO} + 0.25 * \rho_{GNF}$
40. where $\rho_{H2O} \approx 1$ g/cm, $\rho_{MgO} \approx 3.58$ g/cm, and $\rho_{GNF} \approx 0.754$ g/cm (density of Graphene nanofluid).
41. $\rho_{mixture} \approx 2.042$ g/cm
42. Specific Heat Capacity (Cp):
43. Using the mass-weighted average method:
44. $Cp_{mixture} = 0.5 * Cp_{H2O} + 0.25 * Cp_{MgO} + 0.25 * Cp_{GNF}$
45. where $Cp_{H2O} \approx 4.184$ J/g·K, $Cp_{MgO} \approx 0.887$ J/g·K, and $Cp_{GNF} \approx 1.054$ J/g·K (specific heat capacity of Graphene)
46. $Cp_{mixture} \approx 2.531$ J/g·K
47. Thermal Conductivity (k):
48. Using the Maxwell-Garnett model for nanofluids:
49. $k_{mixture} = k_{H2O} * (1 + 3 * \varphi * (k_{GNF} / k_{H2O} - 1) / (k_{GNF} / k_{H2O} + 2))$
50.
51. where $k_{H2O} \approx 0.613$ W/m·K, $k_{GNF} \approx 5000$ W/m·K (thermal conductivity of Graphene), and $\varphi = 0.25$ (volume fraction of Graphene nanofluid).
52. $k_{mixture} \approx 3.859$ W/m·K
53. Dynamic Viscosity (μ):
54. Using the Einstein-Batchelor model for nanofluids:
55. $\mu_{mixture} = \mu_{H2O} * (1 + 2.5 * \varphi)$
56. where $\mu_{H2O} \approx 8.9 \times 10^{-4}$ Pa·s.
57. $\mu_{mixture} \approx 1.122 \times 10^{-3}$ Pa·s

MESHING

Meshing is the process of dividing a complex geometric domain into smaller, simpler shapes called elements or cells. In computational fluid dynamics (CFD) and finite element analysis (FEA), meshing is used to discretize the geometry, here element size used 5mm

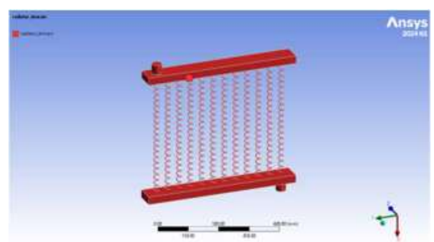


Fig 1: Radiator domain

Inlet mass flow rate → 0.0064 kg/s or 4Lpm

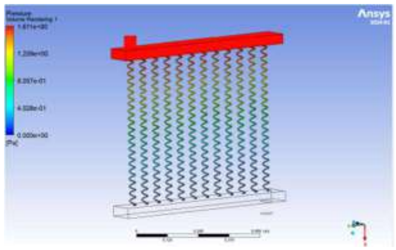
Inlet temperature → 97*C or 370K

Wall temperature → convection → 5 w/mm^2 film coefficient value with 303 ambient temperature

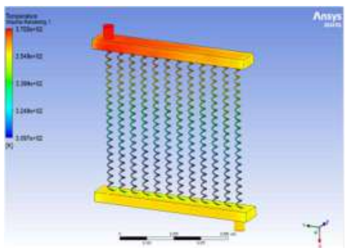
RESULTS

Water+Mgo+silver

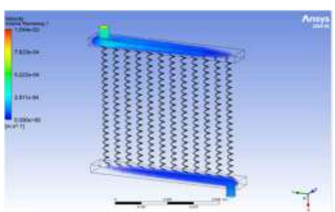
Pressure



Temperature



Velocity



Area-Weighted Average Static Temperature	[K]
inlet	370
outlet	359.55675
walls	350.65281

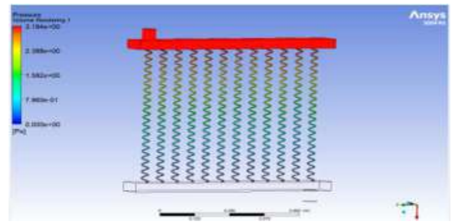
Inlet outlet temperature

Mass-Weighted Average Wall Adjacent Heat Transfer Coef.	[W/(m^2 K)]
radiator_domain	179.06477

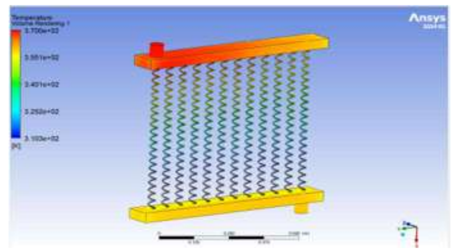
Heat transfer rate coefficient

Water+Mgo+ graphene Nano fluid

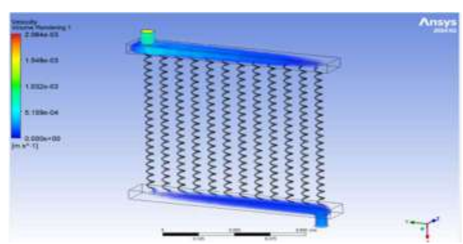
Pressure



Temperature



Velocity



Area-Weighted Average Static Temperature	[K]
inlet	370
outlet	358.68718
walls	348.97922

Inlet outlet temperature

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              Mass-Weighted Average
Wall Adjacent Heat Transfer Coef.          [W/(m^2 K)]
-------------------------------- --------------------
                 radiator_domain           488.42684
```

Heat transfer rate coefficient

	Water +mgo+ silver	Water +mgo+ graphe Nano fluid
Pressure (Pa)	1.611	3.184
Maximum Temperature (K)	370	370
Minimum Temperature (K)	309.7	310.3
Velocity (m/s)	1.044e-3	2.064e-3
Inlet temperature (K)	370	370
outlet temperature(K)	359.55	358.68
Heat transfer coefficient	179.06477	488.42

Conclusion

In this project radiator model designed with the help of solid works and analysed with the help of Ansys workbench, radiator analysed with hybrid Nano fluids (50% Water (H2O) +25% Magnesium Oxide (MgO)+ 25% Silver Nanofluid (Ag)) and (50% Water (H2O) +25% Magnesium Oxide (MgO) +25% Graphene nanofluid (GNF))

From analysis results - The maximum temperature and minimum temperature values are similar for both combinations, indicating that the temperature range is consistent.

- The velocity of the fluid is higher for the Water + MgO + GNF combination, which could indicate improved fluid dynamics.

- The heat transfer coefficient is significantly higher for the Water + MgO + GNF combination (488.42) compared to the Water + MgO + Ag combination (179.06477). This suggests that the Graphene Nano Fluid hybrid nanofluid is more effective in enhancing heat transfer.

Based on the analysis results, the Water + MgO + Graphene Nano Fluid hybrid nanofluid combination exhibits better heat transfer performance and fluid dynamics compared to the Water + MgO + Silver combination. This suggests that the addition of Graphene Nano Fluid to the base fluid (Water) and MgO nanoparticles enhances the thermal conductivity and convective heat transfer coefficient, leading to improved radiator performance. it is recommended to use the Water + MgO + Graphene Nano Fluid hybrid nanofluid combination for radiator applications, as it shows superior heat transfer performance and fluid dynamics. This hybrid nanofluid has the potential to improve the efficiency and effectiveness of radiators in various industrial and automotive applications.

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