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Car Antifreeze and Coolant: Comparing Water and Ethylene Glycol as Nano Fluid Base Fluid

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ABSTRACT

Most internal combustion engines are fluid cooled using liquid coolants mostly water and ethylene glycol, whose heat transfer capabilities are limited. An alternative for improving their thermophysical properties is the addition of metal oxides so as to make Nanofluids. This study investigates car antifreeze and coolants by comparing water-based and ethylene glycol based Nanofluids to determine the Nanofluid which provides optimum cooling. The governing equations are non-dimensionalised using similarity transformation and the resulting equations solved numerically using the Runge–Kutta fourth order scheme. Graphical results of pertinent parameters on fluid velocity, temperature, skin friction and rate of heat transfer are presented and discussed in depth putting into consideration the industrial application. It was observed that the magnetic field slows the fluid flow while increasing the fluid temperature. Also ethylene glycol Nanofluid offers better cooling capabilities.

Key Words: Nano-fluid, Antifreeze, Runge-Kutta, Coolant.

1. INTRODUCTION

Continuous technological development in the world has led to drastic increase in the demand of automobiles. According to [2] automobile industries have a great challenge to provide an efficient and economical engine in terms of fuel supply, lubrication system, transmission system and of most important the cooling system among other systems. It has become of necessity to design an engine with greatly improved performance.

Cooling system is one of the most important systems amongst all in automobile engines which is responsible for carrying large amount of heat waste to surroundings for efficient working of an engine. It enhances heat transfer and fuel economy which leads to maximization of performance of the engine. Most internal combustion engines are fluid cooled using either air or liquid coolant which runs through a heat exchange radiator cooled by air. Heat transfer through the radiator can be increased by maximizing the heat transfer area and increasing the heat transfer coefficient.

The heat transfer coefficient can be either can be increased either by using more efficient heat transfer methods or by improving the thermo physical properties of the heat transfer material that is the coolant. Water has been widely used in radiators as coolant due to its good ability to hold heat, transfer heat and is readily available. Mixture of water and ethylene glycol was later introduced as a coolant. Advancement of nanotechnology has led to development of a new generation of heat transfer fluids called Nano fluids. Researchers have found that these fluids offer high thermal conductivity compared to that of convectional coolants. [2] reported that Nano fluids consist of a carrier liquid like water, ethylene glycol dispersed with tiny Nano-scale particles known as nanoparticles.

1.1 Anti – freeze

It is a solution of suitable organic chemical (mostly Ethylene glycol, diethylene glycol or propylene glycol) in water used when water-based coolant has to withstand temperature below 00C or its boiling point has to be raised [18]. Very pure deionised water has low electrical conductivity hence used to cool some electrical equipment e.g. high power transmitters and high power vacuum tubes, heavy water is a neutron moderator used in some nuclear reactors.

1.2 Coolant

It is a fluid which flows through or around a device to prevent its overheating by transferring the heat produced by the device to other devices that use or dissipate it. Characteristics of an ideal coolant include: high thermal capacity, low viscosity, affordability, non-toxic and chemically inert neither causing nor promoting corrosion of the cooling system. The term coolant is used in automotive applications while heat transfer fluid is used in industrial processing. Coolant can either keep its phase and stay liquid or gaseous or undergo phase transition with the latent heat adding to the cooling efficiency. Most common coolant is water [18] which transfers heat effectively; it has high heat capacity which makes it suitable heat transfer medium. It is used with additives like corrosion inhibitors and antifreeze.

1.2.1 Water as a Coolant

Water is one of the most common coolants; this is because of its high heat capacity, its low cost and its local availability. These characteristics makes it suitable heat transfer medium with addition of corrosion inhibitors and anti – freezers like ethylene glycol or diethylene glycol used when the water based coolant has to withstand temperature below 00 or when its boiling point has to be raised. Water as a coolant can be applied to cool nuclear reactors, car radiators while oil can be used where water is not suitable for example in transformers as well as lubricants. A new generation of coolant is Nano fluids.

1.3 Nano – fluids

It is a new class of coolants which consists of a carrier liquid such as water dispersed with tiny Nano-scale particles known as nanoparticles, [2]. Purpose designed nanoparticles e.g. copper oxide (CuO), Titanium dioxide, Carbon nanotubes, silica or metals e.g. copper or silver Nano rods dispersed into the carrier liquid enhances the heat transfer capabilities of the resulting coolant compared to the liquid alone. They offer higher thermal conductivity compared to the conventional coolants.

Table 1: Thermo Physical Properties of Ethylene Glycol, Water and Nano particles

Material	$\rho(\text{kg/m}^3)$	$C_p(\text{J/kgk})$	$K(\text{w/mk})$	$\beta \times 10^{-5}(\text{K}^{-1})$	$\sigma(\text{s/m})$	Viscosity $\mu(\text{N/m}^2)$
Copper	8933	385	401	1.67	5.95×10^6	-
Silver	10500	235	429	1.89	6.3×10^7	-
Aluminum	2701	902	237	2.31	3.5×10^7	-
Iron	7570	460	80	58	1.0×10^7	-
Copper Oxide (CuO)	6510	540	18	0.85	5.96×10^7	-
Alumina (Al_2O_3)	3970	765	40	0.85	3.5×10^6	-
Titania (TiO_2)	4250	686.2	8.9538	0.9	2.6×10^6	-
Iron Oxide (Fe_2O_3)	510	670	80.4	20.6	1.12×10^5	-
Ethylene glycol	1114	2415	0.252	57	1.07×10^{-6}	0.00304
Pure water	997.1	4179	0.613	21	5.5×10^{-6}	-
Engine Oil	884	1909	0.145	70	1.0×10^{-7}	-
Mineral Oil	920	1670	0.138	64	1.0×10^{-7}	-

Theoretically the enhancement can be as high as 350% though experiments have not proved so high thermal conductivity improvements but shown a significant increase of the critical heat flux of the coolant. For example significant improvements are achievable using silver Nano rods of 55 ± 12 nm diameter $12.8 \mu\text{m}$ average length at 0.5 volume percentage increased the thermal conductivity of water by 68%, 0.5 volume percentage of silver Nano rods increased thermal conductivity of ethylene glycol based coolant by 98%. Alumina particles at 0.1% can increase the critical heat flux of water by as much as 70%. Nano fluid with concentration more than 5% acts like non-Newtonian fluids. The Nano fluids have significantly improved heat transfer performance because:

1. The suspended nanoparticles increase the surface area and the heat capacity of the fluid.
2. The suspended nanoparticles increase the effective thermal conductivity of the fluid.
3. The interaction and collision among particles, fluid and flow passage surface are intensified.
4. The mixing fluctuation and turbulence of the fluid are intensified,
5. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

1.3.1 Nano fluid Coolant

Nano fluids can be used as coolant, fuel additives, lubricants and shock absorbers in automobiles, and as refrigerants. The current fluids in use such as engine oil, automatic power transmission fluids, coolants and lubricants have heat transfer properties. This has resulted to the application of Nano fluids which have improved thermal conductivity than ordinary fluid. They are commonly used in cooling radiators for automobiles, trucks and power electronics for hybrid electric vehicles. Use of Nano fluids has led to improved aerodynamic design of vehicles with economical fuel consumption since the fluids are efficient in heat transfer. Due to this manufactures have reduced the amount of energy needed to overcome viscous drag of air on the road due to reduced size and better positioning of radiator.

At high speed approximately 65% of the total energy consumed by a truck is used in overcoming aerodynamic drag. This can be attributed to large radiator in the front of the engine positioned to maximise the cooling effect by oncoming air. However, the use of Nano fluids as coolants has allowed for smaller size and better positioning of the radiators.

Due to the fact that there would be less fluid due to improved efficiency, coolant pumps would be made smaller and hence vehicle engines could be operated at higher temperatures and still meet the optimum emission capacity. Engines designed to use Nano fluids as coolants are lighter and smaller in size hence less fuel consumption minimising emissions and reducing environmental pollution. [20], researchers at Argonne National Laboratories during their studies on the uses of Nano fluids in radiators suggested that the use of Nano fluids can lead to a modified frontal area. This included reduction of the radiator size by up to 10% which would reduce the aerodynamic drag leading to fuel saving of up to 5%. It would also result to reduction of friction and wear hence further fuel saving of up to more than 6%.

1.4 Statement of the Problem

Automobile demand is almost at its peak, but it has been faced by a great challenge of designing an effective and efficient high performance engines due to problem of heat transfer and dissipation of waste heat to the surroundings, [2]. This has been caused by lack of efficient coolants with high thermal conductivity and excellent heat transfer properties. This then has led to an immediate quest for better coolant with improved thermal properties to curb the situation which would improve the performance of the engines with a smaller and efficient cooling system.

1.5 Objectives of the Study

1.5.1 General Objectives

To investigate car antifreeze and coolant by comparing water and ethylene glycol as Nano fluid base fluid.

1.5.2 Specific Objectives

- i. To analyse ethylene glycol and water as base fluids for a Nano fluid coolant.
- ii. Compare ethylene glycol and water as base fluids.
- iii. Compare Copper Oxide and Aluminium oxide nanoparticles.
- iv. Analyse the effects of nanoparticles and magnetic strength on the velocity, temperature profiles as well as skin friction and Nusselt number.

1.6 Significance of the Study

In automobiles, fuel and air produce power in the engine through combustion. All power generated is not supplied to the automobile but some is wasted in form of exhaust and heat. If the excess heat is not removed then the engine temperatures become too high resulting to overheating which lowers the performance of the engine. To control this, an efficient cooling system is required. The heat dissipation takes place in the radiator whereas the coolant circulates it carries with it excess heat from the engine hence keeping thermal equilibrium between the engine and the surrounding relatively lower.

This study is interested in studying the behaviour of water and ethylene glycol base fluids both dispersed with copper oxide and aluminium oxide nanoparticles. This will be done by varying the parameters of the nanoparticles and then studying how the thermal conductivity of each base fluid is affected in an attempt to get the best base fluid and the nanoparticles which gives better enhancement of thermal conductivity for cooling purposes.

Researches and experiments have been done on base fluids dispersed with different nanoparticles and it was found that there was improvement in thermal conductivity and heat transfer characteristics compared to the conventional base fluids [12]. However, the researchers have never given a suggestion of which base fluid and nanoparticles gives a better coolant and that is what this project is going to address.

2. LITERATURE REVIEW

The automobile industry is continuously involved in a strong competitive career to obtain the best automobile design in terms of performance, fuel consumption among others. Due to these challenges, an optimisation process is mandatory to obtain the best design to compromise between performance, size and shape. In an attempt to arrest this situation different researches and experiments have been carried out to investigate heat transfer characteristics for automotive radiators using ethylene glycol and water dispersed with CuO and Al₂O₃ nanoparticles among others.

[21] studied a three - dimensional laminar flow and heat transfer with Al₂O₃ and CuO in ethylene glycol/water mixture circulating through the flat tubes of an automobile radiator to evaluate their superiority over the base fluid. Convective heat transfer coefficient along the flat tubes with the Nano fluid flow showed considerable improvement over the base fluid.

[15] have recently investigated the application of Al₂O₃ /water Nano fluids in the automobile radiator by calculating the tube side heat transfer coefficient. They have recorded the interesting enhancement of 45% comparing with the pure water application under highly turbulent flow condition. In another study [17] have used different base fluids including ethylene glycol and their binary mixtures with Al₂O₃ nanoparticles and once again it has proved that Nano fluids improve the cooling performance of an automobile radiator extensively.

[15] found that thermal conductivity of CuO/water Nano fluids was much higher than that of base fluid water. He found that the overall heat transfer coefficient increases with the enhancement in the Nano fluid concentration from 0 to 0.4 vol %. Conversely the implementation of Nano fluid increases the overall heat transfer coefficient up to 8% at Nano fluid concentration of 0.4 vol % in comparison with the base fluid.

[8] found that thermal conductivity of the Nano fluid depends on the volume fraction of particle and thermal conductivity of base fluid and particles. [13] investigated the effect of temperature, particle size and volume fraction on thermal conductivity of water based Nano fluids of copper oxide and Alumina. Authors suggested that the thermal characteristics can be enhanced with increase of particles, volume fraction, and temperature and particle size. The authors also found that, the smaller the particle size, the greater the effective thermal conductivity of the Nano fluids at the same volume fraction.

[12] showed that different Nano fluids (i.e. Al₂O₃- water, SiO₂- water and TiO₂- water combinations) generated a thermal conductivity increase of up to 30% at volume fractions of less than 4.3%. Such an enhancement phenomenon was also reported by [7] for CuO – water and Al₂O₃ – water Nano fluids. Also [12] measured the thermal conductivity of Nano fluids containing Al₂O₃ (13 nm), SiO₂ (12 nm) and TiO₂ (27 nm) nanoparticles, with water as the base fluid. They observed an enhancement of 32.4% for the effective thermal conductivity of 4.3 vol % Alumina- water Nano fluids at 31.850C.

In their studies [10] based on CuO- water/ Ethylene glycol Nano fluids with particle diameters 18.6 and 23.6 nm as well as Al₂O₃- water/ Ethylene glycol Nano fluids with particle diameters 24.4 and 38.4 nm, they discovered a 20% thermal conductivity increase at a volume fraction of 4%. In both cases it was found that thermal conductivity increases linearly with particle volume fraction. Wang et al., (1999) showed a 12 % increase in thermal conductivity for 28 nm diameter Al₂O₃ – water and 23 nm CuO – water Nano fluids with 3% volume fraction. For the case of 8 vol % Al₂O₃ – water Nano fluid, thermal conductivity enhancement as high as 40% was achieved. From their results [14] showed a 20% increase in thermal conductivity for Al₂O₃ – water Nano fluids.

In their work [5] and Abareshi et al., (2010) noted significant increase in thermal conductivity with increase in temperature. In their study [5] they used Al₂O₃ (38.4 nm) water and CuO (28.6 nm) water Nano fluids at different temperatures ranging from 210C to 510C. It was observed that for 1 vol % Al₂O₃/ water Nano fluid, thermal conductivity enhancement increased from 2% at 210C to 10.8% at 510C, and for 4 vol % thermal conductivity enhancement increased from 9.4% at 210c to 24.4% at 510C. This is expected theoretically since, with the increment of the Nano fluids bulk temperature T, molecules and nanoparticles are more active due to enhanced Brownian motion and are able to transfer more energy from one location to another per unit time.

From the research and experiments conducted by the several prominent scientists mentioned above, it is very clear that addition of nanoparticles to the base fluids like water and Ethylene glycol improved thermal conductivity of Nano fluids compared to the conventional base fluids. It also evident that majority of the scientists mainly preferred use of water as base fluid with addition of nanoparticles which mainly were CuO and Al₂O₃.

Also from their experiments there are factors that were affecting the rate of enhancement of thermal conductivity of the base fluid with addition of nanoparticles. Some of these factors include volume fraction of particles, thermal conductivity of the base fluid, particle size, temperature and particle shape. All these factors were affecting the thermal conductivity of the base fluids differently in the positive manner. Furthermore, with the addition of nanoparticles the heat transfer coefficient was also affected and improved for the Nano fluids. However it is evident from the research that, Ethylene glycol as a base fluid was not extensively discussed and how its thermal properties and capabilities were affected by addition of nanoparticles of CuO and Al₂O₃, though some researchers have briefly mentioned the thermal conductivity was affected by some nanoparticles. Moreover the literature does not compare between Ethylene glycol and water as base fluids. It is then that due to this gap that this research sought to compare between water and Ethylene glycol base fluids and recommended which is a better base fluid Nano fluid coolant and antifreeze with reference to their characteristics. The research extensively analysed the characteristics of the Nano fluid coolants by adding CuO and Al₂O₃ nanoparticles. It also investigated the effects of the nanoparticles and magnetic strength on skin friction and Nusselt number of the base fluids.

3. METHODS AND MATERIALS

3.1 General Equations Governing Nano fluids Flow

3.1.1 Continuity Equation

This equation is based on the mass conservation law which states that “mass cannot be created or destroyed”. This implies that the rate of change of particle mass is zero. The equation of continuity is

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho v = 0 \quad (1)$$

For incompressible fluid flow, density, ρ is constant ($\rho = \text{constant}$), hence $\frac{\partial \rho}{\partial t} = 0$ therefore the continuity equation for incompressible flow becomes; $\nabla \cdot v = 0$, where

$$\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$$

The above equation can be written as;

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} + \frac{\partial u}{\partial z} = 0 \quad (2)$$

where $\nabla \cdot v$ is the divergence of velocity, which physically is the rate of change of volume of a moving fluid element per unit volume.

3.2 Momentum (Navier–Stokes) Equation

It is derived from Newton’s second law of motion ($F = ma = m \frac{du}{dt}$). It is also known as Navier- Stokes equation. The equation governing the flow of a Nano-fluid is given as

$$\frac{\partial v}{\partial t} + (v \cdot \nabla)v = \frac{1}{\rho_{nf}} [-\nabla P + \mu_{nf} \nabla^2 V^2] + F \quad (3)$$

Where F = forces acting on the flow. Taking into account force due to gravity (g), thermal expansion and the Lorentz force due to the earth’s magnetic field, the Navier-Stokes equation becomes

$$\frac{\partial v}{\partial t} + (v \cdot \nabla)v = \frac{1}{\rho_{nf}} [-\nabla P + \mu_{nf} \nabla^2 V^2] + (\rho\beta)_{nf} g \Delta T + \frac{1}{\rho_{nf}} j \times B \quad (4)$$

where V is velocity, P is Pressure, ρ_{nf} is density of the Nano fluid, μ_{nf} is dynamic viscosity of the Nano fluid, g is force due to gravity, β_{nf} is thermal expansion coefficient of the Nano fluid and j is electric current density.

3.3 Energy Equation

This equation is derived from the first law of thermodynamics which states that the amount of heat added to the system dQ equals to the change in internal energy dE plus work done dW . This means that if a net energy transfer to a system occurs the energy stored in the system must raise by an equal amount to the amount transferred.

The first law of dynamics then requires that;

$$(\rho C_p)_{nf} \left[\frac{\partial T}{\partial t} + (V \cdot \nabla)T \right] = k_{nf} \nabla^2 T + q''' \quad (5)$$

Where $(\rho C_p)_{nf}$ is heat capacitance of the Nano fluid, T is local temperature of Nano fluid, ρ_{nf} is the density of the Nano fluid, k_{nf} is the thermal conductivity of the Nano fluid, V is velocity and q''' is the heat flux.

The Nano fluid properties; density, dynamic viscosity, thermal expansion coefficient, thermal conductivity and heat capacitance are defined in terms of base fluid and nanoparticle properties as shown

$$\left. \begin{aligned} \rho_{nf} &= \rho_f(1-\varphi) + \varphi\rho_s \\ \mu_{nf} &= \frac{\mu_f}{(1-\varphi)^{2.5}} \\ \beta_{nf} &= \beta_f(1-\varphi) + \varphi\beta_s \\ (\rho C_p)_{nf} &= (1-\varphi)(\rho C_p)_f + \varphi(\rho C_p)_s \\ k_{nf} &= k_f \left[\frac{(k_s + 2k_f) - 2\varphi(k_f - k_s)}{(k_s + 2k_f) + \varphi(k_f - k_s)} \right] \end{aligned} \right\} \quad (6)$$

3.4 Maxwell's Equations

These equations govern the evolution of electric current due to flow of a fluid in a magnetic field and vice versa. Since earth is global magnet, then the Nano fluid flow in the radiator in presence of earth's magnetic field has an associated electric field. The equations are given as follows;

$$\text{Ampere's law; } \nabla \times B = \mu_0 j \quad (7)$$

$$\text{Faraday's law; } \frac{\partial B}{\partial t} = \nabla \times E \quad (8)$$

$$\text{Ohm's law; } j = \sigma(E + V \times B) \quad (9)$$

Where μ_0 is magnetic permeability, B is magnetic field, j is electric current, E is electric field and σ is electrical conductivity.

3.5 Method of Solution

The model problem which is a boundary value problem is solved using shooting method together with Fourth- order Runge-Kutta scheme. The problem is first transformed into a set of initial value problem with unknown variables which are to be determined by either linear or non – linear shooting depending on the boundary equations. The Runge–Kutta method is used to give iteration until the given boundary conditions are satisfied. Further computation is done by use of computer software which gives numerical results to the problem.

4. MODELLING OF ANALYSIS OF ETHYLENE GLYCOL AND WATER BASE FLUIDS DISPERSED WITH COPPER OXIDE AND ALUMINIUM OXIDE NANO PARTICLES

With the rising challenge of developing an excellent coolant for automobiles, scientists have embarked on serious researches and experiments to control the situation. This research has led to the growth of a new class of coolants called Nano fluids which are described as a solid-liquid mixture consisting of base fluid and low concentration of solid nanoparticles of high conductivity. These fluids are prepared by dispersing and suitably suspending nanometre size of various solid particles in base fluids. This study will be particularly interested in thermal performance of Nano fluid coolants using ethylene glycol (EG) and water as base fluids.

Recently heat transfer has got many engineering applications which includes heat exchanger, piping system, solar collectors and electric conductors. These wide applications have necessitated the development of an appropriate convective heat transfer fluids. In automobile engines the heat transfer component is the radiator. It is mainly used for cooling internal combustion engines, piston engines of aircrafts, trains, motorcycles and stationary generating plants.

The coolant circulates through the engine block where it is heated then pumped through the radiator where it losses heat to the atmosphere through natural convection and fins then back to the engine. Due to the high amount of heat generated in the engine there is need to develop a high conducting and efficient coolant for effective dissipation of heat to the surrounding which will improve performance of the engines.

One way of increasing heat dissipation is by addition of the number of cooling fins and the number of fans used in the radiator. Also heat dissipation can be increased by use of a coolant fluid with high conductivity coefficient or by also improving conductivity of common coolant, water and ethylene glycol whose thermal conductivity coefficient is very low. Several theoretical and experimental studies on enhancement of conduction heat transfer by suspending nanometre size particles in common coolants have been done.

A successful attempt to come up with Nano fluids was addition of Nano-sized particles to conventional liquids such as water and ethylene glycol [3]. This addition of metallic particles to base fluids produced an increase in the thermal conductivity of fluids [9]. Commonly used nanoparticles in Nano fluids are made of chemically stable metals: Aluminium, gold, Iron and oxides (Al₂O₃, CuO),

carbides, nitrides or non- metals for example graphite or carbon nanotubes with base fluids being conductive fluids such as water and ethylene glycol among others. Their improved convective heat transfer coefficient make Nano fluids the best heat transfer media for cooling although different base fluids dispersed with different nanoparticles are better than others depending on the rate of improvement of convective heat transfer coefficient of the base fluid by the nanoparticles present.

Nano fluids have enhanced thermo physical properties which includes thermal conductivity, thermal diffusivity, thermal viscosity and convective heat transfer coefficient compared to base fluids [6]. [4] investigated use of Nano fluids in heat exchangers and found a high possibility for their use in cooling. [16] used Al₂O₃/water Nano fluids in cooling of electrical devices and noted a lot of improvement of heat transfer coefficient for a low level volume fraction of nanoparticles.

Also [11] studied performance of ethylene glycol/copper Nano fluid and also reported an enhanced heat transfer. Most conventional fluids used in production of Nano fluids are liquids whose their electrical conductivities are lower than that of Nano particle, [19]. Their presence also enhances electrical conductivity hence therefore are more susceptible to influence by magnetic fields from nearby sources or due to earth's magnetic field.

In this study we analysed thermal performance of water and ethylene glycol both dispersed with Al₂O₃ and CuO Nano particles. The nanoparticle that gives the best heat transfer property combination with either base fluid will be recommended and used as base fluid Nano fluid coolant and antifreeze. Following is a formulated model problem, analysed, solved and results tabulated and discussed quantitatively.

4.1 Mathematical Formulation

Cooling takes place at flat plate heat exchanger configuration in the radiator. Heat transfer fluids of different nature and different concentration through the tubes in the radiator where it comes into contact with air is forced to flow by fan and forced convection. A steady incompressible boundary-layer flow of a conducting fluid through the system takes the heat from the hotter fluid from the engine and carries it away to the flat plate. By use of the fan, cold air blown over the fins which lowers temperature of the coolant flowing through the radiator.

The flow of Nano fluids whose base fluid is ethylene glycol or water suspended on them are nanoparticle of different kind giving a coolant which run through the radiator. The Nano fluids used contain CuO and Al₂O₃.

Let x be the direction along the plate and y is normal to it across the tube in the radiator. The part in contact with the plate is considered to have to have temperature T_f and provides thermal heat transfer coefficient h_f . At the centre of flowing coolant is a free stream of Nano fluid at temperature T_∞ . With the use of various Nano fluids, estimation of thermo physical properties for each fluid in order determine the Nusselt numbers and skin friction for particular volume fraction so as to find out the best base fluid Nano fluid coolant would be of advantage to allow for increased amount of heat dissipated from the engine.

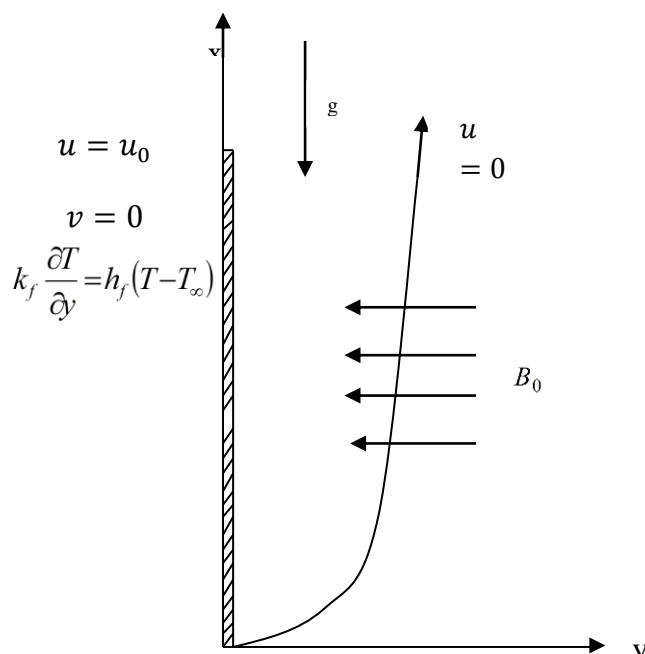


Fig.1. Flow Configuration and Coordinate Theory

The equations of heat transfer in air and Nano fluids are as given in equations 2 to 6. Without slip between nanoparticles and the base fluid, then the governing equations of continuity, momentum and energy in the heat exchanger are expressed as follows;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{10}$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{\mu_{nf}}{\rho_{nf}} \frac{\partial^2 u}{\partial y^2} + \beta_{nf} g(T - T_\infty) - \frac{\sigma_{nf} B_0^2}{\rho_{nf}} u \tag{11}$$

$$\frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{k_{nf}}{(\rho C_p)_{nf}} \frac{\partial^2 T}{\partial y^2} + \frac{\mu_{nf}}{(\rho C_p)_{nf}} \left(\frac{\partial u}{\partial y} \right)^2 + \frac{\sigma_{nf} B_0^2 u^2}{(\rho C_p)_{nf}} \tag{12}$$

where u and v are velocity components in x and y directions respectively, ρ_{nf} density of Nano fluid, T local temperature, μ_{nf} dynamic viscosity of Nano fluid, P fluid pressure, β_{nf} volume expansion coefficient of Nano fluid, k_{nf} heat transfer coefficient of Nano fluid, σ_{nf} electrical conductivity of Nano fluid, B_0 magnetic field, g gravitational vector, $(\rho C_p)_{nf}$ heat capacitance of Nano fluid and C_p specific heat capacity at constant pressure.

The boundary conditions at the plate surface and at the free stream are expressed as;

$$\left. \begin{aligned} u(x,0) = u_0, \quad v(x,0) = 0, \quad -k_{nf} \frac{\partial T}{\partial y}(x,0) = h_f (T_f - T) \\ u(x, \infty) = 0, \quad T(x, \infty) = T_\infty \end{aligned} \right\} \tag{13}$$

Where k_{nf} is thermal conductivity of Nano fluid and h_f is heat transfer coefficient of the plate.

Let the particle concentration be well dispersed and uniformly distributed throughout the system, then the thermo-physical properties of the mixture can be evaluated using the formulae below. These relations can be used to predict Nano fluid physical properties like density, viscosity, thermal conductivity, specific heat and volume expansion at different temperatures and concentrations.

$$\left. \begin{aligned} \rho_{nf} &= \rho_f (1 - \phi) + \phi \rho_s \\ \mu_{nf} &= \frac{\mu_f}{(1 - \phi)^{2.5}} \\ \beta_{nf} &= \beta_f (1 - \phi) + \phi \beta_s \\ (\rho C_p)_{nf} &= (1 - \phi)(\rho C_p)_f + \phi(\rho C_p)_s \\ k_{nf} &= k_f \left[\frac{(k_s + 2k_f) - 2\phi(k_f - k_s)}{(k_s + 2k_f) + \phi(k_f - k_s)} \right] \\ \sigma_{nf} &= \sigma_f \left[1 + \frac{3(r-1)\phi}{(r+2) - (r-1)\phi} \right], \text{ where } r = \frac{\sigma_s}{\sigma_f} \end{aligned} \right\} \tag{14}$$

The subscripts f , p , nf and s refers to fluid, pressure, Nano fluid and nanoparticles respectively.

For simplifications, non dimensionless variables are introduced;

$$\left. \begin{aligned} \eta = \left(\frac{a}{v_f} \right)^{\frac{1}{2}} y, \quad \psi = (av_f)^{\frac{1}{2}} x f(\eta), \\ \theta(\eta) = \frac{T - T_\infty}{T_f - T_\infty} \text{ and } u_0 = ax \end{aligned} \right\} \tag{15}$$

Where η the similarity variable while ψ is the stream function which is defined as

$$u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x} \tag{16}$$

Putting equation (16) into equation (10), then we obtain;

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{\partial^2 \psi}{\partial x \partial y} - \frac{\partial^2 \psi}{\partial x \partial y} = 0 \tag{17}$$

Hence the continuity equation is satisfied.

From equation (15) we obtain;

$$u = \frac{\partial \psi}{\partial y} = \frac{\partial \psi}{\partial \eta} \cdot \frac{\partial \eta}{\partial y} = axf'(\eta) \tag{18a}$$

$$v = -\frac{\partial \psi}{\partial x} = -\left(av_f\right)^{\frac{1}{2}} f(\eta) \tag{18b}$$

$$\frac{\partial u}{\partial x} = \frac{\partial}{\partial x} [axf'(\eta)] = af'(\eta) \tag{18c}$$

$$\frac{\partial u}{\partial y} = \frac{\partial u}{\partial \eta} \cdot \frac{\partial \eta}{\partial y} = axf''(\eta) \cdot \left(\frac{a}{v_f}\right)^{\frac{1}{2}} \tag{18d}$$

$$u \frac{\partial u}{\partial x} = axf'(\eta) \cdot af'(\eta) = a^2 x(f'(\eta))^2 \tag{18e}$$

$$v \frac{\partial u}{\partial y} = -\left(av_f\right)^{\frac{1}{2}} f(\eta) \cdot axf''(\eta) \cdot \left(\frac{a}{v_f}\right)^{\frac{1}{2}} = -a^2 xf'(\eta)f''(\eta) \tag{18f}$$

$$\frac{\partial^2 u}{\partial y^2} = \frac{a^2 xf'''}{v_f} \tag{18g}$$

$$\frac{\sigma_{nf} \beta_0^2 u}{\rho_{nf}} = \frac{\sigma_{nf} B_0^2 axf'(\eta)}{\rho_{nf}} \tag{18h}$$

Also from equation (15) we have

$$T - T_\infty = \theta(\eta)(T_f - T_\infty) \text{ then we obtain;}$$

$$\beta_{nf} g(T - T_\infty) = \beta_{nf} g\theta(\eta)(T_f - T_\infty) \tag{18i}$$

Putting equations (14), (16) and (18a) – (18i) and the dimensionless quantities,

$$\text{Hartman number, } Ha = \frac{\sigma_f B_0^2 x}{\rho_f \mu_0}, \text{ and Grashof number, } Gr = \frac{\beta_{nf} g \theta(\eta)(T_f - T_\infty)}{u_0 a} \tag{19}$$

Into equation (11) and simplifying we obtain;

$$\begin{aligned} & f''' + (1-\phi)^{2.5} \left(1 - \phi + \phi \frac{\rho_s}{\rho_f}\right) ff'' - \\ & (1-\phi)^{2.5} \left(1 - \phi + \phi \frac{\rho_s}{\rho_f}\right) (f')^2 - \\ & Ha(1-\phi)^{2.5} \left(1 - \phi + \phi \frac{\sigma_s}{\sigma_f}\right) f' + \\ & Gr(1-\phi)^{2.5} \left(1 - \phi + \phi \frac{\beta_s}{\beta_f}\right) \left(1 - \phi + \phi \frac{\rho_s}{\rho_f}\right) \phi = 0 \end{aligned} \tag{20}$$

This is the dimensionless momentum equation.

$$\text{Again from equation (15), taking } \theta(\eta) = \frac{T - T_\infty}{T_f - T_\infty}, \text{ then } T = \theta(\eta)(T_f - T_\infty) + T_\infty \tag{21a}$$

$$\frac{\partial T}{\partial x} = 0 \tag{21b}$$

$$\frac{\partial T}{\partial y} = \frac{\partial T}{\partial \eta} \cdot \frac{\partial \eta}{\partial y} = \theta'(\eta)(T_f - T_\infty) \left(\frac{a}{v_f}\right)^{\frac{1}{2}}$$

$$v \frac{\partial T}{\partial y} = -(av_f)^{\frac{1}{2}} f(\eta) \cdot \theta'(\eta) (T_f - T_\infty) \left(\frac{a}{v_f} \right)^{\frac{1}{2}} \quad (21c)$$

$$= -a(T_f - T_\infty) f(\eta) \theta'(\eta)$$

$$\frac{\partial^2 T}{\partial y^2} = \frac{\partial}{\partial y} \left(\theta'(\eta) (T_f - T_\infty) \left(\frac{a}{v_f} \right)^{\frac{1}{2}} \right) = \frac{a}{v_f} (T_f - T_\infty) \theta''(\eta)$$

$$\frac{k_{nf}}{(\rho C_p)_{nf}} \frac{\partial^2 T}{\partial y^2} = \frac{k_{nf}}{(\rho C_p)_{nf}} \frac{a}{v_f} (T_f - T_\infty) \theta''(\eta) \quad (21d)$$

$$\frac{\mu_{nf}}{(\rho C_p)_{nf}} \left(\frac{\partial u}{\partial y} \right)^{\frac{1}{2}} = \frac{\mu_{nf}}{(\rho C_p)_{nf}} \frac{a^{\frac{3}{2}} x^2}{v_f} (f''(\eta))^2 \quad (21e)$$

$$\frac{\eta f B_0^2 u^2}{(\rho C_p)_{nf}} = \frac{\sigma_{nf} B_0^2 (axf'(\eta))^2}{(\rho C_p)_{nf}} = \frac{\sigma_{nf} B_0^2 a^2 x^2 (f'(\eta))^2}{(\rho C_p)_{nf}} \quad (21f)$$

Substituting equations (21a) – (21f), (14), and (19) and using dimensionless quantities;

$$\text{Eckert number, } Ec = \frac{u_0^2}{c_{pf}(T_f - T_\infty)},$$

$$\text{Prandtl number, } Pr = \frac{v_f k_f}{(\rho C_p)_f} \quad (22)$$

Into equation (12), simplifying and rearranging we obtain;

$$\theta'' + \frac{k_f}{k_{nf}} Pr \left(1 - \phi + \phi \frac{(\rho C_p)_s}{(\rho C_p)_f} \right) f \theta' + \quad (23)$$

$$\frac{k_f Ec Pr}{k_{nf} (1 - \phi)^{2.5}} (f'')^2 - \frac{k_f Ha Ec Pr}{k_{nf}} \left(1 - \phi + \phi \frac{\sigma_s}{\sigma_f} \right) (f')^2 = 0$$

This is the dimensionless energy equation. The boundary conditions are transformed as follows;

$$\text{At } y = 0, u = axf'(\eta) \text{ where } u_0 = ax \text{ and } u = u_0 \text{ which gives } u_0 = u_0 f'(0) \text{ thus at } \eta = 0, f'(0) = 1 \quad (24a)$$

$$\text{Also at } y = 0; v = -(av_f)^{\frac{1}{2}} f'(\eta), v = 0, \eta = 0 \text{ hence } f(0) = 0 \quad (24b)$$

$$\text{At } y = \infty; u = 0, u = axf'(\eta), \text{ which gives } 0 = axf'(\infty), \text{ hence } f'(\infty) = 0 \quad (24c)$$

$$\text{Also at } y = \infty, \text{ then } \theta(\eta) = \frac{T - T_\infty}{T_f - T_\infty}, \text{ where } T - T_\infty \text{ and } \eta = \infty \text{ which simplifies to } \theta(\infty) = 0 \quad (24d)$$

$$\text{And finally } \theta'(0) = \frac{h_f}{k_f} (\theta(0) - 1) \quad (24e)$$

Thus the final equations governing the flow are:

$$f'''' + (1 - \phi)^{2.5} (1 - \phi + \phi \rho_s / \rho_f) f f'' - (1 - \phi)^{2.5} (1 - \phi + \phi \rho_s / \rho_f) f'^2$$

$$- Ha (1 - \phi)^{2.5} (1 - \phi + \phi \sigma_s / \sigma_f) f'$$

$$+ Gr (1 - \phi)^{2.5} (1 - \phi + \phi \beta_s / \beta_f) (1 - \phi + \phi \rho_s / \rho_f) \theta = 0$$

$$\theta'' + \frac{k_f}{k_{nf}} Pr (1 - \phi + \phi (\rho C_p)_s / (\rho C_p)_f) f \theta' + \frac{k_f Ec Pr}{k_{nf} (1 - \phi)^{2.5}} (f'')^2$$

$$+ \frac{k_f Ha Ec Pr}{k_{nf}} \times (1 - \phi + \phi \sigma_s / \sigma_f) f'^2 = 0$$

Subject to the following boundary conditions:

$$f(0)=0, \quad f'(0)=1, \quad \theta'(0) = Bi[\theta(0) - 1]$$

$$f'(\infty)=0, \quad \theta(\infty) = 0$$

In this study also the physical quantities skin coefficient, C_f and the local Nusselt number, Nu will be of practical importance where;

$$C_f = \frac{\tau_w}{\rho_f v_0^2}, \quad Nu = \frac{Xq_w}{k_f(T_f - T_\infty)} \quad (25)$$

Where τ_w is the skin friction and q_w is the heat flux. They are defined as:

$$\tau_w = \mu_{nf} \frac{\partial U}{\partial y} \quad \text{and} \quad q_w = -k_f \frac{\partial T}{\partial y}, \quad \text{at } y=0 \quad (26)$$

Putting (26) and (27) into equations (23) and (24a) – (24e) then we obtain

$$\left. \begin{aligned} (\text{Re}_x)^{\frac{1}{2}} C_f &= \frac{1}{(1-\phi)^{2.5}} f''(0), \\ (\text{Re}_x)^{-\frac{1}{2}} Nu &= -\frac{k_{nf}}{k_f} \theta'(0) \end{aligned} \right\} \quad (27)$$

4.2 Numerical Procedure

Results are obtained by solving equations (20) and (23) numerically subject to boundary conditions (24a) to (24e) using linear shooting method and Runge- Kutta scheme after transformation into a set of initial value problems.

The computation was done by **MAPLE** computer programme which uses symbolic and computational language. The first order differential equations are obtained by letting

$$f_1 = f, \quad f_2 = f', \quad f_3 = f'', \quad f_4 = \theta, \quad f_5 = \theta', \quad \text{where the primes represent differentiation of } f \text{ and } \theta \text{ with respect to } \eta.$$

The set of higher order non-linear boundary value problem with their respective boundary conditions are reduced to the following first order differential equations with appropriate initial conditions as below;

$$\left. \begin{aligned} f_1' &= f_2 \\ f_2' &= f_3 \\ f_3' &= (1-\phi)^{2.5} \left(1-\phi + \phi \frac{\rho_s}{\rho_f} \right) f_2^2 + Ha(1-\phi)^{2.5} \left(1-\phi + \phi \frac{\sigma_s}{\sigma_f} \right) f_2 \\ &\quad - (1-\phi)^{2.5} \left(1-\phi + \phi \frac{\rho_s}{\rho_f} \right) f_1 f_3 \\ &\quad - Gr(1-\phi)^{2.5} \left(1-\phi + \phi \frac{\beta_s}{\beta_f} \right) \left(1-\phi + \phi \frac{\rho_s}{\rho_f} \right) f_4 \\ f_4' &= f_5 \\ f_5' &= -\frac{k_f}{k_{nf}} \text{Pr} \left[1-\phi + \phi \frac{(\rho C_p)_s}{(\rho C_p)_f} \right] f_1 f_5 - \frac{k_f Ec \text{Pr}}{k_{nf} (1-\phi)^{2.5}} f_3^2 \\ &\quad - \frac{k_f Ha Ec \text{Pr}}{k_{nf}} \left(1-\phi + \phi \frac{\rho_s}{\rho_f} \right) f_2^2 \end{aligned} \right\} \quad (28)$$

Subject to the initial conditions;

$$f_2(0)=1, f_1(0)=0, f_2(\infty)=0, f_4(\infty)=0, f_5(0) = \frac{h_f}{k_f} [f_4(0)-1]$$

5. RESULTS AND DISCUSSIONS

Numerical solutions for the model equations were computed for the various physical parameters involved which includes magnetic field, Hartman number (Ha), Prandtl number (Pr) which was kept constant throughout the simulations, Grashoff number (Gr) and Eckert number (Ec) were performed. The results and numerical values were plotted in the figures below.

Detailed discussion on the effects of the physical parameters on the velocity profile, temperature profile skin friction and Nusselt number are critically done.

5.1 Effect of Parameter Variation on the Velocity Profiles

The figures below indicate the effects of the thermo physical parameters on velocity profiles of Aluminium oxide and copper oxide-water Nano fluid. This is shown by graphs 2 to 5.

From fig 1 CuO-water and CuO-Ethylene Glycol Nano fluids flows closer to the plate than Al₂O₃-water and Al₂O₃-Ethylene glycol Nano fluid hence more effective heat conductor than Al₂O₃ Nano fluids. Fig 3 shows that increasing magnetic field (Ha) causes a corresponding decrease in velocity of the fluid which is in agreement with theoretical facts. This is because of the Lorentz force induced which acts as retarding force reducing the Nano fluid velocity leading to more heat dissipation through the radiator to the surrounding hence increasing the cooling effect.

The same trend is seen in fig 4 where increase in nanoparticle concentration is reducing the Nano fluid velocity and an increase in Grashoff number (Gr) increases the Nano fluid velocity as seen from fig 5.

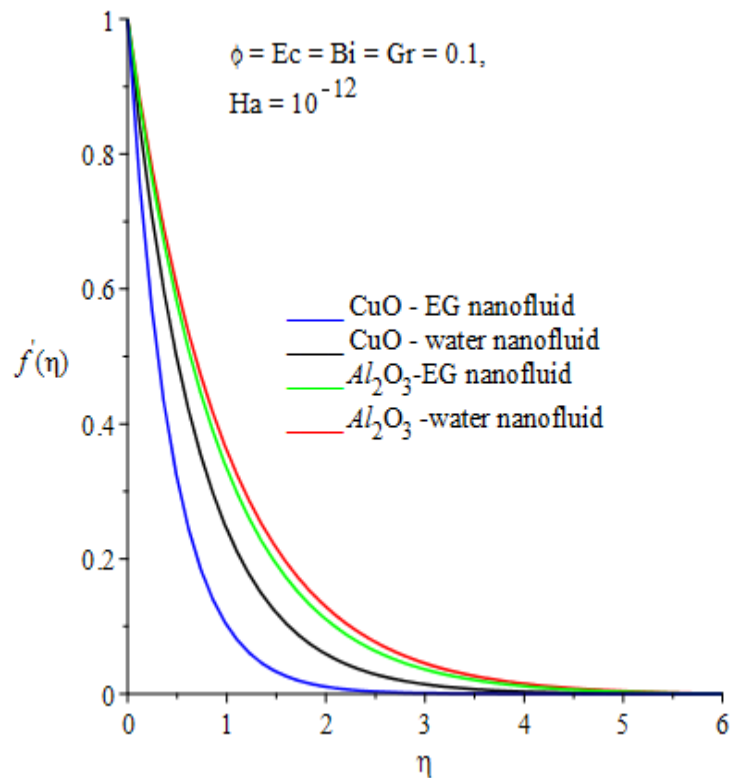


Fig.2. Velocity Profiles for Different Nano fluids

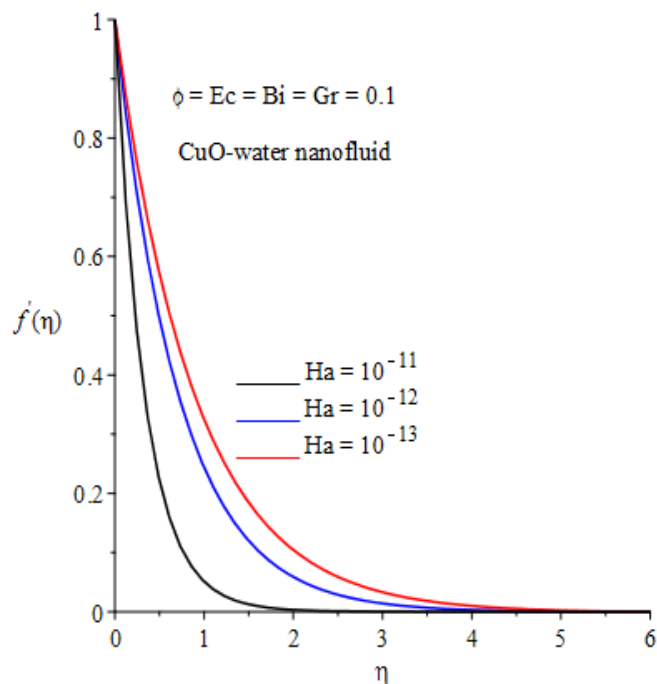


Fig. 3. Velocity Profiles with Varying Magnetic Field Intensity (Ha)

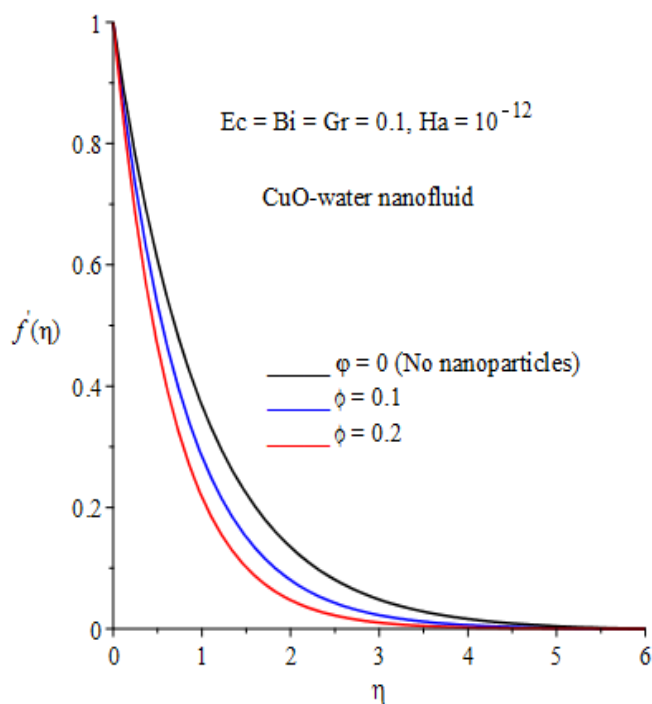


Fig. 4. Velocity Profiles with Increasing Nano particles Volume Fraction (ϕ)

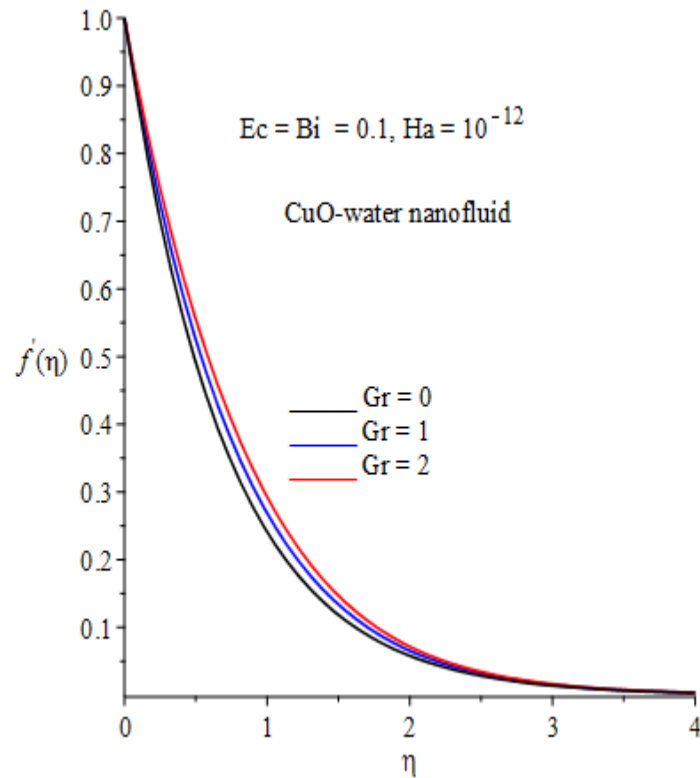


Fig .5. Velocity Profiles with Increasing Grashoff Number (Gr)

5.2 Effect of Parameter Variation on Temperature Profile

Fig 6-10 shows the changes in heat transfer rate with various thermo physical parameters which significantly affect the temperature profile of Nano fluid. The Nano fluid temperature is maximum at the plate due to convective heating and decreases exponentially to zero away from the plate surface which satisfies the boundary conditions.

CuO- Ethylene glycol has the highest temperature compared to the rest due to its closeness to the plate and hence has more ability to draw heat from entire layers and transfer it to the plate surface for dissipation.

From fig 8, increase in magnetic field intensity increases the amount of heat dissipated by the Nano fluid hence more heat is transferred to the plate for conduction. This is due to induced Lorentz force which resists fluid flow hence more heat transfer.

Also increase in nanoparticle concentration consequently increases the thermal conductivity of the Nano fluid. This is attributed to increase in bulk viscosity decreasing the velocity of flow. In fig 9 and 10 increase in Ec number and Bi number increases the thermal transfer capabilities of the Nano fluid which increases heat transfer from the hotter areas of the system for cooling.

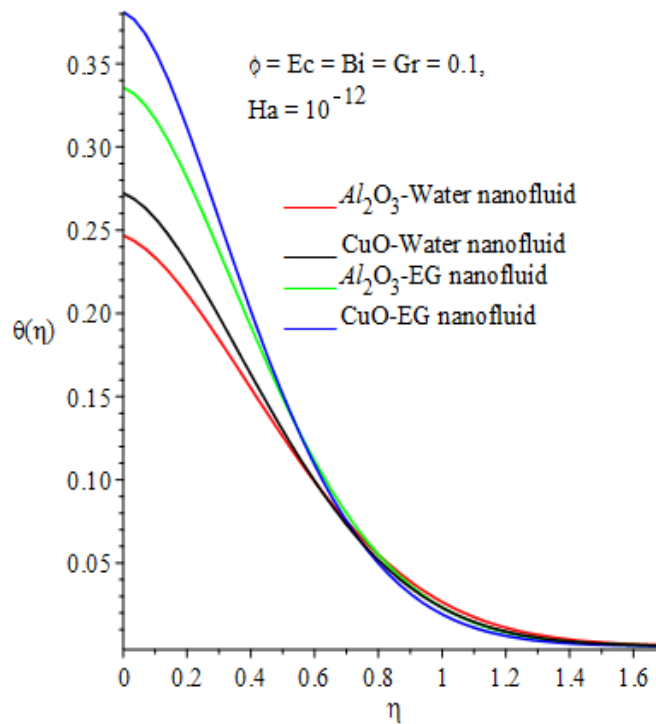


Fig. 6. Temperature Profiles for Different Nano fluids

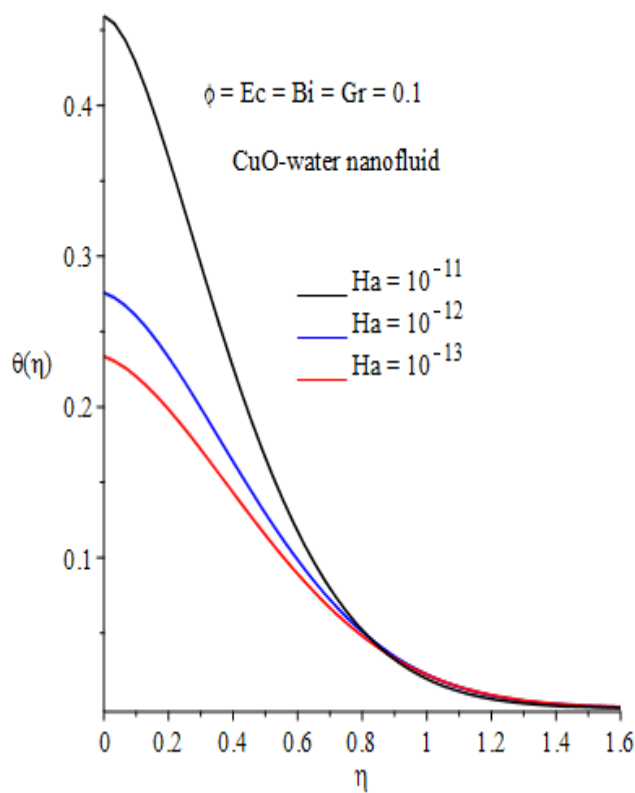


Fig. 7. Temperature Profiles with Increasing Magnetic Field Intensity

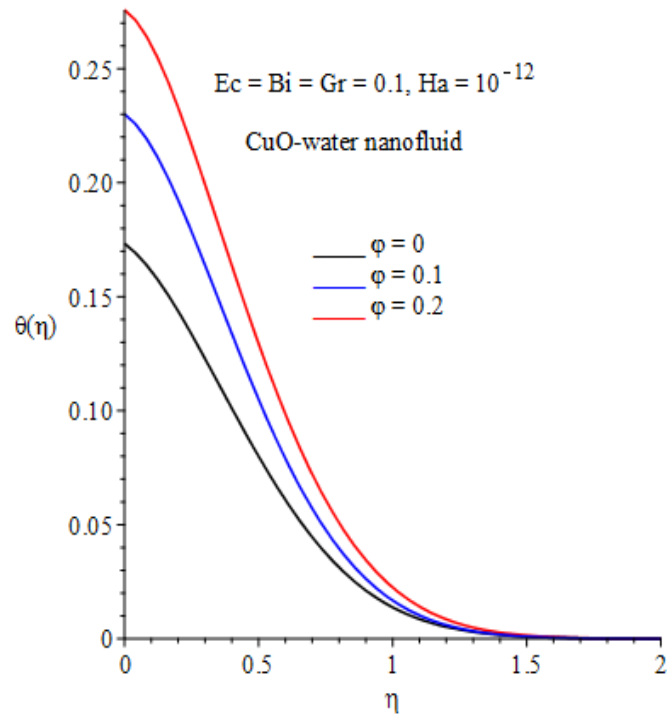


Fig. 8. Temperature Profiles with Increasing Nano Particles Volume Fraction

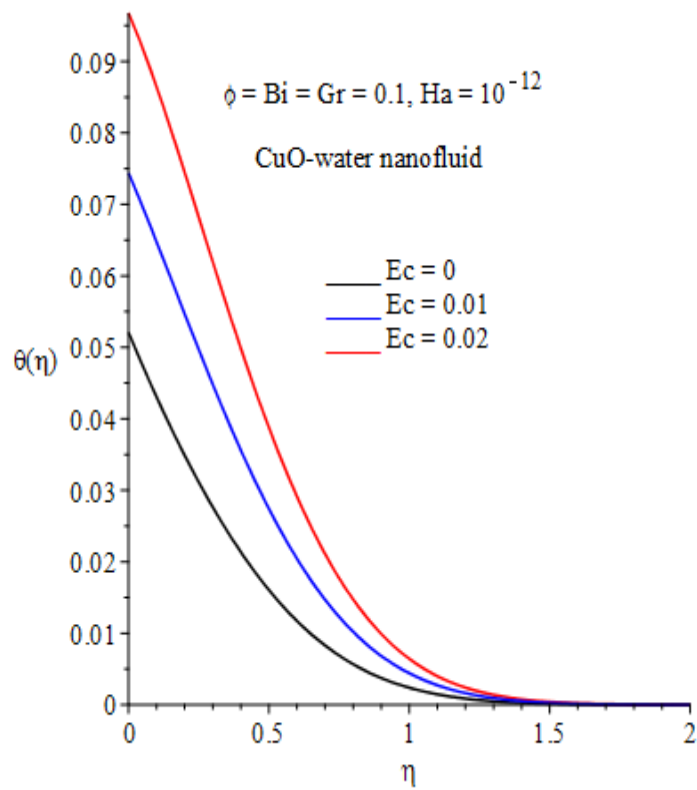


Fig. 9. Temperature Profiles with Increasing Eckert Number (Ec)

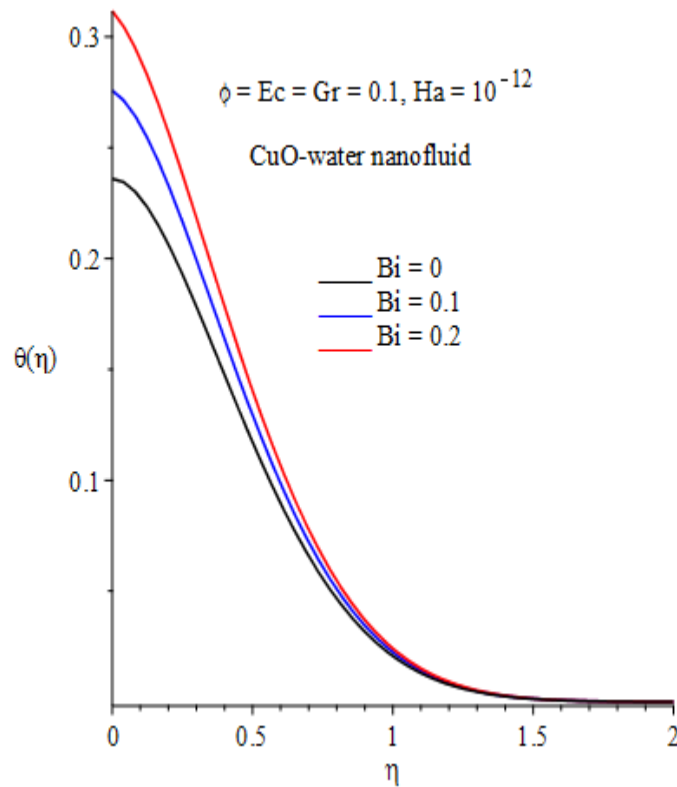


Fig. 10. Temperature Profiles with Increasing Biot Number (Bi)

5.3 Effect of Parameter Variation on Skin Friction

The figures 11 and 12 shows variation of the skin friction with various parameters. Fig 13 shows that the skin friction increases with volume fraction of nanoparticles that is the larger the volume fraction the larger the skin friction.

The skin friction of Al₂O₃- Ethylene glycol is the highest, CuO-Ethylene glycol and Al₂O₃-water Nano fluids shows very small increment and CuO-water Nano fluid has the smallest skin friction.

Fig 12, shows that an increase in magnetic field intensity produces a corresponding increase in skin friction. This is because of induced magnetic force resists the flow of Nano fluid.

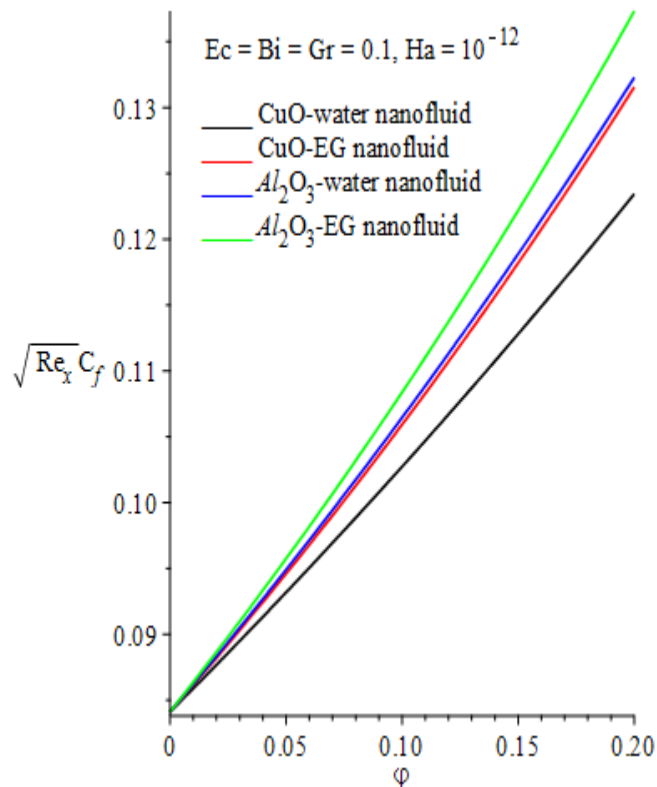


Fig. 11. Skin Friction Profiles for Different Nano fluids

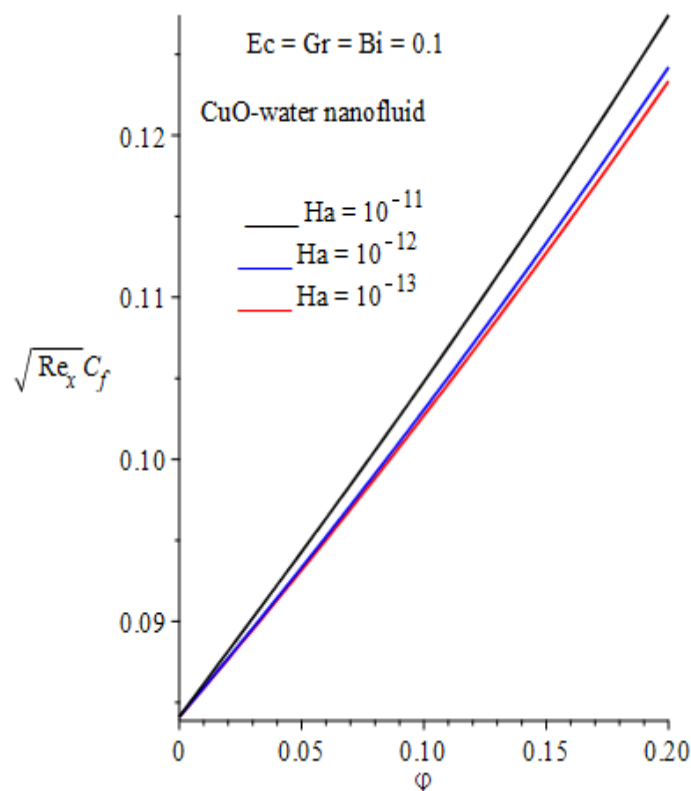


Fig. 12. Skin Friction with Increasing Magnetic Field Intensity

5.4 Effect of Parameter Variation on Nusselt Number

Fig 13 shows that increase in volume fraction of nanoparticles causes a corresponding increase in Nusselt number. Al₂O₃ –Ethylene glycol nano fluid has the highest increase in Nusselt number with volume fraction. Al₂O₃- water and CuO-Ethylene glycol shows infinitesimal increment with increase in volume fraction. CuO- Water Nano fluid has the lowest increase with volume fraction.

CuO-water Nano fluid has the highest heat transfer followed by CuO-Ethylene glycol and Al₂O₃- water Nano fluids which are very close to each other with Al₂O₃-Ethylene glycol Nano fluid coming last.

In fig.14, increase in magnetic field intensity leads to increase in Nusselt number for the CuO-water Nano fluid.

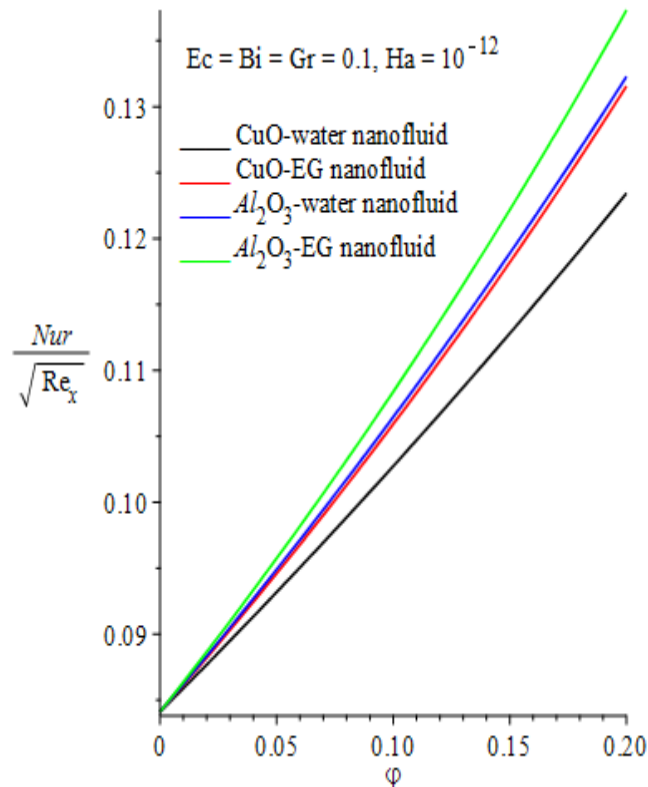


Fig. 13. Nusselt Number for Different Nano fluids

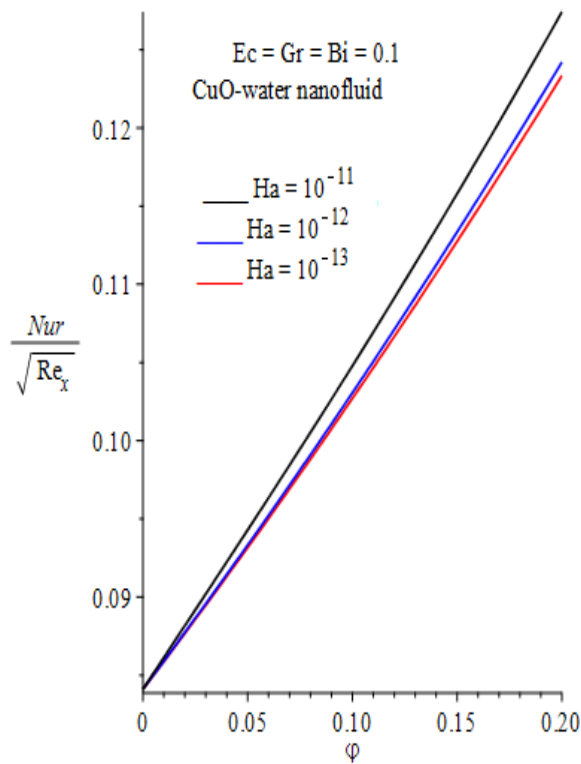


Fig. 14. Nusselt Number for Increasing Magnetic Field (Ha)

6. CONCLUSION

In this study analysis of water and ethylene glycol base fluids is performed. The base fluids are mixed with CuO and Al₂O₃ nanoparticles. They are used as coolant in motor industry for cooling of engines by heat dissipation through the radiator.

Model equations governing the flow of the coolants in the radiator were formulated, transformed and solved numerically using Runge- Kutta and linear shooting method. A computer software MAPLE was used to perform the simulations. More specifically the variation of the thermal conductivities was studied in order to determine best Nano fluid among CuO-water, CuO-Ethylene glycol, Al₂O₃-water and Al₂O₃ – Ethylene glycol.

Particularly from the analysis, CuO based Nano fluids have shown effective and efficient heat transfer properties compared to Al₂O₃ based Nano fluids.

Increase in particle volume fraction, magnetic field intensity and Grashoff number (Gr) increases the thermal conductivity of CuO based Nano fluids more than Al₂O₃ based Nano fluids.

Specifically CuO-Ethylene glycol Nano fluid has the highest temperature and has a higher ability of drawing heat and conducting it through the radiator out of the system. Thermal conductivity of the Nano fluids also increases with increase in Eckert number and Biot number (Bi). Al₂O₃-Ethylene glycol shows the highest skin friction while CuO-water Nano fluid shows the smallest skin friction. Increase in magnetic field intensity produces a corresponding increase in skin friction.

CuO-water Nano fluid shows the highest Nusselt number which also increases with increase in magnetic field intensity.

From the discussion and analysis of the results then both water and Ethylene glycol can be used as base fluid coolants in engines. Their heat transfer capabilities are enhanced by addition if nanoparticles. The trend shows that CuO nanoparticles are slightly better than Al₂O₃ nanoparticles. Also Ethylene glycol base fluid is showing better thermal conductivity than water. Therefore from the analysis then CuO-Ethylene glycol Nano fluid is the recommended Nano fluid coolant for the engine.

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