AN EXPERIMENTAL INVESTIGATION INTO THERMAL CONDUCTIVITY AND VISCOSITY OF Al_2O_3 BASED ENGINE COOLANT (NANOCOOLANT)

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DECLARATION

I hereby declare that thesis entitled, **"An Experimental Investigation into Thermal Conductivity and Viscosity of Al_2O_3 Based Engine Coolant (Nanocoolant)"** is an authentic record of my study carried out as requirements for the award of degree of **M.E. (Thermal Engineering)** at **Thapar University**, under the guidance of **Mr. Kundan Lal**, Assistant Professor, **Department of Mechanical Engineering**, Thapar University, Patiala. The matter embodied in this thesis has not been submitted in part or full to any other university or institute for the award of any degree.

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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge and belief.

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ABSTRACT

Nanocoolant is an engine coolant produced by mixing, of Al_2O_3 nanoparticles of various sizes and shape like; 20 nm (spherical), 40 nm (spherical) and 40 nm (elongated) into conventional coolants. Recent investigations into nanofluids show that they have improved thermophysical properties over the conventional fluids like; water, ethylene glycol etc. In spite of best thermal design, materials, the performance of any engine coolant is restricted due to its inherited poor thermal conductivity. Solution to this problem can be sort out from the newly discovered nanomartials based coolants (nanofluids). It has been also observed that nanofluids have potential to improve the performance of cooling medium as, they shows improved themophyiscal properties over the conventional fluids. This paper represents a brief report on the investigations carried out on thermal conductivity and viscosity of Al_2O_3 based engine coolant, in the temperature range of 25 ºC to 45 ºC. Engine nanocoolant is tested for 0.1, 0.3 and 0.5 volume concentrations of Al_2O_3 nanoparticles. Thermal conductivity is measured by using KD2 pro a thermal property analyzer and Viscosity of nanofluid is measured by using Brookfield Viscometer LV DV-III CP. Experimental investigation revealed that, at lower temperature increase in thermal conductivity is less, whereas at high temperature (35 ºC to 45 ºC) the enhancement is more. It is also found that viscosity decreases with increases in temperature. At a particular temperature results show increases in thermal conductivity with increase in volume concentration % of nanoparticles and viscosity also increases with the increases in volume concentration % of nanoparticles. Nanoparticles of 20 nm size nanoparticles show higher thermal conductivity than 40 nm. At 0.5% volume concentration , the maximum enhancement in thermal conductivity by 20 nm Al_2O_3 (spherical) at 40 ºC is 5.7% and maximum value of viscosity at 25 ºC increases 91.7% for 20 nm and 101% for 40 nm compared to base fluid. The nanocoolants with elongated 40 nm particles show highest thermal conductivity than 20 nm & 40 nm (spherical). At 0.5% volume concentration enhancement is shown by elongated Al_2O_3 nanoparticles compared with base fluid at 45 ºC is 8.4% whereas maximum viscosity enhancement at 25 ºC is 201% compared to base fluid.

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ABBREVATION

Al_2O_3	Alumina Oxide
CuO	Copper Oxide
DNP	Diamond Nanoparticles
EC	Engine coolant
EG	Ethylene Glycol
Fe_3O_4	Ferric Oxide
H_2O	Water
MWCNT	Multi-walled carbon nanotube
SWCNT	Single-walled carbon nanotube
TEM	Transmission Electron Microscopy
TiO_2	Titanium Oxide
XRD	X-Ray Diffraction
ZnO	Zinc Oxide

CHAPTER 1

Introduction

In order to improve the thermal properties of various types of liquids, Maxwell's idea to disperse solid particles into liquid, like metals, carbon nano tubes, oxides and other compounds, into a liquid base has been tested already since 19th century. Initially, these particles have micrometric size and they presented several problems due to the tendency to settle down, high pumping power and the wearing effect on the surfaces. Recently, the new development of nanotechnologies offered the possibility to obtain particles with having nanometric size that have supposed to eliminate these problems when dispersed in the liquid .These new suspensions is called Nanofluids.

Sarit k. Das et al. (2007) Nanofluids which are a mixture of nano-sized (1nm-100 nm) particles (nanoparticles) suspended in a base fluid, are used to enhance the heat transfer rate, via its improved thermophysical properties compared to the base fluid. Since solid materials possess higher thermal conductivities than base fluid. Nanofluids have been projected as a next generation fluid capable of superior heat transfer when compared to conventional heat transfer fluids for a given set of conditions. With very small volume fraction of such nanoparticles the thermal conductivity and convective heat transfer capability of these suspensions are significantly enhanced without the problems encountered in various types of slurries such as high pumping power, clogging, erosion, sedimentation.

Modern nanotechnology can produce various types of metallicor, nonmetallic particles of nanometer sizes. Nanoparticle materials have exclusive chemical properties, mechanical properties, optical, electrical properties, magnetic properties, & thermal properties. Nano fluids (nanoparticle fluid suspensions) is the term invented by **Choi et al. (1995)** to describes this new generation of nanotechnology-based heat transfer fluids that exhibited thermal properties higher to those of their host fluids or conventional particle fluid suspensions. Nano fluid technology, a new inter disciplinary field of great importance where nano sciences, nanotechnology, and thermal engineering encounter, has developed largely over the past decade. The goal of nano fluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably < 1% by volume) by uniform dispersion and stable suspension of nanoparticles (preferably < 10 nm) in host fluids.

To achieve this goal it is vital to understand how nanoparticles enhance energy transport in liquids. Since Choi conceived the innovative concept of nanofluids in the spring of 1993, talented and thoughtful thermal scientists and engineers in the promptly emergent nanofluids community have made scientific development not only in determining unexpected thermal properties of nanofluids, but also in offering new mechanisms behind enhanced thermal properties of nanofluids, developed alternative models of nanofluids, and identifying unusual prospects to develop next-generation coolants such as smart coolants for computers and anodyne coolants for the nuclear reactor’s cooling. As a result, the research matter of nanofluids has been getting increased attention around the worldwide.

In the accumulation of increasing number of articles published per year, there are many indicators that give burden to the argument that nanofluid research is getting more and more active and important. Intensifying interest in nanofluids is based on the comprehension that it is possible to develop ultrahigh-performance coolants whose thermal properties are extremely different from those of conventional heat transfer fluids, because in the nanoscale range, necessary properties of nanomaterials such as nanofluids depend strongly on nanoparticle, material, size, shape, and the surface/interface area.

1.1 Conventional Methods for Heat Transfer

Sarit k. Das et al. (2007) the conventional way to enhance the heat transfer rate in thermal systems is to increase the heat transfer by increasing surface area of cooling devices and the flow velocity or to disperse solid particles in heat transfer fluids. Conversely a new approach to enhancing heat transfer to encounter the cooling challenge is necessary because of the increasing need for more efficient heat transfer fluids in many industries, such as the electronics industries, photonics industries, transportation industries, and energy supply industries. The century old technique used to increase cooling rates is to disperse millimeter or micrometer-sized particles of various metals in heat transfer fluids. The foremost problem with these suspensions of containing millimeter or micrometer, sized particles is quick settle down of these particles. If the fluid is set aside circulating to avoid particle settle down, millimeter- or micrometer, sized particles would wear out pipes, pumps, and bearings.

Additionally, such particles are not relevant to microsystems because they can obstruct in microchannels. These types of solid fluid suspensions are not applied because they require the accumulation of a large number of particles (usually,>10 vol%), resulting in expressively greater pressure drop and pumping power.

The current-day manufacture of microchannel structures with specific dimensions of less than 100 µm and the application of these microchannel structures to heat exchangers

Tuckerman and Peace (1981) characterizes an engineering revolution in heat transfer technology because microscale heat exchangers have the prospective to reduce the size and effectiveness of various heat-exchange devices .

Sarit k. Das et al. (2007) Microscale heat exchangers have abundant aspects, including higher thermal effectiveness, higher heat transfer surface/volume ratio, small size, low weight, low fluid portfolio, and design flexibility. Because their microchannel systems are exceedingly compact and lightweight compared to conventional systems, materials and manufacturing costs could be reduced, an smart advantage that shall draw the interest of many manufacturing firms.. Therefore, with continuous diminishment and increasing heat dissipation in the new age group of products, the cooling issue will strengthen in many industries from electronics and to the transportation, solar energy, energy supply, defense, and medical. Nanofluids are existence technologically advanced in answer to these demanding needs for more efficient heat transfer fluids in many industries.

1.2 Importance of Nanosize

As noted above, the basic concepts of dispersing solids in fluids to enhance thermal conductivity is not new these concepts are used from past long ages; it can be traced back to Maxwell. The addition of solid particles, because they conduct heat far better than do liquids. The main problem with the use of large particles is the speedy settling of these particles in fluids. Other problems are like erosion, abrasion and clogging. These problems are highly objectionable for many practical cooling applications.

Nanofluids have lead the way in overcoming these problems by stably suspending in fluids nanometer size particles as an alternative of millimeter or micrometer size particles, nanoparticles stay suspended much longer and possess a much higher surface area. The surface to volume ratio of nanoparticles is 1000 times larger than that of microparticles. The high surface area of nanoparticles improves the heat conduction of nanofluids since heat transfer occurs on the surface of the particle.

The number of atoms present on the surface of nanoparticles, as conflicting to the inner, is very large. Therefore, these exclusive properties of nanoparticles can be subjugated to develop nanofluids with an unprecedented combination of the two features most highly desired for heat transfer systems: extreme stability and ultrahigh thermal conductivity. Moreover, because nanoparticles are so small, they may decrease erosion and clogging intensely. Other profits proposed for nanofluids include decrease demand for pumping power, reduced inventory of heat transfer fluid, and noteworthy energy savings. Because the key building block of nanofluids is nanoparticles (1000 times smaller than microparticles).

Size is also an important physical variable in nanofluids because it can be used to modify nanofluid thermal properties as well as the suspension stability of nanoparticles. Maxwell’s concept is old, but what is new and innovative with the concept of nanofluids is the idea of using nanometer size particles (which have become available to scientists only recently) to create stable and highly conductive suspensions, primarily for suspension stability (gravity is negligible) and for dynamic thermal interfaces. Nanotechnogy offers excellent predictions for producing a new type of heat transfer fluid that has outstanding thermal properties and cooling capacity, due primarily to unique nanoscale phenomena that upturn our sense of understanding. Therefore, the inventors of nanofluids have taken the solid–fluid suspension concept to an entirely new level.

Comparison of the Micro and Nano size particles

Table 1.1 Contrasts suspensions of microparticles and nanoparticles and shows the benefits of nanofluids containing nanoparticles. [**Sarit k. Das et al. (2007)**]

Properties	**Microparticles**	**Nanoparticles**
Stability	Settle	Stable(remain in suspension nearly indefinitely)
Surface / Volume ratio	1	1000 times larger than that of microparticles
Conductivity (at the same vol. fraction)	Low	High
Clog in microchannel	Yes	No
Erosion	Yes	No
Pumping power	Large	Small
Nanoscale phenomena	No	Yes

1.3 Making of Nanofluids

Materials for base fluids and nanoparticles are varied. Stable and highly conductive nanofluids can be produced by one-step production and two-step production methods. These both methodologies to making nanoparticle suspensions suffer from agglomeration of nanoparticles, which is a important issue in all technology containing nanopowders. Therefore, production and suspension of closely nonagglomerated or monodispersed nanoparticles in liquids is the important to important enhancement in the thermal properties of nanofluids.

1.4 Materials for Nanoparticles and Fluids

Recent manufacture technology provides excessive opportunities to process different material at nanometer scales. Nano-structured or nanophase materials have made of nanometer-size substances engineered on the atomic or molecular scale to produce either new or greater physical properties not showed by conventional solids. All physical mechanisms have a critical length scale below which the physical properties of materials are changed. Therefore solid particles smaller than 100 nm have properties different from those of conventional solids.

Sarit k. Das et al. (2007) the decent properties of nano-phase materials come from the relatively high surface area to volume ratio than micro-particles, Due to the high quantity of integral atoms exist in at the grain borders. The thermal, mechanical, optical, magnetic, and electrical properties of nano-phase materials are superior to those of conventional materials with coarse grain arrangements. Subsequently, research and development investigation of nano-phase materials has drained significant attention from scientists and engineers.

Duncan and Rouvray (1989) carbon nanotubes, silicon carbides (SiC), and composite materials such as alloyed nanoparticles $Al_{70}Cu_{30}$ or nanoparticles core–polymer shell composites. In adding to non-metallic, metallic, and other materials for the nanoparticles, totally new materials and structures, such as various materials "nobbled" with molecules in their solid–liquid interface structure, may also have desired characteristics.

1) Metallic nano particles.
2) Non-metallic nano particles like.
3) Metallic and non-metallic oxides.
4) Carbon nano tubes.
5) Ceramics and composites.

1.5 Host liquid types

Many kinds of liquids , such as water, ethylene glycol, and oil, have been used as host liquids in nanofluids.

1.6 Methods of Nanoparticle Manufacture

Manufacturing process of nanoparticles can be classified into two wide categories:

1.6.1 Physical processes

Kimoto et al. (1963) and Gleiter (1989) presently, a number of methods exist for the manufacturing of nanoparticles. Typical physical methods are inert-gas condensation (IGC), developed by **Granqvist and Buhrman (1976),** and mechanical grinding.

1.6.2 Chemical processes

Chemical methods have included chemical vapor deposition (CVD), chemical precipitation, micro emulsions, thermal spray, and spray pyrolysis. A sono-chemical method has been established to make suspensions of iron nanoparticles stabilized by oleic acid **Suslick et al. (1996)**.

The existing processes for making metal nanoparticles including IGC, Thermal spray Mechanical milling, Chemical precipitation, & Spray pyrolysis. Furthermost, **Chopkar et al. (2006)** produced alloyed nanoparticles $Al_{70}Cu_{30}$ using ball milling. In ball milling, balls instruct a lot of energy to slurry of powder, and in most of cases some chemicals are used to cause physical and chemical changes. These nanosize materials are most commonly produced in the form of powders. In the powder form, nanoparticles are suspended in host liquids for specific applications.

1.7 Dispersion of Nanoparticles in Liquids

Stable suspensions of nanoparticles in conventional heat transfer fluids are produced by two methods: the two-step technique and the single-step technique. The two-step method first makes nanoparticles using one of the above-described nanoparticle processing techniques and then disperses them into base fluids. The single-step method simultaneously makes and disperses nanoparticles directly into base fluids. In either one case, a fine-mixed and evenly dispersed nanofluid is required for successful production or reproduction of enhanced properties and explanation of investigational data. For nanofluids prepared by the two-step method, dispersion procedures such as high shear and ultrasound can be used to create several particle–fluid combinations.

1.7.1 The two-step technique

The two-step method first makes nanoparticles using one of the nanoparticle processing techniques and then disperses them into base fluids. For nanofluids prepared by the two-step method, dispersion techniques like as high shear rate and ultrasound can be used to produce various particle–fluid combinations. Most nanofluids containing oxide nanoparticles and carbon nanotubes reported in the mostly literature are produced by the two-step process Making nanofluids using the two-step processes has continued a challenge because individual particles rapidly agglomerate before dispersion, and nanoparticle agglomerates settle down in the liquids.

In maximum nanofluids prepared by the two-step process, the agglomerations are not completely detached, so nanoparticles are dispersed only moderately. Although nanoparticles are dispersed by ultrasonically in liquid using a bath or tip sonicator with intermittent sonication time to control overheating of nanofluids, two-step preparation process produces significantly low dispersion quality. Because the dispersion quality is low, the conductivity of the nanofluids is low. Therefore, the strategic to success in achieving significant enhancement in the thermal properties of nanofluids is to produce and suspend closely monodispersed or nonagglomerated nanoparticles in liquids.

Akoh et al. (1978) developed a technique for manufacturing nonagglomerating nanoparticles involves condensing nano-phase powders from the vapor phase directly into a flowing low-vapor-pressure fluid is called the VEROS (vacuum evaporation onto a running oil substrate) technique. VEROS has been fundamentally disregarded by the nanocrystalline materials community because of consequent difficulties in separating the particles from the fluids to make dry powders or bulk materials.

Germany Wagener et al. (1997) and **Eastman et al. (1997)** constructed on a modification of the VEROS process developed in developed a direct the difficulties of making stable and well-dispersed nanofluids. The direct evaporation–condensation process yielded a uniform distribution of nanoparticles in a host liquid.

1.7.2 The single-step technique

The single-step method simultaneously makes and disperses nanoparticles directly into base fluids. In whichever case, a fine-mixed and uniformly dispersed nanofluid is needed for successful production or reproduction of enhanced properties and explanation of experimental data. **Zhu et al. (2004)** developed a one-step chemical method for producing stable Cu-in-ethylene glycol nanofluids by reducing copper sulfate pentahydrate ($CuSO_4.5H_2O$) with sodium hypophosphite ($NaH_2PO.H_2O$) in ethylene glycol under microwave irradiation. They claimed that this one-step chemical method is faster and cheaper than the one-step physical method.

Chapter 2

Literature Review

A decade ago, development of thermal engineering stood at the point of increase in heat transfer performance of heat exchangers. Water and ethylene glycol as conventional coolants have been generally used in an automotive car radiator for several years. These heat transfer fluids offer low thermal conductivity. There are numerous researchers reporting different methods for heat transfer enhancement. An innovative way of improving the heat transfer performance of common fluids is to suspend various types of small solid particles, such as metallic, nonmetallic, polymeric particles and etc, in conventional fluids to procedure colloidal. However, suspended particles of the order of μm or even mm may cause some severe problems in the flow channels, increasing pressure drop, causing the particles to quickly settle out of suspension. In recent years.. This term was first introduced by **Choi et al. (1995)** at the Argonne National Laboratory. The ultra-fine nanoparticles are normally smaller than 100 nm and have remarkably higher thermal conductivity than base liquids. With the advancement of nanotechnology, the new generation of heat transfer fluids called, “nanofluids” have been developed and researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants.

Choi et al. (2006) reported a project to target fuel savings for the automotive industries through the development of energy efficient nanofluids and smaller and lighter radiators. A major goal of the nanofluids project is to reduce the size and weight of the vehicle cooling systems by greater than 10% despite the cooling demands of higher power engines. Nanofluids enable the potential to allow higher temperature coolants and higher heat rejection in the automotive engines. It is estimated that a higher temperature radiator could reduce the radiator size approximately 30%. This translates into reduced aerodynamic drag and fluid pumping and fan requirements, foremost to perhaps a 10% fuel savings. It is exciting idea in these years which humans involved in the energy and fuel shortage crisis. According to this idea, scarce experimental and theoretical studies were performed to analyze the application of nanofluids in the car radiator**.**

2.1 Thermal conductivity

The properties of nanofluids depend on the details of their microstructures, such as the component properties, component volume concentrations, particle dimension, particle geometry, particle distribution, particle motion, and matrix–particle interfacial effects. Although the effective thermal conductivity of a mixture can vary in a wide range depending on the microstructures of the mixture, it must lie in between the upper and lower bounds, which correspond to parallel and series particle distributions, respectively, and should reach the bounds under these distributions.

Table 2.1 Thermal conductivity values for some solids and liquids at Room Temperature [**Sarit k. Das et al. (2007)]**

Materials		Thermal Conductivity (W/mK)
Metallic solids	Silver	429
	Copper	401
	Aluminum	237
Non-metallic solids	Diamond	3300
	Carbon nanotubes	3000
	Silicon	148
Metallic liquids	Sodium at 644 K	72.3
Non-metallic liquids	Water	0.613
	Ethylene glycol	0.255
	Engine oil	0.145

2.1.1. Thermal Conductivity of Engine Nanocoolant

Masuda et al. (1993) studied the thermophysical properties of Al_2O_3–water, SiO_2–water and TiO_2–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. (1999) conducted an experiment to measure the thermal conductivity of Al_2O_3 and CuO suspended in water and ethylene glycol. Particle sizes of Al_2O_3 and CuO were 23.6 nm and 38.4 nm, respectively. The transient hot-wire method had used to measure the thermal conductivity of nanofluids at a concentration range of 1–4 vol. %. Their results indicated that nanofluids had higher thermal conductivity than the base fluid, and it increased with the increasing level of concentration. When compared the experimental results with prediction from Hamilton and Crosser model, it was found that the model could predict thermal conductivity of Al_2O_3 nanofluids, but it could not predict for CuO nanofluids.

Wang et al. (1999) studied thermal conductivity of Al_2O_3 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. The engine oil and ethylene glycol base fluids yielded higher enhancement than other types of base fluids. When compared with the theoretical model, a thermal conductivity ratio of the nanofluids was found to be higher.

Eastman et al. (2001) conducted an experiment to measure the thermal conductivity of Cu–ethylene glycol nanofluid with an average copper particle size of 10 nm and concentration level of 0.6 vol. %. A transient hot-wire method was used for measurement. They found that nanofluids had higher thermal conductivity when the concentration level increased. Moreover, acid-added nanofluids had increased thermal conductivity. At 0.3 vol. % concentration level, thermal conductivity of acid-added Cu nanofluid increased dramatically by 40%. Their experimental results were higher than those obtained from the classical model.

The researchers proposed that the shape of particle also had an effect on the increase of thermal conductivity.

Chon and Kihm (2005) studied the increase in thermal conductivity of a nanofluid due to Brownian motion. Al_2O_3–water nanofluid at the concentration of 1 vol. % was used in this experiment. The particle sizes used were 11 nm, 47 nm, and 150 nm in a temperature range of 20–70 ºC. They reported the thermal conductivity of the nanofluid increased more than the base fluid and rise with the increase of temperature. They also establish that smaller particle sizes give higher thermal conductivity. They asserted the increase in thermal conductivity of the nanofluid resulted from Brownian motion or micro-convection mechanism. They argued the increase of temperature caused a greater Brownian motion mechanism.

Li and Peterson (2007) conducted an experiment on the measurement of thermal conductivity of Al_2O_3 nanofluids with particle sizes of 36 nm and 47 nm. The nanofluids were suspended in distilled water at temperatures of 27 ºC – 37 ºC and concentration levels of 0.5–6.0 vol. %. They used a steady-state method for measurement. Their experimental results showed the thermal conductivity of nanofluids increased more than the base fluid and increased with the rise of concentration level and temperature. However, the increase was nonlinear. They also found that particle size was an important parameter for the increase of thermal conductivity. Smaller particles have higher increase than larger particle. In this experiment, the temperature of 32 ºC and concentration levels of 2 vol. % and 4 vol. % were optimal points that had the highest increase of thermal conductivity.

M. Chopkar et al. (2007) studied, Al_2Cu and Ag_2Al nanoparticles dispersing about 0.2–1.5 vol. % these nanoparticles in water and measured the thermal conductivity of nanofluid using modified thermal comparator for thermal conductivity. The results indicate that the present nanofluids records 50–150% improvement in thermal conductivity. The experimental results and analytical study show that the degree of enhancement strongly depends on identity/composition, size, volume fraction and shape (aspect ratio) of the dispersed nanoparticles.

Sundar and Sharma (2008) obtained thermal conductivity enhancement of 6.52% with Al_2O_3 nanofluid, 24.6% with CuO nanofluid at 0.8% volume concentration compared to water.

L. Syam Sunder et al. (2012) studied, enhancement in viscosity for 1.0% volume concentration of 60:40% EG/W nanofluid is 2.94 times, 40:60 % EG/W nanofluid is 1.61 times and 20:80 % EG/W nanofluid is 1.42 times compared to the same base fluids at a temperature of 50 ºC. The enhancement in viscosity for 1.0 % volume concentration of 60:40 % EG/W nanofluid is 2.13 times, 40:60% EG/W nanofluid is 1.92 times and 20:80 % EG/W nanofluid is 1.4 times compared to the same base fluids at a temperature of 0 ºC. The magnetic nanofluids can comfortably use as heat transfer fluids. The unique advantage of these fluids is having magnetic response even if the nanoparticles are fully dispersed in the base fluid.

K.S. Suganthi et al. (2013) performed experiments on preparation of colloidal dispersions of ZnO nanoparticles in propylene glycol to ZnO–propylene glycol nanofluids. Thermal conductivity of nanofluids was measured as a function of nanoparticle concentration (6.2 vol. %), temperature (10–60 ºC) and aggregate size. A strong dependency of thermal conductivity enhancement on temperature with higher enhancements at lower temperatures has been observed. Their results on temperature and aggregation dependence of thermal conductivity enhancement show that the thermal conductivity enhancement in ZnO–propylene glycol nanofluids is attributed to formation of solvation layers (liquid layers) of base fluid on the ZnO nanoparticle surfaces.

S. Harish et al. (2012) in this work, measurements of the effective thermal conductivity of dispersions of single- walled carbon nanotube (SWNT) suspensions in ethylene glycol. The SWNTs had synthesized using the alcohol catalytic chemical vapour deposition method. Resonant Raman spectroscopy had employed to estimate the diameter distribution of the SWNTs based on the frequencies of the radial breathing mode peaks. The nanofluid had prepared by dispersing the nanotubes using a bile salt as the surfactant. Carbon nanotube loading of up to 0.2 vol.% was used. Thermal conductivity measurements had performed by the transient hot wire method. Good arrangement, within an uncertainty of 2%, had found for published thermal conductivities of the host fluids. The enhancement of thermal conductivity was found to increase with respect to carbon nanotube addition. The maximum enhancement in thermal conductivity was found to be 14.8 % at 0.2 vol. % addition of SWNT nanoparticles.

W. Yu et al. (2010) study that stable ethylene glycol based copper nanofluids were prepared through a two-step method, using polyvinyl pyrrolidone as dispersant, which was vital for the long-term stability of nanofluids. The thermal conductivity enhancements seen for the obtained nanofluids. For ethylene glycol based copper nanofluids with 0.5 vol. % at 50 °C, the enhancement ratio was up to 46%. The thermal conductivities depended strongly on the temperature of fluid, and the enhancement ratios increased along with the increasing temperatures. Brownian motions of Cu nanoparticles would play the key role on determining the effects of the temperature on thermal conductivity enhancement of nanofluids. The measured apparent thermal conductivity showed the time-dependent characteristic within 15 min. It indicated that the measurement should be made after 15 min at least to obtain the true thermal conductivities of ethylene glycol based copper nanofluids.

W. Yu et al. (2009) conducted experiments on ethylene glycol (EG) based nanofluids containing ZnO nanoparticles prepared and the thermal transport properties including thermal conductivity and viscosity had measured. The results show that the thermal conductivity of ZnO-EG nanofluids is independent of setting time from 20 min to 360 min. The absolute thermal conductivity increases with temperature for different temperatures ranging from10 to 60 ºC, while the enhanced ratios are nearly constant. The thermal conductivity of ZnO-EG nanofluids depends strongly on particle concentration, and it increases non-linearly with the volume fraction of nanoparticles in base fluid. The enhanced value of 5.0 vol. % ZnO-EG nanofluid is 26.5%, consistent with the estimate values by the combination of the aggregation mechanism with Maxwell and Bruggeman models. The evidences show that there is no magic physics behind nanofluids and the classical theories predict the measurements well. The rheological nature of the nanofluids show that ZnO-EG nanofluids with low volume concentrations reveal Newtonian behaviors, and for higher volume concentrations of the nanofluids, the shear-shinning behavior would be observed, because the effective volume fraction of aggregates is greatly higher than the actual solid volume fraction.

R.S. Khedkar et al. (2012) in this study, the thermal conductivities of CuO–MEG and CuO–water suspensions of nanoparticles (nanofluids) were determined. The results indicate that, as the volume fraction of nanoparticles in the suspension increased, the effective thermal conductivity of the nanofluid also increased. Essentially, adding more nanoparticles to the base fluid resulted in the further enhancement of the thermal properties of the base fluid. Moreover, the thermal conductivity of the nanofluids was further enhanced as the sonication time increased until certain limits. The increased Brownian motion of small particles and agglomeration of that is believed to be the mechanism behind the observation. In addition, the viscosity of the suspending fluid should be an important factor, and the results of this study support that supposition, but do not prove it. The elapsed time dependent thermal conductivity of water based nanofluids shows a decrease in effective thermal conductivity with possible explanation of nanoparticles clustering

L.S. Sundar et al. (2013) in this study, the dispersion behavior of Al_2O_3 and CuO nanoparticles in 50:50% of EG/W mixture and the thermal conductivity were measured experimentally. The thermal conductivity of Al_2O_3 and CuO nanofluids increases with increase particle volume concentration. The thermal conductivity of both the nanofluids increases with increase of temperature compared to base fluid. The thermal conductivity enhancement for Al_2O_3 nanofluid varies from 9.8% to 17.89%, and for CuO nanofluid it varies from 15.6% to 24.56% under the temperature range from 15 ºC to 50 ºC at 0.8% volume concentration compared to the base fluid respectively. The CuO nanofluid exhibits more thermal conductivity compared to Al_2O_3 nanofluid under the same volume concentration and temperature.

W. Yu et al. (2011) in this study, the thermal transport properties of ethylene glycol based nanofluids containing low volume concentration diamond nanoparticles were investigated. In order to obtain homogeneous and stable DNP–EG nanofluids, DNP (diamond nanoparticles) should be purified and surface modified by the mixture acid, which let them possess the rich carboxyl and hydroxyl groups on the surface of diamond nanoparticles, and diamond nanoparticles have good compatibility with polar EG solution in alkaline environment. The DNP–EG nanofluids have good long-term stability when pH is above 8.5, and there is no obvious sedimentation within 6 months, which is vital for the application of nanofluids. Ultrasound and the alkalinity of solution are beneficial for the soft diamond particle aggregation, and the diameters of purified diamond nanoparticles are changed from 30 nm–50 nm to 5 nm–10 nm. The thermal conductivity enhancement values are up to 17.23% for the 1.0 vol. % nanofluid at 30 ºC. Viscosity measurements show that the nanofluids demonstrate Newtonian behavior, and the viscosity meaningfully decreases with the temperature.

Table 2.2 Briefly tabulated presentation of data on the thermal conductivity of nanofluids.

S.no	References	Nanoparticles material	Size (nm)	Base fluid	Concentration	Temperature	Result's and Enhancement in Thermal conductivity.
1	Masuda et al. (1993)	Al_2O_3, SiO_2 and TiO_2		water	4.3 vol. %		32%
2	Lee et al. (1999)	Al_2O_3 CuO	23.6nm 38.4nm		1-4 vol. %		Results shows higher thermal conductivity
3	Wang et al. (1999)	Al_2O_3 , CuO	20 nm	Water, ethylene glycol			EG and EC yielded higher enhancement than other

				(EG) , enigine oil (EC) vaccum pump oil			types of base fluids
4	Eastman et al. (2001)	Cu	10 nm	ethylene glycol	0.1-0.6 vol %		At 0.6 Vol % Higher thermal conductivity
5	Chon and Kihm (2005)	Al_2O_3	11 nm 47 nm 150 nm		1 vol.%	20-70 ºC	Thermal conductivity rose with temperature and smaller have higher thermal conductivity
6	Li and Peterson (2007)	Al_2O_3	36 nm 47 nm	water	0.5 – 6 vol %	27 – 37ºC	32 ºC and 2 and 4 vol. % were optimal points that and smallest size the highest increase of thermal

							conductivity
7	M. Chopkar et al. (2007)	Al_2Cu Ag_2Al	20 nm to 80 nm	water	0.2 – 1.5 vol %		50 – 150%
8	Sundar and Sharma (2008)	Al_2O_3 CuO		water	0.8 vol %		6.52% 24.6%
9	W. Yu et al. (2009)	ZnO	210	Ethyl ene glycol	5.0 vol %	10 – 60 ºC	26.5%
10	W. Yu et al. (2010)	CuO	5-10 nm	Ethyl ene glycol	0.5 vol %	At 50 ºC	46%
11	S. Harish et al. (2012)	SWNT		Ethyl ene glycol	0.2 vol %	25 to 50 ºC	14.8%
12	L.S. Sundar et al.(2013)	Al_2O_3 CuO	29 nm 47 nm	Ethyl ene glycol		15 – 50 ºC	9.8 – 17.8% 15.6 – 24.5 %

2.1.2 Theoretical models on Thermal Conductivity

Maxwell Model is known as following equation,

Maxwell Model

$$\frac{k}{k_0}=\frac{k_p+2k_0-2\emptyset(k_0-k_p)}{k_p+2k_0+\emptyset(k_0+k_p)} \tag{1}$$

where k_p and $\emptyset$ are the thermal conductivity of nanoparticles and the volume fraction of nanoparticles. For solid–liquid mixtures in which the ratio of conductivity of two phases is larger than 100, Hamilton and Crosser (H–C) developed the following model,

Hamilton and Crosser Model

$$\frac{k}{k_0}=\frac{k_p+(n-1)k_0-(n-1)\emptyset(k_0-k_p)}{k_p+(n-1)k_0+\emptyset(k_0-k_p)} \tag{2}$$

For spherical particles, the H–C model is the same as the Maxwell model. The above two models cannot give a good prediction for the thermal conductivity of nanofluids, and these models usually underestimate the enhancement of thermal conductivity H.S Chen et al. (2007) proposed the aggregation mechanism to interpret the facts. They introduced the concepts k_a and $\emptyset_a$ in the Maxwell equation

H.S Chen Model

$$\frac{k}{k_0}=\frac{k_a+2k_0-2\emptyset_a(k_0-k_a)}{k_a+2k_0+\emptyset_a(k_0-k_a)} \tag{3}$$

where k_a and $\emptyset_a$ are the thermal conductivity of aggregates and the effective volume fraction of aggregates given by $\emptyset_a = \emptyset/\emptyset_{ma}$ with $\emptyset_{ma}$ the maximum packing fraction of aggregates.

2.3 Viscosity

Viscosity of nanofluids is very important transport property like thermal conductivity.

i. Newtonian flow behavior

Isaac Newton found that the shear force acting on a liquid is proportional to the resulting flow velocity. Hence, a fluid is said to be Newtonian if the viscosity remains constant with an increase in shear rate. Newtonian flow behavior is observed in low molecular liquids such as water, mineral oils (without polymer additives) and solvents. However, more complex flow behavior is expected for fluids containing suspended particles.

ii. Non-Newtonian flow behavior

Fluids, whose viscosity changes with an increase in shear rate, are referred to as Non-Newtonian. These fluids could be further classified according to their flow behavior. Shear-thinning and shear-thickening flow behavior is discussed in the following sections.

a) Shear-thinning flow behavior

For samples that display shear-thinning behavior, the shear viscosity is reliant on the degree of shear load. Thus, the viscosity decreases with an increase in shear stress. In dispersions, shearing can cause the particles to orient in the flow direction and in the direction of the flow gradient. This can lead to disintegration of agglomerates or change in particle form. The interaction forces between particles may decrease during the process and cause a lowering in the flow resistance. Examples of shear-thinning materials include shampoos, paints and polymer solutions.

b) Shear-thickening flow behavior

Similar to shear thinning fluids, the shear viscosity of samples displaying shear-thickening behavior is also dependent on the degree of shear load. However, the viscosity increases with an increase in shear stress. With highly concentrated suspensions, the probability of particle interaction is much higher and may result in particles becoming wedged together and thus increase the flow resistance.

2.3.1. Viscosity of Engine Nanocoolants

H. Chen et al. (2007) Studied, shear viscosity (μ) as a function of shear rate at two temperatures of 20 and 40 ºC for pure EG and 8.0 wt % nanofluids. The data under other conditions are similar. It can be seen that the viscosity is almost independent of the shear rate, indicating the Newtonian behavior of both EG and EG based nanofluids under the conditions of this work. The shear viscosity is found to depend strongly on temperature. The relative viscosity increase is only a function of concentration but (surprisingly) independent of temperature. This indicates that the viscosity of the base liquid and that of the nanofluids scale with temperature in a similar fashion. We also found that the shear viscosity of water–TiO_2 nanofluids at high shear rates (>100 s^{-1}) also follows similar

P.K. Namburu et al (2007) discussed following points on the viscous behavior of ethylene glycol and water mixture:

1. Copper oxide nanofluids exhibit Newtonian behavior in an ethylene glycol and water mixture for concentrations varying from 0% to 6.12% with temperatures ranging from 35 ºC to 50 ºC.
2. The viscosity of nanofluids increases when the volume concentration of nanoparticles increases. For example, the viscosity of 6.12% copper oxide volume concentration is about four times the value of the base fluid at 35 ºC.
3. With rise in temperature the viscosity of copper oxide nanofluids decreases exponentially.
4. The relative viscosity of copper oxide nanofluids is dependent on volume percentage and decreases substantially with temperature for higher concentrations.

C.T. Nguyen et al. (2007) in this paper, they have investigated experimentally the influence of both the temperature and the particle size on the dynamic viscosities of two particular water-based nanofluids, water–Al_2O_3 and water–CuO nanofluids. For the measurement of nanofluid dynamic viscosities by using a ‘piston-type’ calibrated viscometer based on the Coquette flow inside a cylindrical measurement chamber. Experimental ata were collected for temperatures ranging from 25 ºC to 75 ºC, for water–Al_2O_3 mixtures with two different particle diameters, 36 nm and 47 nm, as well as for water–CuO nanofluid with 29 nm particle size. The results indicate that for particle volume fractions lower than 4%, viscosities for 36 nm and 47 nm particle-size alumina–water nanofluids are approximately equal. For higher particle fractions, viscosities of 47 nm particle-size are visibly higher than those of 36 nm size. Viscosities for water-oxide copper are the highest between the nanofluids tested. The temperature effects had been investigated thoroughly. A complete viscosity data base was presented for the three nanofluids measured, with several experimental correlations proposed for low particle volume fractions. They found that the application of Einstein's formula and those derived from the linear fluid theory seems not to be appropriate for nanofluids. The hysteresis phenomenon on viscosity measurement, which is supposed to be the first observed for nanofluids, had raised thoughtful anxieties regarding the use of nanofluids for heat transfer enhancement purposes.

J.H. Lee et al. (2008) experimentally investigated the effective viscosities and thermal conductivities of the water based nanofluids containing at very low concentrations of Al_2O_3 nanoparticles (Al_2O_3–water nanofluids). For this, they produced Al_2O_3–water nanofluids with several concentrations from 0.01 to 0.3 vol. % by two step method with ultrasonication and without any addition of surfactant to nanofluids. To inspect the suspension and dispersion characteristics of the Al_2O_3–water nanofluids, they studied the zeta potential and TEM micrograph of the Al_2O_3 nanoparticles. Measurements of zeta potential and TEM micrograph of the alumina nanoparticles in the Al_2O_3–water nanofluids show that 5 or more hours of ultrasonic vibration can uniformly disperse the alumina nanoparticles in DI water with little evidence of clustering. Viscosity measurements show that the viscosity of the Al_2O_3–water nanofluids significantly decreases with increasing temperature. They had also detected that the alumina nanofluids have a nonlinear relation between their viscosity and the nanoparticle concentration even at very low (0.01–0.3 vol. %) nanofluid increases with increasing nanoparticle concentration and decreases with increase in temperature.

L. Syam Sundar et al. (2012) in this study viscosity of nanofluid measured at different concentrations and different base fluids like 60:40% EG/W, 40:60% EG/W is and 20:80% EG/W under the temperature range from 0 ºC to 50 ºC. It indicates that, viscosity increases with increase of volume concentrations and decreases with increase of temperatures. For all the base fluids, the enhancement in viscosity is more at a temperature of 50 ºC compared to temperature of 0 ºC. The viscosity enhancement is more for 60:40% EG/W based nanofluid compared to 40:60% and 20:80% EG/W based nanofluid under same percentage of volume concentration. At a temperature of 50 ºC, the viscosity of 1.0% volume concentration of 60:40% EG/W nanofluid is 2.94 times, 40:60% EG/W nanofluid is 1.61 times and 20:80% EG/W nanofluid is 1.42 times more compared to the same base fluids. At a temperature of 0 ºC, the viscosity of 1.0% volume concentration of 60:40% EG/W nanofluid is 2.13 times, 40:60% EG/W nanofluid is 1.92 times and 20:80% EG/W nanofluid is 1.4 times more compared to the same base fluids.

Table 2.4 Briefly tabulated presentation of data on the Viscosity of nanofluids.

S.no	References	Nanoparticles Material	Base fluid	Concentration	Temperature	Results and Conclusions
1	H. Chen et al. (2007)	TiO_2 / EG	EG	8.0 wt %	20 to 40 ºC	The relative viscosity increase is only a function of concentration but surprisingly independent of temperature.

2	P.K. Namburu et al (2007)	CuO	EG	0 to 6.12 %	35 to 50 ºC	1.Nanofluids exhibit Newtonian behavior in an EG/water mixture. 2. At 6.12 % viscosity inc 4 times at 35 ºC 3. viscosity of nanofuid decreases exponentially with increases in temperature.
3	C.T. Nguyen et al. (2007)	Al_2O_3 (36, 47 nm) CuO (29)	Water Water		25 to 75 ºC	1. 47 nm have higher viscosity than 36 nm Al_2O_3 2. CuO has highest viscosity among them.
4	J.-H. Lee et al.	Al_2O_3	water	0.01 to 0.3 vol %		Viscosity of nanofluid decreases

	(2008)					with temperature and shows non liner behavior
5	M. Kole and T.K. Dey (2010)	Al_2O_3 (50 nm)	Car coolant	0.001 and 0.015	10 to 50 ºC	Viscosity increases with concentration and decreases with increases in temperature.
6	L. Syam Sundar et al.(2012)	Fe_3O_4	a. 20:80 EG:water b. 40:60 EG:water c. 60:40 EG:water	1.0 vol %	0 to 50 ºC	At 50 ºC viscosity increment a. 1.42 times b. 1.61 times c. 2.94 times

2.3.2 Theoretical models on Viscosity

There exist few established theoretical models that may be used to predict the effective viscosity of nanofluids and most of such models are derived from **Einstein model (1956).** As nanofluid is a two-phase fluid, one may expect that it would have common features with solid liquid mixtures. However, the question regarding the applicability of these classical models for use in nanofluids still remains doubtful. Some of the widely used models for nanofluids are mentioned below.

Einstein Model (1956) can be used for very low volume concentration Ø < 0.02 %, which is given below:

Einstein Model

$$\mu_{nf} = \mu_{bf}(1 + 2.5Ø) \tag{4}$$

Where μ_{nf} is the viscosity of the nanofluid, μ_{bf} is the viscosity of the base fluid.

H.C Brickman Model (1952) is the extension of Einstein model, which can be used for moderate volume concentrations.

H.C Brickman Model

$$\mu_{nf} = \mu_{bf}\left(\frac{1}{(1-Ø)^{2.5}}\right) \tag{5}$$

G.K Batchelor Model (1957) can be considered with nanoparticle Brownian motion and their interaction.

G.K Batchelor Model

$$\mu_{nf} = \mu_{bf}(1 + 2.5 + 6.5Ø^2). \tag{6}$$

These entire equations based on the assumptions that the viscosity of the nanofluid is only a function of the base fluid viscosity and the particle concentration and that the nanoparticles can be modeled as rigid spherical particles. All these equations are predicted more or less same values under same volume concentration and temperature.

The above models predict the viscosity at low volume concentrations and for higher volume concentrations most of the authors considering the **I.M Krieger & J. Dougherty (1957)** equation.

I.M Krieger & J. Dougherty (1957) Model has a form:

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 - \frac{\varnothing_a}{\varnothing_m}\right)^{-[n]\varnothing m} \qquad (7)$$

Where $\varnothing_m$ is maximum concentration, $\varnothing_a$ is effective volume concentration of aggregates and [ɳ] is the intrinsic viscosity, which for monodisperse systems has a typical value of 2.5.

H.Chen et al. (2007) modified the **I.M Krieger & J. Dougherty (1957)** equation by considering

H.Chen Model

$$\varnothing_a = \varnothing\left(\frac{a_a^{3-D}}{a}\right). \qquad (8)$$

Where, a_a and a are the radii of aggregates and primary nanoparticles, respectively. The term 'D' is defined as fractal index, **R. Prasher et al. (2005)** and **H. Chen et al. (2007)** which for nanoparticles has a typical value of 1.8. A simple expression was proposed by **T. Kitano et al. (1981)** involving ($\varnothing_m$) was also used to predict the viscosity of two phase mixture:

T. Kitano Model

$$\frac{\mu_{nf}}{\mu_{bf}} = \left(1 - \frac{\varnothing}{\varnothing_m}\right)^{-2} \qquad (9)$$

In order to apply the Eqs. (7) and (9) $\varnothing_m$ should be calculated. In the present analysis the maximum volume concentration was considered is 1.0%. This volume concentration is restricting the validity range of the models, *($\varnothing_m$)* was calculated based **on D.M Liu (2000),** on all the experimental data, being 5.25% for Fe_3O_4 nanofluids.

P.K Namburu et al. (2007) proposed viscosity correlations for 60:40% EG/W mixture based CuO nanofluid was for (60 : 40% EG=W based CuO nanofluid) for (0 < Ø < 6:12%)

P.K Namburu Model

$$\text{Log}\ (\mu_{nf}) = Ae^{-BT} \qquad (10)$$

Where,

$$A = 165.56 - 29.643\ (Ø) + 1{:}8375\ (Ø)^{-2} \qquad (11)$$

$$B = 0.0186 - 0{:}001(Ø) + 4*10^{-6}(Ø) \qquad (12)$$

CHAPTER 3

RESEARCH GAPS AND OBJECTIVES

3.1 Research Gap

In the literature, the research about the effects of various parameters on thermal conductivity and viscosity shows lack in consistency and reposted results show wide discrepancies. Hence further research is required to investigate the effects of these parameters. For the practical application of engine nanocoolant in auto-mobile industries, these discrepancies should be eliminated by investigating the effects of some parameters on thermal conductivity and viscosity of engine nanocoolants.

In the literature mainly work is done on the thermal conductivity of engine coolants. The mixture of ethylene glycol (EG) and water at various concentrations like 20:80, 30:70, 40:60 and 50:50 respectively. There is a gap of combined studied about thermo physical properties like thermal conductivity and viscosity, and also a very limited literature is available on the effect of shape factor on engine nanocoolants. For experimental investigation we have chosen 30:70 ratio of engine coolant and water respectively. The material of nanoparticles is chosen as Al_2O_3 because its cost is less as compare to other oxides which will be helpful for implementation in engine nanocoolant.

1. Different coolants like water + EG have been tested various research but so far actual commercial available coolant + water not has been tested so far.
2. Combined effect of various parameters on thermal conductivity and viscosity has not been studied thoroughly.

3.2 Research Objectives

i. To investigate the effect of temperature (25 to 45 ºC) on thermal conductivity and viscosity of Al_2O_3/ engine nanocoolant.

ii. To investigate the effect of volume concentration % of Al_2O_3 nanoparticles on thermal conductivity and viscosity of Al_2O_3/ engine nanocoolant.

iii. To investigate the effect of size (20 & 40 nm) of Al_2O_3 nanoparticles on thermal conductivity and viscosity of Al_2O_3/ engine nanocoolant.

iv. To investigate the effect of shape spherical and elongated of (40 nm) Al_2O_3 nanoparticles on thermal conductivity and viscosity of Al_2O_3/ engine nanocoolant.

CHAPTER 4

METHODOLGY

4.1 Introduction

The main aim of this thesis is to prepare nanofluids with Al_2O_3 nanoparticles in engine coolant as a base fluid for improving the heat transfer characteristics of the engine coolant. In this work the thermal conductivity and viscous behavior of engine coolant is studied by using Al_2O_3 nanoparticles. These analyses are performed by measuring thermal conductivity and viscosity at different temperatures for the different volume concentrations and different size and shape of nanoparticles of nanofluids.

4.2 Materials used for preparing Nanofluids

1 Nanoparticle:

- Al_2O_3 (Average size- 20 nm (spherical)
- Al_2O_3 (Average size- 40 nm (spherical)
- Al_2O_3 (Average size- 40 nm (elongated)

4.3 Details of nanoparticles

Alumina, Al_2O_3 -20 nm (spherical) nanoparticles were purchased from Nanoshel - Intelligent materials pvt. Ltd. U.S.A.

Alumina, Al_2O_3 40 nm (spherical) and Al_2O_3 40nm (elongated) nanoparticles were purchased from Reinste Nano Ventures lab.

Nanofluids are prepared by two step process. The nanoparticles are dispersed into the base fluid engine coolant having different concentration.

1. 30:70 engine coolant (concentrate) and water respectively.

4.3.1 Volume Concentration Used

1. 0.1%
2. 0.3%,
3. 0.5%

By mixing of nanoparticles in 50 ml of engine coolant. To make the nanoparticles more stable and remain more dispersed in water, ultra sonicator is used. Sonication was done for 3 hours before testing thermal conductivity & viscosity of the nanofluids. By this nanoparticles become more evenly dispersed in engine coolant.

4.4 Techniques

Various instruments that are used to describe the physical structure, transport properties etc, have been discussed in detail.

4.4.1 X-Ray Diffraction (XRD)

4.4.2 Transmission Electron Microscopy (TEM)

4.4.3 Ultrasonication

4.4.4 Magnetic stirrer

4.4.5 KD 2 Pro, Thermal Property Analyzer

4.4.6 Viscosity measurement

4.4.1 X-Ray Diffraction (XRD)

English physicists Sir W.H. Bragg and his son Sir W.L. Bragg developed a relationship in 1913 to explain why the cleavage faces of crystals appear to reflect X-ray beams at certain angles of incidence (theta, Ө). The variable ***d*** is the distance between atomic layers in a crystal, and the variable lambda l is the wavelength of the incident X-ray beam; ***n*** is an integer. This is an example of X-ray wave interference (Roentgenstrahlinterferenzen), generally known as X-ray diffraction (XRD), and was direct indication for the periodic atomic structure of crystals assumed for numerous centuries.

Bragg's Law

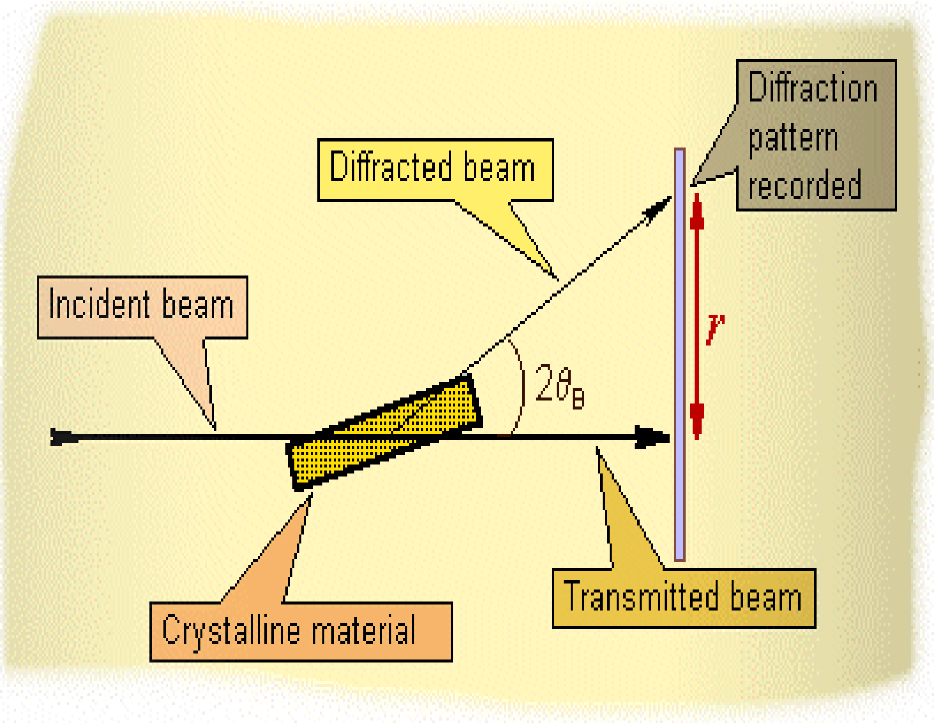
$$n\lambda = 2d\sin\Theta \tag{13}$$

X-ray diffraction is important tool used to understand the properties of synthesized materials. Metals have simple crystal structures and accordingly fewer peaks in the diffraction pattern. The normal diffraction line is of finite width, due to numerous factors. These include the finite line width of the excitation source and the imperfections in the focusing geometry.

In X-ray diffraction work, typically distinguish between single crystal and polycrystalline or powder applications. The single crystal sample is a perfect (all unit cells aligned in a perfect extended pattern) crystal with a cross section of about 0.3 mm. The single crystal diffractometer and associated computer package is used mainly to elucidate the molecular structure of advanced compounds, either natural products or man-made molecules.

Powder diffraction is frequently used for "finger print identification" of numerous solid materials, e.g. asbestos, quartz. In powder or polycrystalline diffraction it is significant to have a sample with a smooth plane surface. If possible, normally grind the sample down to particles of about 0.002 mm to 0.005 mm cross section. The perfect sample is homogeneous and the crystallites are casually distributed (we will later point out problems which will happen if the specimen deviates from this ideal state). The sample is hard-pressed into a sample holder so that we have a smooth flat surface.

If at all possible now have arbitrary distribution of all possible h, k, l planes. Only crystallites having reflecting planes (h, k, l) parallel to the specimen surface will contribute to the reflected intensities. If we have a really arbitrary sample, each possible reflection from a specified set of h, k, l planes will have an equal number of crystallites donating to it. Only they have to rock the sample through the glancing angle THETA in order to produce all possible reflections. [www.scintag.com]



[www.micro.magnet.fsu.edu]

Fig 4.1 Illustration depicting X-ray diffraction (XRD).

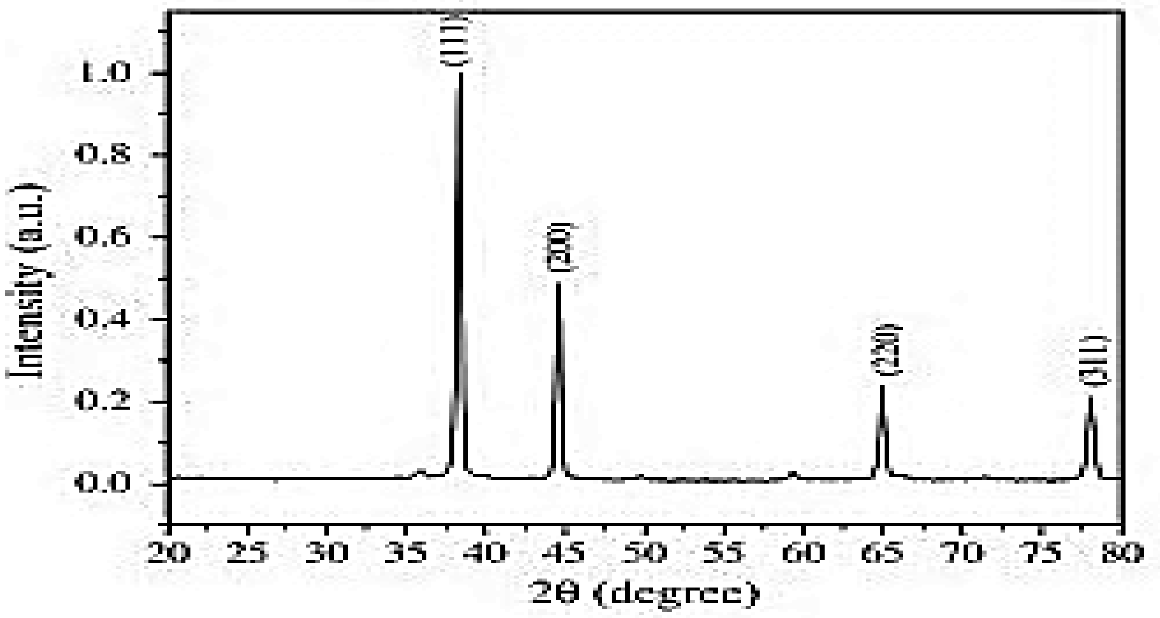


Fig 4.2 XRD Graphical representation of 20 nm Al_2O_3 nanoparticles.

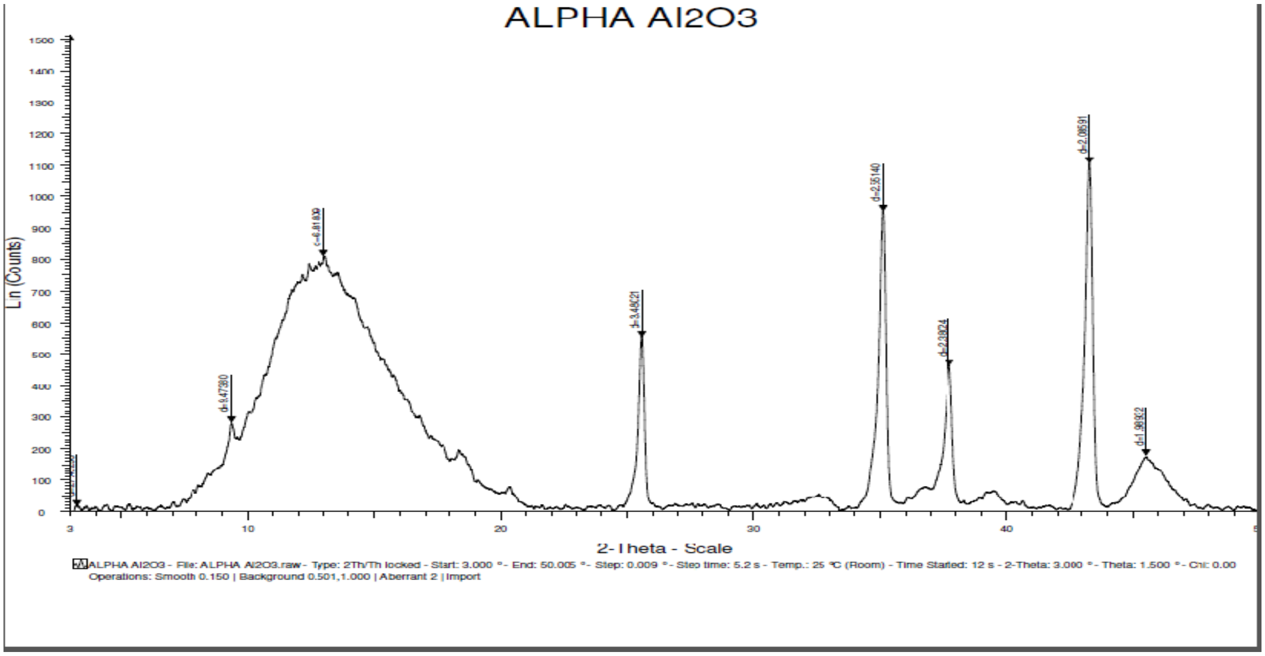


Fig. 4.3 XRD Graphical representation of 40 nm (elongated) Al_2O_3 nanoparticles. **[NIPER]**

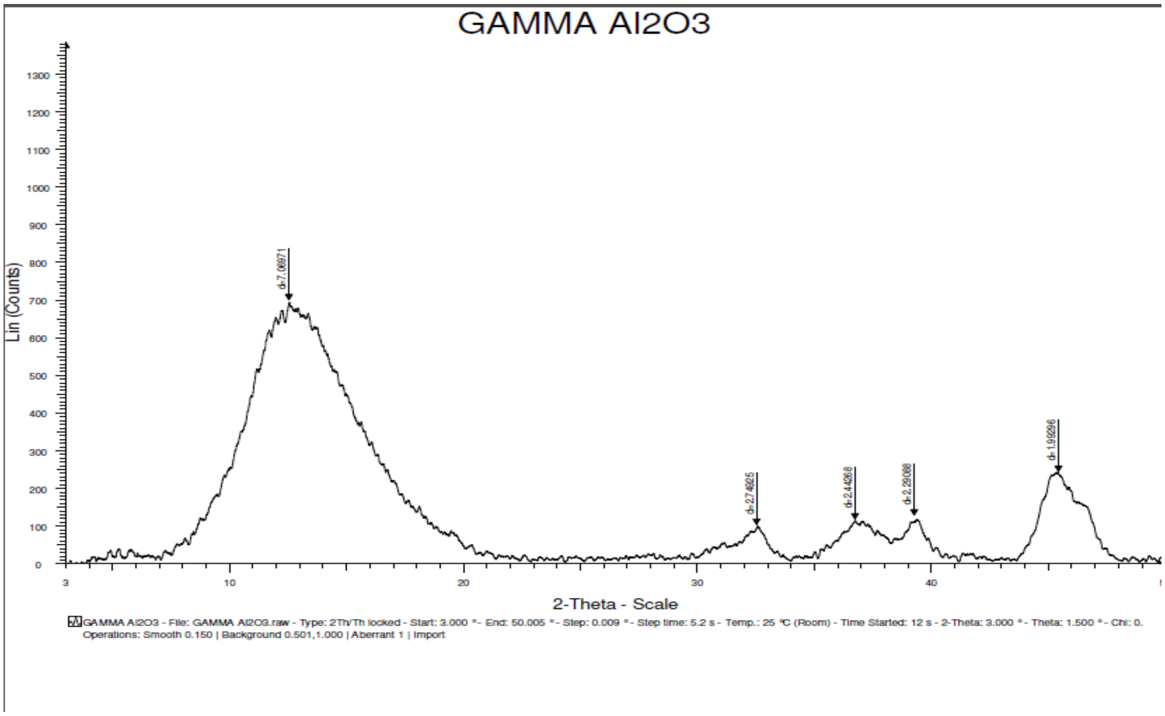


Fig. 4.4 XRD Graphical representation of 40 nm (spherical) Al_2O_3 nanoparticles. **[NIPER]**

4.4.2 Transmission Electron Microscopy (TEM)

The formation of nanoparticles is best studied by transmission electron microscopy (TEM), which gives two types of information in routine examination. The first is the particle size distribution, which is normally represented in terms of a mean diameter and a standard deviation. Both are not calculated rigorously in most studies; instead, a histogram of size distribution is presented along with the TE micrograph. The second type of information is the of a sample, obtained through electron diffraction or nanodiffraction. More detailed information on particle shape, phase transitions, two- and three-dimensional ordering, in-situ nanomeasurements, and evaluation of other properties are possible using TEM.8

Electron column of the TEM

The electron column contains of an electron gun and set of 5 or even more electromagnetic lenses operating in vacuum. It is convenient to divided TEM into three main components: the illumination system, the objective lens, and the imaging system. Figure 4.5 the illumination system involves the gun and the condenser lenses and its part is to take the electrons from the source and transfer them to the specimen. The electron beam is accelerated to an energy in the range 20 - 1000 keV in the electron gun then the electron beam permits though set of condenser lenses in order to produce a beam of electrons with a desired diameter. The illumination system could be operated in two main principal modes: parallel beam and convergent beam.

The first mode is used first and foremost for TEM imaging and selected area diffraction (SAD), while the second is used mainly for scanning (STEM) imaging, analysis via X-ray and electron spectrometry, and convergent beam electron diffraction (CBED). The objective lens and the specimen holder/stage system is the heart of the TEM. Here is where all of the beam-specimen interactions take place and the two fundamental TEM operations occur, namely, the creation of the various images and diffraction patterns (DP) that are subsequently magnified for viewing and recording.

The imaging system uses several lenses to magnify the image or the DP produced by the objective lens and to focus these on the viewing screen or computer display via a detector, CCD, or TV camera. Images are recorded on a conventional film positioned either below or above the fluorescent screen or digital capture can be utilized using CCD or TV cameras.

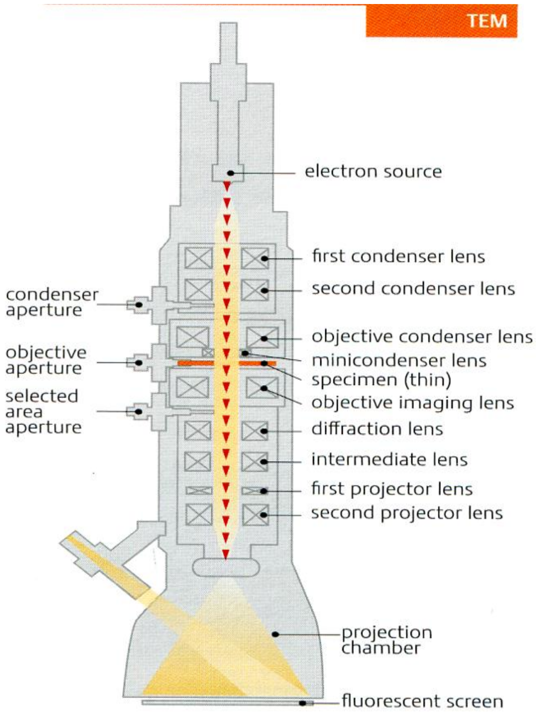


Fig 4.5 Electron column of the TEM

Fig 4.6 TEM Instrument photograph

[NIPER]

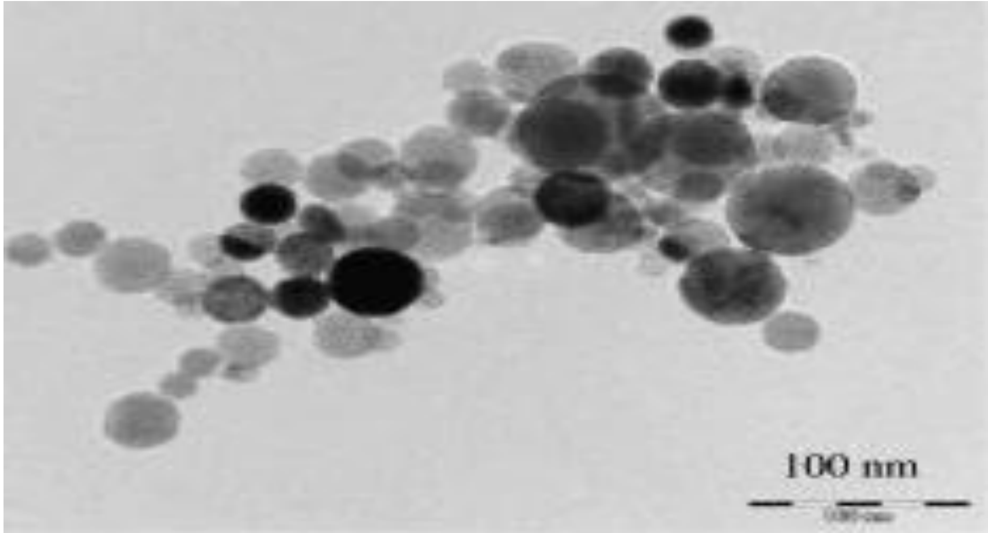


Fig 4.7 TEM image of 20 nm (spherical) Al_2O_3 nanoparticles.

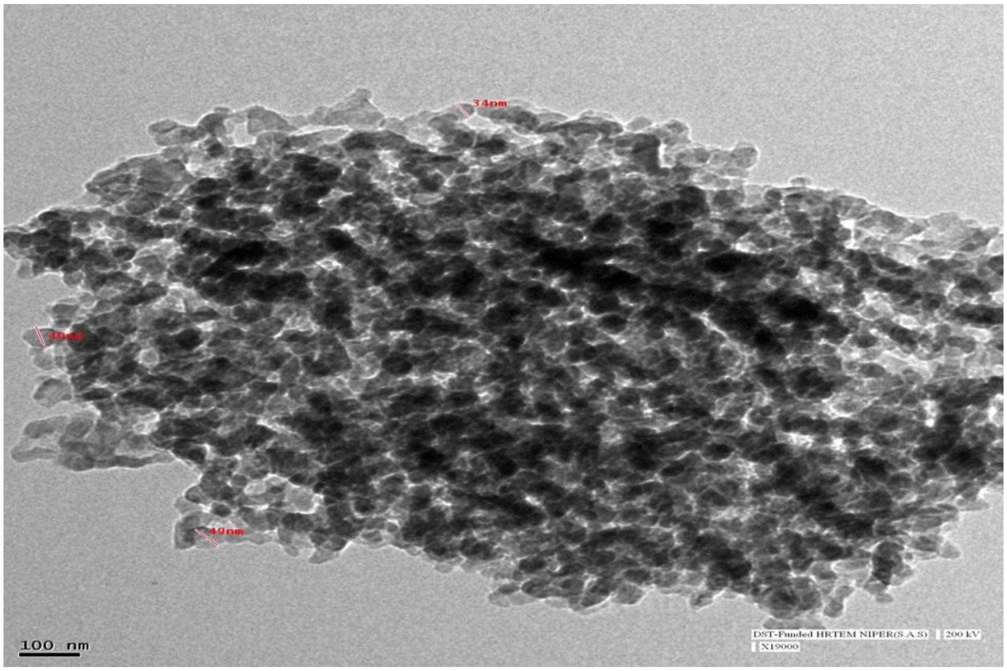


Fig 4.8 TEM image of 40 nm (spherical) Al_2O_3 nanoparticle

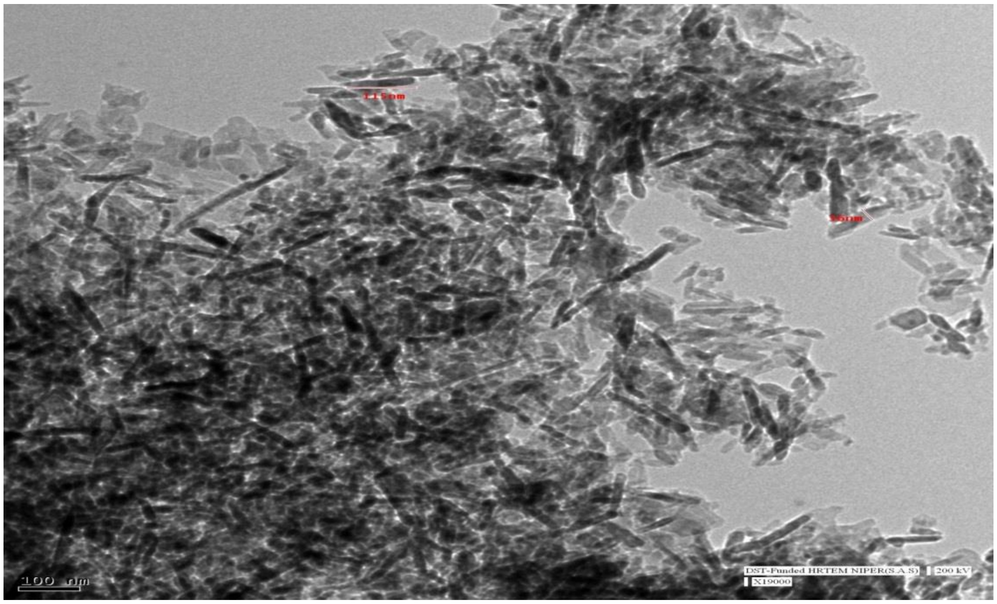


Fig 4.9 TEM image of 40 nm (elongated) Al_2O_3 nanoparticles.

4.4.3 Ultrasonication

Lee S et al. (1999) it is a technique for the preparation of nanofluids. Ultrasonic wave permits through a liquid medium, an enormous number of microbubbles form, grow, and collapse in the very short time of a few microseconds, called ultrasonic cavitation. The ultrasonic cavitation generate instantaneous high temperature and high pressure. The bubble collapse will lead to the formation of free radical, mechanical shocks, high shear gradients.

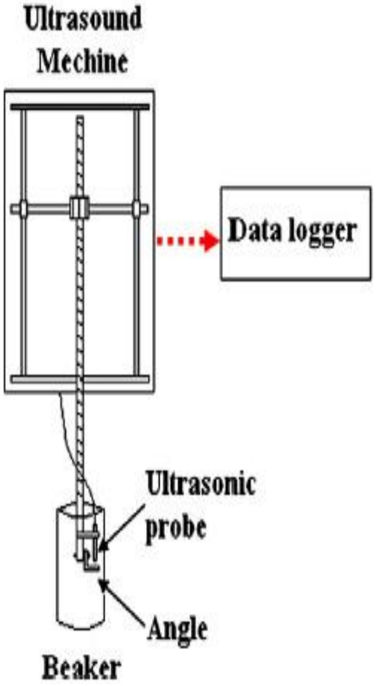


Fig 4.10 Schematic diagram of Experimental setup of Ultrasound testing Probe type Sonicator. **[S. Chakraborty (2011)]**

Fig 4.11 Snapshot of Probe type Sonicator

4.4.4 Magnetic stirrer

A magnetic stirrer is a laboratory device that employs a rotating magnetic field to cause a stir bar (magnet) immersed in a liquid to spin very fast and magnetic stirrer also provide heat to the solution . The rotating field may be created either by a rotating magnet . Placed the vessel with liquid on it. Since glass does not affect a magnetic field and most chemical reactions take place in glass vessels, magnetic stir bars work well in glass vessels. On the other hand, the limited size of the bar means that magnetic stirrers can only be used for relatively small experiments. The another advantage of magnetic stirrer to mechanical stirrer is there is no cavitation occur.

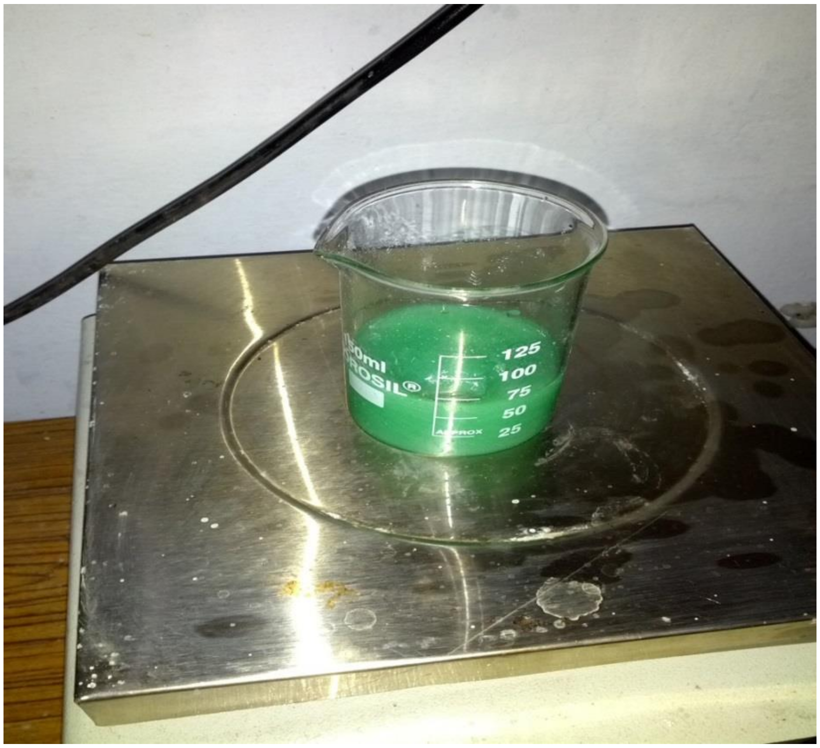


Fig 4.12 Snapshot of Magnetic stirrer

4.4.5 KD2 Pro, Thermal Property Analyzer

Thermal properties analyzer (Decagon Devices, Inc. USA). It consists of a handheld microcontroller and sensor needles. The KD2's sensor needle contains both a heating element and a thermistor. The controller module has a battery, a 16-bit microcontroller/AD converter, and power control circuitry. The thermal conductivity measurement assumes several things like:

(i) The long heat source can be treated as an infinitely long heat source

(ii) The medium is both homogeneous and isotro- pic, and at uniform initial temperature, T_0.

Although these assumptions are not true in the sense, they are suitable for accurate thermal properties measurements. The sensor needle used was KS- 1 which is made of stainless steel having a length of 60 mm and a diameter of 1.3 mm, and narrowly approximates the infinite line heat source which gives least disturbance to the sample during measurements. The sensor needle can be used for measuring thermal conductivity of fluids in the range of 0.2–2 W/mK with an accuracy of ±5%. Each measurement cycle consists of 90 s. During the first 30 s, the instrument will equilibrate which is then trailed by heating and cooling of sensor needle for 30 s each. At completion of the reading, the controller computes the thermal conductivity using the change in temperature (∇T) from the data.

$$K = \frac{q(ln\, t_2 - ln\, t_1)}{4(\nabla T_2 - \nabla T_1)}$$

For accurate measurements, the needle was inserted fully into the fluid, and oriented vertically and centrally inside the vial without touching the side walls of the vial. Insertion of the sensor needle probe into the fluid in this orientation will minimize errors from free convection. In addition, the vial of nanofluid was turned upside down on the top of the needle so that any bubbles in the fluid would float to the top away from the needle as shown in Fig 4.13.

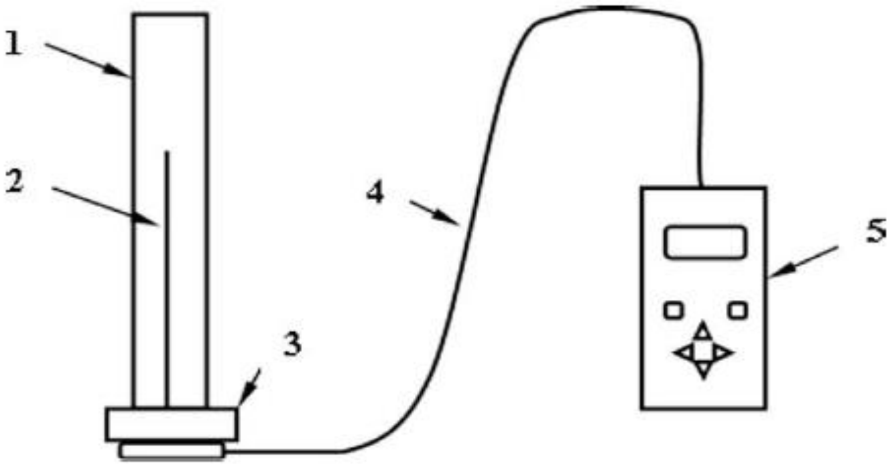


Fig 4.13 KD2 Pro thermal properties analyzer. 1 – Vial, 2 – sensor, 3 – septum, 4 – cable, 5 – microcontroller. [**S. Chakraborty (2011)**]

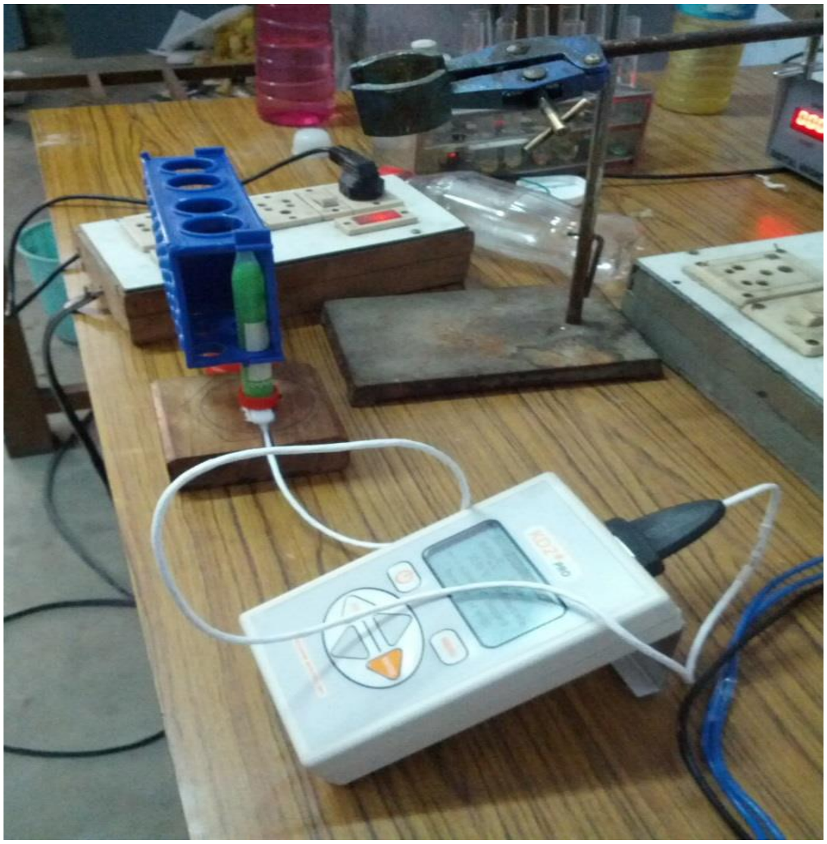


Fig 4.14 Snapshot KD 2 Pro instrument

4.4.6 Viscosity measurement

The viscosity of the nanofluid was measured using Brookfield cone and plate viscometer (DV-III Ultra) supplied by Brookfield engineering laboratories of USA. The cone is connected to the spindle drive while the plate is mounted in the sample cup. The Brookfield DV-III Ultra Programmable Rheometer measures fluid parameters of Shear Stress & Viscosity at particular Shear Rates. Viscosity is a measured by fluid's resistance to flow. The principle of working of the DV-III Ultra is to rotate the spindle (which is submerged in the test fluid) by a calibrated spring. The viscous drag of fluid against the spindle is measured by the spring deflection. Spring deflection is measured by a rotary transducer.

Fig 4.15 Brookfield cone and plate viscometer

CHAPTER 5

RESULTS AND DISCUSSION

The engine coolants in common use are ethylene glycol and propylene glycol. These materials, commonly referred to as antifreeze, are mixed with water prior to adding the mixture to the vehicles coolant system. Since antifreeze, especially ethylene glycol, is corrosive to metals, manufacturers add chemical corrosion inhibitors to the antifreeze in order to help protect the metals in the engine coolant system. The manufacturers also provide tables, to purchasers of antifreeze, which inform the users about the recommended temperature range of the coolant, according to what percentage water is added to the antifreeze. The manufacturers recommend 50% water to 50% antifreeze for normal use and for more extreme cold temperatures, to use up to 30% water to 70% antifreeze. They warn, however, against using more than a 70% ratio of antifreeze because it will lead to a breakdown of the chemical corrosion inhibitors, to reduced heat transfer performance from the coolant, and to decreased freeze protection. [Wikipedia]

Table 5.1 Ethylene glycol boing and freezing point vs. concentration in water. [Wikipedia]

Weight Percent EG (%)	Boling Point (ºC)	Freezing point (ºC)
0	100	0
10	102	-4
20	102	-7
30	104	-15
40	104	-23
50	107	-34
60	110	-48
70	116	-51
80	124	-45
90	140	-29
100	197	-12

Thermal Conductivity & Viscous behavior of Engine nanocoolant

Experiments are performed to measure the Thermal conductivity & viscosity of Al_2O_3-Engine Coolant at based nanofluid. In the ratio of 30:70, Engine coolant (EC):Water, respectively A detailed report on the observed results are presented and discussed in this chapter.

5.1 Thermal Conductivity behavior of Engine Nanocoolant

5.1.1 Effect of temperature on thermal conductivity of Engine nanocoolant

5.1.1.1 Engine nanocoolant with 20 nm (spherical) Al_2O_3 nanoparticles:

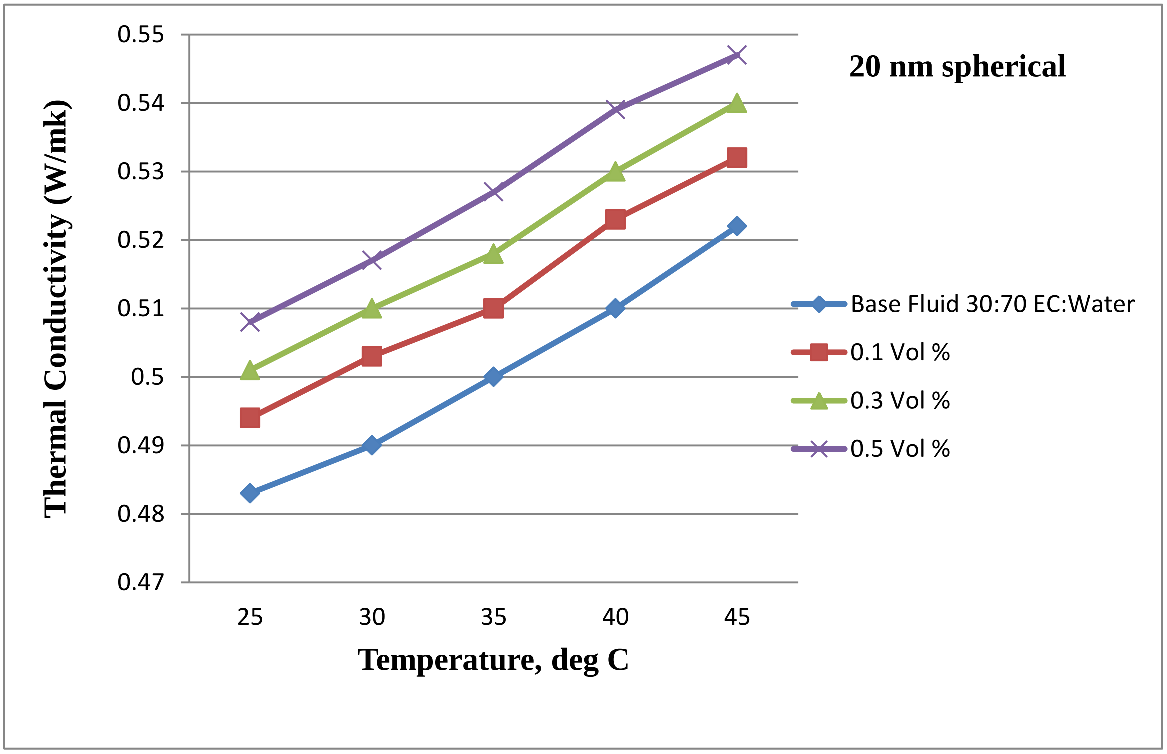


Fig. 5.1 Thermal conductivity v/s Temperature at 0.1, 0.3 and 0.5% volume conc. for 20 nm nanoparticles

5.1.1.2 Engine nanocoolant with 40 nm (spherical) Al_2O_3 nanoparticles:

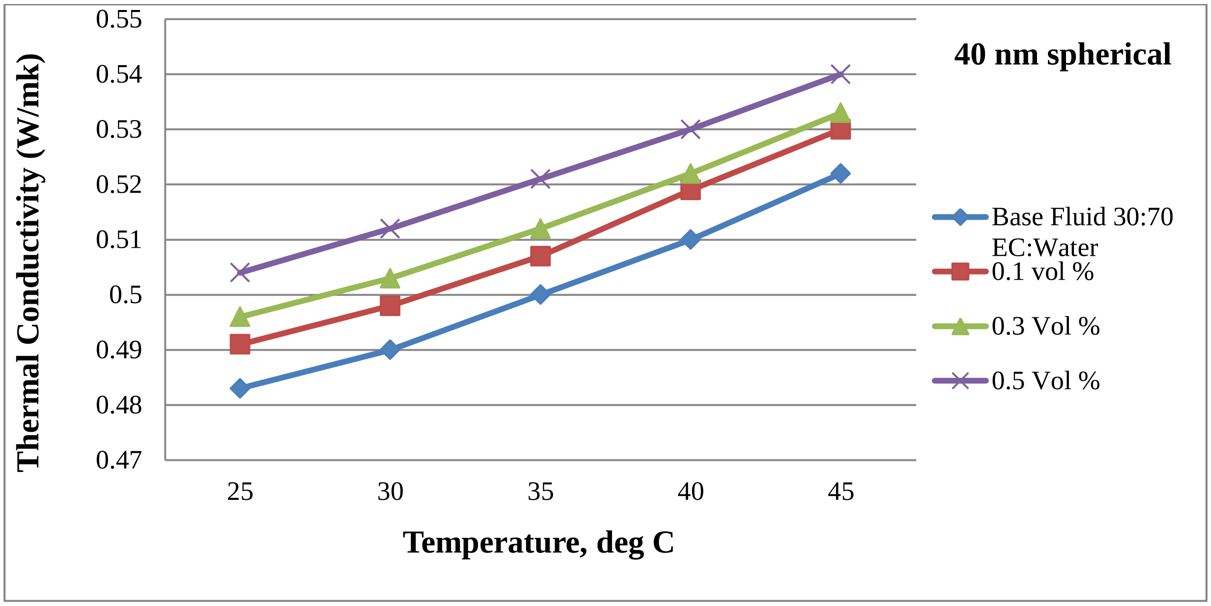


Figure 5.2 Thermal conductivity v/s Temperature at 0.1, 0.3 and 0.5% volume conc. for 40nm nanoparticles

5.1.1.3 Engine Nanocoolant with 40 nm (elongated) Al_2O_3 nanoparticles:

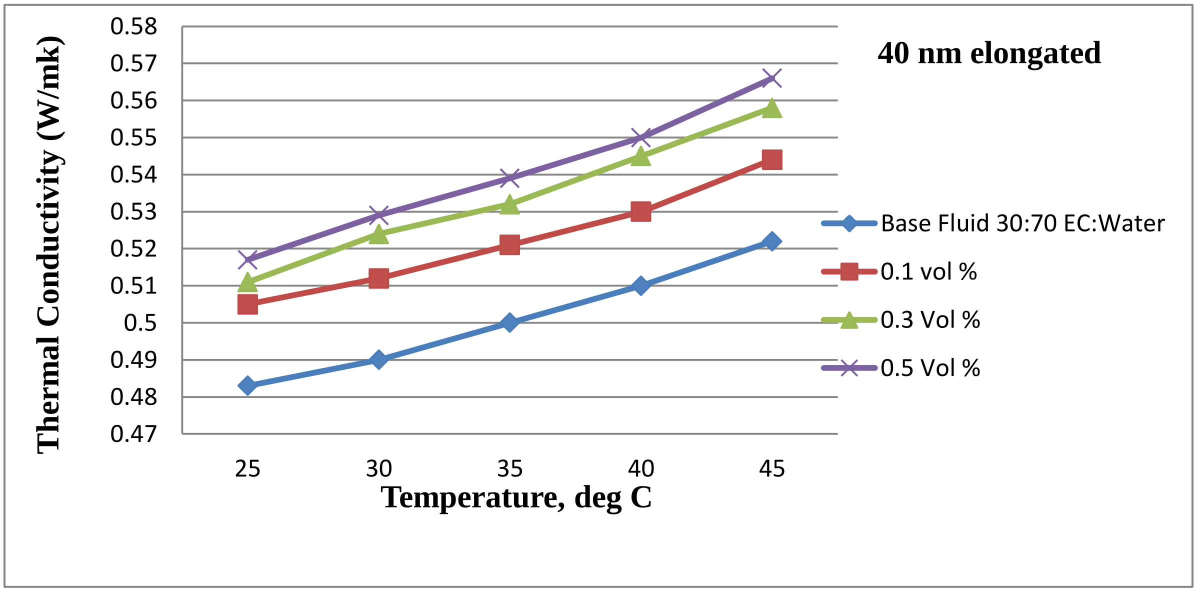


Fig. 5.3 Thermal conductivity v/s Temperature 0.1, 0.3 and 0.5% volume conc. for 40nm (elongated) nanoparticles

Thermal conductivity of engine coolant (base fluid) and engine nanocoolant increases almost linearly with temperature (25 to 45 °C).

At constant volume concentration (0.1%, 0.3% and 0.5%) of nanoparticles (Al_2O_3) the thermal conductivity enhancement is almost liner w.r.t temperature. At lower temperature increase in thermal conductivity is less, as compared to increases in thermal conductivity at higher temperatures (35 – 45 ° C).The mechanism behind the thermal conductivity enhancement such as Brownian motion, micro convection, explains the conductivity enhancement. At high temperature Brownian motion assisted micro convection are responsible for the Thermal conductivity enhancement. Brownian or random motion increases with increases in temperature that's why the thermal conductivity increases with temperature.

5.2.2 Effect of volume concentration on thermal conductivity of Engine nanocoolant.

5.2.2.1 Engine nanocoolant with 20 (spherical) nm Al_2O_3 nanoparticles:

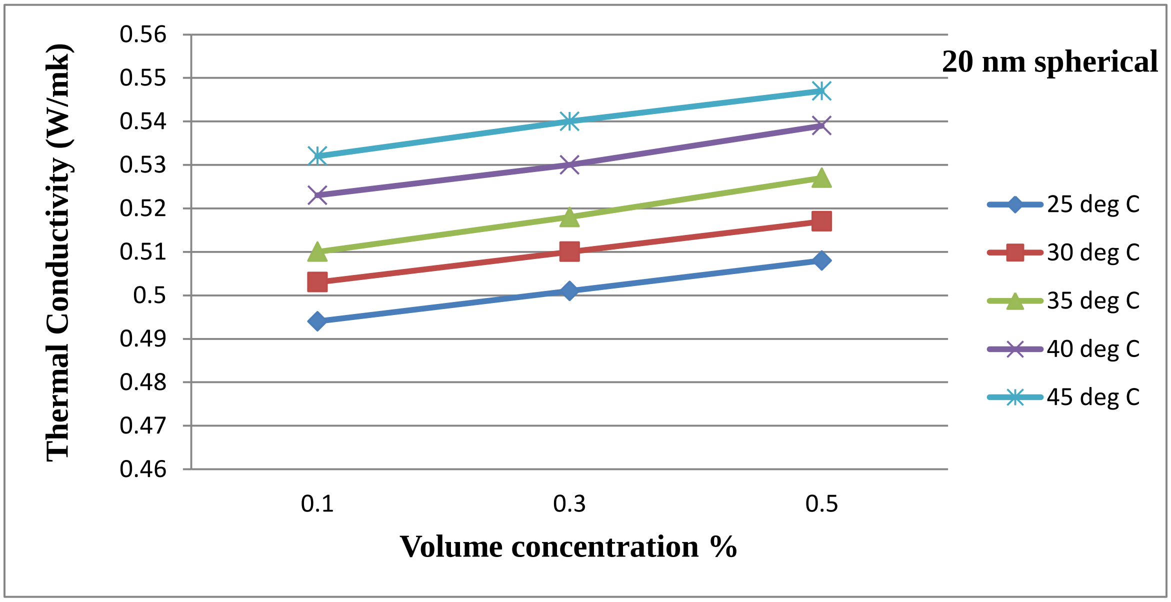


Fig. 5.4 Thermal conductivity v/s Volume concentration % with 20nm (spherical) nanoparticles

5.2.2.2 Engine nanocoolant with 40 nm (spherical) Al_2O_3 nanoparticles:

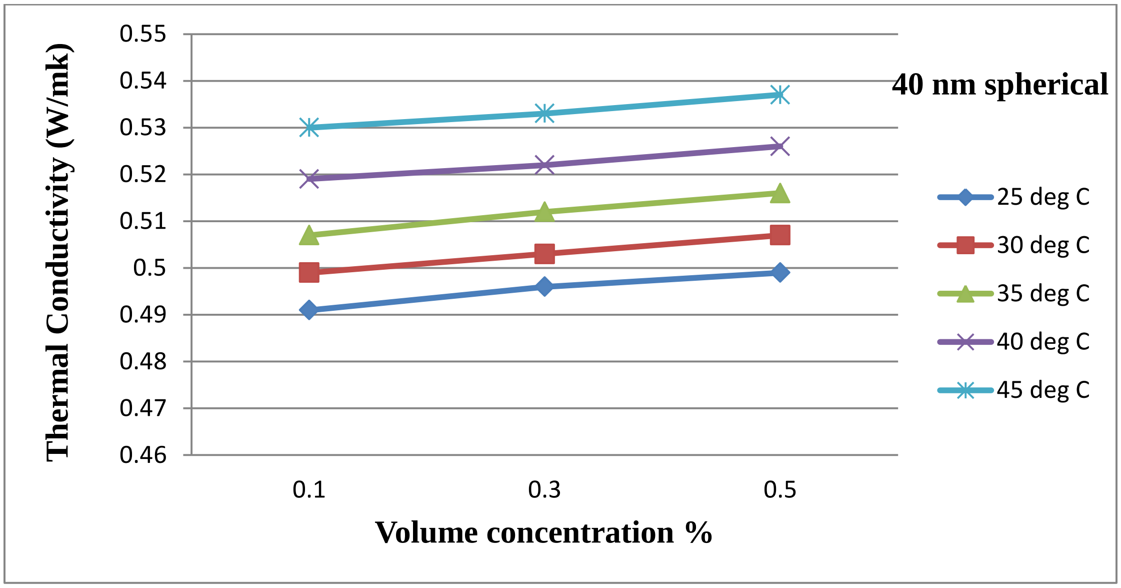


Figure 5.5 Thermal conductivity v/s Volume concentration % with 40nm (spherical) nanoparticles

5.2.2.3 Engine nanocoolant with 40 nm (elongated) Al_2O_3 nanoparticles:

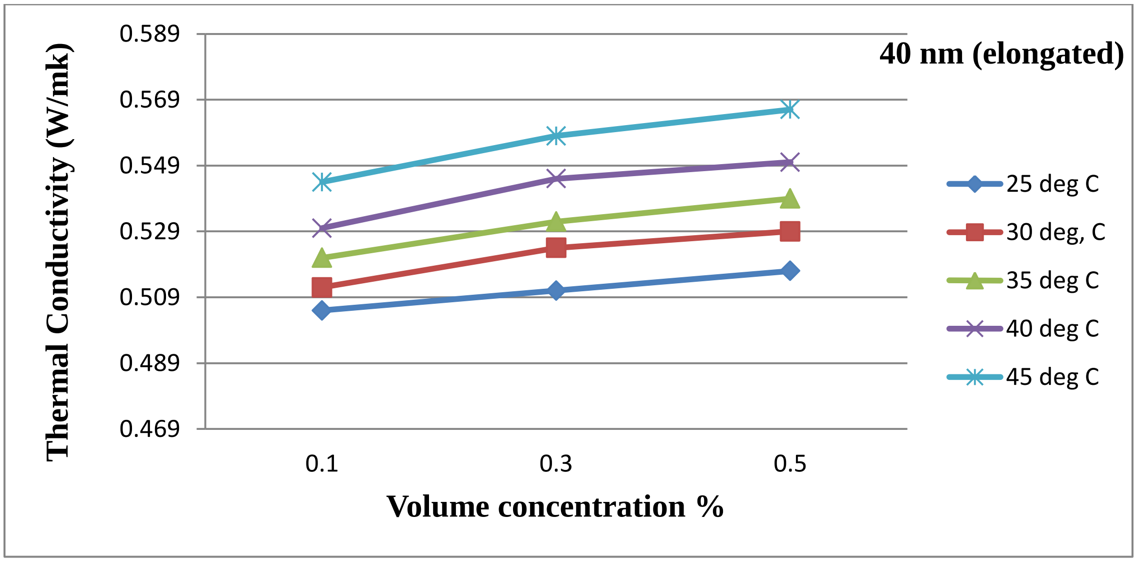


Figure 5.6 Thermal conductivity v/s volume concentration % with 40nm (elongated) nanoparticles

Thermal conductivity of engine nanocoolant increases with the increases the volume concentration (0.1%, 0.3%, and 0.5%) loading, at constant temperature. The enhancement in thermal conductivity with respect to volume concentration % shows linear behavior at constant temperature.

At a particular temperature results shown increases in thermal conductivity with increase of volume concentration % and also results shows there is less difference in thermal conductivity enhancement from 0.1 to 0.5 % volume concentration. The reason behind this behavior is clustering of nanoparticles at higher concentrations.

5.2.3 Effect of Nanoparticle size on thermal conductivity of Engine nanocoolant.

5.2.3.1 Size effect with 0.1 % vol. fraction

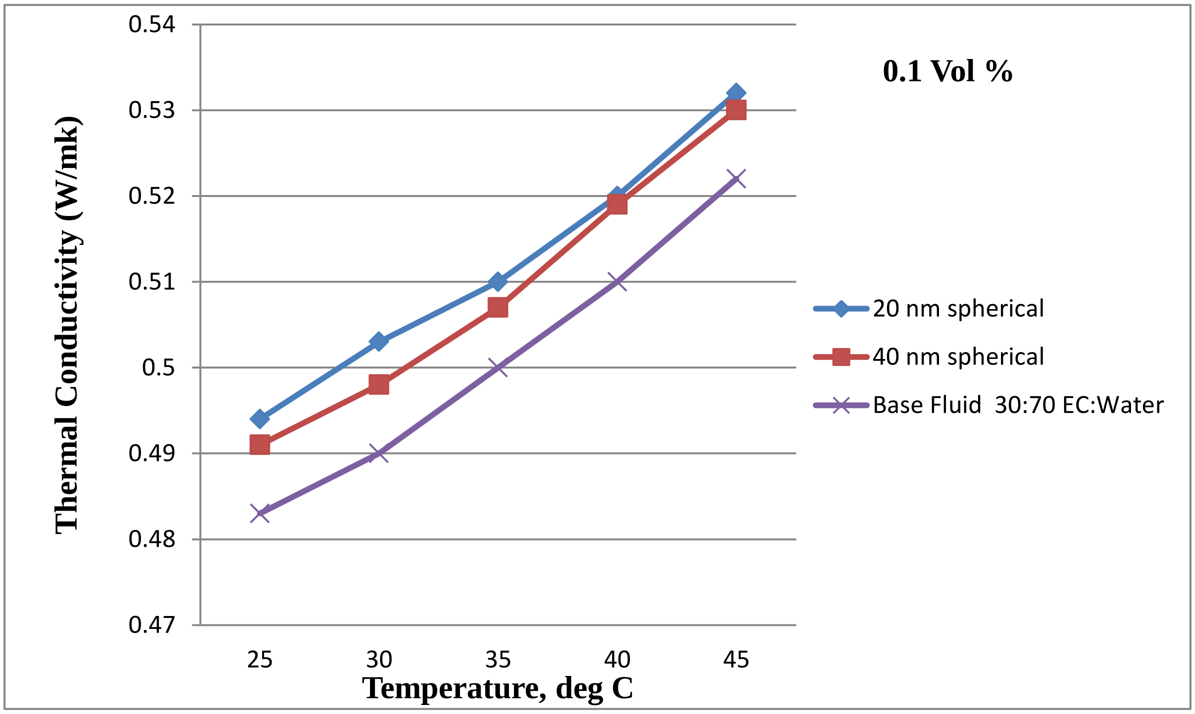


Figure 5.7 Thermal conductivity v/s Temperature at 0.1% volume concentration .

5.2.3.2 Size effect with 0.3 % vol. fraction

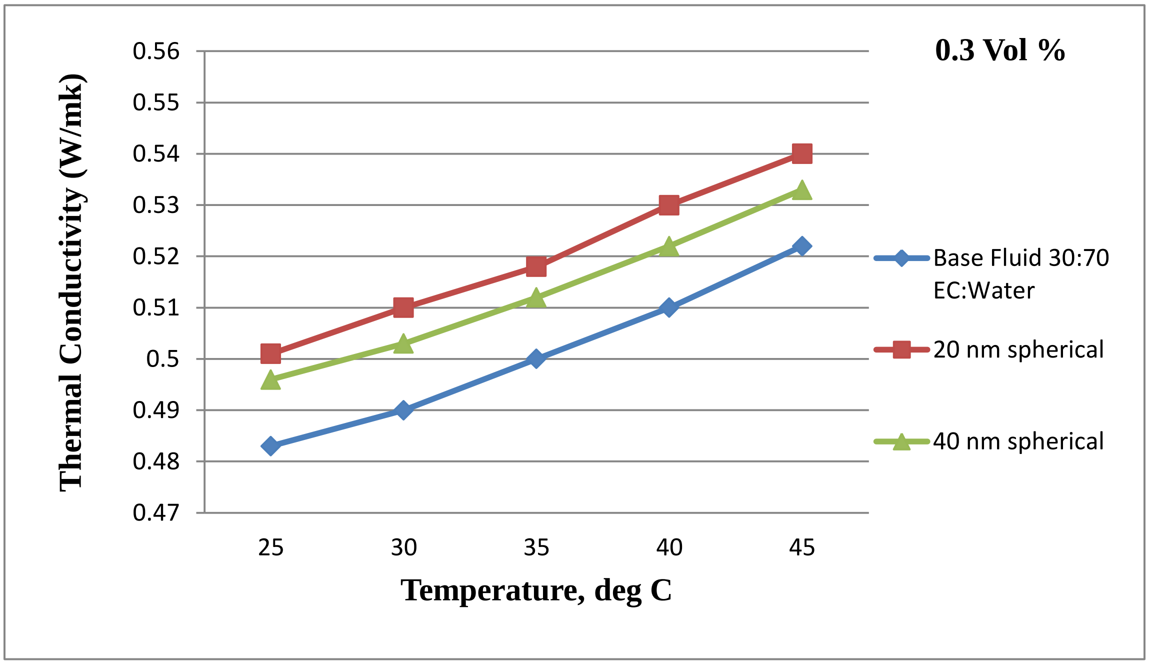


Figure 5.8 Thermal conductivity v/s Temperature at 0.3% volume concentration .

5.2.3.3 Size effect with 0.5 volume concentration %

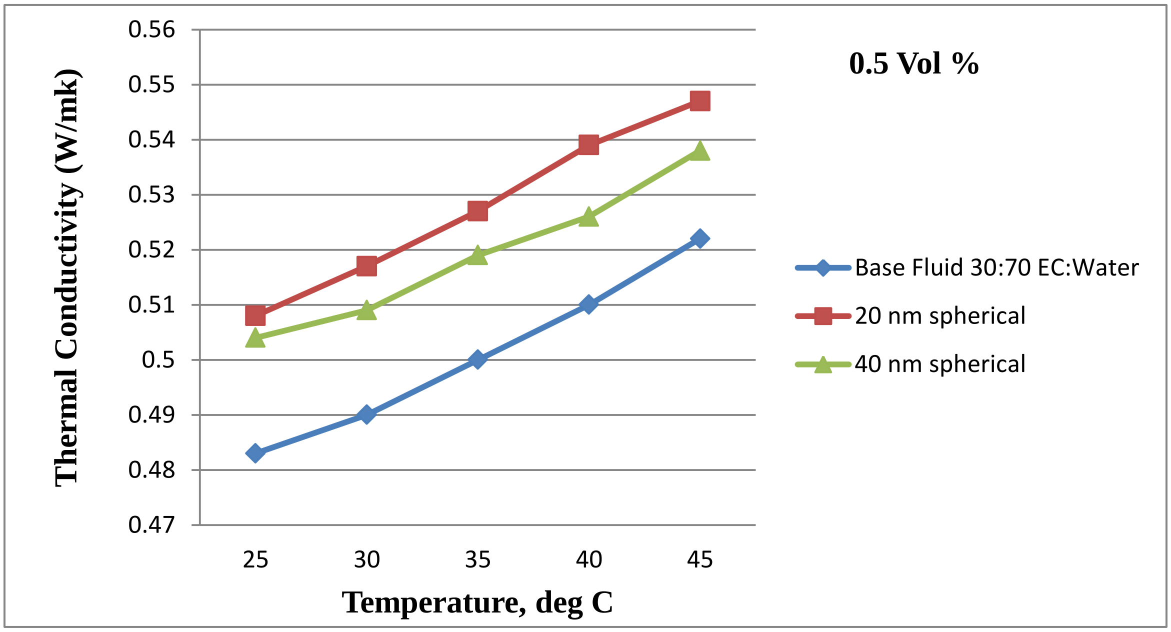


Figure 5.9 Thermal conductivity v/s Temperature at 0.5% volume concentration .

The size of nanoparticle has direct effect on the thermal conductivity of nanofluid, the size effect is compared between 20 nm and 40 nm Al_2O_3 (spherical) nanoparticles, thermal conductivity increases with decreases in the size of nanoparticle size.

At 0.1% volume concentration, 20 nm has slightly high thermal conductivity than 40nm nanoparticles, but difference is very less at high temperature is almost same.

At 0.3% and 0.5% volume concentration, 20 nm shows clear enhancement in thermal conductivity compared to 40 nm.

At 0.5% volume concentration %, the maximum enhancement shown by 20 nm Al_2O_3 (spherical) in the thermal conductivity at 40 ºC is 5.7%.

5.2.4 Effect of nanoparticle Shape on Thermal conductivity of Engine nanocoolant

5.2.4.1 Shape effect of nanoparticles with 0.1 volune concentration %.

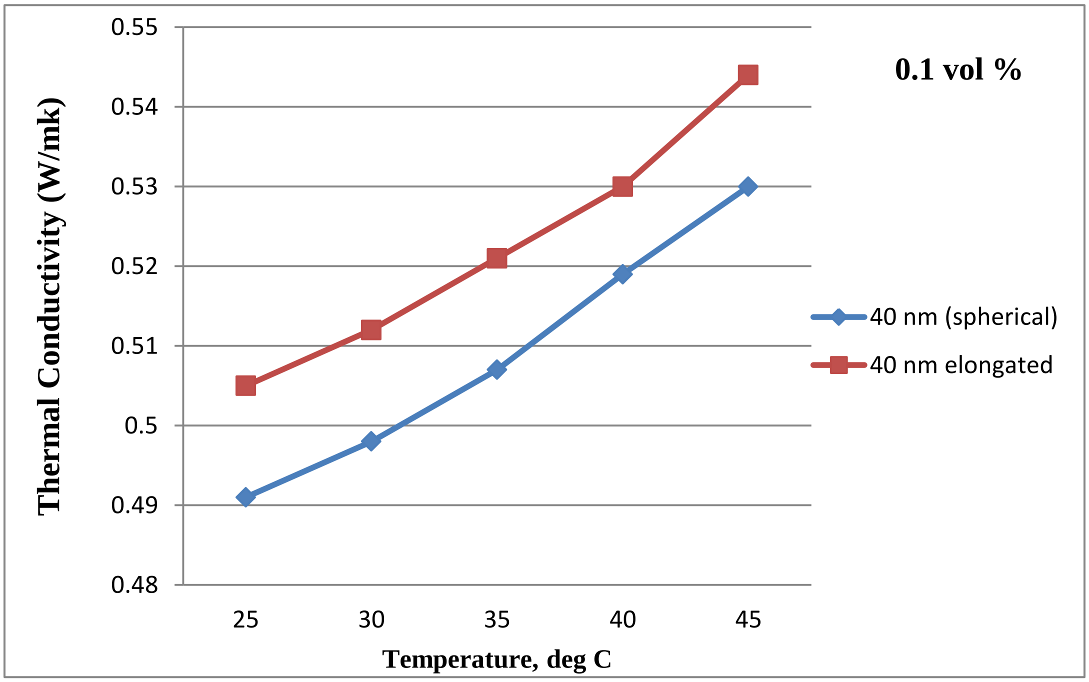


Figure 5.10 Thermal conductivity v/s Temperature at 0.1% volume concentration ..

5.2.4.2 Shape effect of nanoparticles with 0.3% volume concentration

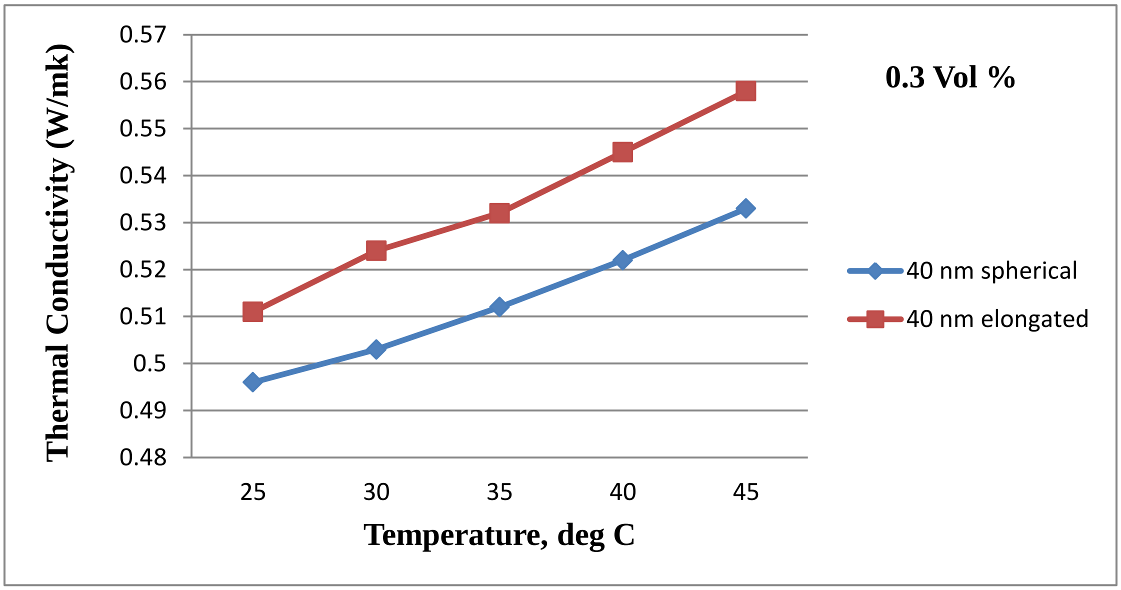


Figure 5.11 Thermal conductivity v/s Temperature at 0.3% volume concentration .

5.2.4.3 Shape effect of nanoparticles with 0.5% volume concentration

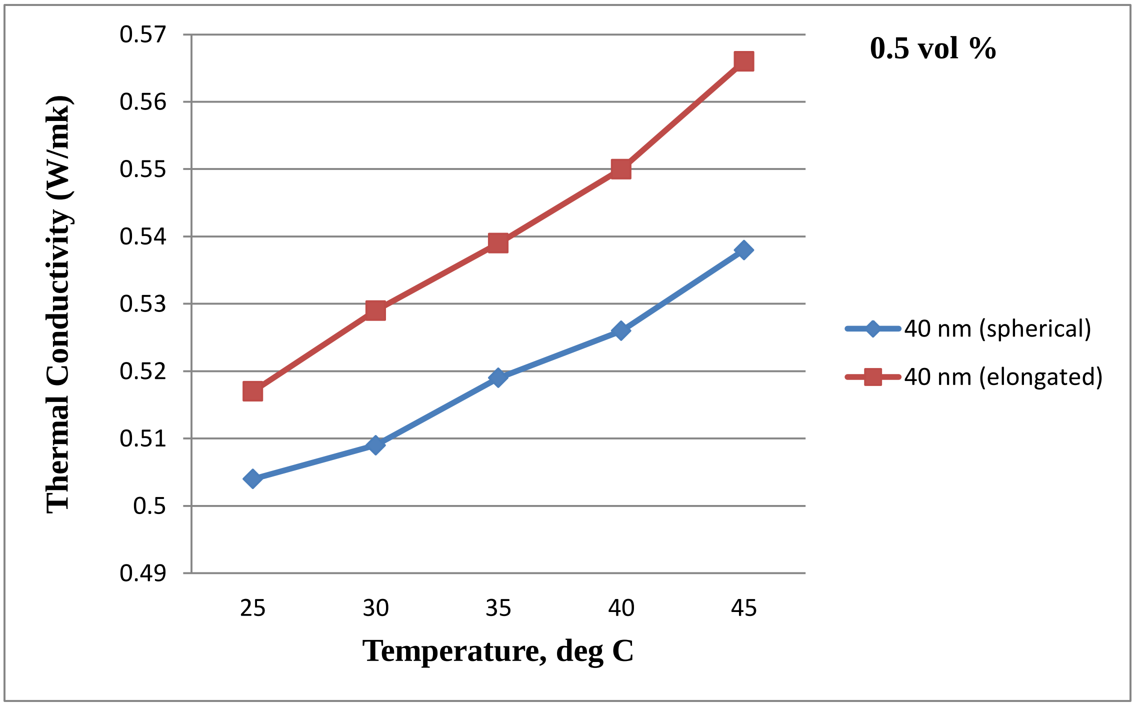


Figure 5.12 Thermal conductivity v/s Temperature at 0.5% volume concentration.

Nanoparticle shape is also one of very important parameter on the thermal conductive behavior of nanofluids. Here shape factor is studied on 40 nm Al_2O_3 nanoparticles.

Out of spherical and elongated shapes, elongated nanoparticles of 40 nm shows higher thermal conductivity enhancement as compared to spherical particles because larger area of contact with base fluid.

At 0.5% volume concentration maximum enhancement is shown by elongated Al_2O_3 nanoparticles compared with same size (40 nm) at 45 ºC is 1.67%

At 0.5% volume concentration enhancement is shown by elongated Al_2O_3 nanoparticles compared with base fluid at 45 ºC is 8.4%

5.3 Viscosity behavior of Engine nanocoolant

5.3.1 Effect of temperature on viscosity of Engine nanocoolant

5.3.1.1 Effect of temperature (20 nm Al_2O_3) on Viscosity

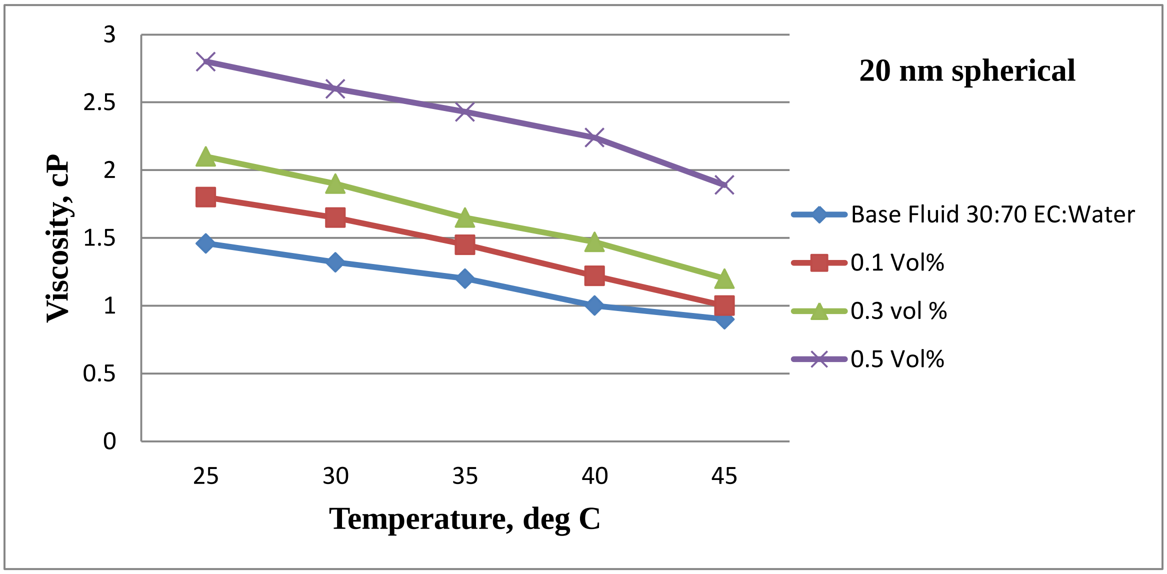


Figure 5.13 Viscosity v/s Temperature for 20 nm Al_2O_3 nanoparticles.

5.3.1.2 Effect of temperature 40 nm (spherical) Al_2O_3 on viscosity

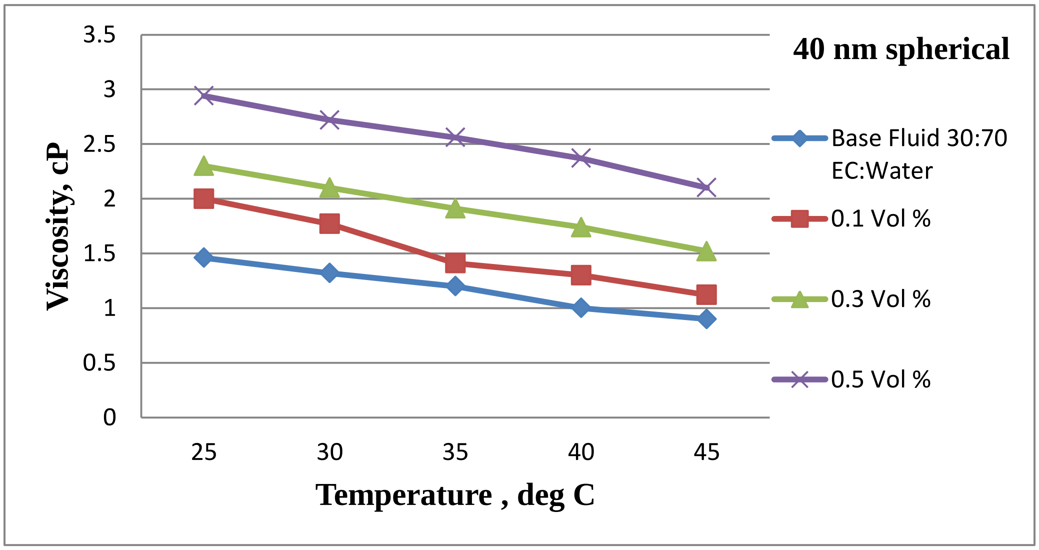


Figure 5.14 Viscosity v/s Temperature for 40 nm (spherical) Al_2O_3 nanoparticles.

5.3.1.3 Effect of temperature 40 nm (elongated) Al_2O_3 on Viscosity

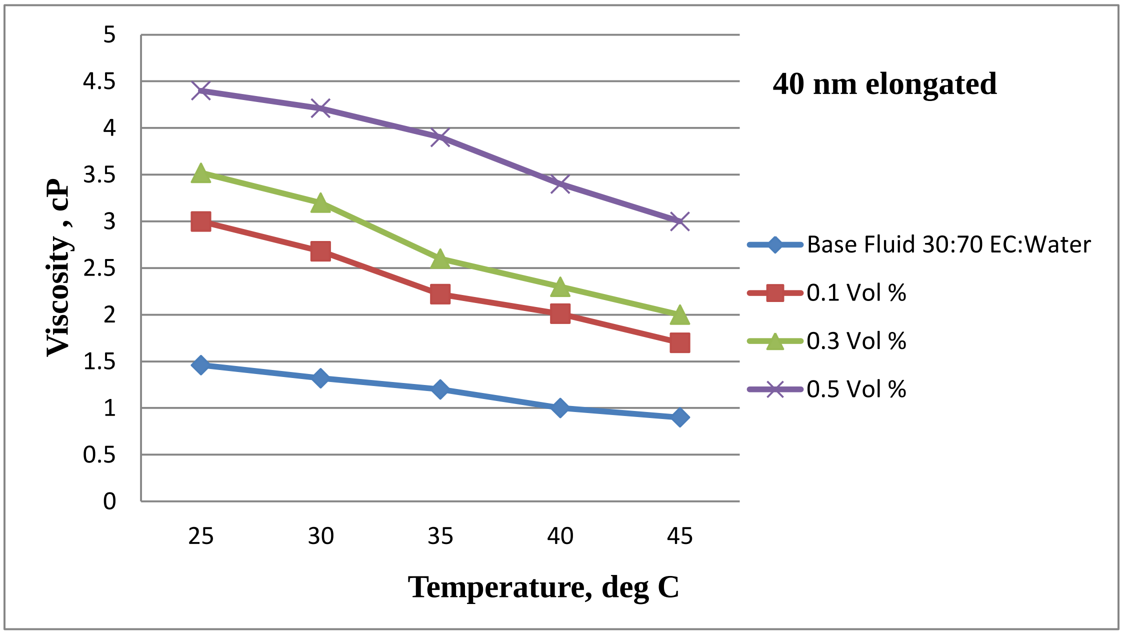


Figure 5.15 Viscosity v/s Temperature for 40 nm (elongated) Al_2O_3 particles.

Viscosity of engine nanocoolant deceases with increases in temperature, Due to increase in temperature intermolecular bonding forces decrease which decrease viscosity.

Viscosity decrease sharply in higher temperature ranges.

5.3.2 Effect of volume concentration % on viscosity of Engine nanocoolant.

5.3.2.1 Effect of volume concentration % on viscosity with 20 nm Al_2O_3 nanoparticles.

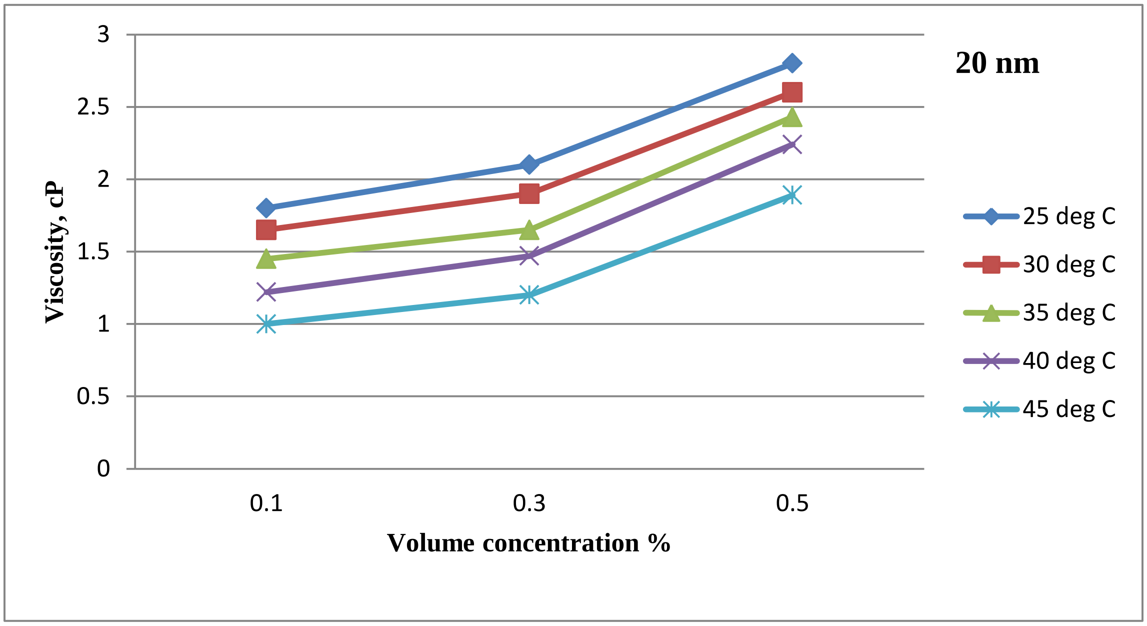


Figure 5.16 Viscosity v/s Volume concentration % for 20 nm (spherical) Al_2O_3 particles.

5.3.2.2 Effect of volume concentration % with 40 nm (spherical) Al_2O_3 nanoparticles

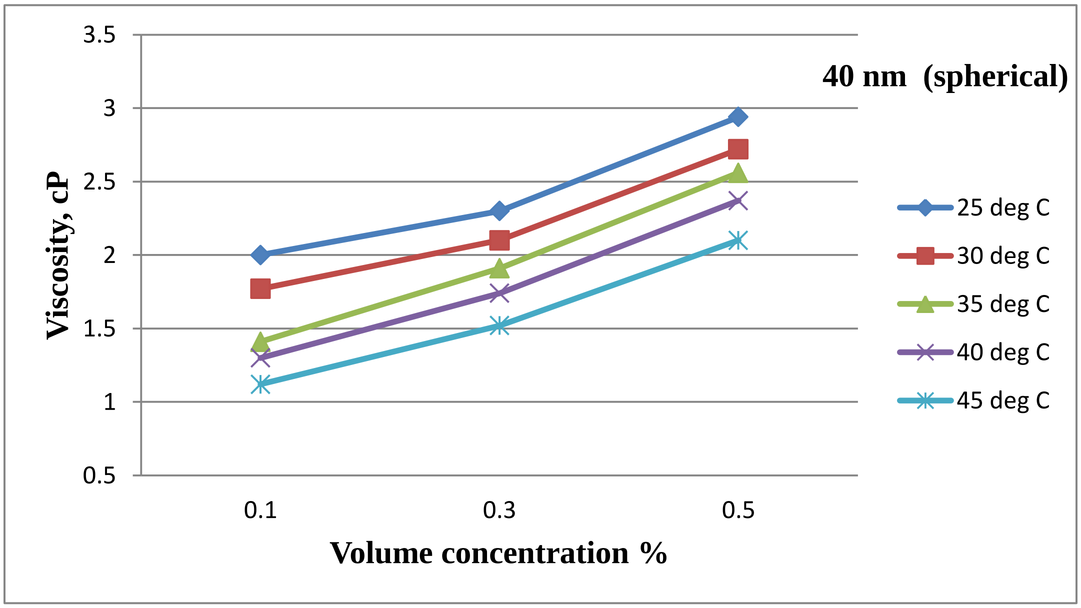


Figure 5.17 Viscosity v/s Volume concentration % for 40 nm (spherical) Al_2O_3 nanoparticles.

5.3.2.3 Effect of Volume concentration % on Viscosity with 40 nm (elongated) Al_2O_3

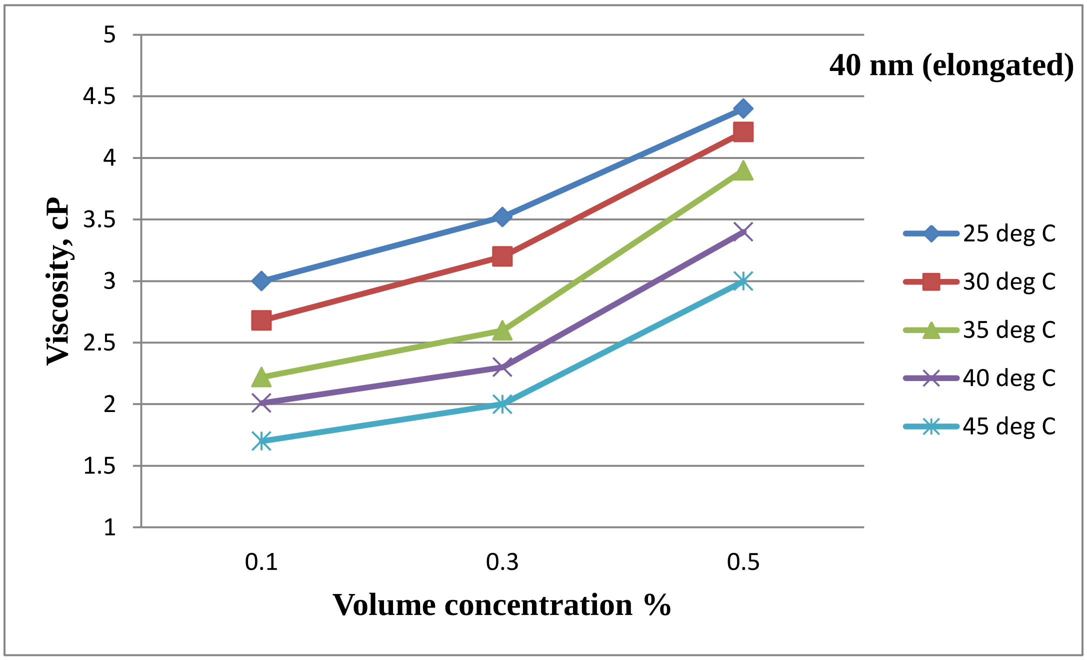


Figure 5.18 Viscosity v/s Volume concentration % for 40 nm (elongated) Al_2O_3 nanoparticles.

Viscosity of engine nanocoolant increases with the increases in nanoparticles loading at constant temperature. Due to increase in concentration of nanoparticle, particle to particle bonding increase which results in more rise in viscosity.

The results show that viscosity increases with the nanoparticles concentration, while going from 0.3 to 0.5 %volume conc. viscosity increases very sharply shown in results.

1. At 25 ºC the enhancement in viscosity for 20 nm (spherical) nanoparticles:

   a. In range (0.1 to 0.3% vol.) is 16% b. In range (0.1 to 0.5 % vol.) is 55.5%

2. At 25 ºC the enhancement in viscosity for 40 nm (spherical) nanoparticles:

   a. In range (0.1 to 0.3% vol.) is 15% b. In range (0.1 to 0.5% vol.) is 47%

3. At 25 ºC the enhancement in viscosity for 40 nm (elongated) nanoparticles:

   a. In range (0.1 to 0.3% vol.) is 17.3 b. In range (0.1 to 0.5% vol.) is 46.6

5.3.3 Effect of Nanoparticle size on viscosity of Engine nanocoolant.

5.3.3.1 Size effect on viscosity with 0.1% volume concentration of nanoparticles.

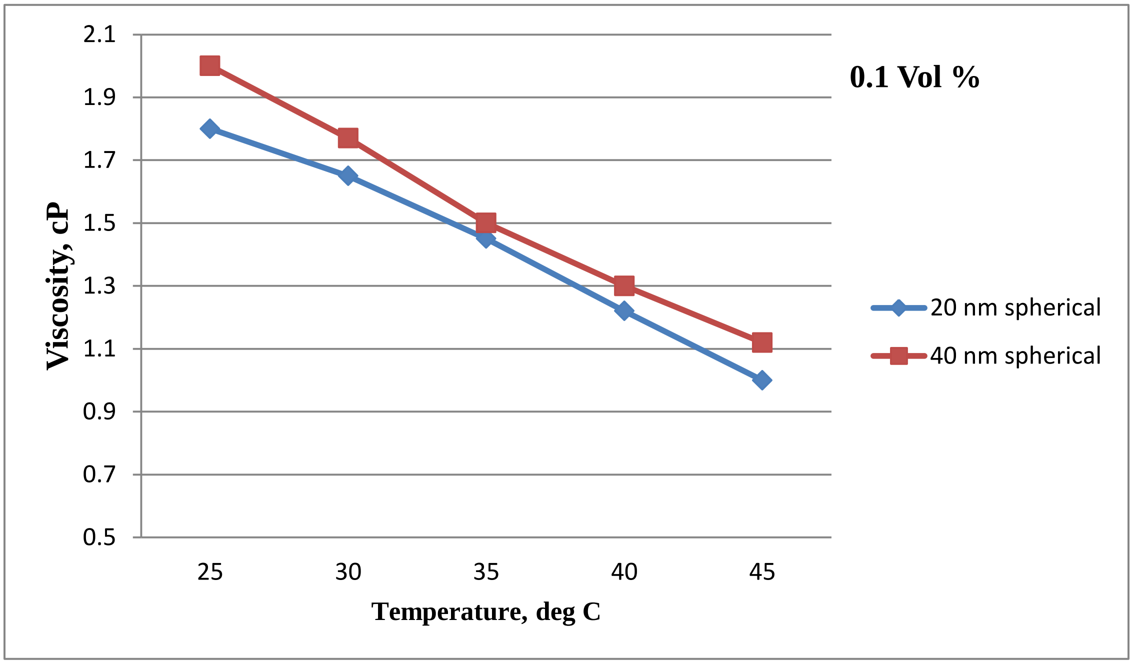


Figure 5.19 Viscosity v/s Temperature at 0.1 volume concentration %.

5.3.3.2 Size effect on viscosity with 0.3% volume concentration of nanoparticles.

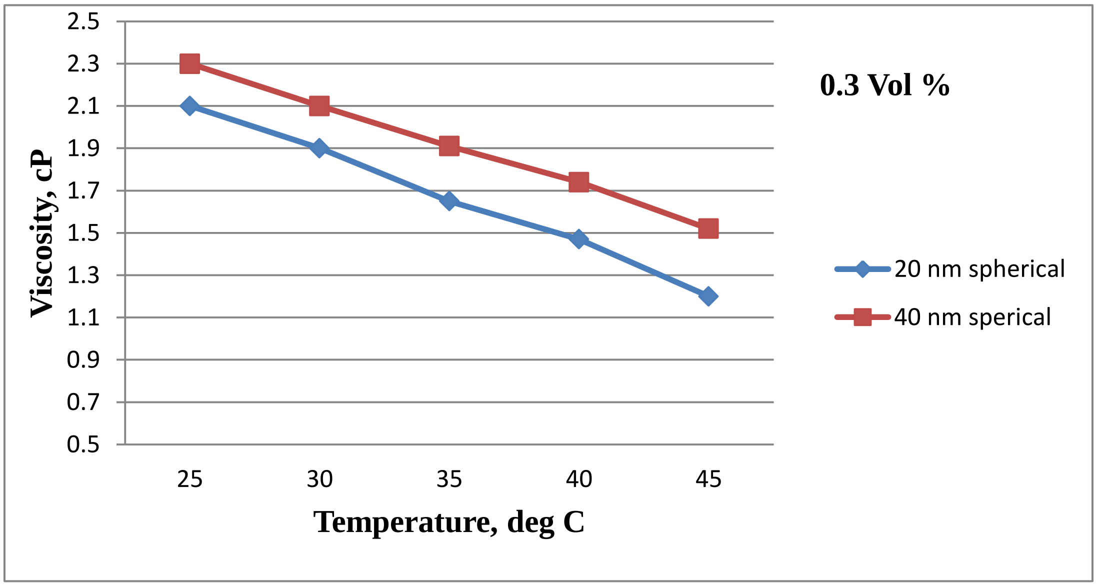


Figure 5.20 Viscosity v/s Temperature at 0.3% volume concentration .

5.3.3.3 Size effect on viscosity with 0.5% volume concentration of nanoparticles.

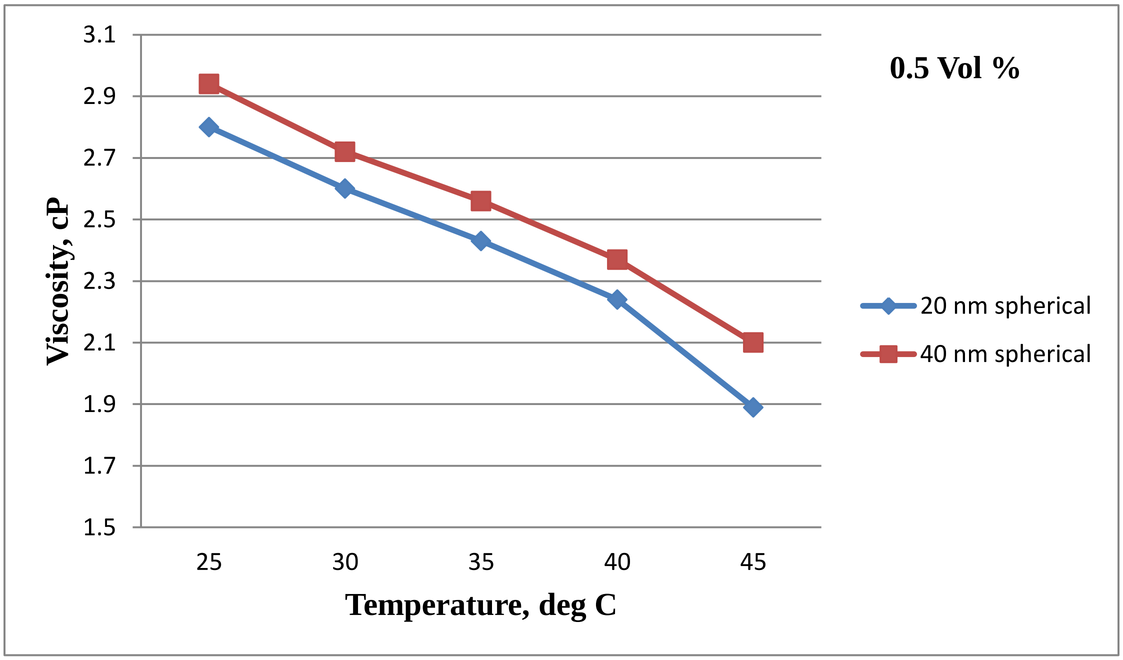


Figure 5.21 Viscosity v/s Temperature at 0.5% volume concentration.

On the basis of size effect, viscosity of engine nanocoolant increases with the increases size of nanoparticles at constant temperature.

The results shows that 40 nm (spherical) nanoparticles have greater viscosity than 20 nm (spherical) at constant temperature

1. At 0.5% volume concentration, 40 nm (spherical) nanoparticles have 5% higher viscosity as compared to 20 nm (spherical) nanoparticles at constant temperature.
2. Results show that in comparison to base fluid at 0.5% vol. conc. for 20 nm size the enhancement in viscosity is 91.7%.
3. Results also show that in comparison to base fluid at 0.5% vol. conc. for 40 nm size the enhancement in viscosity is 101%.

5.3.4 Effect of Nanoparticle shape on Viscosity of Engine nanocoolant.

5.3.4.1 Shape effect of alumina nanoparticles with 0.1% vol. concentration

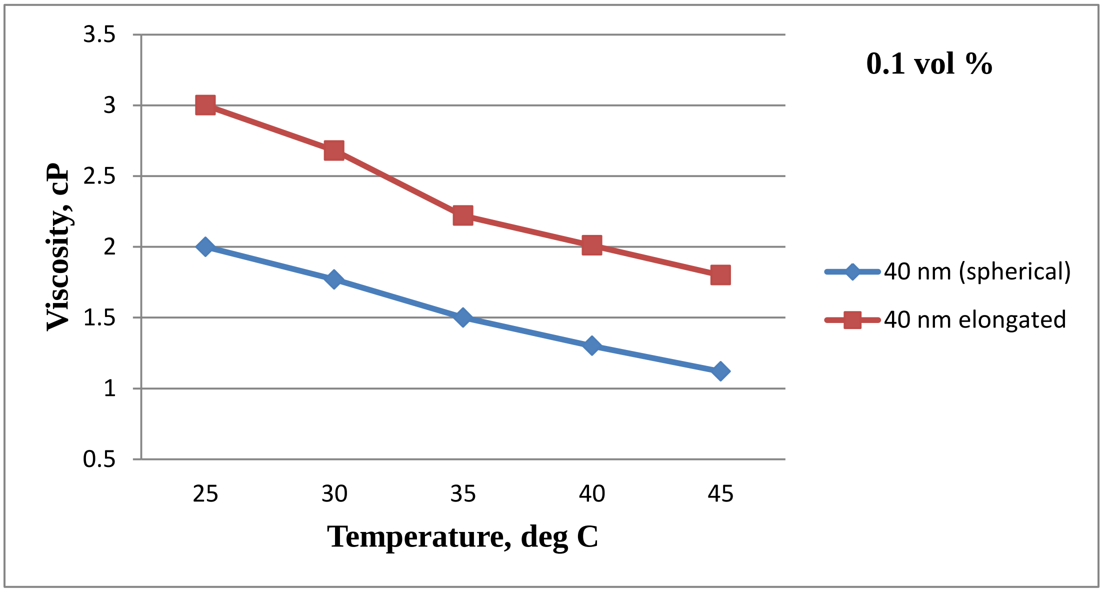


Figure 5.22 Viscosity v/s Temperature at 0.1% volume concentration .

5.3.4.2 Shape effect of alumina nanoparticles with 0.3% vol. concentration

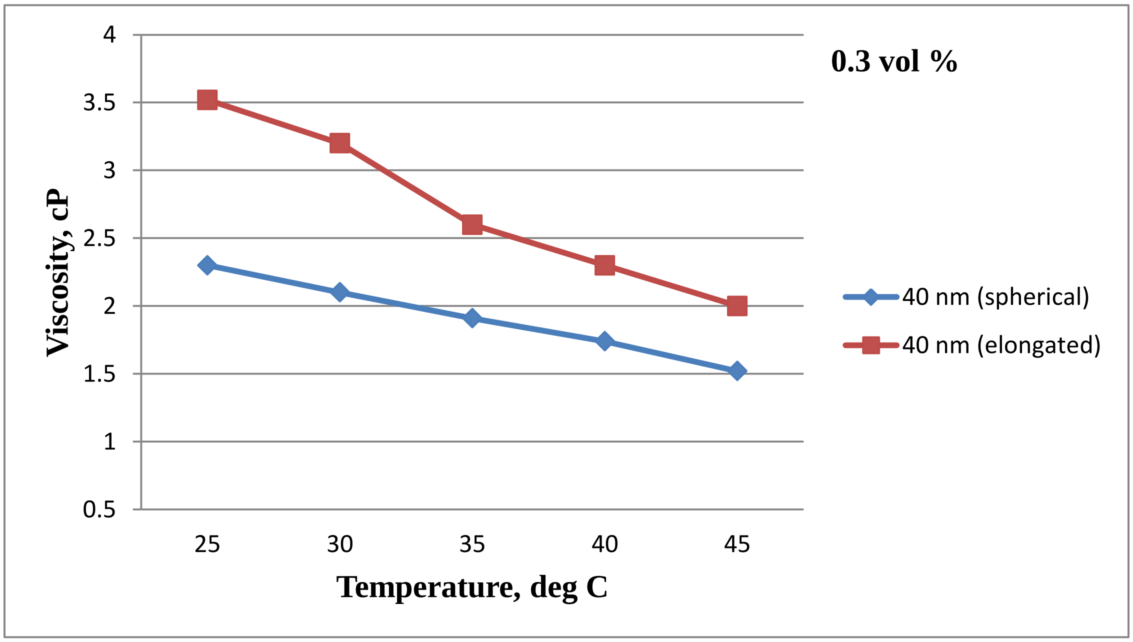


Figure 5.23 Viscosity v/s Temperature at 0.3% volume concentration

5.3.4.3 Shape effect of alumina nanoparticles with 0.5% vol. concentration

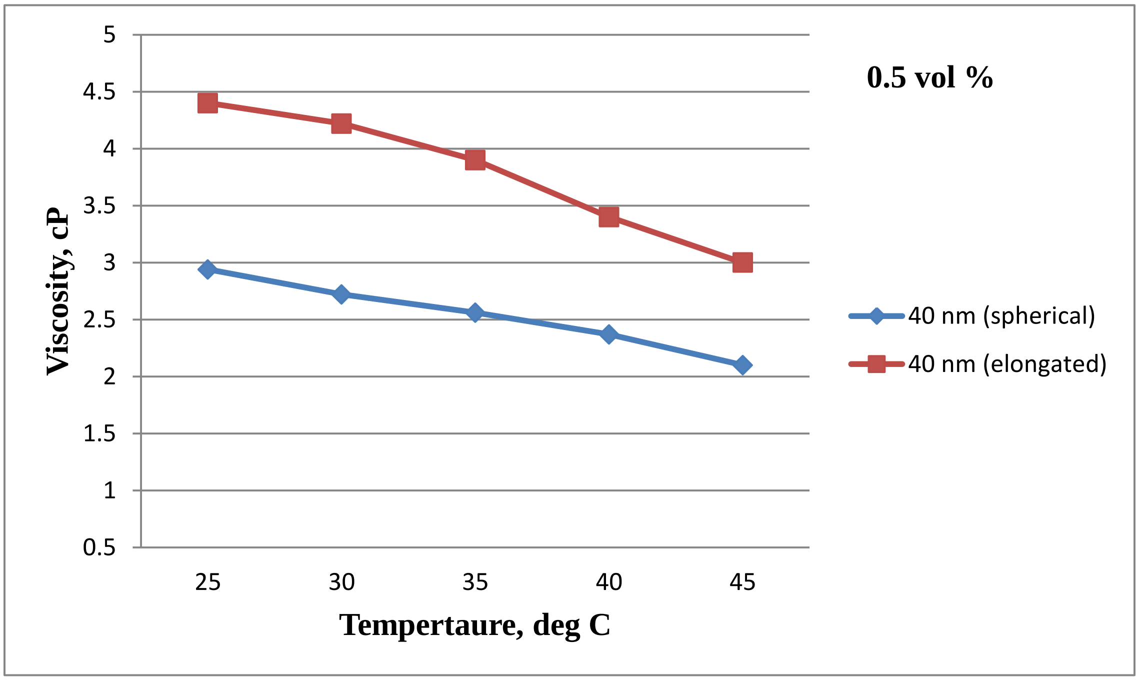


Figure 5.24 Viscosity v/s Temperature at 0.5% volume concentration

Figures show elongated particles results higher viscosity which is expected due to to more intramolecular forces between them as compared to spherical particle due to their more area of contact with other elongated nanoparticles. In elongated particles agglomeration of particles occurs which results in more increase in viscosity as compared to spherical particles.

1. At 0.5% volume conc. elongated nanoparticles have 50% higher viscosity compared to spherical nanoparticles at 25 ºC, with the increases in temperature this enhancement in viscosity decreases.
2. Enhancement in viscosity compared between base fluid and 0.5% volume conc. of 40 nm elongated size is 201%

CHAPTER 6

CONCLUSIONS

6.1 Conclusions on Thermal Conductivity

1. Thermal conductivity of engine coolant (base fluid) and engine nanocoolant increases almost linearly with temperature (25 to 45 ºC).
2. At constant volume concentration of nanoparticles (Al_2O_3) the thermal conductivity enhancement is almost liner w.r.t temperature. This rise in the thermal conductivity is more at high temperature (35 ºC to 45 ºC). Same is true for higher value of volume concentration of nanoparticles. The mechanism behind the thermal conductivity enhancement such as Brownian motion, micro convection, explains the conductivity enhancement. Brownian motion assisted micro convection are responsible for the Thermal conductivity enhancement. Brownian or random motion increases with increases in temperature that's why the thermal conductivity increases with temperature.
3. Thermal conductivity of engine nanocoolant increases with the increases the volume concentration (0.1%, 0.3%, and 0.5%) loading, at constant temperature. The enhancement in thermal conductivity with respect to volume concentration shows almost linear behavior at constant temperature. At a particular value of temperature corresponding enhancement in thermal conductivity is less in the volume concentration range from 0.1 to 0.5%. The reason behind this behavior is clustering of nanoparticles at higher concentrations.
4. The size of nanoparticle has direct effect on the thermal conductivity of nanofluid, the size effect is compared between 20 nm and 40 nm Al_2O_3 (spherical) nanoparticles and it is found that thermal conductivity increases with decreases in the size of nanoparticle size. At 0.1% volume concentration, 20 nm has slightly higher thermal conductivity than 40 nm nanoparticles, but difference is very less at high temperature. At 0.3% and 0.5% volume concentration, 20 nm shows clear enhancement in thermal conductivity compared to 40 nm. At 0.5% volume concentration, the maximum enhancement shown by 20 nm Al_2O_3 (spherical) in the thermal conductivity at 40 ºC is 5.7 %

5. Nanoparticle shape is also one of important parameter which effects the thermal conductivity of nanofluids. Here shape factor is studied on 40 nm Al_2O_3 nanoparticles, i.e. spherical and elongated. Results show that elongated nanoparticles shows higher thermal conductivity enhancement as compared to spherical particles because larger area of contact with base fluid.
6. At 0.5% volume concentration maximum enhancement is shown by elongated Al_2O_3 nanoparticles compared with same size (40 nm) at 45 ºC is 1.67% and at 0.5% volume concentration enhancement shown by elongated Al_2O_3 nanoparticles compared with base fluid at 45 ºC is 8.4%

6.2 Conclusions on Viscosity

1. Viscosity of engine nanocoolant deceases with increases in temperature, Due to increase in temperature intermolecular bonding forces decrease which decrease viscosity. Viscosity decrease sharply in higher temperature ranges.
2. Viscosity of engine nanocoolant increases with the increases in nanoparticles loading at constant temperature. Due to increase in concentration of nanoparticle, particle to particle bonding increase which results in more rise in viscosity. The results show that viscosity increases with the nanoparticles concentration, while going from 0.3 to 0.5% vol. conc. and this viscosity increase is sharp as shown in results.
3. On the basics of size effect, viscosity of engine nanocoolant increases with the increases size of nanoparticles at constant temperature. The results show that 40 nm (spherical) nanoparticles have greater viscosity than 20 nm (spherical) at constant temperature
4. At 0.5 vol. % 40 nm (spherical) nanoparticles have 5% higher viscosity as compared to 20 nm (spherical) nanoparticles at constant temperature.
5. Compared enhancement in viscosity between base fluid and 0.5% volume concentration of 20 nm size nanocoolant is 91.7%
6. Compared enhancement in viscosity between base fluid and 0.5% volume concentration of 40 nm size nanocoolant is 101%
7. Elongated particles results show higher viscosity as expected due to more intermolecular forces between them as compared to spherical particle due to their more area of contact with other elongated nanoparticles. In elongated particles agglomeration of nanoparticles

occurs which results in more increase in viscosity as compared to spherical particles. At 0.5% volume concentration, elongated nanoparticles have 50% higher viscosity compared to spherical nanoparticles at 25 ºC, with the increases in temperature this enhancement in viscosity decreases. Enhancement in viscosity between base fluid and 0.5% volume concentration of 40 nm elongated size is 201%.

CHAPTER 7

Application and future scope in auto-mobile

There is a limited resource of petroleum and with the increasing world population, the number of auto-vehicles also increasing, hence there is need to be design and build the more and more efficient auto-vehicles. Nanofluid as a coolant is one medium where it is believed that this will make the system more efficient by increasing their thermal performance. The proper cooling of auto-mobile engine delivers better efficiency, the addition of nanoparticles in base coolant provides us higher heat transfer. The addition of nanoparticles in base coolant fluid also reduces the size of auto-mobile radiator for given heat transfer rate using only coolant. As a result, the weight and size of radiator reduces.

1. The hybrid nanofluids (having the combination two or more type of nanoparticle like) may provide better results.

2. Nanofluid with higher concentration can be checked for better performance.

3. Nanocoolant at high temperature (more than 45 ºC) can be tested for better results.
4. Different nanomaterial can also be testing for their performance in the nanocoolants.

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