THE OPTICAL PROPERTIES OF ALUMINIA AND TITANIA NANOFLUIDS

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THE OPTICAL PROPERTIES OF ALUMINA AND TITANIA NANOFLUIDS

ABSTRACT

Fossil fuel are known to be the driving force of climate change because they emit substantial amount of greenhouse gases. One way in reducing greenhouse gases into the atmosphere is by changing it into green energy; harnessing and making them much more efficient. Adding nanofluids into base fluids was proven to enhance its physical properties such as thermal conductivity and light absorption. Nanofluids can be used as heat transfer fluid in many heat transfer application. Based on previous studies the most suitable nanofluids that can be used in solar thermal collectors would be carbon based and metal oxide based nanofluids, as both types of materials showed significant enhancement on thermal conductivity with good suspension stability. Therefore in this study the light absorption and transmittance of alumina and titania nanofluids are being investigated. Two step preparation method was used to prepare the sample, with 40 min ultrasonication and PVP as the surfactant. The samples were prepared with volume concentration ranging from 0.02 vol% to 0.1 vol%. The prepared sample were also observed for its stability. The outcome of the results showed that alumina nanofluids was stable for a long period compared to titania nanofluids. Moreover, the samples showed better stability when the pH was maintained at 6.8-7 for titania nanofluid and pH 6.0 to 6.8 for alumina nanofluids. As for the optical properties, distinguishably titania nanofluids showed better light absorption compared to alumina nanofluids. Moreover as for particle loading, light absorbance increases when the nanoparticle concentration increases regardless to the type of nanofluid examined. As For transmittance the result shows that light transmittance for titania nanofluid was lesser. As for nanoparticle concentration to light transmittance, the higher the concentration the lower the transmittance.

Keywords: Alumina nanofluids, Titania nanofluids, transmittance, absorbance, solar

SIFAT OPTIK ALUMINA DAN TITANIA NANOFLUIDA

ABSTRAK

Bahan bakar fosil dikenali sebagai faktor penggerak kepada perubahan iklim kerana ia menjerus kepada kesan rumah hijau. Salah satu cara untuk mengurangkan kesan rumah hijau adalah dengan mentransformasikan tenaga hijau kepada cara yang lebih efektif dan cekap. Penambahan nanopartikel dalam cecair asas terbukti dapat meningkatkan sifat fizikalnya seperti kekonduksian terma dan penyerapan cahaya. Penemuan ini berjaya ditemui oleh Choi di Makmal Nasional Argonne pada tahun 1995 dan kini dikaji oleh ramai penyelidik dari pelusuk dunia. Berdasarkan kajian- kajian terdahulu, nanofluida yang paling sesuai dalam pengumpulan haba ialah berasaskan karbon dan logam oksida. Hal ini demikian kerana, kedua-dua jenis bahan ini menunjukkan peningkatan yang ketara pada kekonduksian terma dan juga menunjukkan penstabilan untuk jangka masa yang lama. Sehubungan itu, penyerapan dan transmisi cahaya alumina dan titania nanofluida dikaji secara mendalam dalam kajian ini. Sampel dihasilkan dengan menggunakan dua kaedah penyediaan iaitu dengan ultrasonification 40 min dan PVP pula digunakan sebagai surfaktan. Sampel disediakan dengan kepekatan 0.02 vol % hingga 0.1 vol %. Sampel yang disediakan diperhatikan untuk kestabilannya. Hasil kajian menunjukkan bahawa nanofluida alumia berada dalam keadaan yang stabil untuk jangka masa yang lama berbanding dengan titania nanofluid. Selain itu, sampel menunjukkan kestabilan yang lebih baik apabila PH dibekalkan pada 7 hingga 6.8 untuk titania nanofluida dan PH 6.8 hingga 6.0 untuk nanofluida alumina. Bagi sifat optik, membrane nanofluida titania menunjukkan penyerapan cahaya yang lebih baik jika dibandingkan dengan aluminium nanofluida. Secara konklusinya, apabila jumlah kepekatan nanopartikel meningkat jumlah penyerapan cahaya juga meningkat.

Kata Kunci: Alumina nanofluida, Titania nanofluida, transmisi, penyerapan, solar

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LIST OF SYMBOLS AND ABBREVIATIONS

Al_2O_3	:	Aluminum oxide / Alumina
CNT	:	Carbon nanotube
CTAB	:	Hexadecyltrimethyl ammonium bromide
CTAC	:	Cetulti-methyl-ammonium chloride
CuO	:	Copper oxide
CO_2	:	Carbon dioxide
DI	:	Deionized water
DW	:	Distilled water
EG	:	Ethylene glycol
EM	:	Electro magnet
GA	:	Gum Arabic
IEP	:	Isoelectric point
MWCNT	:	Multi-wall carbon nanotube
Ni	:	Nickel
PEG	:	Polyethylene glycol
PUMWCNT	:	Partially unzipped multi-wall carbon nanotube
PVA	:	Polyvinyl alchol
RSM	:	Response Surface Methodology
SDBS	:	Sodium dodecyl benzene
SDS	:	Sodium dodecyl sulfate
TiO_2	:	Titanium Dioxide / Titania
UV	:	Ultraviolet
Wt%	:	Weight percentage
Vot%	:	Volume percentage

CHAPTER 1: INTRODUCTION

1.1 Background

The ever increasing need of energy and the worsening climate change has caused a major dilemma in the method of energy harnessing. It has been illustrated statistically that over the years the percentage of greenhouse gasses in the atmosphere has been in the rise (Leong et al. 2016). Greenhouse gases are important in a way it trap and absorb solar radiation and keeps the earth's surface warm for life to sustain. But as its presence rises it has cause a major disruption to the climate. Although debatable but it can't be denied that the use of fossil fuel energy is one major contributor for the increase of greenhouse gases, owing that the byproduct of using fossil fuel energy is CO_2 gas, which is a greenhouse gas.

Therefore in recent years there have been many contribution from the scientific world to reduce and remove CO_2 gases from the atmosphere. One way in reducing the footprint of carbon dioxide gas is to improve the use of renewable energy sources. From all the current renewable energy sources available solar energy seems to be the most favorable pick. As it is available thought the year and can be harnessed easily. Solar energy can be tapped from two method, those are by photovoltaic cells and the other by solar thermal system (Kasaeian, Eshghi, et al. 2015).

PV cells uses a silicon based panel that is able to directly convert solar energy into electrical energy. Its process of conversion does not release greenhouse gasses but its manufacturing process releases toxic chemicals as a byproduct.

As for solar thermal system, it uses the science of thermodynamics. In application wise solar thermal system functions like a heat exchanger. The heat source which is the sun, is used to harness its energy though a working fluids in the solar thermal system in which it is used to drive turbines or to heat up water. This whole process is considered to be less environmental damaging and does not release any greenhouse gases into the atmosphere. But the disadvantage is that it needs a large operable place and it's also not cost effective (Kasaeian, Daviran, et al. 2015).

One way to make the solar thermal system to use a smaller foot print and make it more cost effective is to increase its working fluids ability to absorb solar radiation. Solar radiation consist of 3% ultraviolet radiation, 44% visible light and 53% infrared radiation and currently the majority of low temperature and medium temperature solar collector uses water as the working fluid to absorb solar radiation, whereby only 13% of the energy form the sun is harnessed (Rose et al. 2017). Therefore one way to increase its ability to absorb more energy is to add addictive into the fluid to making it more appealing.

Based on previous studies on nanofluids, it was mentioned that one beneficial application of nanofluids is that it can be used as a solar thermal fluid. First discovered by Choi in Argonne National Laboratory in 1995, the term nanofluids has been exploded over the years and its nature of behavior has been deeply studied. Nanoparticles, when added into the base fluid the properties of the fluid changes drastically. Based on previous studies, adding certain amount of alumina (Al_2O_3) into ethylene glycol can produce a better thermal fluid. This is because nanoparticles has a higher surface area to volume ratio making it able to absorb more heat compared to different size particles of the same material. Although able to produce a better thermal fluid one major challenges in nanofluid science is to making the medium stable and homogenous over a period of time (Kumar & Amirtham 2016).

Besides thermal properties there also have been studies that the optical properties of a based fluids can also be improved by adding certain types of nanofluids into the basefluid. There have been interest on how nanofluids can play a vital role in capturing heat from the sun. Properties such as absorption coefficient, reflective index, scattering coefficient and transmittance coefficient are such that can be manipulated by adding in certain types of nanoparticles into a desired based fluid. By doing so the percentage of energy that is being absorb form the sun can be increased (Sajid Hossain et al. 2015).

Therefore, the corresponding research question to this study is be to determine whether adding nanoparticles into water can increase the optical properties of a base fluid, moreover this study is also conducted to determine if the variation of the types of nanoparticles and its concentration used can affect optical properties of the base fluid. It can be hypothesized that a higher volume concentration can cause a higher rate of solar absorbance. Therefore, in this experiment alumina and titania nanoparticles were used to determine the corresponding absorption of solar radiation. The particles were dispersed in distilled water with volume factions from 0.02% to 0.1% and experiments conducted with setting other parameters constant those are temperature and preparation method. The optical properties of transmittance and absorbance are focused the main study as these two properties can directly co-relate to the amount of energy being harnessed.

1.2 Project Objective

In this investigation the following objectives are being achieved in order to have a comprehensive study over the optical properties of nanofluids.

1. To produce a stable and homogeneous aluminum oxide (Al_2O_3) and titanium dioxide (TiO_2) nanofluids using two-step preparation method.
2. To investigate on the transmittance and absorbance of light of the produced titania and alumina nanofluids by varying the particle concentration.

1.3 Project Scope

In this study the scope of the project is specified into investigating the optical properties of alumina and titania nanofluids. Based on literature reviews in is shown that nanofluids have potential application to be used in solar thermal systems. A study done to investigates the efficiency of flat plate solar collector shows that when 0.2 wt% of alumina nanoparticles were disbursed into water, an enhancement of 28.3% in solar energy absorption can be achieved (Yousefi et al. 2012). Besides it is also shown that different types of nanofluids produces different types of corresponding results. (Kameya and Hanamura 2011) studied the absorption of Ni nanofluids, their findings show that the absorption increased in visible and near-infrared wavelengths. Therefore by selecting two different types of nanofluids, conducting experiments and comparing the results obtained can help give a better understanding on how nanofluids optical behavior can improve solar absorption.

The values that would be in interest in this study is the percentage of light that can be absorbed by the nanofluids. Solar radiation emits around 44% of visible light, therefore if the amount of visible light that can be absorbed becomes significant, the efficiency of the solar thermal system will also increase. This value of absorbance can be attained by using a UV-Spectrometer. The UV-Spectrometer uses the beer lambert law equations to measure the amount of light that can be absorbed (Ayompe & Duffy 2013).

Using a UV-Spectrometer to measure the absorbance is considered to be the most realistic approach, as the machine can emit light wavelength as similar to the solar spectrum. Lastly the whole measurement of the optical values needs to be carried out while the nanoparticles are stable and homogeneously suspended in the base fluid. If it begins to lose its stability and sediment the values obtain won’t be accurate.

CHAPTER 2: LITERATURE REVIEW

2.1 Nanofluids preparation and characterization

There are two ways in preparing nanofluids, those are single step preparation method and the two step preparation method. In a two-step preparation method, the nanoparticles are synthesized separately by physically or chemically means before being disbursed in a base fluid and physically or chemically treated to form a homogenous solution. Whereas in a single-step preparation method the synthesis of the nanoparticles in the base fluid is done simultaneously via high end equipment and sophisticated methods (Kumar & Amirtham 2016).

After preparing the nanofluids the main constrain is maintaining a stable and homogeneous suspension for a long period of time. As after the nanofluids have been prepared the particles in the solution tends to agglomerate and form sediments. The course of cluster formation can be directed towards the Brownian motion of the particles in the medium (Leong et al. 2016).

Based on previous studies there has been procedures used to form a stable nanofluids that are prepared by two-step preparation method. One common procedure used would be the addition of surfactant, by doing so the surface tension of the nanoparticles is altered to avoid cluster formation (Devendiran & Amirtham 2014).

Besides, the use of ultrasonic vibration of dispersing the nanofluids and changing the pH of the solution are two other common methods used to get a stable and homogeneous solution (Devendiran & Amirtham 2014; Kumar & Amirtham 2016).

In solar thermal systems the most common nanoparticles used are Al_2O_3, TiO_2, Multiwall carbon nanotubes (MWCNT), or CuO water base nanofluids. The preparation and stability of the mentioned nanofluids are as discussed below (Rose et al. 2017).

In this study four types of nanoparticle has been considered for sample preparation. Those are alumina based, titania based, carbon based and copper based. These for types of nanoparticle has been studied frequently as they have good thermal properties and they are able to be stably suspended in the fluid for a long time. From this four types of nanoparticle alumina and titania has been selected for sample preparation. The reason being is that alumina and titania are cost effective compared to copper and multiwall carbon nanoparticle. Moreover the preparation of copper based nanoparticle is time consuming therefore it would be efficient to purchase the nanoparticle rather the producing in the lab.

2.1.1 Alumina nanofluids

Aluminum based nanofluids have been widely studied over the years, mainly due to its availability and cost effectiveness. Based on the study done by (Jung et al. 2012) whereby the stability of the water-based alumina nanofluid was investigated. The samples were prepared with and without polyvinyl alcohol (PVA) as the surfactant and was disbursed using an ultrasonic probe disrupter for 2 hours. The surfactant (PVA) was disbursed as the same amount of the nanoparticle concentration. The outcome of the study showed that the PVA did not have any effect on the suspension. Both the samples had suspension particle size of 300nm and the sample was stable for more than a month.

Another study done by (Rose et al. 2017) showed that alumina nanofluids can be stabilized in water using pH manipulation method. PH manipulation method changes the surface charge of the suspension away from the isoelectric point. Isoelectric point is where the zeta potential (repulsive force) is zero. PH manipulation is best situated for water based nanofluids, as the acid treatment can cause the hydrophobic nature of the suspension to hydrophilic. In her experiment two different sizes of Al_2O_3 nanoparticle was disbursed in ethylene glycol and water. The water base nanofluids were stabilized by a few drops of hydrochloric acid. The pH value was fixed at 4 and the corresponding zeta potential was measured to be 58.7 mV. From her experiment it was concluded that water based alumina nanofluid was shown to have a better stability at level value ranging from 3.5 to 5.0. As for alumina nanoparticles suspended in ethylene glycol, the solution was able to be stable with just ultrasonic treatment.

Alumina nanofluids suspended in water can be produced with just ultrasonic treatment without pH manipulation and addition of surfactant, but the ultrasonic treatment process will take longer hours. As carried out by (Esmaeilzadeh et al. 2013), water based alumina nanofluids was produced through a 4 hours ultrasonication at 50Hz. The outcome showed that no sedimentation was detected after sample preparation and thought the experiment process.

(Yousefi et al. 2012) produced water based alumina nanofluids with and without Triton X-100 as dispersant. Both types of solution underwent ultrasonic vibration of homogeneous dispersion. In the experiment Al_2O_3 powder with particle dimension 15nm with weight concentration of 0.2% and 0.4% were produced using double distilled water. As for the sample with Triton X-100 an optimum weight concentration of 0.021% was used. Both types of sample underwent 30min of sonication. The stability time of Al_2O_3 powder in aqueous solutions with and without Triton X-100 were different. In case of Al_2O_3/Triton X-100, the stability was about three days after sonication which was greater than the other case.

2.1.2 Titania nanofluids

Another commonly used metal oxide nanoparticle for nanofluid preparation would be titanium dioxide nanoparticles. Brookite, Anatase and Rutile are the three types of naturally forming titania crystal. Anatase and Rutile crystal are favorable over Brookite as these both have an many industrial uses from white pigmentation to heat resistance, while Brookite is unfavorable because its unstable behavior (Devendiran & Amirtham 2014).

(Utomo et al. 2012) studied on the nanofluids suspension size formation for alumina and titania nanofluids with samples prepared between 30–40 wt%. The samples were prepared with constant pH value and ultrasonication time of 3min per sample. Two different surfactant was used octylsilane for alumina and polyacrylate for titania. From his studies it was concluded that the nanoparticles formed large agglomerates size in the order of 200nm and 140nm for alumina and titania nanofluids respectively.

(Longo & Zilio 2011) verified on the physical dispersion efficiency of Alumina and Titania based nanofluids. The samples were prepared with 15 wt% and 25 wt% respectively. The dispersion technics that was experimented was mechanical stirring and ultrasonication at 25 Khz for 48 hours. The outcome concluded that ultrasonic treatment produced a better suspended solution with stability for more than a month.

(Saidur et al. 2012) prepared of 0.1% and 0.3% v/v of alumina and Titania water based nanofluids to study on the optical properties. Based on the conclusion it is found that PEG for TiO2/DW and PVP for Al2O3/DW are the best surfactant respectively. A high pressure homogenizer was used to disperse the nanoparticles. Also it was concluded that even though TiO_2 has better optical properties in comparison, Al_2O_3 was proven to be more stable.

2.1.3 MWCNT based nanofluids

Cylindrically formed carbon nanoparticles are called carbon nanotubes (CNT) while multiwalled carbon nanotubes (MWCNT) are known to be multiple concentric tubes formed in a single configuration. One of the challenging part when working with carbon based nanolfuids is dispersing in water. Carbon are known to be hydrophobic and does not form a stable and homogenous nanofluids due to their strong Van der Waal's force. Though having difficulty to produce carbon based nanofluids the fluid is much desired by researchers as it has extraordinary thermal, mechanical and electrical properties making them potentially attractive materials for use in different fields. There are generally two methods available to disperse carbon nanotubes in base fluids, chemically by surface modification (functionalizing) or addition of surfactant and mechanical though ultrasonic dispersion (Shende & Ramaprabhu 2016).

The most commonly used surfactant by researches are sodium dodecyl benzene sulfonate (SDBS), sodium dodecyl sulfate (SDS), hexadecyltrimethyl ammonium bromide (CTAB), cetylti-methyl-ammonium-chloride (CTAC), Nanosperse AQ and Gum Arabic (GA). From previous work it was mentioned that SDBS is not a good surfactant for high temperature studies, moreover it was also concluded that GA is a better surfactant compared to SDS and CTAC for dispersing carbon nanotubes in deionized water (Zhang et al. 2016; Shende & Ramaprabhu 2016).

(Lamas et al. 2012) used chemical vapor deposition method to functionalized MWCNT. The procedure involved refluxed acid treatment at 413K using nitric acid and sulfuric acid at 1:3 volume ratio for 30min. The procedure followed by continuous washing with distilled water until no traces of acids were detected. The washed MWCNT was then dried in an oven at 373 K, for at least 72 hours.

The functionalized MWCNT nanofluids was prepared with dispersing in 50ml of base fluid, first magnetic stirred than proceeded with 60 min ultrasonication. Lamas also mentioned that during observation, after 24 hours the sedimentation rate was slow and constant.

Also, (Su et al. 2011) performed surface modification of CNTs by functionalizing with nitric acid. F. Su's method involved adding 1g or CNT in 40ml of concentrated nitric acid and refluxing for an hour at 120 °C. Once completed the supernatant washed until the pH was neutral and dried in oven at 55 °C. For preparing the CNT nanofluids, ultrasonication was used for 2 hours at 100 kHz. The outcome showed that a stable and homogeneous suspension was achieved when dispersed in aqueous ammonia.

2.1.4 Copper Oxide Nanofluids

Copper metal is considered to be the best suited material to be used in all heat exchanger application as its cost effective as well its nonpoisonous as led and high resistance to corrosion. A research done by (Kathiravan et al. 2010) whereby copper oxide nanofluids was prepared by two step preparation method. Initially copper nanoparticles were prepared by sputtering method and later on the copper oxide nanofluids was prepared by dispersing in water by an ultrasonic bath for a duration of 10 hours. SDS was used as the surfactant with 9.0 wt%. The outcome showed copper oxide nanofluids were not able to be stable for more than a month.

2.2 Optical properties of nanofluids

An electromagnetic field is a type of wave that propagates into space carrying radiant energy. The radiant energy carried by the wave includes microwaves, radio waves, x-ray, infrared radiation and also visible light. It is known that each of this waves have their own wavelength and this whole lot of waves can be categorized into the electromagnetic spectrum according to their frequencies or wavelength ranging from 300EHz to 3Hz or 1pm to 100Mm. Therefore, when it comes to studying about the optical properties of a material, the interested region of the electromagnetic spectrum would be the visible light region as optics deal with bending, scattering or focusing light by a medium. Visible light is to have a wavelength ranging from 0.39 to 0.77 μm which is in the frequency of 430 to 750 THz (Mahian et al. 2013; Lomascolo et al. 2015).

The sun is the main source for visible light and using solar thermal collators to harness this energy is a type of renewable energy. The current solar thermal technology was developed to collect the infrared energy of the sun and not to harness visible light but, as wavelength of infrared, UV and visible light are closely intertwine improving the optical properties of the operating fluid can subsequently improve the thermal performance of the solar thermal collectors (Leong et al. 2016). In current technology a flat plate solar thermal collector uses water as its working fluid and it is known to have a collector efficiency of 40% to 50% and a system efficiency of around 30% whereas water is able to absorb 13% of the solar energy (Ayompe & Duffy 2013; Leong et al. 2016). Therefore, by adding nanoparticles into the working fluid and forming a nanofluid, the performance of the working fluid can increase. It was reported that when a silicon based nanofluid is used there was an increase in efficiency compared to water but the values was not significant (Noghrehabadi et al. 2016).

The optical properties of a nanofluid highly depends on nanoparticles size shape and type. Besides, the volume concentration of nanoparticles and type of surfactant used also effects the optical properties of the nanofluid (Said et al. 2014; Leong et al. 2016). The optical properties that is being investigated by researches not only includes absorption and scattering but also includes the extinction coefficient of the nanofluids. Absorption as defined by Hossain et al referred as incident light's losses as it passes though the working medium and scattering is known to be the deviation of the light taken due to obstacles on its path of incident. Extinction coefficient which is the summation of absorption and scattering coefficient is said to be an imaginary component of complex reflective index (Leong et al. 2017; Sajid Hossain et al. 2015). Hossain also mentioned that the dielectric constant and the particle loading on the base fluid also effects the extinction coefficient of the nanofluids. Since extinction coefficient involves both absorption and scattering effect of the nanoparticles and the base fluid. But the calculation it is not done in a simple addition due to the complex nature of the nanofluid and the base fluid.

2.2.1 Theoretical Models

Based on previous researches, there are four most famous models that are used to study on the optical properties of nanofluids. Those accordingly are Rayleigh scattering approach, Maxwell–Garnett effective medium approach, Lambert–Beer approach and Mie and Gans approach (Ahmad et al. 2017; Leong et al. 2016; Sajid Hossain et al. 2015).

Rayleigh scattering approach is known to be the best in predicting the extinction coefficient and the reflective index of nanofluids. This theory developed by Lord Rayleigh was initially used to measure the scattering effect of light on gas particles in the atmosphere. It is to imply this formula when the particle size is much smaller than the wavelength of the incident electromagnetic radiation. As mentioned by

(D. Song et al. 2016) to use this model for nanofluids it is needed that the particle size to be lesser then 20nm as when is so, the scattering coefficient can be neglected and only consider the absorption coefficient (Song, Wang, et al. 2016; Wu et al. 2015). This was also mentioned by Z. Said et al. that the model was used when the $\alpha < 1$ where by α is a dimensionless constant calculated in terms of D the nanoparticle diameter and λ the incident wavelength as expressed in the equation (Said et al. 2014).

$$\alpha = \frac{\pi D}{\lambda} \qquad [2.1]$$

Thus to find the scattering coefficient Q_s the formula is;

$$Q_s = \frac{8}{3}\alpha^4 \left[\frac{m^2-1}{m^2+2}\right]^2 \qquad [2.2]$$

And to find the absorption coefficient Q_a the formula is;

$$Q_a = 4\alpha lm \left[\frac{m^2-1}{m^2+2}\left\{1 + \frac{\alpha^2}{15}\left[\frac{m^2-1}{m^2+2}\right]\frac{m^4+27m^2+38}{2m^2+3}\right\}\right] \qquad [2.3]$$

Finally, the extinction coefficient is calculated as the summation of both absorption and scattering coeffect.

$$Q_{e(pr)} = Q_s + Q_a \qquad [2.4]$$

As based on the equation m is considered to be the complex reflexive index of and I is the light intensity which can be calculated by Lambert–Beer approach. Since the scattering effect is considered to be negligible the extinction coefficient of the particle can be reduced as;

$$Q_{e(pr)} = \frac{3}{2} f_v \frac{Q_a}{D} \qquad [2.5]$$

Whereby f_v is the particle volume fraction, hence the whole extinction coefficient is calculated by adding the extinction coefficient of the base fluid and the nanoparticle. The base fluid is assumed as totally visible and infrared radiations are strongly absorbed by water. The following equation is used in order to obtain the extinction coefficient.

$$Q_{e(bf)} = \frac{4\pi k_{basefluid}}{\lambda} \qquad [2.6]$$

Where k is complex component of refractive index (Leong et al. 2016; Sajid Hossain et al. 2015).

As for the Maxwell–Garnett effective medium approach, this model is used to determine the complex refractive index of nanofluid. Once the dielectric constant of the nanofluids has been determined the components of the complex refractive index can be calculated by formulas stated in Maxwell-Garnett model. In this model the scattering effect is also considered negligible when the particle size is considered to be small. As mentioned by M. Sajid Hossain et al (Sajid Hossain et al. 2015), even the theory is developed for both metal and nonmetal nanofluids, it is best used for water-based graphite nanofluids. For both the water and oil based metal nanofluids and oil-based graphite nanofluids, the model deflection is much more than usual. As to Lambert-beer law the spectral transmissivity T can be calculated, which is transmitted light intensity over incident intensity. Whereby surface material transmittance is the effectiveness of transmitting radiant energy and internal transmittance refers to energy loss by absorption.

Lastly Mei scattering theory, as similar to Rayleigh scattering theory it mentions about theoretically calculating the absorption, scattering and extinction coefficients. But in contrary Mei scattering theory does not consider the particle size to be smaller than that of the incident wavelength but equal or larger, thus Mei and Gans scattering theory is much used when considering particle agglomeration (Song, Hatami, et al. 2016; Said et al. 2014).

2.2.2 Experimental Works

Besides developing theoretical models and predicting the physical quantities of nanofluids there are many research done experimentally investigate those physical properties. (Said et al. 2014) studied the optical properties of alumina oxide and Titania oxide nanofluids theoretically and experimentally. From his study, it can be deduced that TiO2 nanofluids are to have higher values of extinction coefficient and refractive index compared to Al2O3 nanofluids in the visible light region for all concentrations used in the study. As to having better result the drawback is TiO_2 is less stable in comparison.

A study done by (Menbari et al. 2016) in which the optical properties of a binary nanofluids, the combination of CuO and Al_2O_3 was performed experimentally using ethylene glycol as the base fluid. From the experiment, it was mentioned that the binary nanofluids have an extinction coefficient approximately equal to the sum of those of the constituent components. Finally, the extinction coefficient of the nanoparticles dispersed in the mixture of ethylene glycol–water is determined to be greater than that of ethylene glycol.

Another study on Al_2O_3 water based nanofluids was done by (Yousefi et al. 2012) in this work the experiment was done using a flat plate solar collector. The results show that, in comparison with water as absorption medium using nanofluids as working fluid has increased the efficiency of the flat plate collector. For 0.2 wt% of nanofluid the increased in efficiency was 28.3%.

Besides just observing the optical properties, (Karami et al. 2016) observed both the thermal and optical properties of nanofluids. In his study, nanofluids was prepared with a base fluid mixture of 70% water and 30% ethylene glycol. The experiment was carried out with manipulating the solution temperature and CuO volume fraction in the base fluid. The corresponding results shows that the nanofluids had a higher absorption coefficient compared to the base fluid for wavelength between 200nm to 2500nm. It was also mentioned by Karami that the fraction of energy absorbed with 0.01 vol% of CuO nanofluids is 4 times more than that of the base fluid at solar collector depth of 1 cm. As for the thermal conductivity its increase in value is proportional with the increase of volume fraction of CuO nanoparticles in the base fluid.

(Shende & Ramaprabhu 2016) also experimented on the thermo-optical properties of nanofluids by adding partially unzipped multiwalled carbon nanotubes (PUMWNTs) into water and EG. The results shows that the extinction coefficient of nanofluids showed great significant improvement as compared to the base fluids even at low volume concentration. As for the thermal improvement the results showed that the thermal conductivity of the samples with different volume fractions enhanced remarkably at 27% and 20.97% in water and EG respectively. Therefore it was concluded that PUMWNT nanofluids are found to be promising to be used in direct solar collector.

2.3 Application of nanofluids in solar system

Solar collectors are categorized in two types, those are non-concentrating and concentrating collectors. Non- concentrating solar collectors are usually used for low and medium temperature applications such as space heating and cooling, water heating, and desalination. While concentrating solar collectors are used in high temperature applications such as electricity generation. Although being able to generate adequate energy there are still room for improvements and one such way is by using Nanofluids. Nanofluid has shown to have a good ability in enhancing the efficiency of solar systems (Leong et al. 2016)

(HK et al. 2014) did a study on the efficiency of water base alumina nanofluids to be used for direct absorption solar collector at three flow rates. The flow rates were 1.5, 2 and 2.5 usgpm and the experiment was set as according to ASHRAE standard 93-86. The outcome of the experiment revealed that the optimum flow rate that produced maximum solar collector efficiency were 2.5 and 2.0 usgpm for water and nanofluids respectively.

(Yousefi et al. 2012) also used ASHRAE Standard 86-93 when experimenting on flat plate solar collector using nanofluids as the working fluid. Their experiment setup involved using an absorption area of 1.51m^2, copper for the internal pipe and the absorber surface and a 45 ° tilt angle for the flat plate during the testing. In this study the factors that were manipulated were the volume flow rate (1 to 3 l/min), mass fraction of alumina nanoparticles (0.2 % to 0.4 %) and the type of surfactant used in this study. In order to investigate the thermal performance of the collector, instantaneous efficiency for various combinations of incident radiation, ambient temperature and inlet fluid temperature were obtained. The experiment working fluid was set at steady and quasi steady state condition and the measurement was taken for the energy absorbed by the working fluid from solar radiation.

The author concluded that Triton X-100 was the preferable surfactant in terms of increasing the solar collector's performance. In addition, there was a 28.3% increase in solar collector performance when 0.2 wt% of alumina was used.

As for flat plat solar collector one challenging aspect that needs to be investigated is the sedimentation issues when nanoparticles were uses as the working fluid. (Colangelo et al. 2013) investigated the aspect of flat plat solar collector to reduce particle sedimentation. Their experiment involved the use of two flat panel solar collectors with transparent tubes, one similar to commercially available design, while the other was designed to have a constant velocity inside the bottom and top header. The experiment proved that flow velocity is the dominant factor in affecting the particle sedimentation problem. Therefore the modified design of the solar collector was proven to be the best as it was able to maintain the flow rate at the collector bottom and top header and consequently solving the particle sedimentation issue.

(Kasaeian, Daviran, et al. 2015) designed and manufactured a trough solar collector and tested it with carbon nanotube nanofluids suspended in oil with volume faction of 0.2 and 0.3 %. By running the experiment with 0.2 vol % of MWCNT nanoparticle suspended in oil it was shown that an enhancement of 4 to 5 % was achievable. When the concentration of MWCNT increased to 0.3% an enhancement of 5 to 7 % was recorded. Kasaeian concluded that the enhancement of the solar collector was mainly due to the improvement in heat transfer coefficient and thermal conductivity. This was in par with the formation of particle cluster and the effect of Brownian motion. The transmittance of energy is linked with the particle cluster formation and nano-convection is caused by the Brownian motion. It can be said that Brownian motion is significant when the fluid is moving rather than being static.

CHAPTER 3: RESEARCH METHODOLOGY

The research flow begins with the purchasing of the required precursor, those are alumina and titania nanoparticles together with the surfactant. Once the precursor has been obtained a stable and homogenized nanofluid suspension was prepared using the two step preparation method. Once a stable nanofluid suspension was prepared the optical properties which are the absorbance and transmittance values were measured. The optical properties of both types of nanofluids, alumina and titania nanofluids, was investigated and compared to determine their differences of the properties. The overview of the research methodology is presented in a flow diagram as seen in Fig. 3.1.

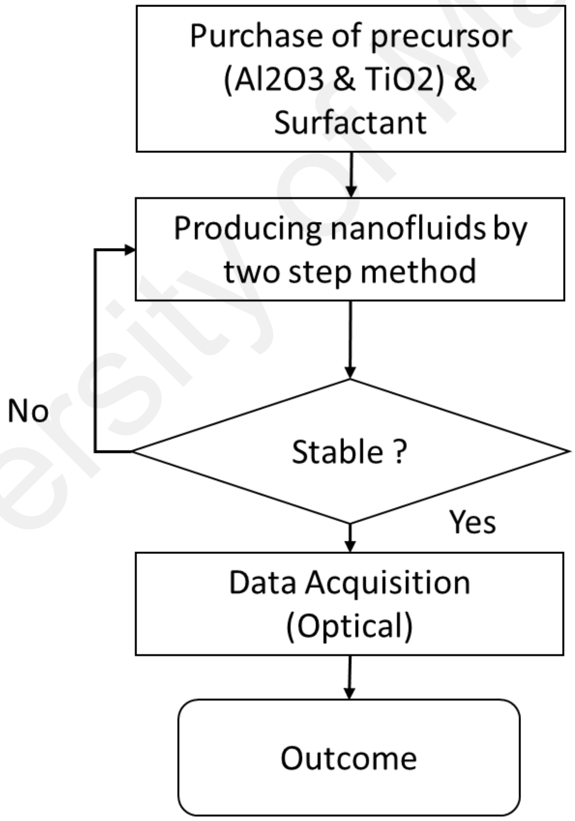

Figure 3-1 Research flow overview

3.1 Preparation of Nanofluids

3.1.1 Materials

The precursors used to prepare a stable nanofluid normally consist of the nanoparticle, a base fluid and surfactant. For this study the nanoparticles selected for investigation were spherical shape aluminum oxide ($A1_2O_{3)}$ with 99.8% trace metal basis with average size of 13nm and titanium dioxide (TiO_2) with 99.5% trace metal basis with average size of 21nm. Both materials were commercially available and was purchased from Sigma-Aldrich Malaysia. As for the base fluid, laboratory prepared distilled water was utilized. To insure the nanoparticles will be suspended in the base fluid homogeneously and stable thought the experimental period, polyvinylpyrrolidone (PVP) was used as the surfactant which was also purchased from Sigma-Aldrich.

3.1.2 Preparation of Samples

The two-step preparation method was adapted in the preparation of the titania and alumina nanofluids. Initially nanoparticles with volume concentration ranging from 0.02% to 0.1% were disbursed in 100ml of distilled water, followed by adding a 1:2 weight ratio of surfactant. The suspension was then stirred using a magnetic stirred for 5min before ultrosnicated in a high power ultrasonic probe. The ultrasonic time was set at 40min and the frequency was set at 50Hz with a pulse of 3:2 (3 second vibrate & 2 second rest. Figure 3.2 describes the flow of the sample preparation and the volume concentration of the sample was determined from equation 3.1

The prepared samples were then measured for their pH values using a pH meter and later on visually observed for its stability for a period of 3 weeks. The stability of the samples were documented by capturing pictures of the sample in a weekly basis from the date of the sample preparation.

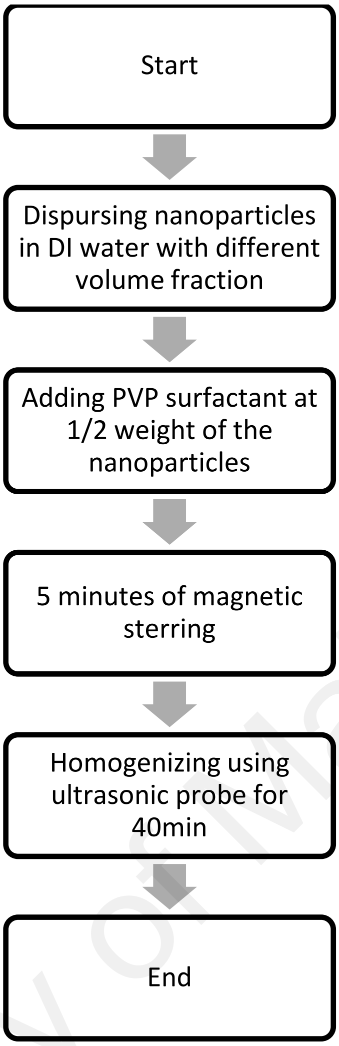

Figure 3-2 : Sample preparation flow.

$$\text{Volume Concentration (vol\%)} = \frac{{W_p}/{\rho_p}}{\left({W_p}/{\rho_p}\right)+\left({W_{bf}}/{\rho_{bf}}\right)} \tag{3.1}$$

Where w represents the mass in kg and ρ is the material density in kg·m$^{-3.}$ The subscripts p represents the nanoparticle while bf is for the base fluid. The density of the titanium dioxide and aluminum oxide is taken as 4260 kg·m^{-3} and 3950 kg·m^{-3}, respectively.

3.2 Optical Measurement

The absorbance and transmittance were measured by using a UV–Vis spectrophotometer (SPEKOL 1500). The solar spectrum consist of EM radiation of ultraviolet with wavelength from 290 to 380 nm, visible with wavelength from 380 to 780 nm, and infrared with wavelength 780 to 2500 nm. As for application of solar thermal systems most of the energy absorbed (98%) lies within the visible and infrared region. Thus, only the wavelength between 320nm to 1100nm was considered in the present study. The measurements were taken at a constant room temperature of 25 °C. The UV-Vis spectrophotometer utilized consisted of 2 cuvettes as it used a double-beam photometric system. One acted as a reference (filled with base fluid), and another cuvette was filled with the sample (nanofluid). Baseline correction was performed using distilled water to the measurement to eliminate noise and improve the accuracy of the measurement. Figure 3.2 shows the UV-spectrometer used in this study.

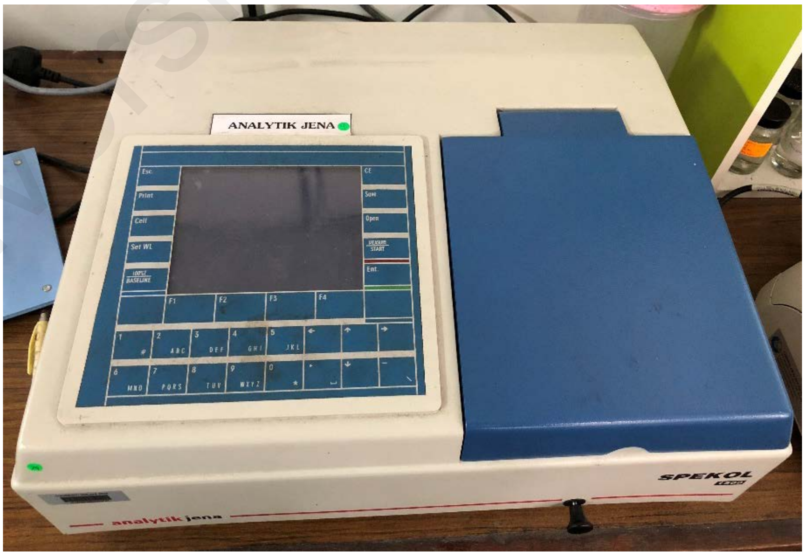

Figure 3-3 : UV-Vis spectrometer

CHAPTER 4: EXPERIMENTAL RESULTS AND DISUCSSION

4.1 Nanofluids stability results

As soon after the samples were prepared the pH were measured and tabulated as shown in table 4.1. The pH value can help to indirectly indicate the isoelectric point (IEP) of the nanoparticles. The IEP point is where the nanofluids zeta potential becomes zero and the suspension loses its stability (Mahian et al. 2013). A fluid that has zeta potential value further way from zero, the fluid can be stable for a period of time, when the value comes close to zero it becomes unstable leading to agglomeration and sedimentation. Thus measuring the pH values is one way to indicate the IEP of the sample.

Although stable once prepared the samples will eventually form sedimentation due to the loss in its repulsive force. This happens as the suspended nanoparticles loses its zeta potential and tends to agglomerate with other nanoparticles, it can also be mentioned in a way when the particles Brownian motion gives way to the Van der Waals force of attraction, the particles will then agglomerate and begin the sediment (Said et al. 2014). Figure 4.1 to 4.4 shows the changes in stability over time for the titania nanofluids and Figure 4.5 to 4.8 shows the changes in the stability over time for the alumina nanofluids.

Table 4.1 pH values of prepared samples

Titania Nanofluids			**Alumina Nanofluids**		
Sample name	Volume concentration (vol %)	pH Value	Sample name	Volume concentration (vol %)	pH Value
T1	0.02	6.8	A1	0.02	6.0
T2	0.04	7.1	A2	0.04	6.8
T3	0.06	7.5	A3	0.06	6.4
T4	0.08	7.3	A4	0.08	6.6
T5	0.1	8.5	A5	0.1	7

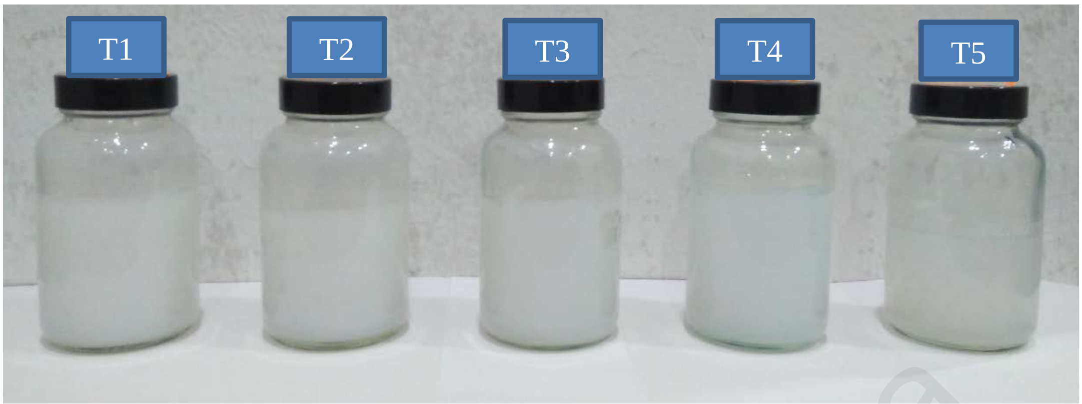

Figure 4-1 TiO_2 Nanofluids on the day of sample preparation.

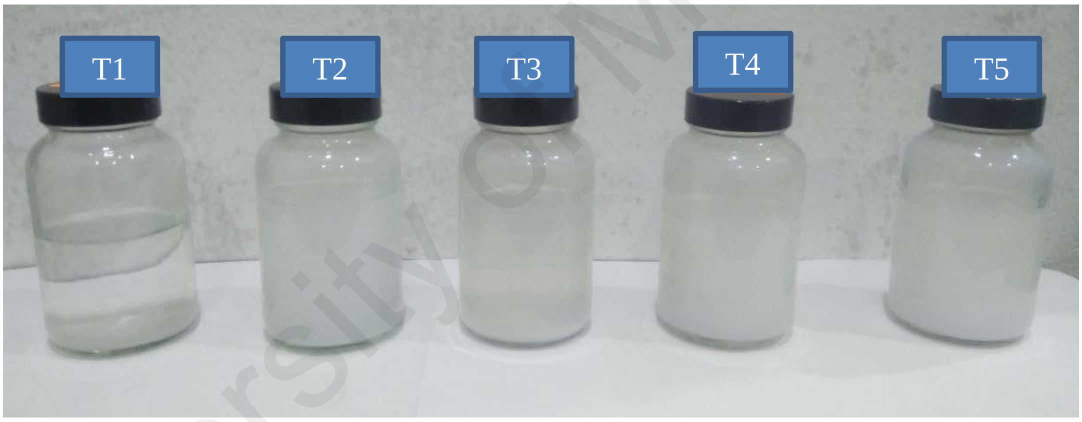

Figure 4-2 TiO_2 Nanofluids one week after sample preparation.

Figure 4-3 TiO_2 Nanofluids two weeks after sample preparation.

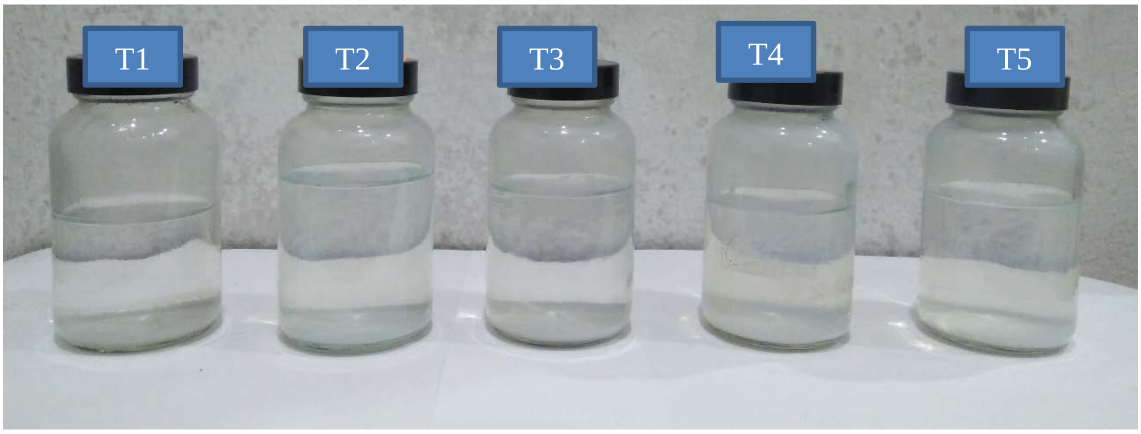

Figure 4-4 TiO_2 Nanofluids three weeks after sample preparation.

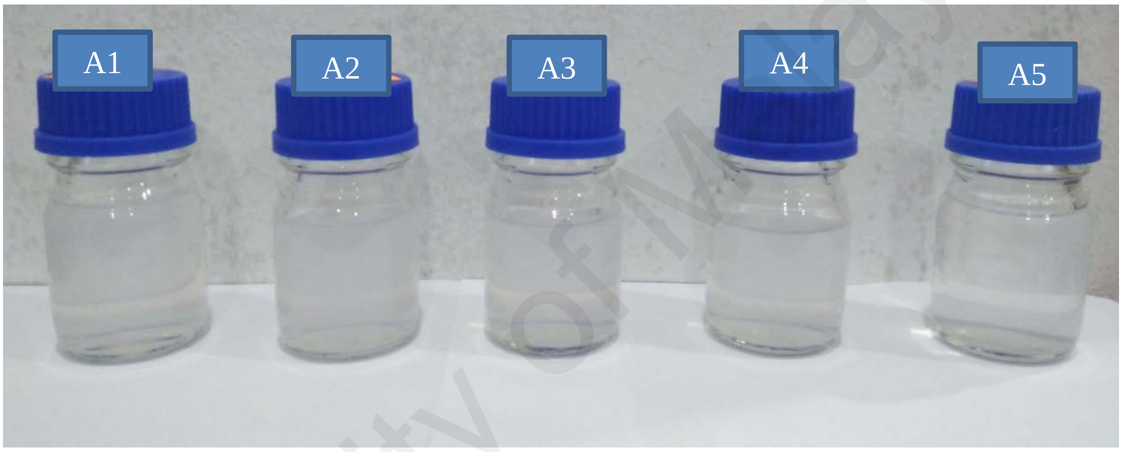

Figure 4-5 Al_2O_3 on the day of sample preparation.

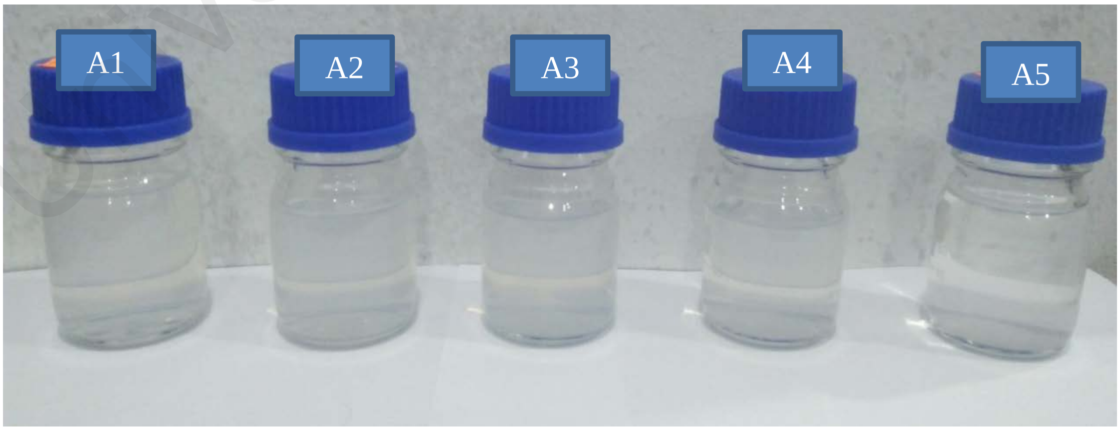

Figure 4-6 Al_2O_3 on week after sample preparation.

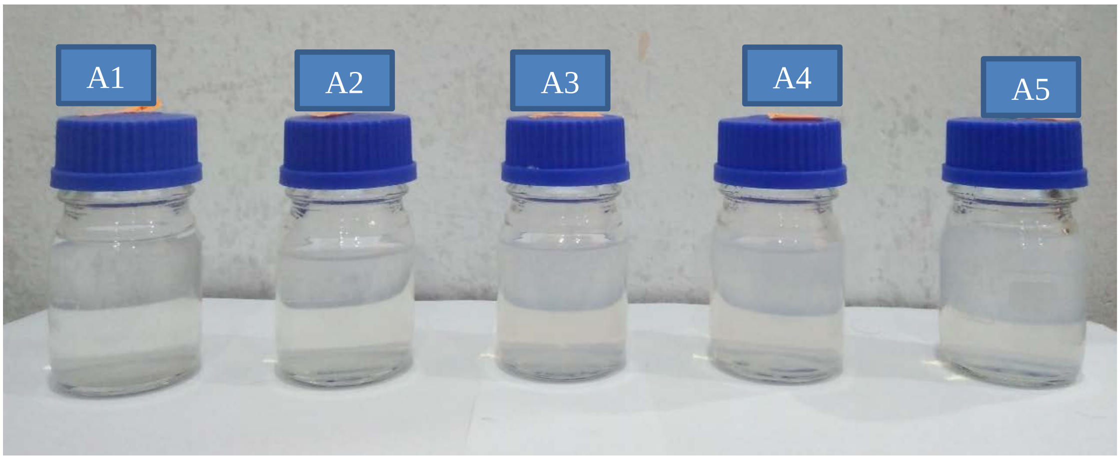

Figure 4-7 Al_2O_3 two week after sample preparation.

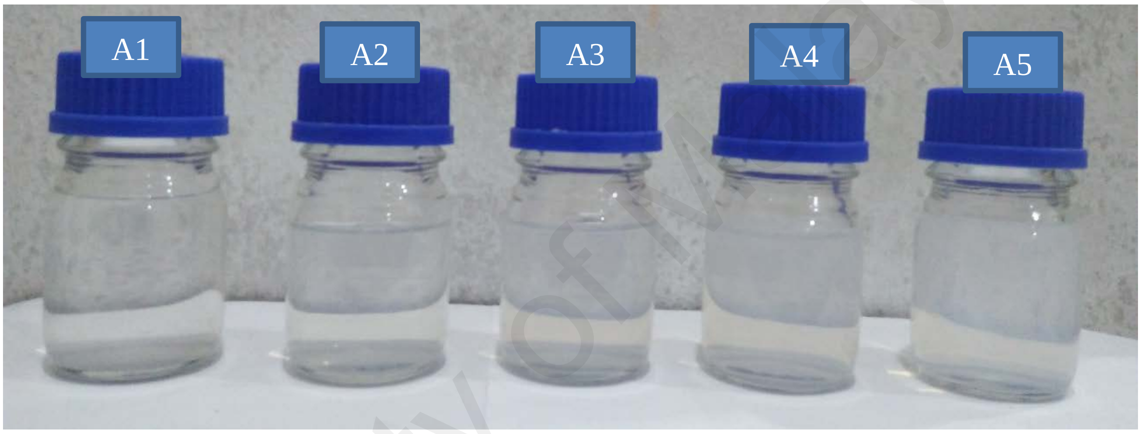

Figure 4-8 Al_2O_3 three week after sample preparation.

All samples were prepared using the same surfactant, polyvinylpyrrolidone (PVP) with an ultra-sonication time of 40min at 50Hz. The results shows that the samples were able to be stable for a duration of one week before sedimentation started to form. Based on the figures above it can be observed that for titania nanofluids, the sedimentation of particles began at one week after sample preparation. As for the alumina nanofluids sedimentation of particles began after two weeks of sample preparation, showing with few levels of particle deposits at the bottom.

Based on results obtained its observed that sample no T5 with a pH value of 8.5 was the first sediment after one week of sample preparation, followed by T3 which had a pH of 7.5 formed sediments one weeks after sample preparation and fully settled on the second week . Sample no T2 and T4 with similar pH values of 7.1 and 7.3 formed full sedimentation at week three and lastly sample no T1 completely settled on the fourth week and it has a pH value of 6.8. The change in the pH values is due to the adding of surfactant, PVP which has a pH between 7 and 9 would have caused the pH to shift to become more alkaline. Moreover the surfactant was added based on weight percentage therefore T5 has the higher value of surfactant causing it to have a more alkaline pH. Also (Leong et al. 2017) mentioned that titania nanofluids samples prepared with PVP as the surfactant have the weakest zeta potential and tend to sediment quickly. She also mentioned that samples that has a pH 5 showed a better stability then samples with pH 9.

As for alumina nanofluids based samples no sediments were formed on the first week of sample preparation and only sample A5 formed slight sediments after the second week of sample preparation. Throughout the experiment period the Alumina nanofluids sample remained consistent for the whole period of investigation. The pH of A5 was measured to be at pH 7. While other samples had its pH ranging from 6.0 to 6.8. (Kumar & Amirtham 2016) mentioned that a stable alumina nanofluids suspension can be achieved when the pH is set around 3.5 to 5. Based on (Leong et al. 2017) the selection of the type of surfactant determines the stability of the suspension, from her study PVP based nanofluids were not preferred as the zeta potential value is close to zero. Moreover it was also reported that samples without surfactant shows better stability compared to samples with surfactant. Therefore in this study sample A5 was considered to be the least stable sample as it contained higher amount of PVP from the other samples.

Although prepared with the same method it can be observed that the sedimentation of the nanoparticles does not correlate with the volume concentration of the disbursed nanoparticles as its pH value is the factor that determine its stability (Devendiran & Amirtham 2014). Moreover, when comparing the nanofluids suspension it can be observed that the titania nanofluids produce a cocky suspension compared to the alumina nanofluids whereby the solution is much clear in nature. The visual differences in its transparency can give an insight about its optical behavior of the solutions, it can be postulated that the titania nanofluid will generate a much lower transmittance results compared to the alumina nanofluids as light can’t pass though the medium effectively.

4.2 Optical properties results

The optical properties that was recorded and compared in this experiment was the light absorbance and light transmittance properties. Both of this properties to certain level can be mentioned that are inversely proportional to each other. As light is passed through a medium its path of direction if no obstacles it would create a straight path with 100% light transmittance but if there are obstacles on the light part, the direction would be refracted and reflected with certain portion of the light energy absorbed into the medium.

Distilled water is considered to be a pure medium with no particles suspension, therefore when light is passed through it all will be transmitted with zero absorption. In order to calibrate the equipment and verify its generated results a sample test was carried out using water. The results of the experiment is as shown in figure 4.9 and figure 4.10. Based on the result it can be concluded that light as the ability to transmit light fully with nearly zero absorption (Leong et al. 2017).

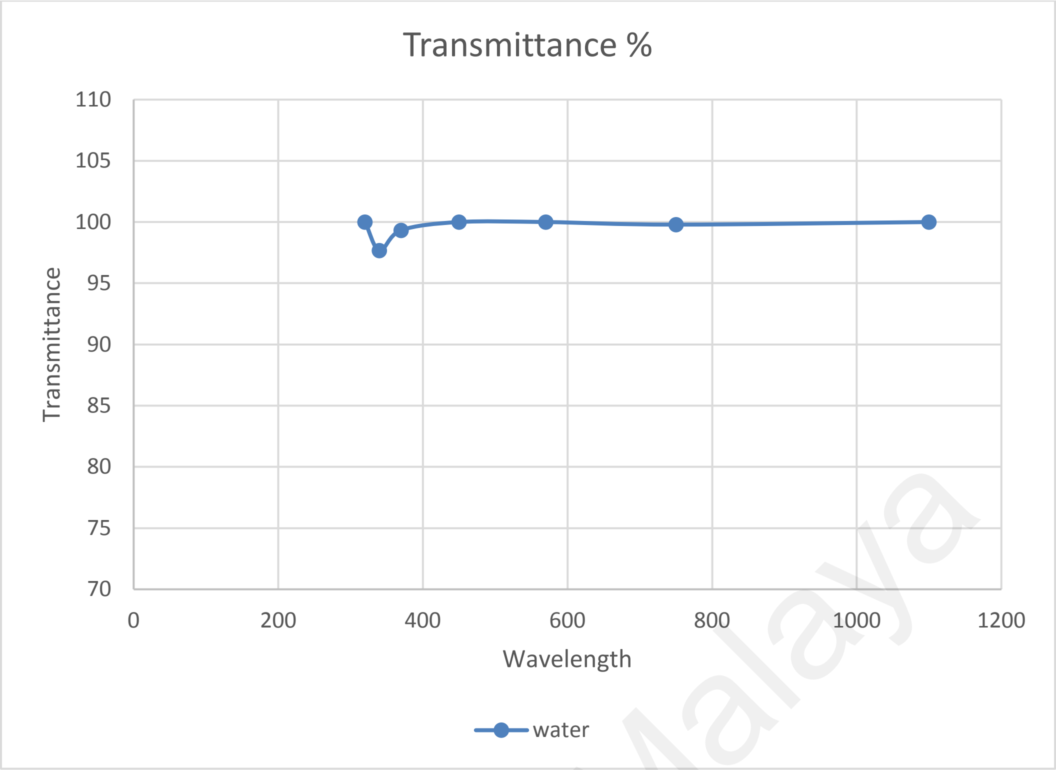

Figure 4-9 Light Transmittance of Water

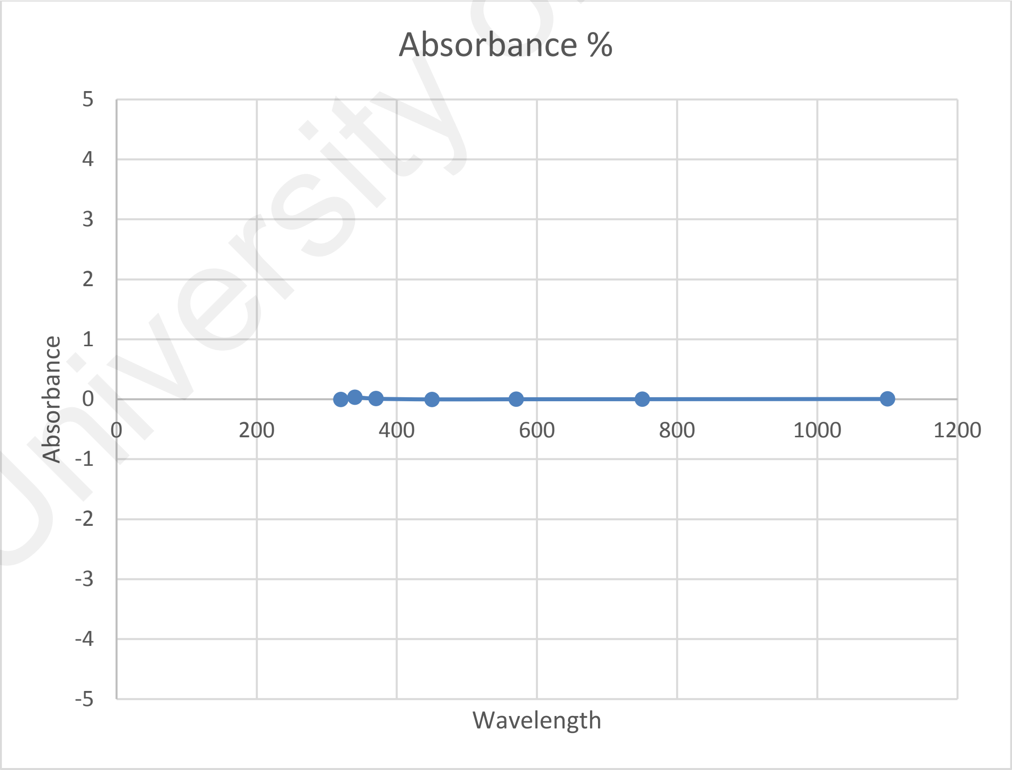

Figure 4-10 Light Absorbance of Water

4.2.1 Absorbance of light result

Absorbance signifies the ability of a medium to absorb energy propagated through the electromagnetic spectrum. Light energy prominently generated during nuclear fusion of the sun can be harnessed using solar thermal devices. Table 4.1 and 4.2 tabulates the results for the light absorbance of titania nanofluids and alumina nanofluids respectively. In addition figure 4.11 shows the absorbance results of titania nanofluids and figure 4.12 shows the absorbance of alumina nanofluids. Both the graphs illustrates the increase in absorbance percentage as the value of the wavelength decreases. Moreover when comparing the results from the tables it can be deduced that titania based nanofluids have a higher value of absorbance when compared with alumina based nanofluids. It also can be deduced from the results that as the percentage of nanoparticle concentration increases the absorbance percentage increases.

From the prepared samples, titania nanofluids absorbance peaked at 500nm for particle concentration 0.1% and 0.8% as for concentration 0.6% the peak absorbance was reported to be at 450nm. As for sample with concentration of 0.4% and 0.02% the peak was recorded to be at 370nm. As for the findings between the particle loading and the optical absorbance, at longer wavelength the rate of absorbance is proportional to the particle loading. The concentration increases so does the absorbance but as the wavelength approaches 400nm the absorbance rate showed nearly similar results for all sample concentration except for 0.02%. It is recorded that the highest absorbance value that can be achieved is 1.85% for particle loading of 0.1% Titania nanoparticle. In addition at 320nm wavelength all samples showed a spike in reading.

As for alumina nanofluids absorbance peaked at 370nm for all particle concentration and the findings between particle loading and the optical absorbance, it’s reported that the values are proportional to each other for all wavelength. As for the absorbance for sample concentration of 0.4%, 0.6% and 0.8% the values are nearly similar with less deviation. It is recorded that the highest absorbance value that can be achieved is 0.36 % for particle loading of 0.1% alumina nanoparticle. In addition at 320nm wavelength all samples showed a steep drop in reading.

These finding were as similar as reported by (Said et al. 2014). Based on their finding it was concluded that titania showed better response then alumina nanofluids. Besides Said et al (Leong et al. 2017) also reported the same trend in light absorption of both the nanofluids. In their report it was recorded that titania nanofluid at 0.01 vol% was able to achieve above 3.0 light absorbance at 400nm while the outcome of this experiment showed the maximum that was able to be achieved was 1.7 light absorbance at 450nm for titania of 0.1 vol %. In addition it is mentioned that theoretically as the concentration increases the yield of absorbance will also increase. As more particles are added the additional area is exposed to the light beam eventually leading to more light energy to be absorbed (Said et al 2014)

Moreover their results showed that both the nanofluids had increased absorption criteria at low wavelength. The wavelength that observed increase in absorption was at 550nm to 400nm (Leong et at. 2017) similarly in this experiment observed a steep rise in absorption when the wavelength was at 600nm and peaked at 400nm before showing a deep in measurement. 400mn in wavelength is the border region between ultraviolet radiation and visible light boundary, therefore it can be mentioned that the nanofluids have better absorbance at shorter wavelength then to longer wavelength. This corresponding value can be closely to the wavelength intensity (Song et al 2016).

Table 4.2 Absorbance of Titania Nanofluids

Wavelength	*0.02 % TiO2*	*0.04 % TiO2*	*0.06 % TiO2*	*0.08 % TiO2*	*0.1 % TiO2*
1100	0.049	0.127	0.237	0.248	0.295
1000	0.048	0.155	0.275	0.308	0.366
950	0.067	0.195	0.333	0.394	0.455
850	0.058	0.257	0.426	0.481	0.576
750	0.086	0.339	0.556	0.691	0.829
700	0.097	0.418	0.676	0.844	1.032
600	0.12	0.629	0.963	1.286	1.493
570	0.132	0.718	1.084	1.413	1.591
520	0.15	0.963	1.381	1.735	1.853
450	0.183	1.254	1.54	1.654	1.713
370	0.275	1.557	1.475	1.452	1.393
340	0.215	0.724	0.649	0.568	0.591
320	0.257	2.147	2.04	1.958	1.963

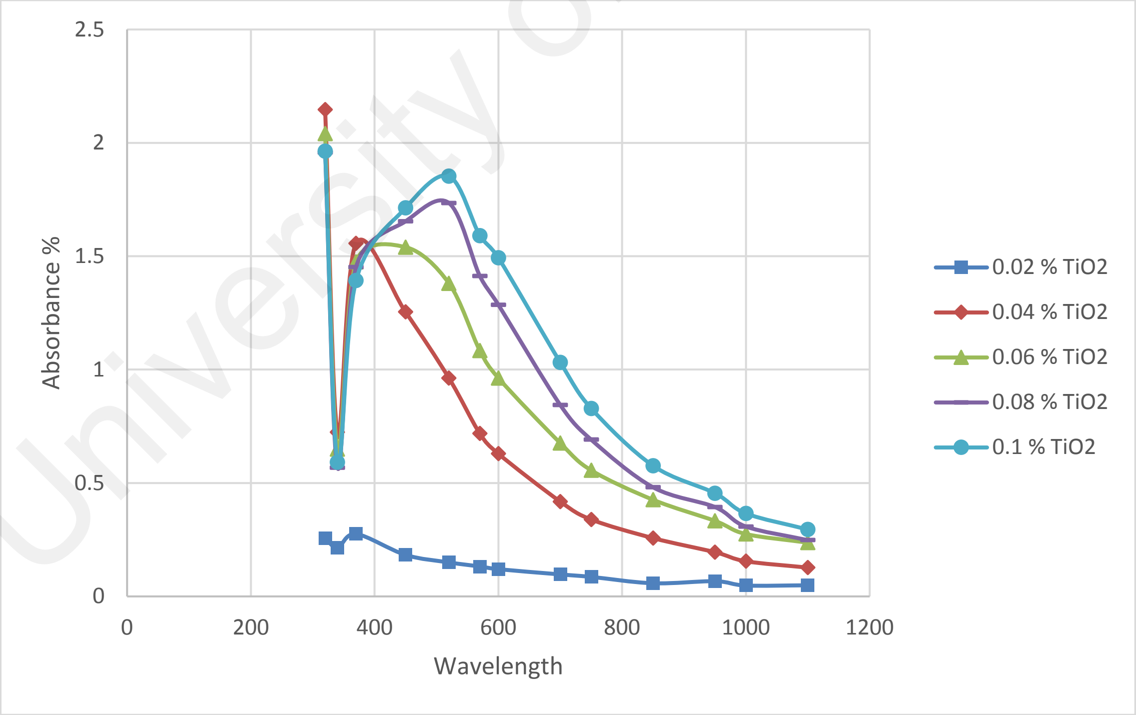

Figure 4-11 Light absorbance of Titania Nanofluid

Table 4.3 Absorbance of Aluminia Nanofluids

Wavelength	*0.02 % AlO2*	*0.04 % AlO2*	*0.06 % AlO2*	*0.08 % AlO2*	*0.1 % AlO2*
1100	0.015	0.026	0.006	0.02	0.031
1000	0.017	0.031	0.013	0.026	0.04
950	0.019	0.034	0.017	0.03	0.044
850	0.021	0.04	0.027	0.041	0.057
750	0.025	0.048	0.04	0.054	0.069
700	0.031	0.052	0.05	0.065	0.078
600	0.037	0.068	0.076	0.089	0.104
570	0.039	0.072	0.086	0.102	0.112
520	0.05	0.091	0.124	0.136	0.143
450	0.069	0.122	0.171	0.194	0.195
370	0.141	0.217	0.318	0.341	0.362
340	0.15	0.219	0.261	0.305	0.351
320	0	0	0	0	0

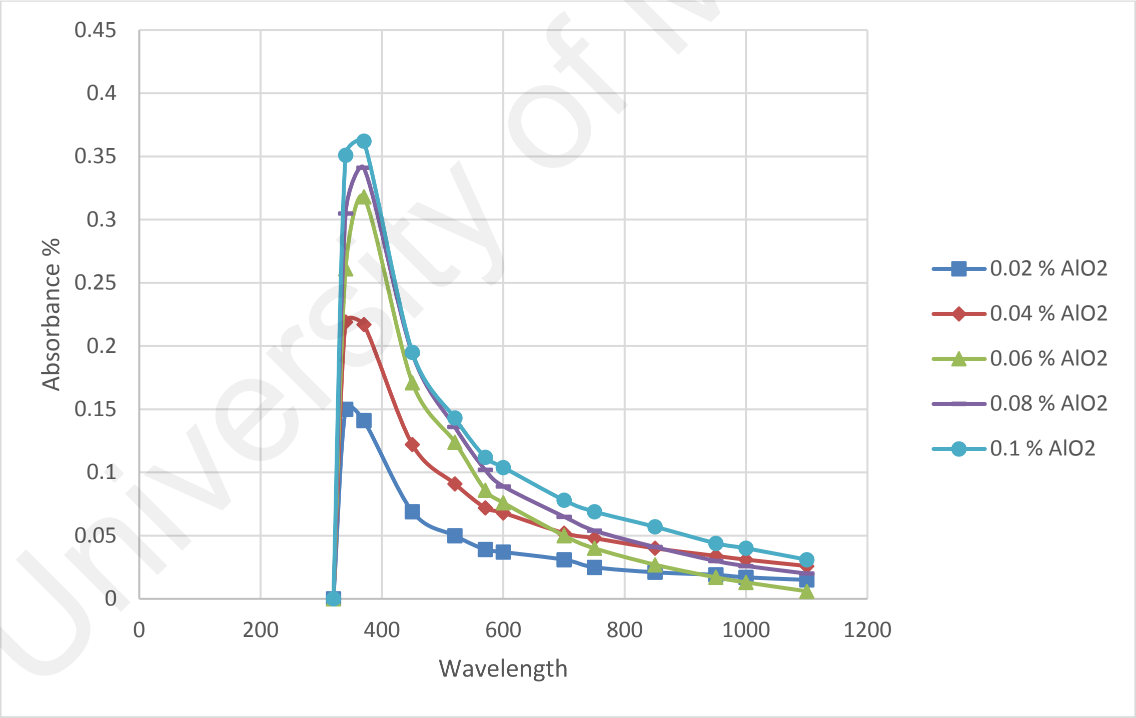

Figure 4-12 Light absorbance of Titania Nanofluid

4.2.2 Transmittance of light results

The transmittance denotes as how much light is transmitted when it travels through a medium. Absorbance and transmittance are intertwined with each other in a way when one increases in value the other decreases. Although closely related, the sum of both does not give the total incident light. Table 4.3 and 4.4 tabulates the results for the light transmittance of titania nanofluids and alumina nanofluids respectively. In addition figure 4.13 shows the transmittance results of titania nanofluids and figure 4.14 shows the transmittance of alumina nanofluids. Both the graphs illustrates the decreases in transmittance percentage as the value of the wavelength decreases. Moreover when comparing the results from the tables it can be deduced that titania based nanofluids have a lower value of transmittance when compared with alumina based nanofluids. It also can be deduced from the results that as the percentage of nanoparticle concentration increases the transmittance percentage decreases.

From the prepared sample titania nanofluid showed poor transmittance characteristic. The transmittance values decreased as the wavelength becomes shorter. As for the particle concentration and the corresponding transmittance value, it’s illustrated that as the particle loading increases the amount of light transmitted becomes lesser. At 370nm all samples showed a spike in reading except for sample concentration of 0.02%. In contrary the sample showed further decrease in value before spiking at 320nm.

As for alumina nanofluids, the transmittance characteristic showed a better result than titania nanofluid. When comparing the results between the both types of nanofluids it can said that titania nanofluids transmittance ranged from 85% to 0% and for alumina nanofluid the transmittance had a higher value with ranged from 90% to 40%. Similarly particle loading also effected the transmittance of light though Alumina nanofluids. Lower the concentration the better the transmittance. As for volume concentration of

0.4%, 0.6% and 0.8% of Alumina nanoparticles the transmittance value had close proximity to each other in the values collected. It is recorded that the highest transmittance value that can be achieved is 97.79% for particle loading of 0.02% Alumina nanoparticle. In addition at 320nm wavelength all samples showed a steep rise in reading.

The finding shows that titania nanofluids has a poorer transmittance capability compared to alumina nanofluid which implies that it has a better optical properties, as not much light can pass though the medium.

Table 4.4 Transmittance of Titania Nanofluids

Wavelength	*0.02 % TiO2*	*0.04 % TiO2*	*0.06 % TiO2*	*0.08 % TiO2*	*0.1 % TiO2*
1100	85.22	71.62	55.83	54.09	48.68
1000	84.7	66.98	50.48	47.32	41.61
950	83.2	63.05	45.54	40	35.17
850	80.66	54.91	37.01	29.39	24.74
750	78.21	44.51	26.8	19.49	14.44
700	76.45	38.21	20.27	13.88	8.93
600	71.79	22.53	10.11	4.77	2.98
570	69.75	18.36	7.76	3.45	2.34
520	65.56	10.5	4	1.7	1.28
450	60.45	5.26	2.64	1.97	1.75
370	48.13	1.56	2.07	2.39	2.81
340	43.53	11.09	12.07	16.83	19.01
320	49.56	0.5	0.58	0.73	0.76

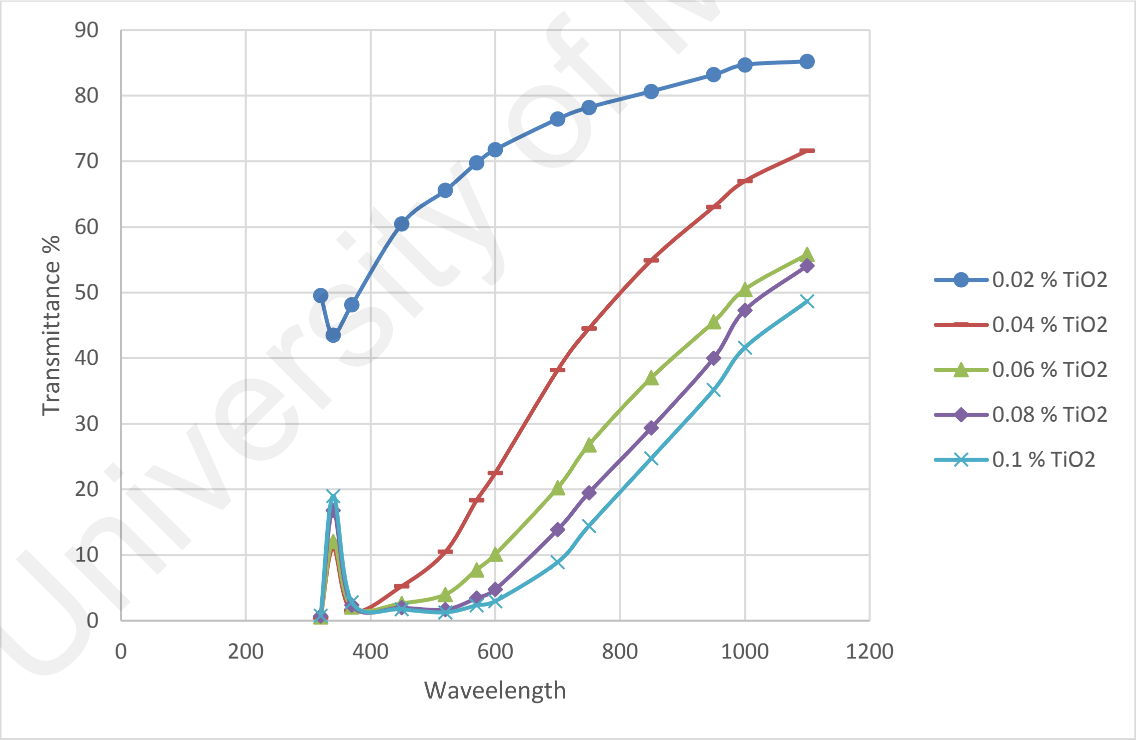

Figure 4-13 Light transmittance of Titania Nanofluid

Table 4.5 Transmittance of Alumina Nanofluids

Wavelength	*0.02 % AlO2*	*0.04 % AlO2*	*0.06 % AlO2*	*0.08 % AlO2*	*0.1 % AlO2*
1100	97.79	95.48	92.79	93.68	90.11
1000	96.68	95.09	92.06	92.61	89.05
950	96.04	95.03	91.86	91.74	88.46
850	94.61	94.39	90.3	90.24	86.21
750	93.84	91.3	88.76	87.13	83.84
700	93.12	88.94	87.4	85.07	82.25
600	91.43	84.42	83.62	79.5	76.61
570	90.52	83.32	81.45	77.71	75.02
520	88.36	79.33	75.76	71.89	70.5
450	84.82	74.33	66.9	63.09	62.43
370	71.8	59.48	47.55	44.36	42.47
340	60.62	51.8	44.25	44.4	39.9
320	100	100	100	100	100

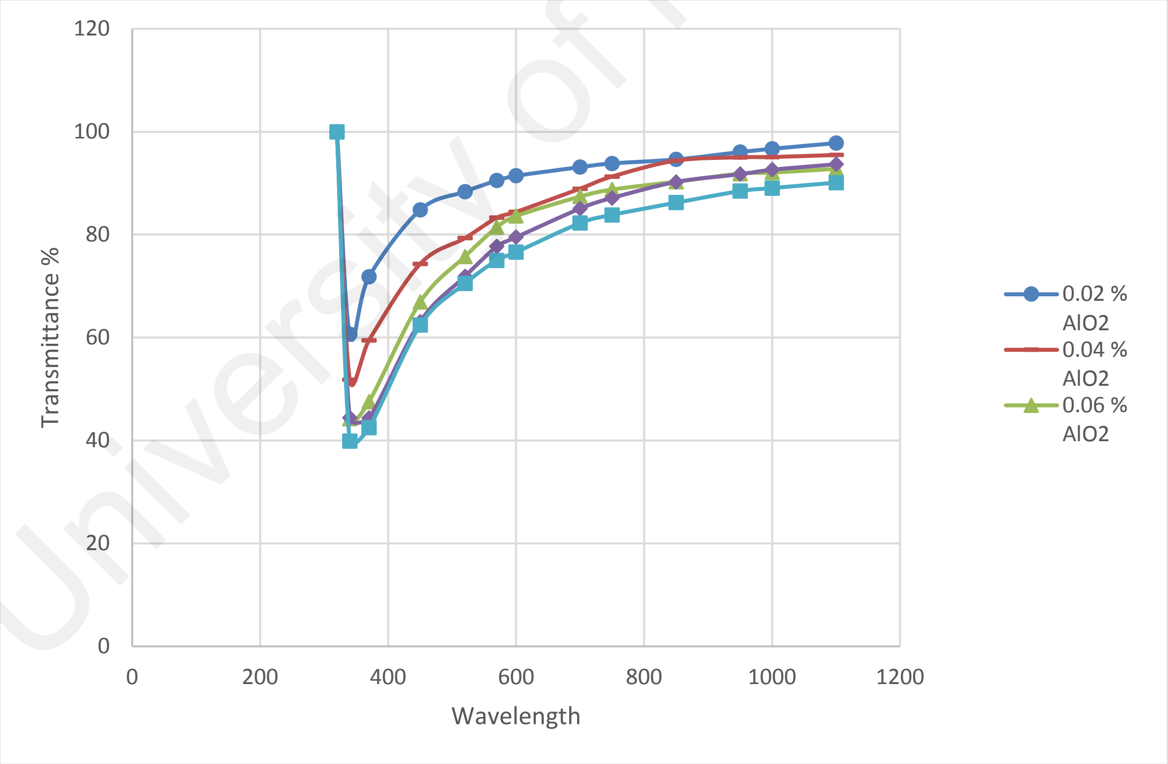

Figure 4-14 Light transmittance of Aluminia Nanofluid

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study the optical properties of titania and alumina nanofluids were investigated. The samples were produced using two step preparation method and PVP was used as the surfactant. The samples were prepared with different volume concentration ranging from 0.02 vol% to 0.1 vol%.

There are two major conclusions that can be drawn from this study, one being that alumina based nanofluids tend to have a better stability in comparison to titania based nanofluids. This was concluded based on the images taken thought the 3 weeks of sample observation. From the images it was seen that alumina nanofluids samples were still suspended even after 3 weeks of sample preparation. The prepared samples had pH values ranging from 6 to 7 stating that the zeta potential is further away from the IEP.

The other major conclusion that was drawn from this experiment was that titania nanofluids had a better solar absorbance results when compared to alumina nanofluid. At particle concentration of 0.1 vol% the titania based nanofluid was able to absorb a total of 1.853 % of the incident light. Meanwhile alumina nanofluid was able to absorb 0.362 % of the incident light, making a difference of 1.491%. Therefore titania nanofluid would be a preferred solution to use in a solar thermal collector as it has the ability to harness more energy from the light spectrum.

5.2 Recommendation and future works

As recommendation, a further study can be carried out on improving the stability of titania based nanofluids. Studies such as using different types of surfactant or pH manipulation can be carried out to determine the best method to produce a longer stable titania nanofluids. Moreover, RSM can be utilized to enhance the optical property of the nanofluids. Based on the result outcome the absorbance of light is proportional to practical loading in the base fluid but other factors can to be included to determine the best values of light absorption that can be achieved. Factors such as temperature change, choice of surfactant can be factors to be included to produce an optimize nanofluid for solar thermal application. As for future works, experiments can be carried out using titania nanofluids in flat bed solar thermal collator to investigate the total amount of solar energy it can absorb with different particle loading and compare the result with water.

REFERENCES

Ahmad, S.H.A. et al., 2017. Optical properties of various nanofluids used in solar collector: A review. *Renewable and Sustainable Energy Reviews*, 73(October 2016), pp.1014–1030. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032117301843.

Ayompe, L.M. & Duffy, a., 2013. Analysis of the thermal performance of a solar water heating system with flat plate collectors in a temperate climate. *Applied Thermal Engineering*, 58(1–2), pp.447–454. Available at: http://www.sciencedirect.com/science/article/pii/S1359431113003335.

Colangelo, G. et al., 2013. A new solution for reduced sedimentation flat panel solar thermal collector using nanofluids. *Applied Energy*, 111, pp.80–93. Available at: http://dx.doi.org/10.1016/j.apenergy.2013.04.069.

Devendiran, D.K. & Amirtham, V.A., 2014. A review on preparation methods and challenges of nano fl uids ☆. , 54, pp.115–125.

Esmaeilzadeh, E. et al., 2013. Experimental investigation of hydrodynamics and heat transfer characteristics of γ-Al2O3/water under laminar flow inside a horizontal tube. *International Journal of Thermal Sciences*, 63, pp.31–37. Available at: http://www.sciencedirect.com/science/article/pii/S1290072912001925.

HK, G., GD, A. & Mathur, J., 2014. Effect of Al 2 O 3 -H 2 O nanofluid concentration on heat transfer in a loop heat pipe. , 5, pp.1–10.

Jung, J.Y., Kim, E.S. & Kang, Y.T., 2012. Stabilizer effect on CHF and boiling heat transfer coefficient of alumina/water nanofluids. *International Journal of Heat and Mass Transfer*, 55(7–8), pp.1941–1946.

Kameya, Y. & Hanamura, K., 2011. Enhancement of solar radiation absorption using nanoparticle suspension. *Solar Energy*, 85(2), pp.299–307. Available at: http://dx.doi.org/10.1016/j.solener.2010.11.021.

Karami, M. et al., 2016. Thermo-optical properties of copper oxide nanofluids for direct absorption of solar radiation. *Solar Energy Materials and Solar Cells*, 144, pp.136–142. Available at: http://dx.doi.org/10.1016/j.solmat.2015.08.018.

Kasaeian, A., Daviran, S., et al., 2015. Performance evaluation and nanofluid using capability study of a solar parabolic trough collector. *Energy Conversion and Management*, 89, pp.368–375. Available at: http://dx.doi.org/10.1016/j.enconman.2014.09.056.

Kasaeian, A., Eshghi, A.T. & Sameti, M., 2015. A review on the applications of nanofluids in solar energy systems. *Renewable and Sustainable Energy Reviews*, 43, pp.584–598. Available at: http://dx.doi.org/10.1016/j.rser.2014.11.020.

Kathiravan, R. et al., 2010. Preparation and pool boiling characteristics of copper nanofluids over a flat plate heater. *International Journal of Heat and Mass Transfer*, 53(9–10), pp.1673–1681. Available at:

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2010.01.022.

Kumar, D. & Amirtham, V.A., 2016. A review on preparation , characterization , properties and applications of nano fl uids. *Renewable and Sustainable Energy Reviews*, 60, pp.21–40.

Lamas, B. et al., 2012. Assessing colloidal stability of long term MWCNT based nanofluids. *Journal of Colloid and Interface Science*, 381(1), pp.17–23. Available at: http://dx.doi.org/10.1016/j.jcis.2012.05.014.

Leong, K.Y. et al., 2016. An overview on current application of nanofluids in solar thermal collector and its challenges. *Renewable and Sustainable Energy Reviews*, 53, pp.1092–1105. Available at: http://dx.doi.org/10.1016/j.rser.2015.09.060.

Leong, K.Y. et al., 2017. Investigation on Stability and Optical Properties of Titanium Dioxide and Aluminum Oxide Water-Based Nanofluids. *International Journal of Thermophysics*, 38(5), p.77. Available at: http://link.springer.com/10.1007/s10765-017-2218-6.

Lomascolo, M. et al., 2015. Review of heat transfer in nano fl uids : Conductive , convective and radiative experimental results. *Renewable and Sustainable Energy Reviews*, 43, pp.1182–1198. Available at: http://dx.doi.org/10.1016/j.rser.2014.11.086.

Longo, G.A. & Zilio, C., 2011. Experimental measurement of thermophysical properties of oxide-water nano-fluids down to ice-point. *Experimental Thermal and Fluid Science*, 35(7), pp.1313–1324.

Mahian, O. et al., 2013. A review of the applications of nanofluids in solar energy. *International Journal of Heat and Mass Transfer*, 57(2), pp.582–594. Available at: http://dx.doi.org/10.1016/j.ijheatmasstransfer.2012.10.037.

Menbari, A., Alemrajabi, A.A. & Ghayeb, Y., 2016. Experimental investigation of stability and extinction coefficient of Al2O3-CuO binary nanoparticles dispersed in ethylene glycol-water mixture for low-temperature direct absorption solar collectors. *Energy Conversion and Management*, 108, pp.501–510. Available at: http://dx.doi.org/10.1016/j.enconman.2015.11.034.

Noghrehabadi, A., Hajidavaloo, E. & Moravej, M., 2016. Experimental investigation of efficiency of square flat-plate solar collector using SiO2/water nanofluid. *Case Studies in Thermal Engineering*, 8, pp.378–386.

Rose, B.A.J. et al., 2017. Investigations into nanofluids as direct solar radiation collectors. , 147, pp.426–431.

Said, Z., Saidur, R. & Rahim, N.A., 2014. Optical properties of metal oxides based nanofluids. *International Communications in Heat and Mass Transfer*, 59, pp.46–54. Available at: http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.10.010.

Saidur, R. et al., 2012. Evaluation of the effect of nanofluid-based absorbers on direct solar collector. *International Journal of Heat and Mass Transfer*, 55(21–22), pp.5899–5907. Available at:

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2012.05.087.

Sajid Hossain, M. et al., 2015. Spotlight on available optical properties and models of nanofluids: A review. *Renewable and Sustainable Energy Reviews*, 43, pp.750–762.

Shende, R.C. & Ramaprabhu, S., 2016. Thermo-optical properties of partially unzipped multiwalled carbon nanotubes dispersed nanofluids for direct absorption solar thermal energy systems. *Solar Energy Materials and Solar Cells*, 157, pp.117–125. Available at: http://dx.doi.org/10.1016/j.solmat.2016.05.037.

Song, D., Wang, Y., et al., 2016. Investigation and prediction of optical properties of alumina nanofluids with different aggregation properties. *International Journal of Heat and Mass Transfer*, 96, pp.430–437. Available at: http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.01.049.

Song, D., Hatami, M., et al., 2016. Prediction of hydrodynamic and optical properties of TiO2/water suspension considering particle size distribution. *International Journal of Heat and Mass Transfer*, 92, pp.864–876. Available at: http://dx.doi.org/10.1016/j.ijheatmasstransfer.2015.08.101.

Su, F., Ma, X. & Lan, Z., 2011. The effect of carbon nanotubes on the physical properties of a binary nanofluid. *Journal of the Taiwan Institute of Chemical Engineers*, 42(2), pp.252–257. Available at: http://dx.doi.org/10.1016/j.jtice.2010.06.005.

Utomo, A.T. et al., 2012. International Journal of Heat and Mass Transfer Experimental and theoretical studies of thermal conductivity , viscosity and heat transfer coefficient of titania and alumina nanofluids. *International Journal of Heat and Mass Transfer*, 55(25–26), pp.7772–7781. Available at: http://dx.doi.org/10.1016/j.ijheatmasstransfer.2012.08.003.

Wu, Y. et al., 2015. Optical and thermal radiative properties of plasmonic nanofluids containing core-shell composite nanoparticles for efficient photothermal conversion. *International Journal of Heat and Mass Transfer*, 82, pp.545–554.

Yousefi, T. et al., 2012. An experimental investigation on the effect of Al 2O 3-H 2O nanofluid on the efficiency of flat-plate solar collectors. *Renewable Energy*, 39(1), pp.293–298.

Zhang, L. et al., 2016. Effect of morphology of carbon nanomaterials on thermo-physical characteristics , optical properties and photo-thermal conversion performance of nano fl uids. *Renewable Energy*, 99, pp.888–897. Available at: http://dx.doi.org/10.1016/j.renene.2016.07.073.