THE PERFORMANCE OF EVACUATED TUBE SOLAR COLLECTOR (ETSC) USING CeO_2 / WATER NANOFLUID

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Field of Study: ENERGY

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ABSTRACT

The interest of researchers on the research of solar technology have increased tremendously from year to year due to a serious pollution to the environment caused by the emission of coal and fuels. Evacuated tube solar collector (ETSC) gain interest by the researchers because it have a lower heat loss and can achieve higher temperature compared to flat plate solar collector (FPSC). Implementing nanofluid to the ETSC have increased from years to years because nanofluid can enhance the performance and increase the efficiency of the solar collector as they have a higher thermal conductivity compared with distilled water. A mean diameter of 25nm (10^{-9}m) of cerium (IV) oxide (CeO_2) nanoparticles were used in this research of study. The stability of the nanofluid was tested by using the sedimentation method. It is the most common and cost saving method. The CeO_2 nanofluid can stable up to 28 days. Three different concentration of nanofluid were synthesized comprising of 0.02%, 0.04% and 0.06% volume concentration respectively. This research of study were carried out at University of Malaya (UM). The experiment was conducted at sunny day from 0900 morning to 1800 evening. The thermal efficiency of the solar collector were carried out by using different flow rates that are 0.5L/min, 1.0L/min and 1.5L/min. The inlet temperature, outlet temperature, ambient temperature, solar radiation and etc. were recorded throughout the experiment for analysis of the performance of ETSC. The collector showed the highest efficiency of 73.46% with the use of 0.06% CeO_2 nanofluid, which is 27.63% higher compared to the distilled water at volumetric flow rates of 1.5L/min. From the experiment, we can concluded that the higher concentration of the nanofluid, the higher heat gain, the higher solar efficiency of the solar collector can achieved.

Keywords: Evacuated Tube Solar Collector (ETSC), Cerium (IV) oxide nanoparticles, CeO_2/water nanofluid, Collector's Efficiency, University Malaya (UM)

ABSTRAK

Penyelidikan teknologi solar telah meningkat dengan pesat dari tahun ke tahun oleh para penyelik disebabkan pencemaran yang serius terhadap alam sekitar yang disebabkan oleh pelepasan arang batu dan bahan api. *Evacuated tube solar collector* (ETSC) lebih digemari oleh para penyelidik kerana ia mempunyai kehilangan haba yang lebih rendah dan boleh mencapai suhu yang lebih tinggi berbanding dengan *flat plate solar collector* (FPSC). Pelaksanaan cecair nano ke ETSC telah meningkat dari tahun ke tahun kerana cecair nano dapat meningkatkan prestasi dan meningkatkan kecekapan pengumpul suria kerana ia mempunyai kekonduksian termal yang lebih tinggi berbanding dengan air suling. Cerium (IV) oksida (CeO_2) berdiameter 25nm (10^{-9}m) digunakan dalam sepanjang kajian ini. Kestabilan cecair nano diuji dengan menggunakan kaedah pemendapan. Ia adalah kaedah yang paling biasa dan menjimatkan kos. Cecair nano CeO_2 boleh mengekalkan kestabilannya sehingga 28 hari. Tiga kepekatan nanofluid yang dihasilkan terdiri daripada 0.02%, 0.04% dan 0.06% akan digunakan. Kajian ini dijalankan di Universiti Malaya (UM). Eksperimen dilakukan pada hari cerah dari 0900 pagi hingga 1800 petang. Kecekapan pengumpul suria dilakukan dengan menggunakan kadar aliran yang berbeza iaitu 0.5L / min, 1.0L / min dan 1.5L / min. Suhu masuk, suhu keluar, suhu ambien, sinaran suria dan sebagainya dicatatkan sepanjang kajian ini untuk proses analisis untuk kecekapan pengumpula suria ETSC.. Keputusan menunjukkan bahawa peningkatan kecekapan haba sehingga 27.63% apabila CeO_2 / air cecair nano digunakan berbanding dengan air suling. Dari eksperimen ini, kita dapat menyimpulkan bahawa kepekatan cecair nano yang lebih tinggi akan menyebababkan peningkatan haba yang lebih tinggi dan kecekapan solar yang lebih tinggi dari kolektor dapat dicapai.

Kata kunci: *Evacuated tube solar collector* (ETSC), Cerium (IV) oksida, CeO2 / air cecair nano, Kecekapan Pengumpul suria, Universiti Malaya (UM)

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LIST OF SYMBOLS AND ABBREVIATIONS

UM	:	University of Malaya
ETSC	:	Evacuated Tube Solar Collector
FPSC	:	Flat Plate Solar Collector
A_c	:	Surface area of the solar collector (m^2)
C_p	:	Heat capacity of (J/kg K)
C_{pbf}	:	Heat capacity of base fluid (water) (J/kg K)
C_{pnp}	:	Heat capacity of nanoparticles (J/kg K)
C_{pnf}	:	Heat capacity of nanofluid (J/Kg K)
F_R	:	Heat Removal Factor
G_T	:	Solar Radiation normal to collector (W/m^2)
$\dot{m}$	:	Mass flow rate of nanofluid (kg/s)
T_a	:	Ambient Temperature (K)
T_i	:	Collector inlet temperature (K)
T_o	:	Collector outlet temperature (K)
Qu	:	Useful heat energy rate (W)
Rm	:	Ringgit Malaysia
PV	:	Photovoltaic

Subscript

np	:	nanoparticles
bf	:	base fluid
nf	:	nanofluid

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Currently, the worldwide energy demand is mainly supplied by fossil fuel. High usage of fossil fuel such as natural gas, oil, solid waste, wood product, coal and etc. has cause pollution to the environment as the burning of these fossil fuel released CO_2, CO, CH_4 gas and etc. that lead to greenhouse gas warming. The greenhouse gas is the gas that trapped the heat in the atmosphere and eventually cause the temperature to increase every year. The high demand of fossil fuel has led to the depletion of this natural resources' availability every year. A lot of researcher have carried out research to less reliable on these non-renewable energy and searching for an alternative in order can protect our mother of nature as well as generate electricity.

There are a lot of renewable energy such as wind, solar, geothermal, fuel cell, biomass, hydro and etc. that can be an alternative to replace fossil fuel. The most favorable renewable energy is solar energy as it is free, abundant, clean and sustainable that can provide electricity to the remote places by changing the solar irradiance to electricity. Malaysia is situated on the equatorial line. There are no four seasons in Malaysia. Malaysia is hot and humid throughout the year and receive the solar irradiance approximately 400-600MJ/m^2 each year (Mekhilef et al., 2012). Solar energy can be divide into three categories, they are electricity production which mainly use the photovoltaic (PV) panels, passive solar energy and solar thermal energy which mainly use the solar collector (Mussard, 2017).

Typically, water, oil, ethylene glycol (EG), kerosene and etc. employed as base fluid are widely used in industrial area especially in solar energy systems. Unfortunately, employment only based fluid show poor thermal conductivity in the systems (Das, 2017).

The issues of improve thermal conductivity in solar energy system is now the interest for the researchers and the engineer (Elsheikh et al., 2017). Increase the supplementation of nano-sized metal such as metal, metal oxide, metal nitride, metal carbide, carbon based material and etc. to the based fluid bring to the formation of nanofluid (Koca et al., 2018, Sundar et al., 2017).The number of research related to nanofluid either in oil based or water based nanofluid have increased tremendously from year 2011 to 2017 as shown in Figure 1.1.

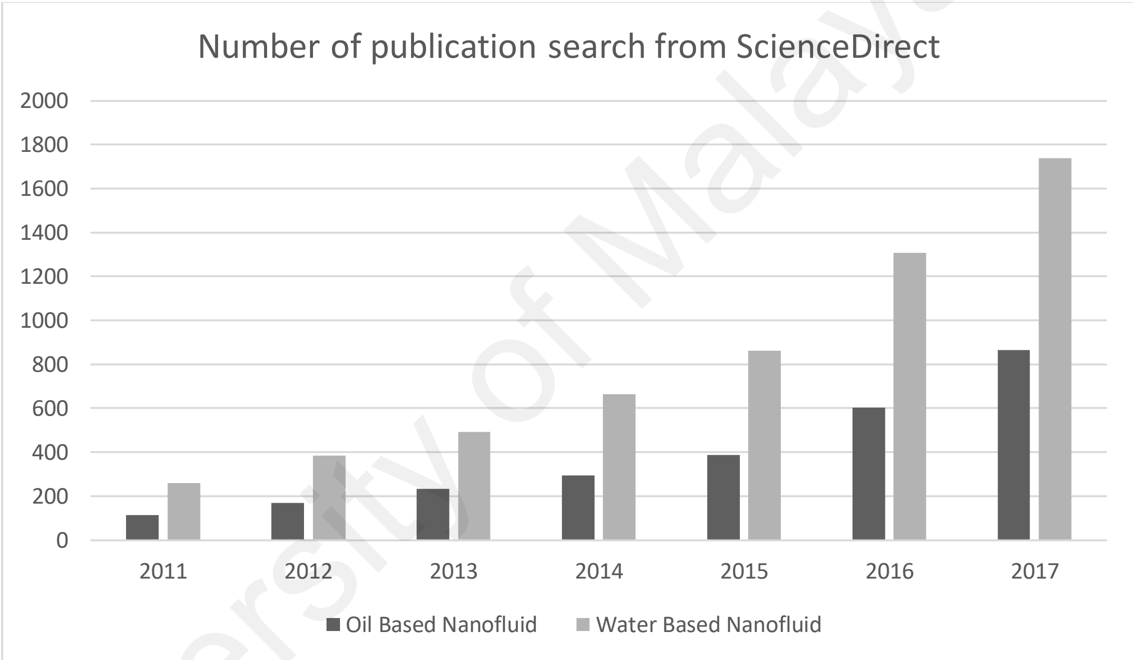


Figure 1. 1 : Number of publication with the term oil based nanofluid and water based nanofluid

There must be some reason of the increase number in research related to nanofluid. Nanoparticles are very small in size, normally it range from 1-100nm. Nanoparticles are normally used to enhance the thermal conductivity of nanofluid even very less volume fraction of nanoparticles are used (Khanafer and Vafai, Cai et al., 2017). According to some of the previous researches, it is not recommended that the size of nanoparticles that dispersed in the base fluid that more than 100nm. Nanofluid have some unique features that drawn attention from lots of researchers to study on, that are nanofluid are small in size as it can easily dispersed into the base fluid, high thermal conductivity, very fast heat transfer ability, high specific surface area, low concentration of the particles help the fluid stay in its Newtonian motion, better stability, reduction in pumping power and etc. (Hussein et al., 2017, Mukherjee and Paria, 2013, Raj and Subudhi, 2018)

1.2 Problem Statement

The interest of researchers on the research of solar technology have increased tremendously from year to year due to a serious pollution to the environment caused by the emission of coal and fuels such as carbon dioxide (CO2), carbon oxide (CO), nitrogen oxide (NOx) and etc. However, the expensive of material cost, manufacture cost, installation cost and etc. of solar collector have led to longer energy payback time (EPBT) of the solar collector. The only used of base fluid such as water, oil, kerosene, ethylene glycol and etc. as working fluid into the solar collector have shown a low efficiency on the solar collector which will make a longer time of the payback time for the solar collector. A lot of researchers have try lots of researches on how to improve the solar collector efficiency such as modification on the solar collector's design and structure, increase the collector absorption area, implementation of nanofluid and etc. They have found out that implementation of nanofluid on the solar collector is one of the economical and easier way in improve efficiency of solar collector and expect to reduce the EPBT. This is because nanofluid have a high thermal conductivity characteristic if compared with base fluid. There are two ways in preparing the nanofluid in laboratory, they are one step method and two step method. Both of this method are the most commonly method that normally used by majority of researchers in producing nanofluid but there are some drawbacks for these both type of methods. One of the most concerning issue is the stability problems of the nanofluid. Lots of researchers are trying to find the best way in preparing the nanofluid.

1.3 Objectives of Study

This study intended to achieve the following objectives which are:

i. To produce a stable water based CeO_2 nanofluid that can be used in the evacuated tube solar collector (ETSC).

ii. To enhance the efficient of nanofluid by optimizing the volume fraction

iii. To analyse the efficiency and performance of evacuated tube solar collector (ETSC) using CeO_2 nanofluid and water as working fluid.

1.4 Scope of Study

The scopes of this study are:

a) The field of study are carried out at the area of Faculty of Engineering, University of Malaya.

b) The substances that will be used to carry out this experiment are distilled water and CeO_2 / water nanofluid.

c) The characteristics of CeO_2 water based nanofluid such as the stability, viscosity and thermal conductivity are determined throughout the study.

d) The data such as inlet temperature (T_i), outlet temperature (T_o), ambient temperature (T_a) and solar radiation are collected during the experiment.

e) The efficiencies of evacuated tube solar collector is then being calculated by using the data that are collected during the experiment.

f) The efficiencies of evacuated tube solar collector is then compared between distilled water and CeO_2 / water nanofluid.

1.5 Significance of Study

The findings of this study will redound the benefit to the society that solar radiation and nanotechnology play an important roles in science and technology today. Malaysia are situated at the equatorial line and received solar radiation throughout the year. Solar radiation from the suns not only can be used by the plants for photosynthesis purposes, let the people feel warm, help to build strong bones and etc. but also can be used as the home heating system that supplied to a family up to 7 to 8 peoples through store the heat from the sun by solar collector that are placed at the roof of our houses.

However, the efficiency of solar collector that using water as base fluid is low and not ideal. Scientist and researchers are trying their effort to find the solution to enhance the efficiency by implementing nanofluid as carrier fluid in the solar collector. The efficiency of solar collector show a significant improvement when nanofluid is used in the solar collector when compared to water as a carrier fluid.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The aim of this chapter is to summarize and review the study that had been done by researches related to the flat plate solar collector and evacuated tube solar collector. The information that are gathered in this chapter are from the technical or research paper that have been published, book as well as information from the internet. Nanofluid have gain interest of researchers from time to time because it can use to enhance the rate of heat transfer. Section 2.2 reviewed the types of nanoparticles that usually use in the solar energy systems. In the sub section 2.2.1 are reviewed about the thermal conductivity of nanoparticles. The properties of carrier fluid in the solar collector such as freezing point, boiling point, thermal conductivities and etc. are reviewed in the section 2.3. For Section 2.4 are about the nanofluid application of solar collector, whereas in the Sub section 2.4.1 and 2.4.2 are explained the nanofluid application for flat plate solar collector and evacuated tube solar collector respectively. For Section 2.5 reviewed about the nanofluid production, sub Section 2.5.1 are reviewed the nanofluid production through one step method while sub Section 2.5.2 are reviewed the nanofluid production through two step method. In Section 2.6 have given clear explanation of challenges, prospective and future work for nanofluid.

2.2 Types of Nanoparticles

Nanoparticles are the particles that size range between 1-100nm. The most common used nanoparticles are shown in Table 2.1.

Table 2. 1: Common Nanoparticles use in the solar energy systems

Types	
Metal	Cu, Au, Ag, Ni
Metal Oxides	Al_2O_3, CuO, Fe_2O_3, Fe_3O_4, SiO_2, TiO_2, ZrO_2
Metal Carbides	SiC

Metal Nitrides	AlN, SiN
Carbon Material	Carbon nanotubes, graphite, diamond

2.2.1 Thermal Conductivity of Nanoparticles

Thermal conductivity is defined as the ability of the substances/material to conduct heat. Table 2.2 below show the thermal conductivity of various metal and non-metal under the temperature of 25ºC.

Table 2. 2: Thermal conductivity (W/m.K) of various material at 25ºC

Materials		Thermal Conductivity (W/m.K)
Metal	Cu	401.0
	Al	205.0
	Ag	429.0
	Au	310.0
Non-Metal	Al_2O_3	30.0
	SiC	270.0
	CuO	76.5
	SWCNT	6000
	MWCNT	3000

2.3 Carrier Fluid in Solar Collector

The heat carrier fluid that commonly used in flat plate and evacuated tube solar collector are water, oil or ethylene glycol. The thermal conductivity for ethylene glycol, water and unused oil at 26.8ºC are 0.258, 0.609 and 0.145 W/m.K respectively. Thermal conductivity of water is the highest among the unused oil and ethylene glycol. However, some researchers investigated that the some of the nanoparticles based nanofluid do not follow this rule (Yang et al., 2017) . The properties of the heat carrier fluid are shown as in Table 2.2.

Table 2. 3: Comparison of heat carrier fluid used in Flat plate and Evacuated tube solar collector

	Ethylene Glycol (%Volume)			Water	Engine Oil (Unused)
	30	40	50		
Freezing Point (^{o}C)	-7.9	-23.5	-36.8	0	
Boiling Point (^{o}C)	105	105	107	100	300
Dynamic Viscosity (mPa.s @25^{o}C)	1.84	2.40	3.08	0.891	682.475
Specific Heat Capacity (J/kg.K @25^{o}C)	3773	3597	3403	4180	1901.75
Specific Gravity (@25^{o}C)	1.049	1.061	1.078	0.997	0.885
Toxicity	High			Neutral	Acute
Thermal Conductivity (W/m.K@ 26.8^{o}C)	0.258			0.609	0.145

2.4 Nanofluid Application in Solar Collector

This sections explained the application of nanofluid in solar energy system. The types of solar collectors that emphasized in this study are flat plate solar collector (FPSC) and evacuated tube solar collector (ETSC). In the previous study, lots of researchers are using only water as a base fluids in the solar collector system, but the results that are obtained are not satisfactory because of low efficiency. Lots of researchers are keep on many attempts to increase the efficiency of the solar collector in order can bring positive impacts to the development in solar energy field. One of the most economical and efficient method in enhance solar collector is by using nanofluids in the solar collector.

2.4.1 Flat Plate Solar Collector (FPSC)

Hottel and Whillier was the first whose developed flat plate collector in the year 1950 (Florschuetz, 1979). A flat plate solar collector (FPSC) is the most common solar collector with simplicity of the design and able to heat up to $100^{o}C$ (Sokhansefat et al., 2018). FPSC is a made up by the components such as absorber, transparent glass cover, coil tube, header tube, insulation and etc. It is a metal box and covered up with a glazing on top and a dark in colored absorber plate on the bottom. The sides and the bottom are designed to be insulated to minimize the heat loss so to enhance the efficiency of the collector (Pandey and Chaurasiya, 2017). The working principal of FPSC is to convert the solar irradiance to the heat energy (Bhowmik and Amin, 2017). Solar radiation will first pass through the glazing and strike the black in colour absorber plate, which will heat up the plate. Then, the heat is transferred to the carrier fluid through pipe which are attached to the absorber plate. FPSC are very useful solar heating system and can be used in domestic water heating, commercial water heating such as heating the swimming pool, building heating, crop drying, industrial processing and etc.(Raj and Subudhi, 2018).

Yousefi et al. (Yousefi et al., 2012) investigated experimentally about the effectiveness of Al_2O_3 / water nanofluid on the FPSC as the working fluid and observed that the efficiency increased by 28.3% with 0.2% weight fraction (w.t) by using the nanoparticles of 15nm. They evaluated the nanofluid with different parameter such as change of the volume fraction, mass flow rate and the surfactant. In this experiment, the 0.2% and 0.4% weight fraction of the nanofluid was prepared. The mass flow rates that used are 1 litre per min (L/m)-3 litre per min (L/min). In the same experiment, Yousefi et al. also concluded that by adding surfactant into the fluid help to enhance the efficiency by 15.63%. Sundar et al. (Sundar et al., 2018) conducted the experiment of Al_2O_3 / water nanofluid of FPSC with twist tape insert ratio (H/D=5) and without twisted tape inserts and observed the thermal effectiveness enhanced to 76% and 58% respectively at a mass flow rate of 0.083kg/s with 0.3% nanofluid. The reason that caused high thermal effectiveness for twisted tape inserts compared to plain tube is due to the tube with twisted tapes exhibits higher Nusselt number values because of the swirl flow that are produced which lead to an extended flow path and enhance the fluid mixing that lead to thinner thermal boundary layer along the tube. Colangelo et al. (Colangelo et al., 2013) also made investigation of different nanofluid such as Al_2O_3, ZnO and Fe_2O_3 / water nanofluid on FPSC. After different nanofluid are used to undergoes several testing on FPSC, Al_2O_3 / water nanofluid was selected as heat carried fluid because of the capabilities of heat transfer coefficient and can reduce sedimentation. The heat transfer coefficient was enhanced by 25% by measure using the hot wire technique with the use of nanoparticle 45nm and the volume fraction of 3%w.t.

Sharafeldin et al. (Sharafeldin et al., 2017) studied experimentally on the performance of FPSC using WO_3/water nanofluid. The author selected WO_3 (Tungsten Trioxide) as the carrier fluid because this fluid was not used before by the previous researcher. Various volume fraction of 0.0167%, 0.0333% and 0.0666% of WO_3/water nanofluid were prepared using 90nm nanoparticles. Then, the thermal performance of flat plate solar collector using WO_3 nanofluid is tested at different mass flux rates at 0.0156, 0.0183 and 0.0195 $kg/s.m^2$. From the finding, the author concluded that the maximum efficiency can enhanced up to 13.48% compare to water by using 0.0666%w.t and the mass flux rates at 0.0195 $kg/s.m^2$. The same authors (Sharafeldin and Gróf, 2018b) reported that the performance of FPSC using CeO_2 /water nanofluid. Three volume fraction of 0.0167%, 0.0333% and 0.0666% of CeO_2 /water nanofluid were prepared using 25nm nanoparticles. The working fluid mass flux rates were tested at 0.015, 0.018

and 0.019 $kg/s.m^2$. Finding shown that the maximum efficiency increased by 10.74% when the volume fraction was 0.066% and the mass flux rate was 0.019 $kg/s.m^2$. The efficiency of the collector was directly proportional with the mass flux rate, and it seemed that an optimal volume fraction might be the 0.0333% for this research study's ranges.

He et al. (He et al., 2015) investigated the efficiency of FPSC by dispersed Cu nanoparticles in the water. The authors change the parameter such as the particles size and the volume fraction of Cu nanoparticles and observed the effect. From the experimental finding, the efficiency of FPSC was enhanced by 23.83% with Cu/ water nanofluid as a carrier fluid with Cu nanoparticles of 25nm and 0.1% volume fraction. The efficiency of FPSC decrease as the Cu/ water nanofluid with nanoparticles of 25nm and 0.2% volume fraction is used. This indicates that high concentration of fluid not necessary will contribute positive effect onto the efficiency of solar collector. The thermal conductivity of smaller size of Cu nanoparticles is higher than larger size Cu nanoparticles. It is due to the larger surface area of contact between the particles and the base fluid. Hence, the faster heat transfer rate that lead to high efficiency.

Jouybari et al.(Jouybari et al., 2017) investigated the effect of different nanoparticles size, nanoparticles concentration and the flow rate of SiO_2/ deionized water nanofluid flow through FPSC with the metal porous foam filled channel. SiO_2 nanofluid have been selected as their research of study because of the low thermal conductivity but has a great effect on efficiency. Thermal efficiency have improved up to 8.1% in the nanofluid flow. From the findings, they found out that by comparing the parameter of efficiency changes between the nanofluid flow rate and nanofluid concentration, the effect of nanofluid concentration to the FPSC efficiency is more obvious compare to the flow rate. The efficiency of the FPSC is depend on the nanoparticles size. The smaller the particle size, the larger the contact area and thus will increase the Brownian motion. It will lead to improvement of thermal conductivity and heat transfer process. Thus, select a smaller particle size is more feasible than the larger one. Moreover, Energetic, economic and environmental analyses of SiO_2 nanofluid were tested on FPSC by the authors (Faizal et al., 2015). The authors found out that the collector efficiency are reliable on the concentration and the mass flow rates of the nanofluid. Because of these two parameters will lead to the impacts on the collectors' efficiency, it is very important to prepared correct composition of nanofluid in the collector in order to maximize the collector efficiency. From the findings, it found out that used of the SiO_2 nanofluid could reduce the emission of carbon dioxide (CO_2) up to 170kg and save the energy by 26.2%.

Table 2. 4: Summary of the results for the Flat Plate Solar Collector (FPSC)

Authors	Method	Types	Nanoparticles	Particle size (nm)	Volume Fraction (%)	Efficiency enhancement (%)
Sundar et al. (Sundar et al., 2018)	Experimental	Metal Oxide	Al_2O_3	NAV	0.3	49.75
Said et al. (Said et al., 2016)	Experimental	Metal Oxide	Al_2O_3	13	0.3	83.5
Faizal et al. (Faizal et al., 2015)	Experimental	Metal Oxide	SiO_2	15	0.2	23.5
Sharafeldin and Gróf . (Sharafeldin and Gróf, 2018b)	Experimental	Metal Oxide	CeO_2	25	0.066	10.74
Sharafeldin et al.(Sharafeldin et al., 2017)	Experimental	Metal Oxide	WO_3	90	0.0666	13.48
He et al. (He et al., 2015)	Experimental	Metal	Cu	25	0.1	23.83

Jamal et al. (Jamal-Abad et al., 2013)	Experimental	Metal	Cu	35	0.05	24
Sint et al. (Sint et al., 2017)	Theoretical	Metal Oxide	CuO	25	2	5
Moghadam et al. (Moghadam et al., 2014)	Experimental	Metal Oxide	CuO	40	0.4	21.8
Faizal et al.(Faizal et al., 2013)	Experimental	Metal Oxide	CuO	NAV	0.03	38.5
Zamzanian et al. (Zamzamian et al., 2014)	Experimental	Metal	Synthesis Cu	30	0.3	37.5

2.4.2 Evacuated Tube Solar Collector

Evacuated tube solar collector (ETSC) also known as heat pipe solar collector. Evacuated tube solar collector (ETSC) have many advantages compared to FPSC, so it have drawn the interest of studied by researchers in the past recent year. Few authors (Zubriski and Dick, 2012, Morrison et al., 2004) have found out that the ETSC have better thermal performance than the common flat plate solar collector in low light environment and condition as it have lower heat loss due to vacuum inside the tube compared with FPSC. Besides that, ETSC normally used for high temperature application and it can raise higher temperature if compared with FPSC. ETSC is made up of parallel row of transparent row of glass tube that is connected to header pipe and enclosed with the absorber. The main components of ETSC comprises of four main components that are evacuated tube, heat pipe, manifold and mounting frame. The air from the tube is pumped out to decrease the heat loss due to convection (Muhammad et al., 2016). The maturity of the ETSC have been led to widely used of this collector in many area such as the domestic and industrial application (Sabiha et al., 2015). For domestic application, it is used for solar hot water (Ayompe and Duffy, 2013, Feliński and Sekret, 2017), air conditioning (Mehta and Rane, 2013), swimming pool (Sakhrieh and Al-Ghandoor, 2013, Dongellini et al., 2015) and solar cooker (Sharma et al., 2005, Herez et al., 2018), whereas for industrial application, it can be used for heat engine (Madduri et al., 2012), solar drying (Singh et al., 2018, Fadhel et al., 2018) and steam generator (González-Gómez et al., 2018).

The effective heat transfer coefficient with varies volume concentration and mass flow rate of Al_2O_3/distilled water as working fluid had been studied on ETSC by the authors (Ghaderian and Sidik, 2017). The volume concentration of the fluid was taken as 0.03% and 0.06%. The nanoparticles size that are used throughout this experiment was 40nm. This experiment has been conducted with the addition of natural surfactant, Triton

X-100 with the flow rates varies from 20 litre per hour (L/h) to 60 litre per hour (L/h). From the experimental finding, the maximum efficiency that achieved by ETSC was 57.63% with the 0.06% volume concentration and mass flow rates of 60 litre per hour (L/h). From the findings, the authors found that the efficiency of the collector is directly proportional to the volume concentration and the mass flow rate of the nanofluid. ETSC shows the best heat transfer efficiency when with the increase of volume concentration and the mass flow rate. The same authors (Ghaderian et al., 2017) also studied experimentally of the performance of CuO/ distilled water as a working fluid on ETSC water heater with internal coil under thermosyphon system circulation. CuO nanoparticles with the size 40nm were dispersed in the base fluid through two step method. The volume concentration of the fluid was taken as 0.03% and 0.06%, whereas the mass flow rates was fixed from 20 litre per hour (L/h)-60 litre per hour (L/h). From the findings, it is found out that the ETSC efficiency enhancement up to 51.4% with the 0.06% volume of CuO and the mass flow rates of 60 litre per hour (L/h). From the experiment, it has drawn out a conclusion that are the use of very low concentration of CuO nanoparticles that below than 0.01% do not show much effect and have almost similar effect compare to pure water as working fluid in the collector.

Graphene and carbon nanotube (CNT) are known as carbon based material. Nanotubes are held by the Van der Waals forces. Nanotubes are categorized into two groups that are single-walled nanotube (SWNT) and multi-walled nanotubes (MWNT). Due to their unique characteristic of optical properties (Ahmad et al., 2017), thermal properties (Kim et al., 2018), electrical and mechanical properties (Pal and Kumar, 2018), it have drawn the attention of many researches over the recent years. Mahbubul et al. (Mahbubul et al., 2018) had investigated experimentally of single wall carbon nanotube (SWCNT) nanofluid and water on the ETSC. The effective area 42m^2 of ETSC was placed on the roof area with the inclination angle of 25^o. SWCNT nanoparticles was considered in this study is because of the promising thermal and physical properties. In this study, the authors have also pointed out that the performance of the ETSC are not only depend on the temperature difference and mass flow rates of the fluid but also depend on the capacity, which are related on the geometry, construction and the facilities of the system. SWCNT nanofluid with different concentration such as 0.05, 0.1 and 0.2% were prepared. The highest efficiency of 56.7% was observed when the collector is working with the water, whereas 10% higher efficiency is observed when the 0.2% volume concentration of SWCNT nanofluid is used in the solar collector. At the end of the study, the authors found out that the collector efficiency was depend on the flow rates of the water and the solar irradiance. Besides that, the collector efficiency will only increase up to a certain limit with the solar irradiance. After the certain limit of the solar irradiance, there will not much improvement changes to the collectors' efficiency. Tong et al. (Tong et al., 2015) investigated thermal performance of base fluids employing multi-walled carbon nanotube (MWCNT) and recommended that using these fluid in enclosed type evacuated U-tube solar collector could result in increase of efficiency. Results of the study revealed that the use of MWCNT nanofluid with the volume concentration of 0.24% can achieve the highest heat transfer coefficient of 8% that is simply higher than only pure water is used. Naik et al. (Naik et al., 2016) present the mathematical analysis of U-tube solar collector's performance using three different fluid, that are air, water (H_2O) and the aqueous lithium chloride solution (LiCl- H_2O). The effects of working fluid flow rate and inlet temperature, collector length, ambient temperature and solar intensity on the performance of the system are studied. From this findings, the collector length, solar intensity and the working fluid flow rates have a more significant impacts on the performance of this collector, whereas the working fluids inlet temperature does not give much changes to the collector performance. The net heat absorption increases linearly as function of ambient temperature. The higher the solar intensity yields the greater rate of heat absorption by a working fluid. This indicate that, with decrease in solar intensity, there is a significant decrease in radiative heat transfer between the outer glass and the inner glass tube and hence there is a decrease in net heat energy absorbed by the working fluid. This study have proven that the water has highest heat energy absorption capacity compared with the air and the aqueous lithium chloride solution.

The researchers have found that addition of fins onto the ETSC can reduce the cost of production and maintenance. Amanuel et al. (Andemeskel et al., 2017) in this present of study have investigated the effect of aluminium fins thickness coated with a solar paint on the thermal performance of ETSC. Three different thickness of aluminium fins, $11\mu m$, $13\mu m\ and\ 24\mu m$ were prepared. Thurmolax 250 selective black solar collector coating, solar paint was sprayed by the air spray gun on the aluminium fin solar absorber. Solar paint is a combination of pigment, resin, solvent and additives and it has some attractive features such as ease of processing, low cost, ease of field maintenance, and commercial availability. From this study, it is found that the thickness of solar paint was an insignificant effect on the α due to identical α at 0.94 of all the thicknesses. The efficiency (η), heat removal factor (F_R), and overall heat loss coefficient (U_L) of evacuated tube collector increased with decreasing the thickness of aluminium fin solar absorber with 1x solar paint coating. In addition, F_R was predominant on thermal performance of this evacuated solar collector for the increase of η with the decreasing of aluminium fin thickness. Based on thermal collector efficiency equations, it can be concluded that thermal performance of the evacuated solar collector increased with decreasing the thickness of aluminium fin solar absorber. Hence, aluminium fin coated with solar paint is able to apply as a solar absorber in evacuated solar collector with clear double layers evacuated tube due to its relatively higher η, F_R, light weight and low cost.

Hussain (H.A. Hussain, 2015) studied the effect of using Ag and ZrO_2 nanofluid to the evacuated tube solar collector. From his findings, Ag nanofluid showed a higher thermal efficiency if compared to ZrO_2 nanofluid. This is due to the thermal conductivity of Ag is higher than Zr. Another researchers, Ghaderian and Sidik (Ghaderian and Sidik, 2017) also examine the effect of Al_2O_3 nanofluid (metal oxide) on the thermal efficiency of the evacuated tube solar collector. They found out that with the use of 40nm Al_2O_3 nanoparticle with the 0.06% volume fraction the maximum efficiency could achieve up to 57.63% with the enhancement of 28% if compare to the distilled water. Besides this, Ghahedrian et al. (Ghaderian et al., 2017) also published a paper regarding the use of CuO nanofluid on the evacuated tube solar collector. From the finding, the maximum efficiency with the use of 0.06% CuO could achieve up to 51.4% and the enhancement up to 14% if compare to the distilled water. From the research study of Ghaderian, we can realised that Al_2O_3 nanofluid are better than CuO nanofluid because Al_2O_3 nanofluid can achieve more higher efficiency compared to CuO nanofluid. He et al. (He et al., 2011) used two different type of nanofluid that are metal oxides type nanofluid and carbon material type nanofluid to studied the effect of both these nanofluid to the performance of ETSC. The authors used TiO_2 nanofluid and CNT nanofluid to carry out his research of study. At the end of his research, he have found out that CNT nanofluid showed better thermal efficiency if compared to TiO_2 nanofluid.

The researches not only study the effect of metal oxide type's nanofluid on the evacuated tube solar collector. They also carried out research of carbon type material nanofluid on the evacuated tube solar collector. There are few types of carbon type material such as SWCNT, MWCNT, GNP and etc. Iranamesh et al. (Iranmanesh et al., 2017) have studied the effect of Graphene nanoplatelets nanofluid (GNP) as working fluid to the ETSC. GNP with the specific surface area of 750 m^2/g were dispersed into a base fluid and carried out experiment using absorption area of 1.14m^2 evacuated tube solar collector that situated at University of Malaya. From the findings, the solar collector recorded 90.7% thermal efficiency, thermal efficiency enhancement up to 27.6% if compared to the distilled water with the use of 1.5L/min volumetric flow rates.

Table 2. 5: Summary of the results for the Evacuated Tube Solar Collector (ETSC)

Authors	Types	Nanoparticles	Particle size (nm)	Volume Fraction (%)	Maximum Efficiency (%)	Efficiency enhancement (%)
Ozsoy and Corumlu (Ozsoy and Corumlu, 2018)	Metal	Ag	380-450	0.06	70	40
Iranmanesh et al. (Iranmanesh et al., 2017)	Carbon material	GNP	NAV	0.1	90.7	27.6
Tong et al. (Tong et al., 2015)	Carbon material	MWCNT	NAV	0.24	55	8
Sabiha et al. (Sabiha et al., 2015)	Carbon material	SWCNT	NAV	0.2	93.43	71.84
Lu et al. (Lu et al., 2011)	Metal oxide	CuO	50	1.2	60	30
Ghaderian et al. (Ghaderian et al., 2017)	Metal oxide	CuO	NAV	0.06	51.4	14
Ghaderian and Sidik (Ghaderian and Sidik, 2017)	Metal oxide	Al_2O_3	40	0.06	57.63	28
Mahbubul et al. (Mahbubul et al., 2018)	Carbon material	SWCNT	15	0.2	66	10

Mahendran et al. (Mahendran et al., 2012)	Metal oxide	TiO_2	30-50	0.3	73	16.7
Mahendran et al. (Mahendran et al., 2014)	Metal Oxide	TiO_2	30-50	2	85	42.5

2.5 Nanofluid Production

Nano science play an important role on promoting technology. Nanofluid consists of the mixture of nano sized material and the liquid substances that also known as based fluid. Nanofluid preparation is the first step to undergo the experimental research related to nanofluid field. The purpose of nanofluid is to enhance the thermal conductivity of the fluid. Generally, preparation of nanofluid can be divided into two that are one step method and two step method as shown in Figure 2.1.

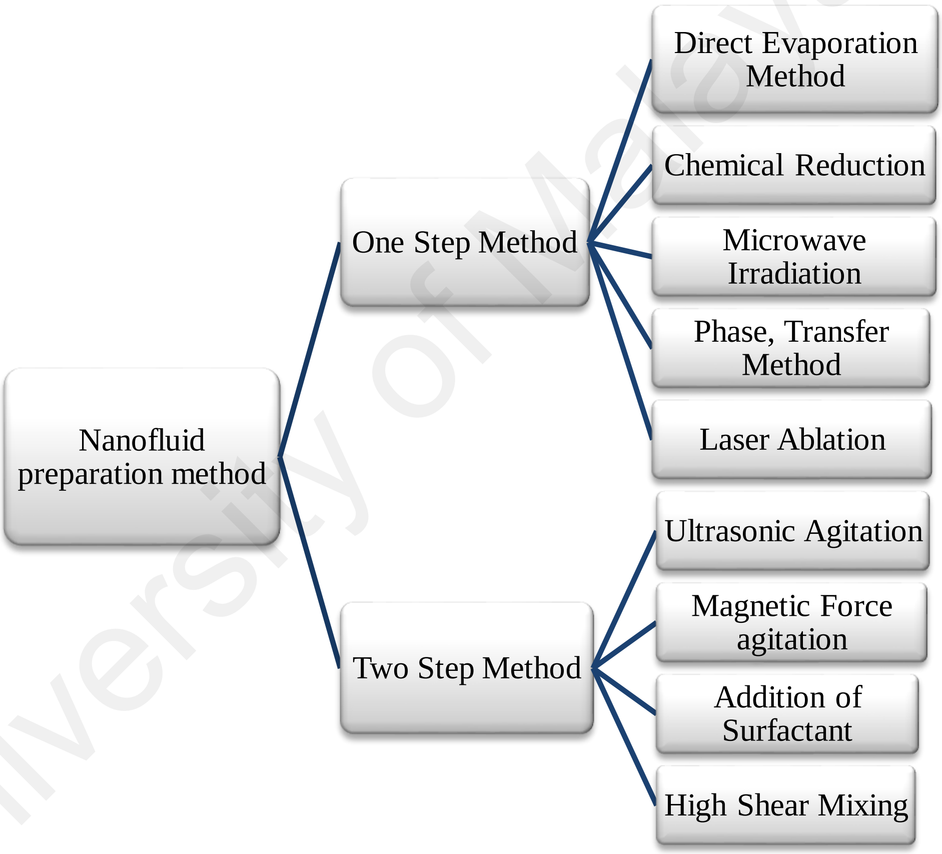


Figure 2. 1: Nanofluid Preparation Method

2.5.1 One Step Method

Nanofluid cannot produced in a large scale through one step method as this method is under developing stages and the cost of producing is quite high. One step method is through dispersed and creating the nanoparticles in the fluid at the same time as shown in Figure 2.2. One step method can minimized the agglomeration of nanoparticles but only suitable for the low vapour pressure fluid. The nanofluid produced through this method is more stable compared to two step method because through this entire processes, the dispersion of nanoparticles area unit, drying and storage can be avoided (Raj and Subudhi, 2018).

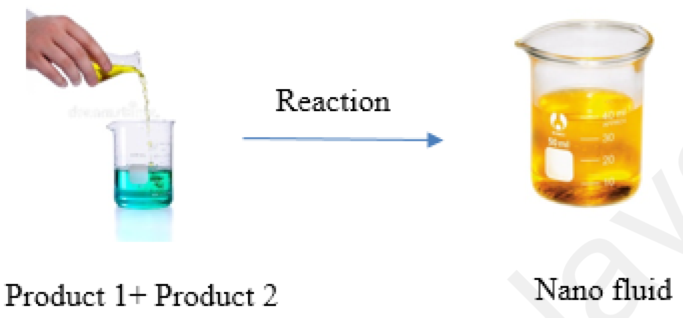


Figure 2. 2: Nanofluid production by one step method

2.5.2 Two Step Method

Two step method is widely used use in the preparation of nanofluid. Figure 2.3 illustrates the nanofluid production by two step method. It is more economical to produce nanofluid in giant quantities through this method because this method have been scaled up to industrial production levels. The dry powder is first produced through synthesized by chemical or physical method or directly purchased. The prepared nanoparticles is then dispersed into the base fluid with the help of intensive magnetic force agitation, high shear mixing, ball milling, ultrasonic agitation and etc. The purpose of ultrasonification is to break up the agglomeration and to promote the nanoparticles into the base fluid in order to get a more stable nanofluid. Most of the researcher do not add surfactant when preparing the nanofluid using two step method, just small amount of researcher add surfactant when produce the nanofluid. Nanoparticles in this method have high tendency to combine with the base fluid. It is necessary to add the surfactant in the fluid to enhance the stabilities and steadiness of nanoparticles. The purpose of adding surfactant is to enhance the bonding between two materials to avoid early sedimentation. However, select the correct type of surfactant added to the particles and the exact amount of surfactant to a specific case is still remain a question and still need to further research (Rafiq et al., 2016). Two step method is good for oxide nanoparticles but not suitable for metallic nanoparticles.

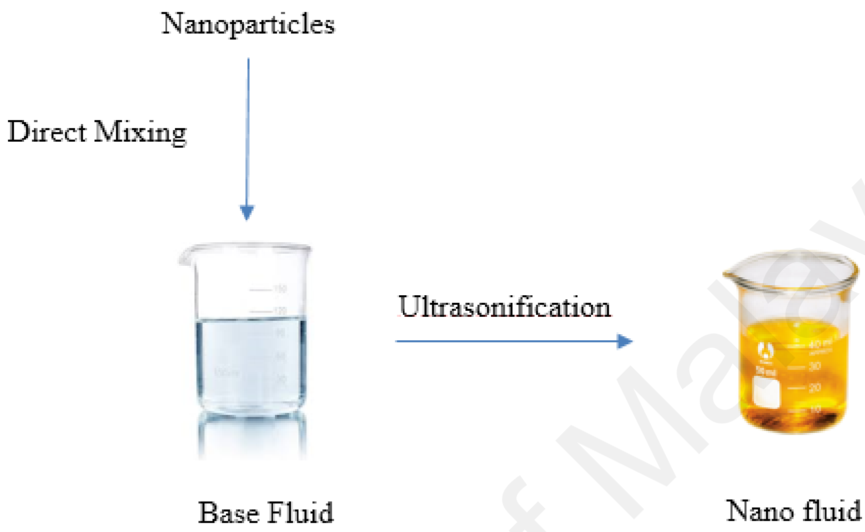


Figure 2. 3: Nanofluid production by two step method

2.6 Challenges, Prospective and Future Work of Nanofluid

Nanofluid can be produced through one step or two step method. It require advanced equipment and technique to produce nanofluid. The drawback of the application of nanofluid is the cost of production of nanofluid is expensive because of the prices of nanopowder is high as shown in Table 2.6.

Table 2. 6: Examples of nanopowder from the website Sigma Aldrich

Nanopowder	Particle Size (nm)	Weight (g)	Purity (%)	Cost (Rm)
Cu	60-80	100	99.5	5100.00
WO_3	<100	100	NAV	3540.00
CeO_2	<50	100	99.95	1320.00
CuO	<50	100	99.95	1860.00
SWCNT	0.83	1	99	5575.00

The main problem of nanofluid prepared through one step method is only low vapor pressure fluid are compatible with such this process. The volume concentration of suspended nanoparticles in fluid and quantities of nanofluid in one step method are much more limited than two step method. The cost of production is expensive for this process. Some of the researchers suggested that prepared the nanofluid through two step method is more suitable for containing oxide nanoparticles than those containing metallic nanoparticles. Moreover, stability of the fluid is the big issue that concerned by researchers. The nanofluid that prepared through this process easily aggregate due to strong Van der Walls force among the nanoparticles. However, the stability is the issue but due to its economic process, it is still popular among the production of nanofluid. The agglomeration of the nanoparticles not only affects clogging of micro channels and clogging, but also decreases the thermal conductivity (Shah et al., 2017).

The measured nanofluid's viscosity normally higher than the common base fluid. High viscosity of nanofluids which lead to the pressure drop of the fluid require more power for pumping the fluid (Elsheikh et al., 2017, Sidik et al., 2014).

It is noted that there are lots of challenges of the nanofluid such as the stability, agglomeration and the high viscosity of the nanofluid. Works of redesign and restructure are needed for most of the solar collector in order for the application of nanofluid. By solving these challenges, it is expected that nanofluid can make significant impact to the industrial and engineering field in order to improve human life (Sidik et al., 2017).

CHAPTER 3: RESEARCH METHODOLGY

3.1 Introduction

The aim of this chapter are explained how was this research of study are carried out. Section 3.2 have illustrated the flow chart representing the present research work methodology. This research of study are divided into two main part. Preparation of nanofluid are categorized in the first part while the second part are to conduct the experiment by using the synthesized nanofluid. In section 3.3, it have explained the preparation of Cerium (IV) oxide / water based nanofluid. CeO_2 /water based nanofluid are produced through two step method using probe type ultrasonicator. Section 3.4 explained about the experimental set up and testing procedure for this research of study. This research of study are conducted in University of Malaya using the available ETSC. This experiment was conducted at sunny day from 0900 morning to 1800 in the evening. The solar radiation are recorded using solar meter. Section 3.5 are the analysis of density, specific heat capacity and thermal conductivity of nanofluid. The properties of nanofluid comprising of three different concentration (0.02%, 0.04% and 0.06%) are evaluated in this section.

3.2 Research Design

Figure 3.1 illustrates the present work methodology. Before carry out this research of work, a few information and background related to the evacuated tube solar collector and nanofluid are reviewed in order to give a better understanding to conduct this research of study. This research of study must be able to meet the objectives and scopes accordingly. Generally, this research of study are divided into two part, that are part I and Part II. Preparation of nanofluid are categorized in part I. By using two step method, the nanoparticles that are purchased from Sigma Aldrich Co. are dispersed with different mass fraction in the base fluid individually. Then, the solution are sent to the ultrasonicator to undergo ultrasonic homogenization (40% amplitude for 35 minutes) to break down the particles size and minimized the percentage of nanoparticles agglomeration. Then, the CeO_2/ water nanofluid are completely produced. Three different concentration of CeO_2 nanofluid with 0.02%, 0.04% and 0.06% volume concentration are synthesized and used for this research of study. For the Part II, is to conduct experimental study on evacuated tube solar collector using nanofluid. The synthesized nanofluid is then poured into the nanofluid tank and set the flow rate using the flowmeter. The volumetric flow rates that have been set for this research of study are 0.5L/min, 1.0L/min and 1.5L/min respectively. The data are started to collect during the sunny day from 9am to 6pm. The study parameter such as inlet temperature (T_i), outlet temperature (T_o), ambient temperature ($T_{ambient,}$) and etc. are recorded into the data logger for further anlaysis of the results. Besides that, the parameter such as solar radiation also required. Solar radiation are captured for every hour using solar meter. Next, the data analysis are carried out The properties of nanofluid such as thermal conductivities, density, specific heat capacity, thermal efficiency, maximum heat gain and etc. are evaluated using graphs or tables. The stability of the nanofluid are evaluated too using sedimention method. It is very importance to produce a stable nanofluid because unstable nanofluid could affected the thermal conductivity of the nanofluid. After the stages of data analysis and discussion, conclusion and some of recommendation for the future work are made.

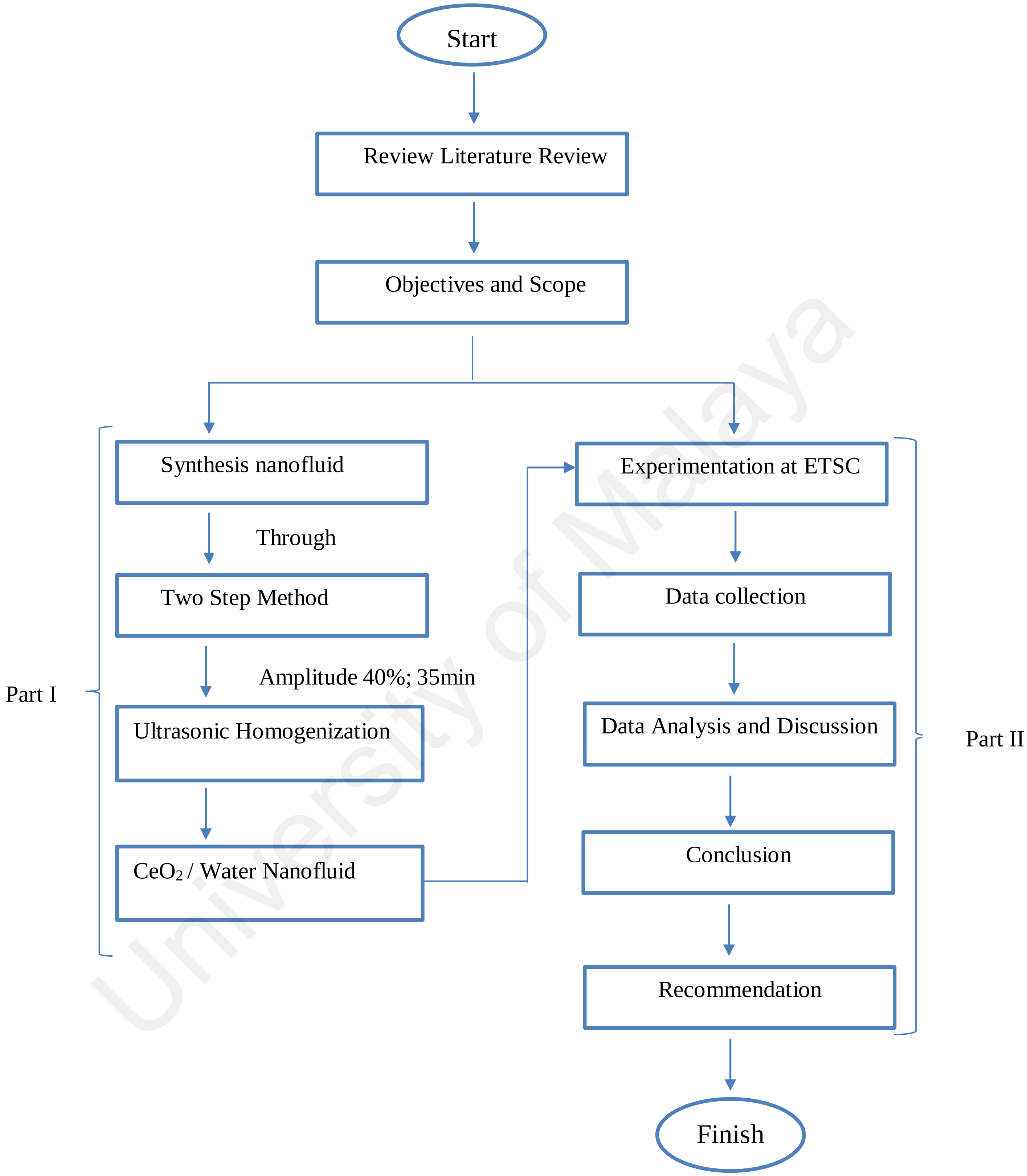


Figure 3. 1: Flow chart representing the present research work methodology

3.3 Preparation of CeO_2 Nanofluid

There are two common method that can be used to synthesize the nanofluids that are through one step or two step method. Both of this method have its advantages and disadvantages respectively. In this research of study, two step method was chosen in order to synthesize the nanofluids based on the available facilities and equipment that are available in University of Malaya (UM). Two step method was selected because it is more economical to produce the nanofluid in a large quantities. Besides that, produce the nanofluid through this method enable more stabilize fluid and reduce the agglomeration of the particles. Cerium (IV) oxide (CeO_2) nanoparticles was purchased from Sigma-Aldrich Co, USA as shown in Figure 3.2.

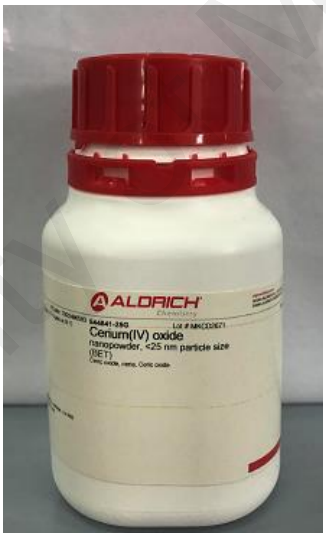


Figure 3. 2: Cerium (IV) Oxide nanoparticles that are purchased from Sigma Aldrich

Properties of CeO_2 nanoparticles are listed in Table 3.1. Distilled water are being use as a base fluid to prepare the CeO_2 nanofluid. The spherical in shape CeO_2 nanoparticles is first dispersed into the base fluid then is sent to the probe type ultrasonicator (output power 500W; 20 kHz) to undergoes ultrasonic homogenization with amplitude 40% for 35minutes continuously. The purpose of carry out ultrasonication is to break up agglomeration between the particles as the particles have strong Van der Waal forces that tend to agglomerate. Besides that, it also can help to enhance the dispersion of nanoparticles with the base fluid together by affecting the surface and structure of nanoparticles to produce a more stable nanofluid as reported in the journal of Mahbubul et al.(Mahbubul et al., 2018)

Table 3. 1: Properties of Cerium (IV) oxide nanoparticles

Parameter	CeO_2
Average Particle Size	<25 nm
Molecular Weight, MW	172.11 g/mol
Density	7.13 g/mL (7130kg/m^3) @25^oC
Appearance (Form)	Powder
Appearance (color)	White to yellow
Purity	99.9%
Thermal Conductivity, K	12 W/m K (Sharafeldin and Gróf, 2018b, Mogensen et al., 2000)
Specific Heat Capacity, C_p	460 J/kg K (Sharafeldin and Gróf, 2018b, Mogensen et al., 2000)

Based on the previous researches, there are not much research on the effect of Cerium (IV) oxide nanoparticles on flat plate solar collector and evacuated tube solar collector as CeO_2 nanopowder have a good thermal conductivity as compared with distilled water. Besides that, the prices of CeO_2 nanopowder is not too expensive as compared with CuO, Cu, WO_3, SWCNT nanoparticles as mentioned in the Table 2.6 and it might have economical potential in the future. According to the product specification, CeO_2 nanopowder is safe to be use. Ease to get will be added as one of the advantages to this nanopowder as this product the commercialize product. According to the authors Sharefeldin et al.(Sharafeldin and Gróf, 2018b), they claimed that CeO_2 nanoparticles will have better stability with the water if compared with other nanoparticles.

The percentage volume of the concentration of nanofluid can be calculated by using the law of mixture formula as shown below:

$$\phi, volume concentration = \frac{\left[\frac{W_{np}}{\rho_{np}}\right]}{\left[\frac{W_{np}}{\rho_{np}} + \frac{W_{bf}}{\rho_{bf}}\right]}$$

The amount of nanopowder needed for a certain volume concentration can be determined by using the equation below:

$$W_{Ceo_2} = \left(\frac{\phi}{100-\phi}\right)\left(\frac{\rho_{ceo_2}}{\rho_{bf}}\right)W_{bf}$$

$$\rho_{ceo_2} = 7.13 g/cm^3; \rho_{bf} = \rho_{distilledwater} = 1 g/cm^3$$

Where, $\phi = volume concentration$; W_{bf} =weight of base fluid;

The exact amount of Cerium (IV) oxide, CeO_2 nanoparticles to prepare different concentration of volume concentration, 0.02%, 0.04% and 0.06% in 4500ml of base fluid are illustrated in the table below.

Table 3. 2: Volume concentration and the amount of nanoparticle required for 4500ml base fluid

Volume concentration %	Amount of nanoparticles required, g
0.02	6.4183
0.04	12.8391
0.06	19.2626

3.4 Experimental Set Up and Testing Procedure

This research of study is conducted by using evacuated tube solar collector (ETSC) that are available in University of Malaya (UM). The experimental set up consists of two pumps, a cooling water tank with capacity around 50L, a nanofluid tank, flow meter, data logger, heat exchangers, four RTD sensors (Pt-100) and etc. as shown in Figure 3.3.

Front View	Back View

Figure 3. 3: Front view and Back view of the ETSC

The specification and dimensions of the ETSC are recorded in the Table 3.3 as shown as below.

Table 3. 3: Specification of Evacuated Tube Solar Collector

Specification	Dimension
Material	Borosilicate Glass 3.3
Length of the tube	1.8 m
Diameter of tube (Outer)	0.058 m
Diameter of tube (Inner)	0.047 m
Number of tubes	12
Collector area	1.92 m^2
Absorbance area	1.14 m^2
Transmittance of collector	0.89
Absorbance of collector	0.93

The angles of ETSC is set to be 33° for the better solar absorption to the solar collector as mentioned in the findings of Iranmanesh et al (Iranmanesh et al., 2017). Three different volumetric flow rates of 0.5L/min (0.00832kg/s), 1.0L/min (0.0167kg/s) and 1.5L/min (0.025kg/s) were set to examine the collector's efficiency. Table 3.4 illustrates the experiment set up condition for this research of work. Four RTD sensors (Pt-100) are connected to the data logger to record the storage tank temperature, ambient temperature, outlet temperature and inlet temperature. The temperatures are recorded every 5 min interval into the data logger in order to get a more accurate result.

Table 3. 4: Experimental Set up Condition

Nanofluid	Cerium (IV) oxide nanoparticles +Distilled water ($CeO_2 + H_2O$)
Concentration (vol %)	0.02 ; 0.04 ; 0.06
Volume flow rate, (L/min)	0.5 ; 1.0 ; 1.5
Volume Flow rate (m^3/s)	$8.33x10^{-6}$; $1.67x10^{-5}$; $2.5x10^{-5}$
Mass Flow rate (kg/s)	0.00832 ; 0.0167 ; 0.0250

The experiment is conducted throughout the sunny day from 9am to 6pm (duration of 9 hours of solar radiation) in order to obtain maximum solar radiation to the solar collector. The solar radiation of the sunlight is recorded by using solar meter. The solar radiation is captured every half an hours by using the solar meter. Figure 3.4 shows the average solar radiation and the ambient temperature for the sunny day. From the figures, the solar radiation that captured increased time to time until reach the peak at 1330pm in the afternoon with 1219W/m^2 then it gradually decrease to 354W/m^2 at the end of the experiment(1800 evening). The ambient temperature are at the range from 29.5^{o}C to 36.73^{o}C throughout the whole day.

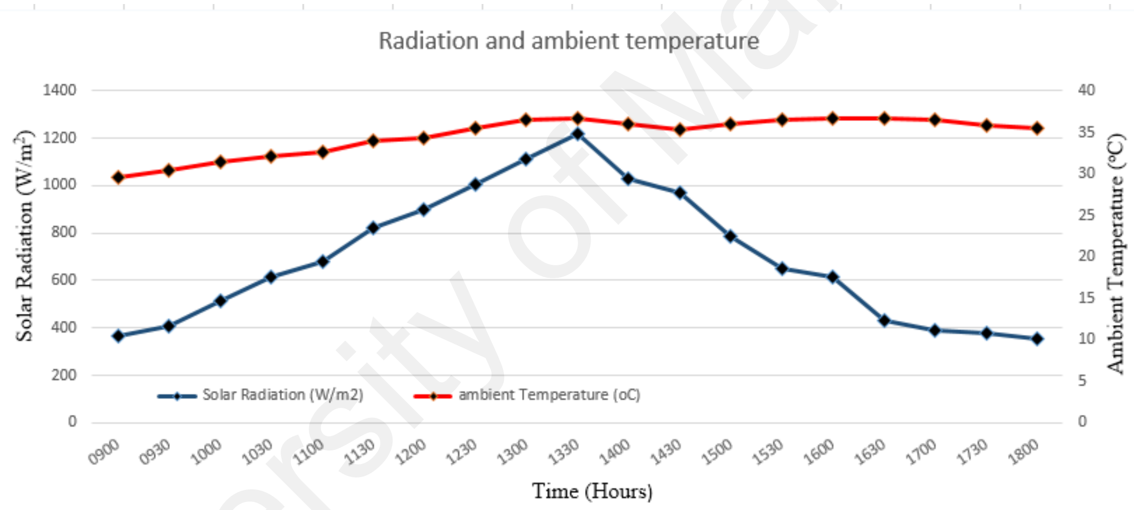


Figure 3. 4: Average Solar radiation and ambient temperature

There are few formulae are being used in order to evaluate the efficiency of solar collector.

Heat gain of the working fluid can be calculated by using the equation, and it is influenced by the mass flow rates of the fluid, the specific heat capacity of the fluid and as well as the inlet and outlet of the fluid temperature.

$$Q_u = \dot{m} C_p (T_{out} - T_{in})$$

Where Q_u is the useful heat gain, $\dot{m}$ is the mass flow rate of working fluid (water or nanofluid) kg/s, C_p is the heat capacity of working fluid (water or nanofluid) at constant pressure kJ/Kg.K, T_{out} and T_{in} are the outlet and inlet temperature in Kelvin (K).

Thermal efficiency of Evacuated Tube Solar Collector (ETSC) was influenced by the parameter of useful energy and the energy input. Thermal efficiency of solar collector are illustrated as shown in below:

$$\eta = \frac{Q_u}{(G_T A_c)} \text{ x100 in (\%)}$$

Where A_c is the solar collector area in m^2 and G_T is the solar irradiance in W/m^2.

Uncertainty analysis is one of the method to verify the accuracy of the experimental set up. Direct observation/ measurement were used when conduct this experiment. Direct measurement/ observation will caused some errors toward the reading if do not calibrate the instrument correctly. The parameters such as solar intensity, temperature and flow rates are taken during the experiment. The data are shown in Table 3.5 showing the calibration accuracy factors. The purpose of calibration accuracy factors is to determine the maximum and minimum error that might be caused by the instrument toward the experiment results.

Table 3. 5: Calibration accuracy factors

Measurement	Unit	Device	Range	Accuracy
Solar intensity	W/m^2	Solar Power Meter	1- 3999W/m^2	$\pm 10W/m^2$ or $\pm 5\%$ of the measured value
Temperature	^oC	Pt-100 RTD Temperature Sensor	0-200 ^oC	$\pm 0.3^oC$
Flow rate	L/min	Flow meter	0-4.0	$<\pm 2\%$

3.5 Density, Specific heat capacity and Thermal Conductivity of Nanofluid Analysis

The density of nanofluid can be calculated by based on the equation shown in below (Zhang et al., 2007):

$$\rho_{nf} = \rho_{np}(\varphi) + \rho_{bf}(1-\varphi)$$

Where φ=volume concentration

According to the author Zhou and Ni (Ni, 2008), the heat capacity of the nanofluid decrease with the increasing of volume fraction , and it has a good agreement with the thermal equibrium model. The heat capacity of nanofluid can be evaluated using model as mentioned in (Ni, 2008):

$$(\rho C_p)_{nf} = (\rho C_p)_{np}(\varphi) + (\rho C_{bf})_{bf}(1-\varphi)$$

Where ρ=density , φ=volume concentration

The thermal conductivity of nanofluid can be calculated by using the Hottel-Whillier equation as shown in below (Sharafeldin and Gróf, 2018a, Zhang et al., 2007) :

$$k_{nf} = k_{bf} \frac{\left[k_{np} + (n-1)k_{bf} - (n-1)\varphi(k_{bf} - k_{np})\right]}{\left[k_{np} + (n-1)k_{bf} + \varphi(k_{bf} - k_{np})\right]}$$

Where n=3 (spherical shape of the particles), φ=volume concentration

The properties of CeO_2 /water nanofluid with different concentration such as the heat capacity, density and thermal conductivity are expressed in the Table 3.6 as shown in below.

Table 3. 6: Value of specific heat capacity, density and thermal conductivity at different concentration

Description	C_p (J/ kg K)	ρ (kg/m^3)	k (W/m.K)
CeO_2 Nano Powder (Sharafeldin and Gróf, 2018b, Sharafeldin and Gróf, 2018a, Mogensen et al., 2000)	460	7130	12
Distilled water	4180	997	0.609
CeO_2- distilled water (0.02%)	4174.684	998.227	0.641
CeO_2- distilled water (0.04%)	4169.386	999.453	0.674
CeO_2- distilled water (0.06%)	4164.096	1000.680	0.709

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The aim of this chapter are to evaluate the properties of nanofluid and the performance of nanofluid on evacuated tube solar collector (ETSC). Section 4.2 and 4.3 are to evaluate the properties of nanofluid such as viscosity and thermal conductivity of the nanofluid. The stability of the nanofluid are expressed in the Section 4.4. The stability of the nanofluid are determine by using the common method that are sedimentation method. The sedimention velocity of the nanofluid are further explained using the stroke law and illustrate in this section. Section 4.5 and Section 4.6 are to show the efficiency of base fluid (distilled water) and different concentration of CeO_2 nanofluid with three different volumetric flow rates on the ETSC. The efficiency of ETSC are illustrated using graphical method for better understanding.

4.2 Viscosity Evaluation of Nanofluid

Viscosity of fluid is the ability of the fluid to resist the flow. Normally, the viscosity of the fluid is referred as the thickness of the fluid. High thickness of the fluid causing the fluid to be more viscous. The viscosity of nanofluid are influenced by several parameter such as the volume fraction of nanofluid, the temperature of nanofluid, the nanoparticles size and etc.(Jabbari et al., 2017) Table 4.1 below illustrated the dynamic viscosity and density of distilled water from 10^{o}C to 80^{o}C. Measuring the viscosity of fluid is very importance in the beginning of the work because this is the importance data that used for designing thermal system and estimated the needed pumping power of fluid to all the system. Besides that, viscosity of the nanofluid could also affect the heat and mass transfer characteristic. Determining the property of base fluid (distilled water) is very importance as it can be used to evaluate the property of the nanofluid.

Table 4. 1: Dynamic viscosity and density of distilled water at various temperature

Temperature , ^{o}C	Dynamic Viscosity μ , $mPa.s$	Density ρ , g/cm^3
10	1.3059	0.9997
20	1.0016	0.9982
30	0.7972	0.9956
40	0.6527	0.9922
50	0.5465	0.9880
60	0.4660	0.9832
70	0.4035	0.9778
80	0.3540	0.9718

Einstein model as shown at below is the first theory developed to predict the viscosity of nanofluid. This model is developed at year 1906. The limitation of this model is it cannot be used to evaluate high concentration of nonofluid. This model is only can be used to predict the viscosity with nanofluid concentration lower than 2% (Bashirnezhad et al., 2016).

$$\mu_{nf} = \mu_{bf}(1+2.5\phi)$$

In year 1977, Batchelor have developed another equation to determine the viscosity of nanofluid. This equation have considered the Brownian motion effect of particles for the suspension of rigid and spherical shapes particles. This equation is suitable to most of the experimental data for nanofluids. This is equation is mentioned in the research of (Rudyak, 2013, Bashirnezhad et al., 2016).

$$\mu_{nf} = \mu_{bf}(1+2.5\phi+6.2\phi^2)$$

The viscosity of distilled water and three different concentration of water based nanofluid, 0.02%, 0.04% and 0.06% from 10^{0}C to 80°C are as shown in Table 4.1 below. From the figure, we can observed that the viscosity of fluid is decreasing with increase of temperature. But, nanofluid that contain nanoparticles have higher viscosity than the distilled water. The highest viscosity of 0.06% CeO_2 is 1.531 mPa.s when it is at 10°C, while the highest viscosity of distilled water is only 1.306 mPa.s.

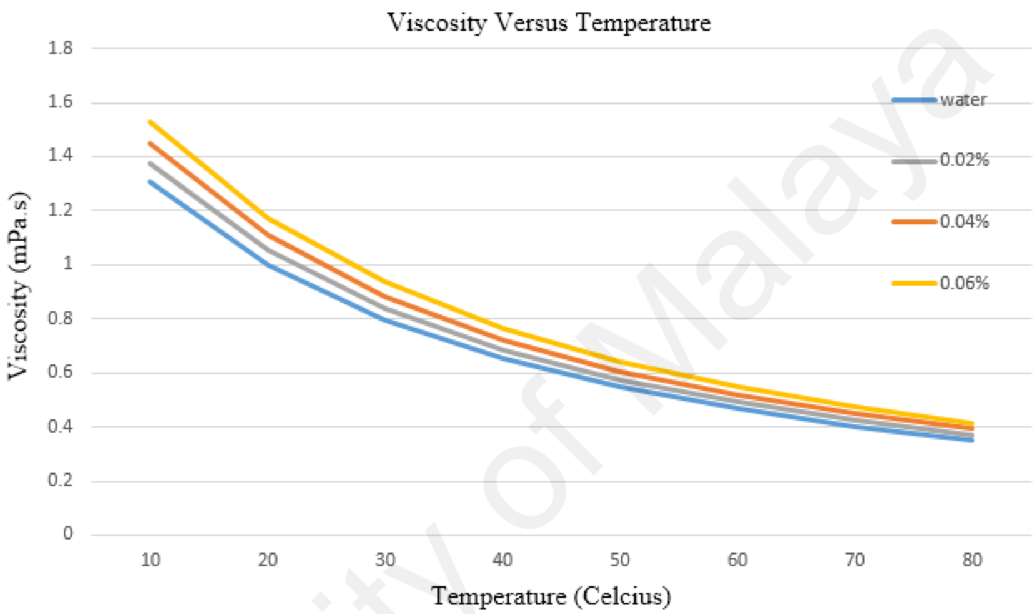


Figure 4. 1: Viscosity of distilled water and various concentration of CeO_2 nanofluid at various temperature

Adding nanoparticles to the base fluid definitely caused increase in viscosity of the fluid although just a little amount of nanoparticles were added. Thus, higher pumping power is required to operate the system. Increase pumping power of the system is not favorable in enhance the thermal performance of the solar collector as it might increase the overall operation cost.

4.3 Thermal Conductivity of Nanofluid

Nanofluid that consists of high conductivity particles that dispersed into working fluid at low concentration are become more popular among the researchers for research for. They might be the future heat transfer medium in the future. The Table 4.2 below expressed the thermal conductivity of distilled water at various temperature. From the table, we can observed that the thermal conductivities are increasing with increase with temperature.

Table 4. 2: Thermal conductivity of distilled water at various temperature

Temperature, ^{o}C	Thermal conductivity K, $W/m.K$
17	0.5917
22	0.6009
27	0.6096
32	0.6176
37	0.6252
42	0.6322
47	0.6387
52	0.6445
57	0.6499
62	0.6546
67	0.6588
72	0.6624
77	0.6655
82	0.6680

The thermal conductivity of nanofluid can be calculated by using the Hottel-Whillier equation as mentioned earlier in last chapter. The Figure 4.2 showed the thermal conductivities of distilled water, different concentration of CeO_2 water based nanofluid comprising of 0.02%, 0.04% and 0.06% from 20^oC to 80^oC. From the figure, we can observed that the thermal conductivities of nanofluid for three different concentration are obviously higher than the distilled water. The thermal conductivities of 0.06% CeO_2 showed the highest among the three different concentration with the highest at 0.7745 W/m.K compare to thermal conductivity of distilled water with just only 0.667 W/m.K That are the reason why the researchers are gain interest to the nanofluid as future heat transfer medium.

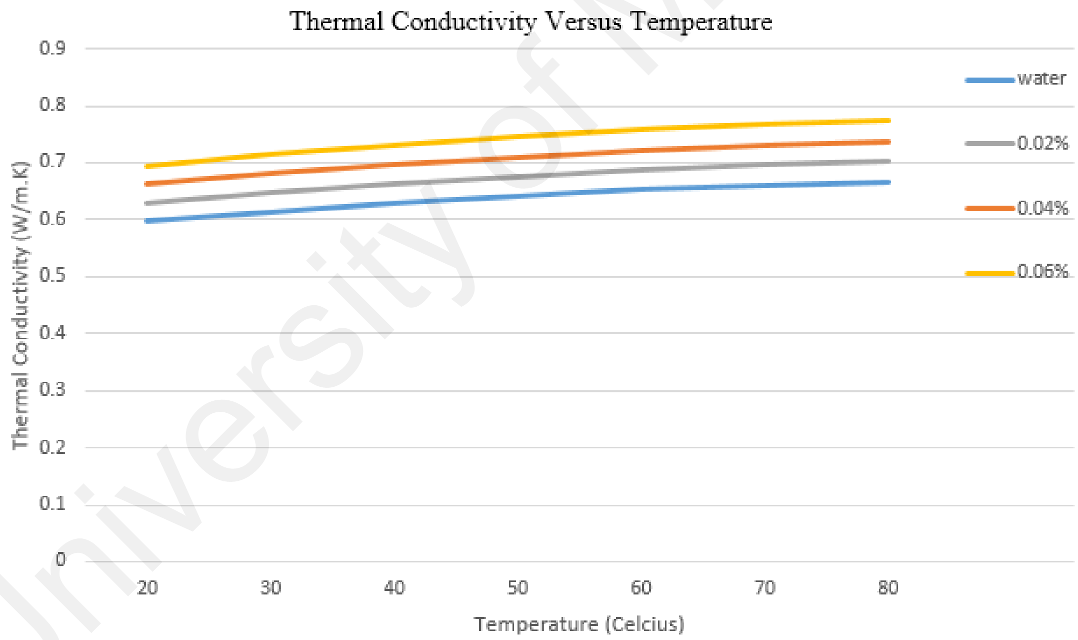


Figure 4. 2: Thermal conductivity of distilled water and various concentration of CeO_2 nanofluid at various temperature

Based on the literature study, most of the findings have showed that the thermal conductivity of nanofluid is higher if compared with base fluid. Thermal conductivity of nanofluid are influence the most by the several parameter such as the concentration of nanofluid, shape of nanoparticles, size of nanoparticles, temperature and etc. (Jabbari et al., 2017, Ahmadi et al., 2018) The authors Sharifpur et al. (Sharifpur et al., 2017) have revealed that the size of nanoparticles play an important role of in thermal conductivity of nanofluid. Thermal conductivity of nanofluid normally show a downward trend when there is increment in particle size. The bigger the size of nanoparticles, the lower the thermal conductivity ratio of nanofluid. The thermal conductivities of nanofluid are increasing with increase of temperature because due to increase of Brownian motion of the nanofluid (Ahmadi et al., 2018).

Experiment of determining the thermal conductivity of aluminium oxide water nanofluid (Al_2O_3/water nanofluid) with various particle size were carried out by the authors Chan et al.(Chan et al., 2005) From the research of study, the authors revealed that the thermal conductivity enhancement are almost twice when 47nm Al_2O_3 nanoparticles was used with compared with 150nm nanoparticles with 1% volume concentration. From the findings of other researchers, it also proved that the increase in particle size could cause decrease in thermal conductivity of nanofluid.

As discussed earlier, nanofluid concentration could give effect to the thermal conductivity of nanofluid as well. Nanoparticles such as Cu, Ag, TiO_2, CuO, MWCNT and etc. have been used by lots of researchers to study the effect of volume concentration to the thermal conductivity of the nanofluid. According to the findings by Patel et al.(Patel et al., 2003) , they observed that there was a 3% thermal conductivity enhancement when 0.001% of Ag nanoparticles was added to the water base fluid. From this research of study, it also found out that by adding the 0.06% CeO_2 nanoparticles to the water shown an increase of 16.12% of thermal conductivity at the room temperature. Besides that, thermal conductivity of TiO_2 / water nanofluid have increased almost double from 7.2% to 13.2% when the nanofluid concentration increase from 0.2% to 2% reported in the journal of Duangthongsuk and Wongwises (Duangthongsuk and Wongwises, 2009)

Based on the literature study and the current research of study, majority of experiment have showed a linearly increase of thermal conductivity with the increase of nanofluid concentration. But, there are also have some experiment results does not show linearly thermal conductivity of nanofluid when there are a very high volume concentration were used.

Most experiment results have showed positive results of increasing in temperature to the thermal conductivity of nanofluid. Arabeshi et al.(Abareshi et al., 2010) have revealed that there are increase of thermal conductivity from 2.8% to 8.9% at the temperature of 10ºC to 40ºC with the use of 1% of Fe_3O_4 nanofluid. The experiment studied that also showed positive effect of thermal conductivity with the increase in temperature can be also found from the journal of Iranmanesh et al.(Iranmanesh et al., 2017), Sabiha et al.(Sabiha et al., 2015) and Chan et al.(Chan et al., 2005).

4.4 Stability Evaluation of Nanofluid

Agglomeration of nanoparticles speed up the sedimentation rate and it definitely reduces the stability time and caused unstable nanofluid. It is very importance to evaluate the stability of nanifluid because unstable nanofluid could alter the thermo physical properties such as thermal conductivity, viscosity, density and etc. and eventually lead to nanofluid lose it great benefit in heat transfer application (Babita et al., 2016). There are few method can be used to measure the stability of the nanofluid such as centrifugal method, zeta potential analysis, spectral absorbency analysis and sedimentation method. One of the most common and cost saving method is conducted through sedimentation method. Sedimentation is defined as the possibility of the nanoparticles to settle out from the base fluid when they are dispersed and let them rest for a period of time. The nanofluid is considered as stable nanofluid if the concentration of the nanoparticles that dispersed in the base fluid remain constant for a period of time without sedimentation. One of the most common and simplest way to conduct this sedimentation method of nanofluid is through capture the photo using camera. The fresh nanofluid with three different volume concentration of 0.02%, 0.04% and 0.06% are first produced and let them to rest as shown in Figure 4.3.

(a) 0.02% CeO_2 (b) 0.04% CeO_2 (c) 0.06% CeO_2

Figure 4. 3: Fresh Nanofluid

In this experiment, the nanofluid is observed for every 1 day (24hours) and the nanofluid condition is captured using camera. Although this method is the most common and is the cost saving method, but it still have some drawback that should be concerned. The disadvantages of using sedimentation method to evaluate the stability of nanofluid are when the there is a high concentration of the nanofluid or the colour of the nanofluid is too dark such as carbon nanotube nanofluid, it might lead to an inaccurate result. Some of the researchers will use sedimentation method together with the zeta potential analysis to evaluate the stability of nanofluid. The stability of various concentration of CeO_2/water nanofluid of 0.02%, 0.04% and 0.06% for a period of time are as shown in the Table 4.3, Table 4.4 and Table 4.5 respectively.

Besides that, some of the researchers will add the stabilizer agent or also known as surfactant to the nanofluid to ensure the nanofluid is stable and not aggregation with time. Adding the surfactant to the nanofluid can provide repulsive force to overcome the particle's strong Van Der Waal attraction force. The examples of surfactant that commonly used by researchers are Triton X-100, SDBS, Gemini, gum Arabic, CTAB and etc.

Stability of 0.02% CeO_2 / water nanofluid are as shown in Table 4.3. From the Table, the fluid are very stable up to 14 days. The particles start to agglomerate and sediment to the base from day 21 onward.

Table 4. 3: Stability of 0.02% CeO_2/ water nanofluid for a period of time

Nanofluid			
Stability period (days)	3	5	7

Nanofluid			
Stability period (days)	14	21	28

Stability test for 0.04% concentration of Cerium (IV) oxide nanofluid are tested and shown in the Table 4.4. The fluid are able to stay stable up to 7 days and it tend to agglomerate from 14 days onward. From the observation, we can make a conclusion that the 0.02% CeO_2 nanofluid are more stable than 0.04% CeO_2 nanofluid.

Table 4. 4: Stability of 0.04% CeO_2/ water nanofluid for a period of time

Nanofluid			

Stability period (days)	1	3	5
Nanofluid			
Stability period (days)	7	14	21

Stability of the nanofluid are affect by its volume fraction of nanoparticles. From this research of study, we can observed that the stability level of the nanofluid decreasing with increase with volume fraction of nanoparticles. Therefore, it is necessary to check the three volume concentration of CeO_2 nanofluid. The stability of the nanofluid should be check with the highest 0.06% volume concentration first. If the highest concentration of nanofluid are stable then it indicate that the 0.02% and 0.04% volume concentration of CeO_2 nanofluid are stable too. Table 4.5 illustrated the stability for 0.06% CeO_2 nanofluid. The fluid has been stable up to a week with no sedimentation occurs and it tend to sediment start from day 7 onward as similar as 0.04% CeO_2 nanofluid. Although high concentration can have better thermal conductivity but the drawback is the fluid tend to be unstable with the higher concentration.

Table 4. 5: Stability of 0.06% CeO_2/ water nanofluid for a period of time

Nanofluid			
Stability period (days)	1	3	5
Nanofluid			
Stability period (days)	7	14	21

The sedimentation velocity of the nanofluid can also be calculated by using the stroke law equation mentioned in the journal of Babita et al. (Babita et al., 2016) as shown in below:

$$V = \frac{2r^2}{9\mu}(\rho_{np} - \rho_{nf}) * g$$

Where V= sedimentation velocity of spherical particles, r=radius of the particles, μ =dynamic viscosity of the liquid medium, g=gravitational acceleration ($9.81 m/s^2$)

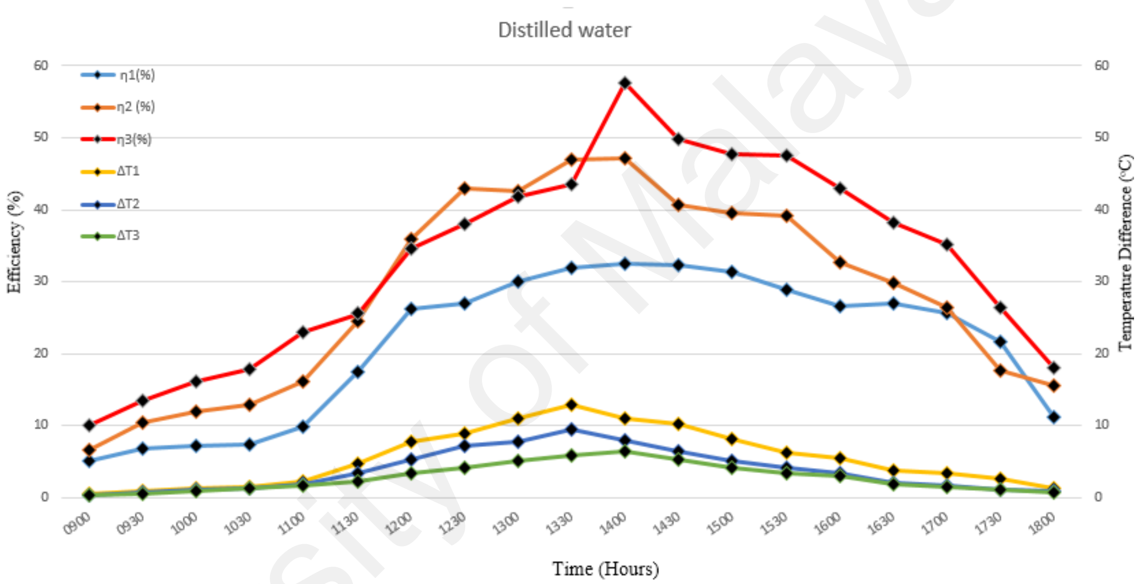
From the stroke law equation, we can concluded that the sedimentation velocity for nanofluid depends on the parameters such as the size of nanoparticles, the density of nanoparticles and fluid medium, the viscosity of the nanofluid and as well as the acceleration due to gravity. The sedimentation velocity of the Cerium (IV) oxide nanofluid with different concentration are illustrated in the Table 4.6 below. From the table, we can observed that the higher the nanofluid concentration, the faster the sedimentation velocity. High sedimentation velocity of nanofluid causing instability and agglomeration of the nanofluid which eventually affect the homogeneity of the nanofluid. Although higher concentration of nanofluid have a high thermal conductivity characteristic(Ahmadi et al., 2018), but it have the drawback of causing instability of the fluid.

Table 4. 6: Sedimentation Velocity of various Nanofluid Concentration

Nanofluid concentration, %	Sedimentation velocity V, m/s
0.02	$2.4894 x 10^{-12}$
0.04	$2.3614 x 10^{-12}$
0.06	$2.2339 x 10^{-12}$

4.5 Efficiency of ETSC with Distilled Water as Working Fluid

The experiment is conducted by using distilled water as a reference to compare with the CeO_2 nanofluid. The purpose of using distilled water as a reference is to validate the experiment results. The efficiency and the temperature difference of ETSC for the period from 0900 morning to 1800 evening is shown as the Figure 4.4 below. The experiment is designed to conduct with using three different flow rates that are 0.5L/min, 1.0L/min and 1.5L/min respectively.



1=0.5L/min; 2=1.0L/min; 3=1.5L/min

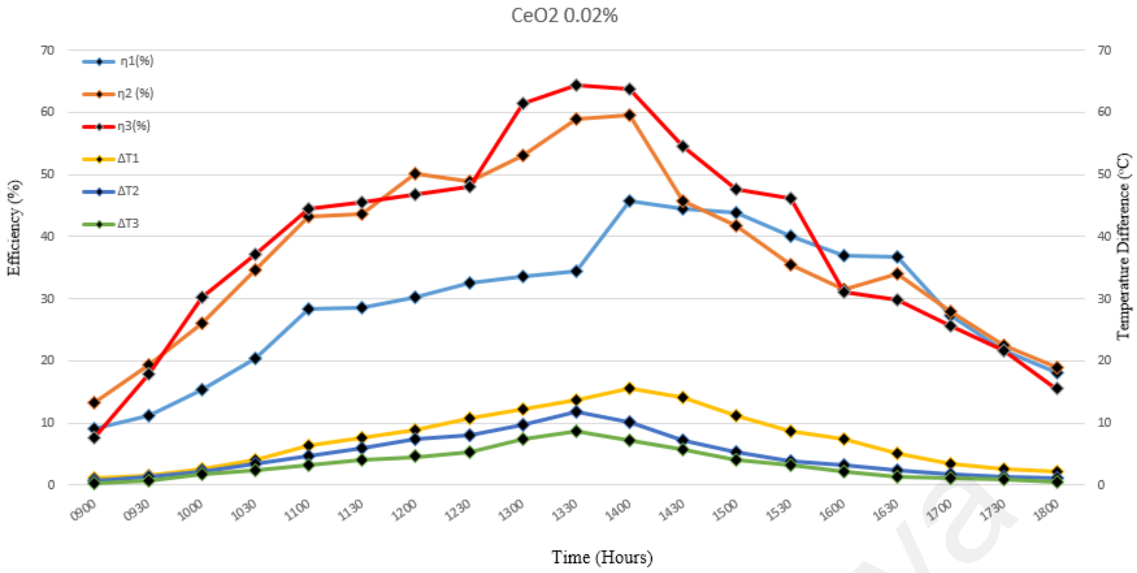
Figure 4. 4: Efficiency and temperature difference of ETSC with distilled water

The efficiency of ETSC with 1.5L/min can achieve up 55.56%, followed by 1.0L/min with 47.23% and 0.5L/min with 32.47% respectively. The highest efficiency normally occur during the noon session because the maximum solar radiation is recorded. The efficiency will be at the peak around that session and it will gradually decreases with the decrease of solar radiation. From the Figure, we can observed that efficiency of ETSC is increasing with the increase of flow rates. This is because the higher the flow rates, the faster the heat removal of fluid from the collector. The maximum temperature difference that are recorded are 12.8ºC, 9.4ºC, 6.5ºC for the flow rates of 0.5L/min, 1.0L/min and 1.5L/min respectively. This phenomena can be explained by the slower the flow rates, the lower the heat removal of the fluid from the solar collector and the higher temperature of the fluid.

The trend of the efficiency of the evacuated tube solar collector that using distilled water as a base fluid are almost the same with the previous researchers (Sabiha et al., 2015, Iranmanesh et al., 2017) that use the same evacuated tube solar collector to conduct their research of study. According to the authors of Sabiha et al. (Sabiha et al., 2015), the maximum efficiency of distilled water with the volumetric flow rates of 1.5L/min (0.025kg/s) occurred at 0230pm with recorded 54.37%, while the authors of Iranmanesh et al. (Iranmanesh et al., 2017) stated that the efficiency of distilled water with volumetric flow rates 1.5L/min are 54.80%. The results of the efficiency of this research of study proved to be valid as the maximum efficiency that recorded are 55.56% with the 1.5L/min volumetric flow rates .The results that obtained are almost the same compared with the previous researcher's finding.

4.6 Efficiency of ETSC with CeO_2 Nanofluid as Working Fluid

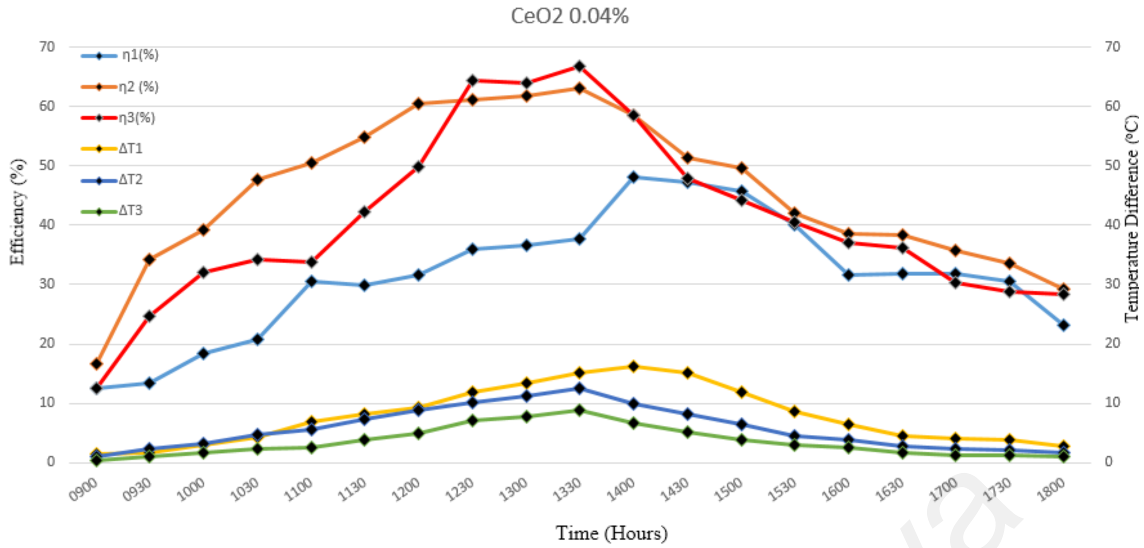
Three different concentration of CeO_2 nanofluid comprising of 0.02%, 0.04% and 0.06% are prepared in order to evaluate the efficiency of ETSC. The experiment is conduct for several hot and sunny day in order to get a more accurate results. The experiment setup such as the flow rates is set to be the same with the distilled water that are 0.5L/min, 1.0L.min and 1.5L/min so can have a clear comparison between them.



1=0.5L/min; 2=1.0L/min; 3=1.5L/min

Figure 4. 5: Efficiency and temperature difference of ETSC with 0.02% CeO_2 nanofluid

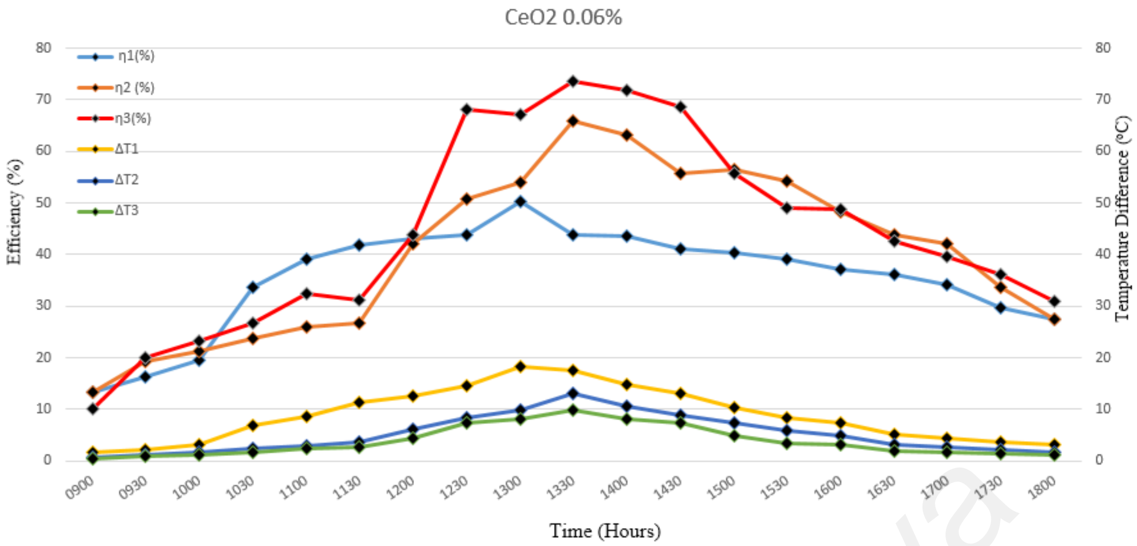
The efficiency and temperature difference of ETSC with 0.02% concentration of CeO_2 nanofluid is as shown in Figure 4.5. The highest temperature difference that are recorded are 15.5°C with using 0.5L/min flow rates, followed by 11.8°C using 1.0L/min and 8.6°C using 1.5L/min flow rates. The efficiency of ETSC recorded using nanofluid is obviously higher than only using distilled water as working fluid. The highest efficiency is recorded as 64.47% by using the 1.5L/min flow rates. This is due with the higher thermal conductivity of the nanofluid with compare with distilled water.



1=0.5L/min; 2=1.0L/min; 3=1.5L/min

Figure 4. 6: Efficiency and temperature difference of ETSC with 0.04% CeO_2 nanofluid

The efficiency and temperature difference of ETSC with 0.04% concentration of CeO_2 nanofluid is as shown in Figure 4.6. The highest temperature difference that are recorded are 16.3°C, 12.6°C and 8.9°C for 0.04% concentration nanofluid at 0.5L/min, 1.0L/min and 1.5L/min flow rates respectively. The efficiency of ETSC recorded using 0.04% concentration nanofluid is higher than 0.02% concentration nanofluid. The highest efficiency is recorded as 66.72% by using the 1.5L/min flow rates.



1=0.5L/min; 2=1.0L/min; 3=1.5L/min

Figure 4. 7: Efficiency and temperature difference of ETSC with 0.06% CeO_2 nanofluid

The efficiency and temperature difference of ETSC with 0.06% concentration of CeO2 nanofluid is as shown in Figure 4.7. The highest temperature difference that are recorded are 18.4 ^{o}C, 13.2 ^{o}C and 9.8 ^{o}C for 0.06% concentration nanofluid at 0.5L/min, 1.0L/min and 1.5L/min flow rates respectively. The temperature difference that are recorded for 0.06% CeO_2 nanofluid are higher compared to 0.04% and 0.02% CeO_2 nanofluid. The highest efficiency is recorded as 73.46% by using the 1.5L/min flow rates.

4.7 Comparison efficiency of distilled water and CeO_2 nanofluid

The efficiency of ETSC of distilled water and CeO_2 / water nanofluid with three different volumetric flow rates of 0.5L/min, 1.0L/min and 1.5L/min are illustrated in the Figure 4.8 as shown below. From the findings, the efficiency of the solar collector varies with several parameter, they are solar radiation, volumetric flow rates, volume loading of the nanofluid and the ambient temperature (Iranmanesh et al., 2017).

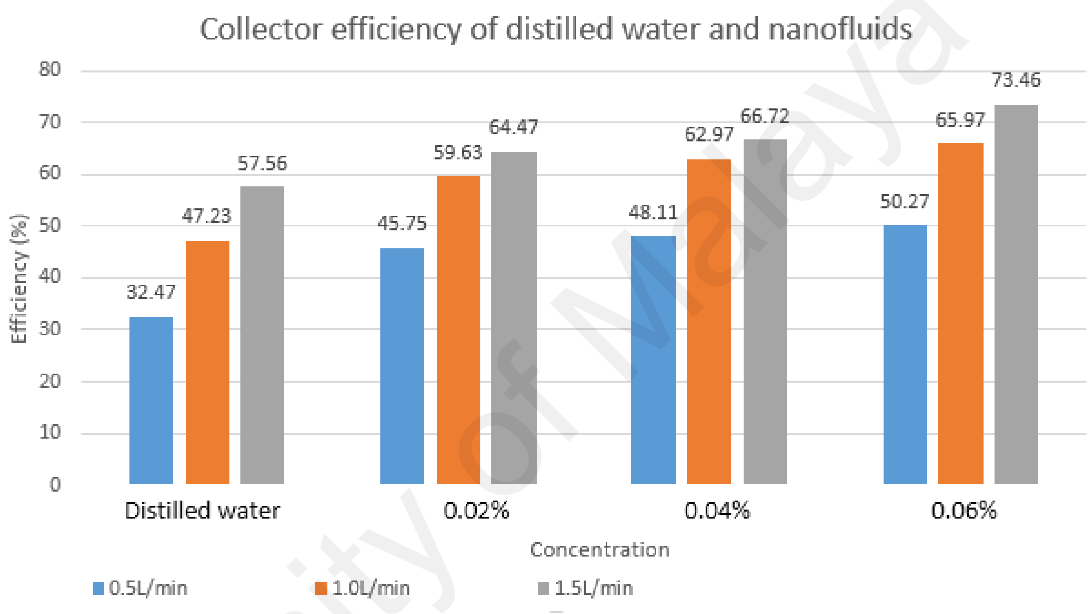


Figure 4. 8: Efficiency of distilled water and various concentration of CeO_2 nanofluid with different flow rates

The thermal efficiency of the ETSC for distilled water are 32.47%, 47.23%, 57.56%; for 0.02% CeO_2 nanofluid are 45.75%, 59.63%, 64.47%; 0.04% CeO_2 nanofluid are 48.11%, 62.97%, 66.72%; for 0.06% CeO_2 nanofluid are 50.27%, 65.97% and 73.46% with the volumetric flow rates of 0.5L/min, 1.0L/min and 1.5L/min respectively. From the Figure 4.8, it is observed that there are significant increment with the use of nanofluid if compared with only distilled water as a base fluid. The ETSC gain the highest efficiency with 73.46% for 0.06% CeO_2 nanofluid whereas distilled water can achieved only 57.56% with the same flow rates. There are up to 27.63% efficiency enhancement compared with distilled water at the 1.5L/min volumetric flow rates. From the graph, the efficiency of ETSC showed an uptrend when there is increase of volumetric flow rates and solar radiation. The overall evacuated tube solar collector (ETSC) was increased from the 0.5L/min volumetric flow rates to 1.5L/min volumetric flow rates because there are more heat are withdraw from the fluid flow (Iranmanesh et al., 2017). Besides that, the solar collector thermal performance also affected by the geometry of the collector such as the length of tube, number of tubes and collector absorption area (Mahbubul et al., 2018). According to the authors Ghaderian and Sidik (Ghaderian and Sidik, 2017), the performance of the solar collector recorded higher when the medium of fluid flow faster. Reynold number (Re) increases as there is increment in volumetric flow rates and thus it enhance the heat transfer mechanism of the solar collector. This phenomena is due to the turbulence flow of the fluid and the mixing between the fluid layers (Sharafeldin and Gróf, 2018a). In this research of study, the same behavior is observed, in which the faster the volumetric flow rates, the higher the efficiency of the solar collector. Added nanoparticles to the base fluid helps in increase in efficiency of evacuated tube solar collector as it help in increase the temperature difference. When the temperature difference recorded to be higher, the efficiency of solar collector will also increase.

From this research of study, it have found out that the use of 0.06% CeO_2 / water nanofluid at the evacuated tube solar collector can have better efficiency enhancement compared to the single wall carbon nanotube (SWCNT) nanofluid as mentioned at the paper of Mahbubul et al. (Mahbubul et al., 2018) . According to the author Mahbubul et al., the highest efficiency of 56.7% was observed when the collector is working with the water, whereas 10% higher efficiency is observed when the 0.2% volume concentration of SWCNT nanofluid is used in the solar collector. The volume concentration that used by the CeO_2 nanofluid is much lower compared with the SWCNT nanofluid, but it could have better efficiency enhancement. Besides that, CeO_2 water nanofluid also perform better than TiO_2 water nanofluid as investigated by the authors of Mahendrian et al. (Mahendran et al., 2012). From the findings of Mahendrian et al., 0.3% volume concentration of TiO_2 could achieved up to 73% efficiency, which is 16.7% higher compared with water. But, from this research of study, it is observed that with the use of 0.06% CeO_2 nanofluid could achieved the efficiency up to 73.46%, which is 27.63% higher than distilled water. From this comparison, we can come to a conclusion that CeO_2 nanofluid is better than TiO_2 nanofluid at the evacuated tube solar collector.

4.8 Maximum Heat Gain and Maximum Temperature Difference of ETSC

Heat gain is defined as how much energy can absorb by the collector. Heat gain are required to calculate in order to determine the efficiency of the collector. The heat gain of the collector can be measured by the equation $Q_u = \dot{m} C_p (T_{out} - T_{in})$. From the equation, heat gain are affected by the parameter such as the mass flow rates, the heat capacity, the inlet temperature of the nanofluid and the outlet temperature of the nanofluid. The properties of heat capacity of the nanofluid are as shown in Table 3.6. Although increase concentration of nanofluid have caused decreased in specific heat capacity of the fluid, but after calculate using the equation as mentioned earlier, there are still have increase in maximum heat gain because there is increase in temperature difference when using the higher concentration of the fluid. The maximum heat gain for distilled water and the CeO_2 nanofluid (0.02%, 0.04% and 0.06%) at different flow rates are illustrated as shown in the Figure 4.9.

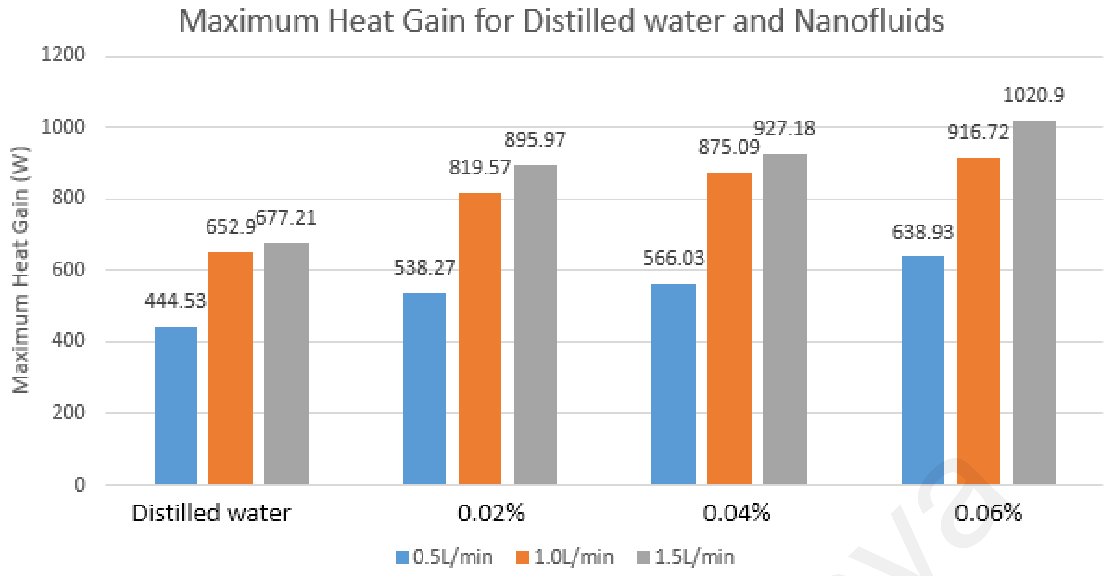


Figure 4. 9: Maximum heat gain for distilled water and various concentration of CeO_2 nanofluid at different flow rates

From the figures, the maximum heat gain for CeO_2 nanofluid is more than distilled water. The maximum heat gain shown an uptrend as the concentration of the nanofluid increase. The maximum heat gain for the 0.06% CeO_2 nanofluid are 638.93W, 916.72W and 1020.90W while the maximum heat gain for distilled water are 444.53W, 652.90W and 677.21W for the flow rates of 0.5L/min, 1.0L/min and 1.5L/min. The evacuated tube solar collector absorbed the highest heat for distilled water and CeO_2 nanofluid when the flow rates set to be 1.5L/min. The maximum increment of the heat gain of 0.06% CeO_2 nanofluid compared with distilled water at the flow rates of 1.5L/min is 50.75%.

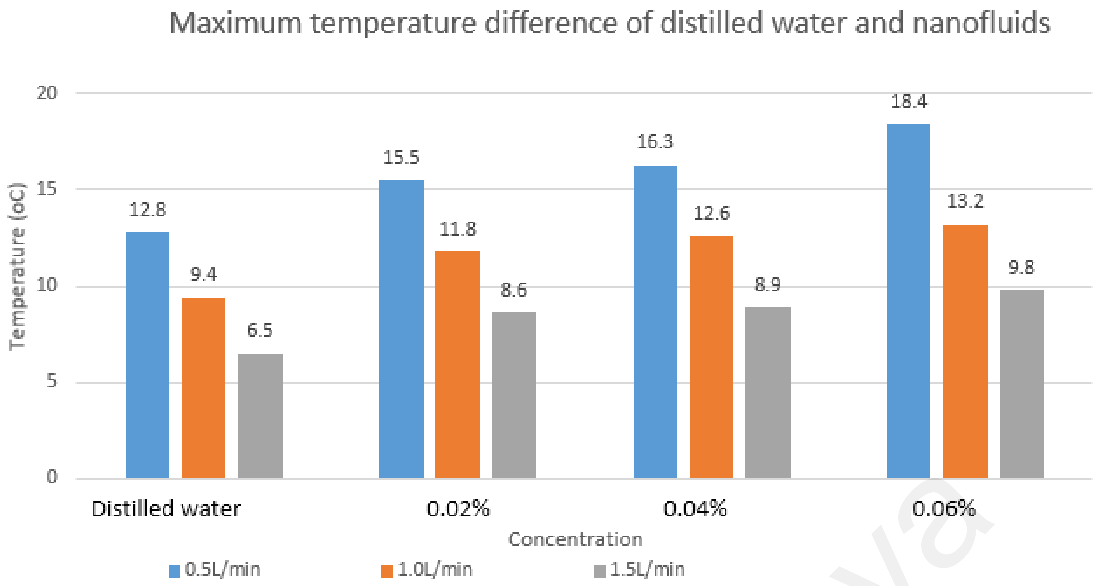


Figure 4. 10: Maximum temperature difference for distilled water and various concentration of CeO_2 nanofluid at different flow rates

Temperature difference are one of the most important parameter to determine the useful heat gain. Figure 4.10 showed the maximum temperature difference for the distilled water and three concentration of CeO_2 nanofluid (0.02%, 0.04%, 0.06%) for the volumetric flow rates at 0.5L/min, 1.0L/min and 1.5L/min. Without temperature difference, we are unable to calculate the useful heat gain by the collector and determine the efficiency of the solar collector. The inlet and outlet temperature of the fluid are recorded. From the Figure 4.10, the temperature difference for the nanofluid are higher than distilled water. Besides that, lower volumetric flow rates gives more temperature difference than the higher volumetric flow rates. Concentration of the fluid are proportional to the temperature differences. The higher the concentration of the nanofluid, the higher the temperature difference because due to the motion between the nanoparticles collide with the liquid particles for a more scientific term it is known as Brownian motion of the fluid. The temperature difference that recorded for 0.02% CeO_2 nanofluid, 0.04% CeO_2 nanofluid and 0.06% CeO_2 nanofluid are 8.6^{o}C, 8.9 ^{o}C and 9.8 ^{o}C for the volumetric flow rates of 0.5L/min, 1.0L/min and 1.5L/min respectively. There are up to 50.77%

enhancement in temperature difference of 0.06% CeO_2 nanofluid compared to distilled water at the volumetric flow rates of 1.5L/min.

The reason behind the high temperature difference of nanofluid recorded as compared with distilled water is due to the change in thermal conductivity. Thermal conductivity play an important role in the temperature difference. The thermal conductivity of nanofluid are higher than distilled water. From the Figure 4.2, the thermal conductivities of 0.06% volume concentration of CeO_2 nanofluid is the highest followed by 0.04% and 0.02% volume fraction of CeO_2 nanofluid. High thermal conductivity helps in enhance the heat transfer mechanism. It enable the fluid absorb more heat from the solar radiation and eventually raised the outlet temperature of the fluid (Sharafeldin and Gróf, 2018a).

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

An experimental study was conducted to determine the effect of Cerium (IV) oxide (CeO_2) nanoparticles on the performance of evacuated tube solar collector (ETSC) that are available in University of Malaya (UM). The CeO_2 /water based nanofluid are produced through two step method by using the probe type ultrasonicator that are available in the lab. The stability of CeO_2 nanofluid are to determine through sedimentation method. This method is the ultimate method but the drawback are very time consuming and not very suitable to dark in colour nanofluid such as carbon type nanofluid because partial sedimention are difficult to determine. A stable nanofluid are produced and can stable up to 28 days. Three different concentration of CeO_2 nanofluid are produced that are 0.02%, 0.04% and 0.06%. Three of these concentration nanofluid were used to determine the performance of the ETSC. This research of study are conducted during sunny day from 0900 morning to 1800 evening in order to get maximum solar radiation. The performance of the ETSC were to determine with different parameter such as the ambient temperature, inlet and outlet temperature, solar radiation, the maximum heat gain of the collector, thermal efficiency and etc. In able to get a better findings, three different volumetric flow rates (0.5L/min, 1.0L/min and 1.5L/min) was employed. From the research of the study, the maximum efficiency of CeO_2 nanofluid was 0.06% with 1.5L/min flow rate while the efficiency enhancement of CeO_2 compared to distilled water was 27.63%. From the findings, the efficiency of CeO_2 nanofluid are obviously higher than the distilled water due to the higher thermal conductivity of the nanofluid. For the maximum heat gain, CeO_2 nanofluid can absorbed 1020.90W at 1.5L/min, while distilled water only can absorbed up to 677.21W at 1.5L/min, 50.75% higher than the distilled water. Hence, it can be concluded that the best performance of

ETSC was using 0.06% volume concentration of CeO_2 nanofluid. As a conclusion, the objectives of this research of study were achieved.

5.2 Recommendation and Future Work

The characteristic of nanofluid such as high thermal conductivity draw attention of many researchers to research for. Water or coolant that being used in many industrial plants could be replaced by nanofluid if nanofluid could stable for a very long period of time because the fluid that usually used by industrial cannot be change too frequently. Change of the fluid need to temporarily shut down the plants and it might affected the schedule of work of the company. Stability of nanofluid is still a challenges to the researches until today. The stability of nanofluid are affected by the ultrasonication time. Study should be carried out to study the optimum frequency and duration that are needed to the produced a stable nanofluid.

Addition nanoparticles to the nanofluid can enhance the thermal conductivity. But on the other hand, addition nanoparticles would affected the viscosity of the fluid compared to base fluid such as distilled water. High viscosity of fluid would require higher pumping power of the pump or motor to pump the fluid to all the systems and it might affects the benefits of using nanofluid. Optimum concentration should be studied so that it might give a high thermal conductivity and not caused high viscosity of the fluid. In conclusion, implementing CeO_2 nanofluid to ETSC still a challenges in the aspect of economic and application.

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