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INVESTIGATION OF THE PERFORMANCE OF A FLAT PLATE SOLAR COLLECTOR

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The thesis with the title of "**Investigation of the Performance of a Flat Plate Solar Collector**" prepared by the Tukur Sani GADANYA, Master Student at the Mechanical Engineering Program at the Department of Mechanical Engineering was accepted by the jury members whose names and titles presented below as a result of thesis defense on September 10th, 2018.

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I hereby declare that all information and results reported in this thesis have been obtained by my part as a result of truthful experiments and observations carried out by the scientific methods, and that I referenced appropriately and completely all data, thought, result information which do not belong my part within this study by virtue of scientific ethical codes.

31/07/2018

Tukur Sani Gadanya

ÖZET

DÜZLEMSEL GÜNEŞ KOLLEKTÖRÜNÜN PERFORMANSININ İNCELENMESİ

Tukur Sani GADANYA

Yüksek Lisans Tezi, Makine Mühendisliği Anabilim Dalı
Tez Danışmanı: Dr. Öğr. Üyesi Mustafa ASKER
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Dünya nüfusu hızla artarken zararlı karbon salınımına neden olan fosil yakıtların fiyatlarındaki dalgalanmalarla beraber, güneş, rüzgar ve hidro yenilenebilir enerjilere olan ihtiyacın giderek artışı küresel olarak kabul görmektedir. Düzlemsel (düz plaka) güneş kollektörünün (FPSC), en önemli parçası güneş ışınımını ısıya çevirip sistemde dolaşan akışkana transfer eden emici yüzeydir (absorber'dir). Bu tezde hacimsel oran % 0-2 aralığında ve 0.02 kg/s kütlesel debi değerlerinde bir FPSC'de akışkan olarak Al_2O_3, CeO_2, Cu, SiO_2 ve TiO_2 olmak üzere beş farklı nanofluid kullanılarak kollektörün performansı incelenmiştir. Tezi doğrulamak için, deneyle ile bir karşılaştırma yapılmıştır ve sonuç olarak iyi bir anlaşma bulundu. Bu tezde yılın en soğuk ayı olarak Ocak ayı için ve en sıcak ayı olarak Temmuz ayı için kütle akış hızı ve düşük sıcaklık gibi parametrelerin performansa, enerjik verime ve ekserjik verime olan etkileri MATLAB programında yazılan bir parametrik çalışmayla ele alınmaktadır. Elde edilen sonuçlar, 0,02 kg/s'lik sabit bir debi ve % 2 hacimsel oran için, SiO_2 akışkanı ile veriminin her iki ay için de % 10 arttığını göstermektedir. Ek olarak, azami ekserji artışı 0.02 kg/s debide ve %2'lik hacimsel oranda Ocak ayında % 2,7 ve Temmuz ayında % 3,1 olarak Cu'da gözlemlenmiştir. Türkiye'de Aydın ilinin çevresel verileri ve özellikleri (sıcaklık ve ışınım) ele alınarak genel bir metodoloji geliştirilmiştir.

Anahtar Kelimeler: Ekserji, Düzlemsel güneş kollektörü, Kollektör performansı

ABSTRACT

INVESTIGATION OF THE PERFORMANCE OF FLAT PLATE COLLECTOR

Tukur sani GADANYA

Master Thesis, Department of Mechanical Engineering
Supervisor: Asst. Prof. Dr. Mustafa ASKER
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As the world population is increasing rapidly and the fluctuation in the price of the harmful fossil fuels, the need for renewable energies such as solar, wind and hdro have gradually been recognized and accepted globally. The absorber is the most important part of a flat plate solar collector (FPSC) which absorbs the solar radiation, converts it to heat and transfer it to the working fluid. This thesis investigates the performance of a FPSC using five different nanofluids including Al_2O_3, CeO_2, Cu, SiO_2, and TiO_2 as the working fluid with a volume fraction range of 0-2% and mass flow rate of 0.02kg/s. To validate the thesis, a comparison was made with an experiment in which a good agreement was found. A parametric study is done using a computer program written in MATLAB to investigate the effects of volume fractions on the performance, energetic and exergetic efficiencies of the collector in the coldest, January and hottest, July, month of the year. The results show that for a constant flow rate of 0.02kg/s and volume fraction of 2%, the maximum efficiency enhancement is observed in SiO_2 by 10% in both months while the maximum exergy enhancement is observed in Cu by 2.7% and 3.1% in January and July respectively for a flow rate of 0.02kg/s and volume fraction of 2%. The overall methodology has been developed on the environmental data (ambient temperature and irradiation), which are characteristics of the city of Aydin in Turkey.

Key Words: Exergy, Flat plat solar collector, Thermal performance

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In the name of Allah the most beneficent, the most merciful, I glorify your Holy name for the success of this work. The success of this thesis is no one man contribution.

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Tukur Sani GADANYA

TABLE OF CONTENTS

NOMENCLATURE

A_c	Collector surface area (m^2)
A_e	Edge surface area (m^2)
C	Constant defined in Eq. (2)
C_p	Specific heat (J/kg.K)
D	Outer diameter of the collector tube (m)
D_i	Inner diameter of the collector tube (m)
$\dot{E}_d$	destroyed exergy rate (W)
$\dot{E}_l$	leakage exergy rate (W)
$\dot{E}_{d,\,\Delta T}$	destroyed exergy rate due to the temperature difference (W)
$\dot{E}_{d,\,\Delta P}$	destroyed exergy rate due to pressure drop (W)
$\dot{E}_{d,\,\Delta Tf}$	destroyed exergy rate due to flow of nanofluid in the collector (W)
F	Fin efficiency
F'	Collector efficiency factor
F_R	Heat removal factor
f	Frictional factor
g	Gravitational acceleration (m/s^2)
h_{fi}	Heat transfer coefficient of fluid ($W/m^2.K$)
h_L	Head loss
h_w	Wind heat transfer coefficient ($W/m^2.K$)
I	Heat flux of solar radiation (W/m^2)
k	Thermal conductivity (W/mK)
L	length (m)
$\dot{m}$	Mass flow rate (Kg/s)
N_g	Number of cover

Nu	Nusselt number
P	Pressure (Pa)
Pr	Prandtl number
Q_u	Absorbed energy by plate (W)
Re	Reynolds number
$\dot{S}_{gen}$	Entropy generation (W/K)
T	Temperature (K)
T_{amb}	Ambient temperature (K)
T_{abs}	Absorber temperature of (K)
t_b	Back thickness (m)
t_e	Edge thickness (m)
U_b	Bottom heat loss coefficient (W/m^2 K)
U_e	Edges heat loss coefficient (W/m^2 K)
U_L	Overall heat loss coefficient (W/m^2 K)
U_t	Top heat loss coefficient (W/m^2 K)
V_w	wind velocity (m/s)
V	Velocity (m/s)
W	Distance between two tubes (m)

Greek symbols

α	Absorption coefficient
β	Collector tilt angle (degree)
μ	Viscosity of fluid (kg/m. s)
λ	Constant defined in Eq. (2)
δ_c	Thickness of absorber plate (m)
ε	Emissivity
ρ	Density (Kg/m^3)

σ	Stefan-Boltzmann constant (W/(m^2 K^4))
$(\tau\alpha)$	Optical efficiency
ϕ	Volume fraction of nanofluids
Subscripts	
p	Particles
w	water
nf	nanofluid
in	inlet
out	outlet

LIST OF ABBREVIATIONS

FPSC	: FLAT PLATE SOLAR COLLECOR
ETC	: EVACUATED TUBE COLLECTOR
CPC	: COMPOUND PARABOLIC COLLECTOR
SWH	: SOLAR WATER HEATER
HTF	: HEAT TRANSFER FLUID
DDW	: DOUBLE DISTILLED WATER
TIM	: TRANSPARENT INSULATION MATERIAL
PTC	: PARABOLIC TROUGH COLLECTOR
CR	: CENTRAL RECEIVER
EDB	: EXTENDED DUFFIE AND BECKMAN
MEC	: MODIFIED CORRELATED MODEL
TFM	: TRANSFER FUNCTION MODEL
QDT	: QUASI-DYNAMIC TEST
MWCNT	: MULTI-WALLED CARBON NANOTUBE
ORC	: ORGANIC RANKINE CYCLE

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The need for renewable energy is gradually been recognized and accepted globally due to the threats the world is facing such as the increase in world population, climate change, fossil fuels price inflation, ever-increasing energy demand and high cost of electricity.

These threats have led to the discovery and development of new, clean and abundant alternative sources of energy called “renewable energies”. Most developed countries like US, UK, Denmark and also developing countries like China, Brazil and Iceland have diversified the means of generating electricity to these alternative sources of energies. Although here in Turkey, the percentage rate of these natural clean energies is relatively low in the market but it has been increasing for over a decade because of the new laws passed, incentivizing the investments in renewable energies such as providing tax exemption, higher feed in tariff and land usage free incentive (UR1). Among these alternative sources of energy includes solar, wind and hydro.

For this thesis, we will concentrate on solar energy for domestic water heating system. Solar energy is a free, abundant and natural radiant light and heat from the sun that is harness by solar collection method. It is the common alternative source of energy used today. It can be utilized directly in two (2) forms: either to generate electricity by exposing a photovoltaic material to sunlight or to generate heat for heating or cooling system. For heating system, the sun’s radiation in form of heat energy is transferred to a working fluid such as the water or oil. These technologies are applicable at either industrial or residential scales. Some industries are using both technologies to generate electricity as well as heating and cooling system. Use of solar energy for water heating is the most common and easiest application with the use of flat plate solar collector (FPSC), evacuated tube collector (ETC) or compound parabolic collector (CPC).

1.1. Problem Statement

Solar energy harvesting is in need of further development so as to regulate the high demand and consumption of fossil fuels because of the ever-increasing cost as well as the threats they bring to our environment. The use of collectors is getting more attention from researchers but still their performances need improvement.

1.2. Motivation

The use of nanofluid as the working fluid instead of water to improve the performance of the collector is gaining more attention. Different nanofluids have been studied by many researchers but few investigate which of the nanofluids would offer a better performance more than the others. This motivated me to investigate the performance of the collector using different nanofluids.

1.3. Solar Water Heating Systems

Solar water heating is the simplest and most direct application of solar energy. It consist of two major parts: solar collector and a storage tank, with the collector been the most important part. The collector receives the sun radiation and transforms it to heat, then transfer the heat into a working fluid mainly water or oil. Solar water heating system can either be active or passive. The active system requires mechanical system (e.g. pump) to tranfer the liquid to the collector while the passive system depends on gravity and natural circulation to circulate the liquid (En 1996).

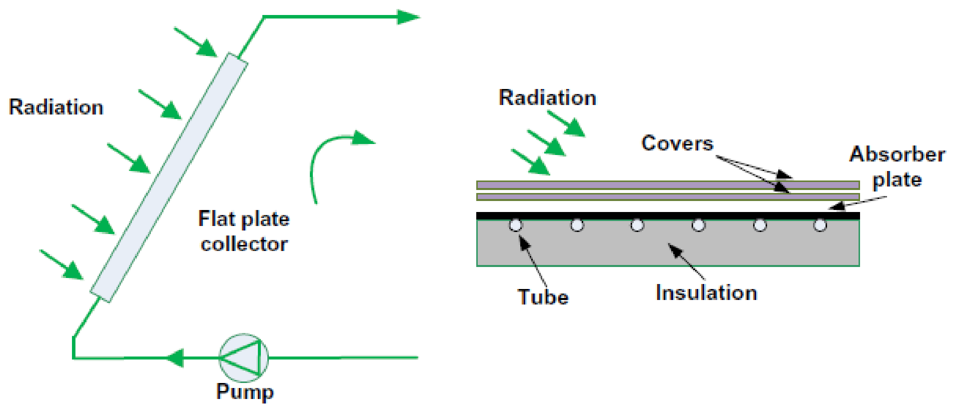


Figure 1.4. Typical active solar water heating system and details of flat plate solar collector **(**Hajabdollahi and Hajabdollahi 2017**)**.

1.4. Thesis Objectives

The aim of this thesis to investigate the performance of a flat plate solar collector (FPSC) using five different nanofluids including Aluminum oxide (Al_2O_3), Cerium oxide (CeO_2), Copper (Cu), Silicon oxide (SiO_2), Titanium oxide (TiO_2). This can be achieved by the following:

1. Utilize the MATLAB software to create a code that can numerically apply the proposed solution method.
2. Validate the code with an experiment from the literature.
3. Performance enhancement by numerical study of FPSC using the five different nanofluids (Al_2O_3, CeO_2, Cu, SiO_2 and TiO_2).
4. Study the effect of nanofluids volume fractons increase on various parameters such as heat transfer coefficient, outlet temperature, thermal efficiency, exergetic efficiency, entropy generation and pressure drop.
5. The meteorological data of Aydin was used for the coldest, January, and hottest, July, months of the year to investigate the performance of the collector.

1.5. Thesis Organization

The thesis consists of five main chapters:

Chapter one contains the thesis background study as well as the thesis objectives.

Chapter two: This chapter reviewed all that has been done in the field from ways of tackling the problems associated with collector to how its efficiency can be enhanced.

Chapter three: This presents the detailed mathematical modeling of the collector as well as the procedure for solving the thesis objective

Chapter 4: This chapter presents the analysis and discussion of results as well as the validation of the thesis work.

Chapter five: Conclusion and future work.

2. LITERATURE REVIEW

A flat plate solar collector (FPSC) is the simplest and user friendly means available for solar energy usage. It is cheap and easy to maintain as well as manufacture. The purpose of using a FPSC is to utilize the absorbed sun's radiation to raise the working fluid temperature to a new one which can be used for various low and medium applications. They use both diffuse and beam solar radiation and are easy to maintain (Duffie and Beckman 2013).

Many researchers have conducted different studies to investigate the effects associated with the collector as well as ways of enhancing its performance.

2.1. Experimental studies

Using nanofluid such CuO, Cu, Al_2O_3 and TiO_2 with high thermophysical properties is one of the ways of improving the performance of a solar collector. Sharafeldin et al., 2018 conducted an experiment to study the effect of using CeO_2 with three different volume fractions (0.0167%, 0.0333%, and 0.0666%) and a mean particle size of 30nm which was kept constant as the working fluid. They found that using CeO_2 nanofluid enhanced the efficiency compared to water. They suggested for a further experiment and study on the nanofluid using different volume fraction.

Verma et al. 2017 also conducted an experiment using a variety of Nano-fluids so as to improve the performance of a FPSC in respect of energy and exergy efficiency by varying the mass flow rate. They found that for an optimum particle volume fraction of 0.75% and mass flow rate of 0.025kg/s, the maximum exergetic efficiency is observed in MWCNTs, Graphene, Cu, Al_2O_3, TiO_2 and SiO_2 respectively. They concluded that the collector can be more frugal and efficient by reducing the collector surface area by about 19.11% as well as the use of MWCNTs nanofluid as the working fluid.

Ahmed et al., 2017 conducted an experiment to investigate the effect of using WO_3 on the thermal efficiency of a FPSC which operates under the weather condition of Budapest, Hungary. The stability of the nanofluid was tested first using Zeta potential tests, followed by the investigation of the nanofluids at different mass flux rates. They found that the use of WO_3 nanofluid alleviate the thermal efficiency of the collector.

Hyeogonin et al. 2017 conducted an experiment to study the effect of nanoparticle size as well as volume concentration of nanofluids on the efficiency of a U-tube solar collector using Al_2O_3 nanofluid as the working fluid. The result obtained showed that for an optimum flow rate of 0.047kg/s and volume fraction of 1%, the efficiency was enhanced by up to 24.1%. They concluded that increasing the concentration beyond optimum decreases the energetic efficiency due to the formation of larger sized agglomerated particles which degrades the stability of the solution.

Said et al. 2016 used a controlled pH treated Al_2O_3 nanofluid as the working fluid to study its effects on the energetic and exegetic efficiencies of a FPSC. An experiment was conducted and the results showed that for an optimum flow rate of 1.5kg/min and volume fraction of 3%, the energetic efficiency increased by 83.5% whereas the exegetic was enhanced by 20.3% for a volume fraction of 1% and flow rate 1kg/min when compared with water.

An experiment was conducted by Jabari et al. 2014 using CuO/water nanofluid to show its effect on the performance of a FPSC. It was found that for an optimum flow rate of 1kg/min the efficiency was enhanced by 16.7%. They concluded that for any working fluid, there is an optimal flow rate that enhances the collector efficiency.

Said et al. 2013 studied the thermophysical properties of Al_2O_3 nanofluid and its effect on the performance of a FPSC. They conducted an experiment to investigate the effect of density and viscosity on the pumping power using ethylene glycol/water and the Al_2O_3. The result obtained showed that Al_2O_3 is preferred against sedimentation and agglomeration and that both their thermal conductivities increases with increase in concentration.

Yousefi et al. 2012 performed an experiment to study the effect of using MWCNT and Triton X-100 as the surfactant. It was found that for a volume fraction of 2% without surfactant the efficiency decrease whereas with surfactant, it increases.

Sabiha et al. used single-walled carbon nanotube (SWCNT) to determine its effect on the thermal efficiency of an evacuated tube collector. They did an experiment according to ASHRAE standard 93-2003 and the results obtained showed the efficiency improved using the nanofluid instead of water as the working fluid. It also showed great enhancement in efficiency by increasing the volume fraction and flow rate.

Noghrehabadi et al. 2016 investigated the effect of using SiO_2 nanofluid on the efficiency of a square FPSC without surfactant. An experiment was performed under ASHRAE standard to investigate the effect of working parameters such as mass flow, solar radiation and temperature variation on the efficiency. It was found that using SiO_2 enhances the thermal efficiency and temperature performance compared to water.

The use of heat enhancer in a flat plate solar collector was done by (Balaji et al. 2018) to investigate the exergy of a riser tube experimentally. The result obtained showed the using rod heat transfer enhancer leads to a higher exergy efficiency instead of tube heat transfer enhancer or plain flat plate collector. They concluded that the use of enhancer reduces overall heat loss with a small increase in pressure drop.

Jouybari et al. 2017 conducted an experiment to investigate the effect of porous material as well as a nanofluid on the thermal performance of a FPSC. They used SiO_2/deionized water nanofluid with volume concentration of 0.2%, 0.4% and 0.6%. Based on ASHRAE standard, the thermal behavior of the nanfluid was examined on a porous channel collector. The results obtained from the experiment showed that the thermal efficiency was enhanced by up to 8.1% with the nanofluid. They also noticed that both the porous media and nanofluids resulted to an increase in pressure drop. They concluded that the FPSC thermal efficiency improvement results to a higher outlet fluid temperature.

Among the problems also affecting the performance of a collector is overheating. Hussain and Harrison 2015 conducted an experiment as well as a 3D numerical study to investigate the natural cooling of a flat plate solar collector in order to control the overheating under stagnation conditions. They found that by mounting an air cooling channel as well as a control valve at the outlet opening heat transfer rate increases and keeping the absorber plate maximum temperature over the range of stagnation condition. They concluded that a back mounted collector or air-channel with a good tilt angle can control overheating passively under stagnation conditions.

2.2. Theoretical Studies

Hawwash et al. 2018 conducted a numerical investigation on the performance of a flat plate collector using Double distilled water (DDW) and Al_2O_3 nanofluid at different volume fraction. The result obtained showed using Al_2O_3 nanofluid enhances the efficiency compared to DDW by about 3-18% at both small and high temperature differences. They developed a model using ANSYS 17 software which can test the performance of a FPSC using DDW or any other working fluid. An experiment was conducted to verify the numerical result in which a good agreement was observed between the two results. They concluded that increasing the volume fraction of the nanofluid beyond 0.5% will have a negative effect on the performance of the collector and also, increasing the volume fraction results to increase in pressure drop.

Said et al. 2015 also used TiO_2 and Polyethylene Glycol (PEG) dispersant to enhance the performance of a FPSC. Working parameters like mass flow rate and volume fraction were varied and also the PEG 400 dispersant to obtain the thermophysical as well as reduced sedimentation of the nanofluid. The result obtained showed that for a constant flow rate of 0.5kg/min and volume of 0.1%, both the energetic and exegetic efficiencies increased by 76.6% and 16.9% respectively. Moreover, both the pressure drop and pumping power of the nanofluid were almost the same with that of the base fluid at the same condition.

Qinbo et al. 2015 used Cu nanofluid to investigate the effects of working parameters such as temperature, heat gain, frictional resistance and thermal conductivity of the nanofluid on the efficiency of a FPSC. It’s shown that for a constant flow rate of 140L/h, volume fraction of 0.1% and particle size of 25nm, the thermal conductivity was enhanced as well as the efficiency by 23.83%. They concluded that using Cu as a working fluid enhances both the performance and efficiency of the collector.

Mahian et al. 2014 performed the analytical analysis to investigate the performance of a minichannel base solar collector using three different nanofluids including Cu, Al_2O_3, TiO_2 and SiO_3. First and second law analysis was done for all the nanofluids in turbulent region and was shown that the highest heat transfer coefficient was obtained using Al_2O_3 and the smallest using SiO_2 for the first law. Also, Cu gives the highest outlet temperature, followed by TiO_2, Al_2O_3, and SiO_3 respectively. It was shown from the second law analysis that among all the nanofluids used Cu results to smaller entropy generation. They recommended the development of Nusselt number and frictional factor correlation for any types of nanofluid under the same conduction to be done as well as the study to increase the stability of the nanofluids in order to avoid sedimentation in the collector tube.

Genc et al. 2018 performed a transient numerical study on the thermal performance of a FPSC using Al_2O_3 nanofluid with a volume fraction range of 1-3% for three different months in the city of Izmir, Turkey. The effect of the nanofluid thermophysical properties and at different flow region was investigated by varying the flow rate. The results obtained showed that at 0.004kg/s and volume fraction of 3% the outlet temperature is at its maximum increase (7.20%) in the month of July and the efficiency also at its highest increase (83.90%) at 0.06kg/s and volume fraction of 1%.

The integration of solar collection with a system is an area that recently received great attention. Toghyani et al. 2016 investigated the performance of a parabolic trough solar collector integrated with a Rankine cycle using four different nanofluids i.e. CuO; SiO_2; TiO_2 and Al_2O_3. The effect of various parameters such as solar intensity, dead state temperature and volume fraction on the exegetic efficiency was also studied. The result obtained showed that the more the concentration, the higher the energetic and exegetic efficiencies. They concluded that among all the nanofluids Al_2O_3 provides the highest overall exegetic efficiency.

Bellos and Tzivanidis 2018 investigated the cooling of a solar system by using an absorption chiller driven by nanofluid base flat plate collector. Cu nanofluid is used as the working fluid and pure water as the base fluid, were examined and compared under steady state condition. They found that the thermal efficiency was enhanced by using the nanofluid up to 2.5%. They also optimized the system in the same condition using a multi-objective procedure with energetic as well as exegetic criteria. The results obtained with the nanofluid showed the exegetic performance was improved by up to 4% and also increase in refrigeration production on daily basis. They concluded that the higher the volume fraction, the higher the thermal performance.

Erden et al. 2017 investigated the performance of hydrogen production as well as the electricity generation with a flat plate solar collector facilitated by a solar pond. The first and second law analysis of the system was done and it was found that a high amount of electrical energy was produced by using Organic Rankine Cycle (ORC) which works with the thermal energy that comes from the integrated system. Moreover, up to 2.25kg/day hydrogen production rate by the electrolysis of water by the system. They concluded that the hydrogen production performance can be increase by increasing the performance of the thermal system.

Koholé and Tchuen 2018 presented an optimization of a FPSC for thermosiphon water heating system. They developed a genetic algorithm that helps in obtaining the appropriate optimum design parameters combinations that maximizes the performance of the collector. The results obtained by the optimization showed that the heater can provide a high performance with low collector area as well as low price.

Freezing is also a problem affecting the performance of a FPSC in cold climate. Zhou et al. 2017 conducted an experiment as well as a numerical study of the freezing process of a FPSC exposed to cold ambient air. The results obtained showed that the antifreeze performance of the collector can be enhanced by reducing the pipe distance; increasing the pipe diameter or header diameter as well as reducing the emissivity of both the absorber and glass cover. They suggested the use of transparent insulation materials (TIM) which improve the antifreeze performance as well as put off the frozen time of the collector. Julian D. Osoria et al. studied the use of transparent insulation materials (TIM) of three (3) different type of solar collector i.e. FPSC, Parabolic Trough collectors (PTCs), and Central Receiver collector (CR). It was shown that the use of TIM decreases thermal losses, as a result leads to higher collector efficiencies at high absorber temperature.

Carbonell et al. 2013 analyzed the dynamic modeling and validation of 2 flat-plate solar collectors under thermosiphon conditions: an extension of the physical model described by Duffie and Beckman (EDB) and a modified correlated model (MEC) based on the test efficiency curved obtained from European standard. They used a virtual test with strong variation of some parameter such as G_t, T_{in} and $\dot{m}$ thermosiphon unsteady system conditions so as to investigate the model response under transient condition. They concluded that the EDB model proposed was able to predict the main characteristic of the collector when submitted to strong variation of the parameters mentioned above whereas the MEC could not predict the physical behavior because of the linearity of the temperature profile beside the assumption of a single control volume for the fluid flow.

Helvaci and Khan 2015 used refrigerant HFC-134a as the working fluid of the collector for a simulation. They developed a model of a FPSC that will investigate working parameter like fluid mean temperature, useful heat gain and heat transfer coefficient along the collector tube. They found that the model can predict the point in the tube in which the fluid undergoes a phase change as well as the state at which it leaves the tube under given conditions. Moreover, the heat transfer coefficient was found to be dependednt on flow rate i.e. by increasing the mass flow rate, the Reynolds number of the flow increases as well, thus, the flow becomes turbulent. They also compared the efficiency with two working fluids (R-134a and HFE-700) for the same working condition and found that R-134a provides higher efficiency due to its surpassing properties at a given condition.

Zhang et al. 2016 investigated the thermal performance of a modified flat-plate solar collector for air heating and water heating. The effect of mass flow rate was investigated using the model and experiment was done to test the real performance of the collector. The results showed that the collector efficiency for air heating and water heat achieved 51.3% and 51.3% when the mass flow rate of the fluid was 0.024kg/s and 0.13kg/s respectively. The maximum temperature rise of air and water reached 66.4^{0}C and 59.8^{0}C in both modes. They suggested that in order to enhance the efficiency and outlet temperature of the fluid, air flow rate between 0.02kg/s and 0.025kg/s was recommended for air heating whilst water flow rate between 0.06kg/s and 0.08kg/s was recommended for water heating.

Murari and Chaurasiya 2017 reviewed the analysis and development of a solar flat-plate collector. They suggested different techniques that can be employed to enhance the efficiency of a flat-plate collector such as the use of Nano-fluid as the working fluid; adjusting the absorber plate design to receive enough sola radiation;

use of polymer; use of mini channels for fluid flow; use of phase change materials and use of enhancement devices such as inserts and reflector.

The effect of fluid temperature in the storage tank as well as depth difference between collector loop connections at the tank on freeze protection of a FPSC at clear nights was investigated on thermosiphon domestic solar water heater by (Tang et al. 2010). Results obtained in an experiment showed, T_{out} for a vertical cylindrical tank was slightly higher than that of horizontal cylindrical tank for a given fluid temperature. Also, T_{out} increases as the temperature of water in the tank increases but lower than the ambient air temperature all night.

Diego-Ayala and Carrillo 2016 investigated the thermal performance of a FPSC for water heating stystem working under operating conditions in a hot sub-humid region, Yucatan, Mexico. Thermosiphon conditions as well as the use of a submersible pump under forced flow condition were used to evaluate the water heater. Thermal performance of the collector was invetigested in both cases to determine the impact of flow on the working temperature as well as the efficiency of the collector. A comparison of the temperature values for both cases has shown that both outlet temperature of the collector and temperature difference between the inlet and the outlet of the collector have reduced significantly. Also, higher efficiency was obtained when the water heater was working under force flow. They concluded that the use of submersible pump could control the optimum working temperature in a solar collector in the region as well as providing a positive effect on the efficiency.

Lukic 2015 investigated the use of a flat plate reflective surface to enable absorption from a lower absorber surface of a double exposure, flat plate collected. An experiment was conducted to determine the feasibility of the model. They found the double exposure flat plate solar collector to perform significantly better than the conventional solar collector.

Many researches have been done in order to enhance the performance of a flat plate solar collector. Sami et al. 2015 suggested that to improve the performance of solar collector, the absorption of solar radiation should be enhanced and heat loss to the surroundings by radiation and convection should be minimized. Moreover, they showed that the heat transfer rate from the absorber plate to the working fluid can be improved by use of Nano fluid.

Jeon et al. 2016 studied the use of blended plasmonic Nano fluid as the heat transfer fluid to investigate the thermal performance of a flat plate volumetric solar collector. An experiment was done to verify the proposed model and the result found showed that the available temperature gain can be increased by increasing the channel depth and reducing the mass flow rate.

Dagdougui et al. 2011 developed a model that investigates the effect of the number and type of covers, on the top heat loss as well as thermal so as to help decision makers determine the most cost-effective design. They also used the model to investigate the effect of various parameters on the performance of the collector. They found that mass flow rate was the most effective on the collector efficiency as well as fluid outlet temperature.

3. MATERIAL AND METHOD

This chapter includes the theoretical study on how to calculate parameter such as absorbed energy, heat loss, heat transfer coefficient, and energy and exergy efficiencies. Moreover, a computer program written in Matlab to show the iterative procedure as well as parametric study is explained in details. A standard flat plate solar collector specifications as well as nanofluids thermophysical properties tables are given.

3.1. Mathematical Modeling

In steady state, the performance of a collector is expressed by an energy balance which shows the distribution of incident solar energy into 3 different parameters i.e. useful energy gain, thermal losses, and optical losses (Duffie and Beckman 2013). When a solar radiation with intensity $I_{incident}$ falls on the glass cover of solar collector (Fig. 3.1), strikes the absorber in which a part of it is absorbed by the working fluid (Q_u) as useful heat gain and the remaining part is dissipated to the surrounding as overall heat loss.

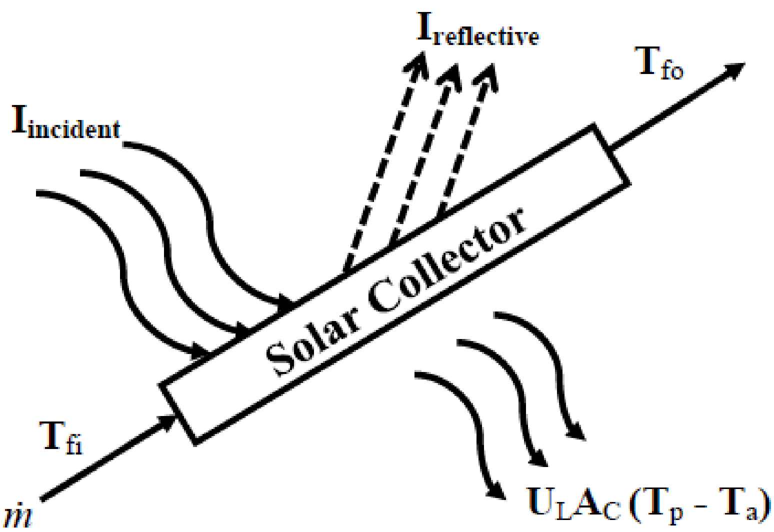


Figure 3.1: Energy balance of FPSC

The following assumptions are made for the analysis:

- A steady state system.
- The thermophysical properties of the working fluids are constant
- Ambient temperatures T_{amb} of 285 K and 308 K for January and July respectively are selected.
- Solar radiations of 450 W/m^2 and 562 W/m^2 for January and July respectively are selected.
- The fluid flow inside the pipe is uniform.
- The inlet temperature is constanst and assumed to be T_{amb} +5 K
- The guess temperature is assumed to be T_{guess}=T_{in}+10 K.
- Mass flow rate of 0.02 kg/s is selected.
- Wind velocity is selected as 2 m/s for Aydin city.

The following simplified steps were used to analyze the performance of the collector

In order to get the outlet temperature as well as the energetic and exergetic efficiencies of the solar collector, the overall heat losses to surrounding is to be determined first (Mahian et al. 2014) , followed by the useful energy output.

There are basically two types of losses that occur in a FPSC which are optical and thermal. The optical loss is shown as I_T (τα), where (τα) is the optical efficiency depending on the materials properties whereas the thermal loss is further divided into three i.e. top loss, bottom loss and edge loss (Duffie and Beckman 2013).

The Overall heat loss U_L is the summation of the top, back and edge losses (Duffie and Beckman 2013)

$$U_L = U_t + U_b + U_e \qquad (1)$$

To find U_t the following correlation is used (Duffie and Beckman 2013).

$$U_t = \left[\frac{N_g}{\frac{C}{T_p}\left[\frac{T_{abs} - T_{amb}}{N_g + \lambda}\right]^e} + \frac{1}{h_w} \right]^{-1} + \frac{\sigma\left(T_{abs} + T_{amb}\right)\left(T_{abs}^2 + T_{amb}^2\right)}{\left(\varepsilon_p + 0.0059 N_g h_w\right)^{-1} + \frac{2N_g + \lambda - 1 + 0.133\varepsilon_p}{\varepsilon_g} - N_g} \qquad (2)$$

Where:

N_g = number of glass cover

ε_p= emissivity of absorber plate.

ε_g= emissivity of glass.

T_{abs} = absorber temperature

T_{amb} = ambient temperature

$$\lambda = \left(1 + 0.089 h_w - 0.1166 h_w \varepsilon_p\right)\left(1 + 0.07866 N_g\right)$$

$C = 520\left(1 - 0.000051\beta^2\right)$ For $0^0 < ß < 70^0$; for $70^0 < ß < 90^0$ use $ß = 70^0$

$$e = 0.430\left(1 - {}^{100}\!/\!{}_{T_{abs}}\right)$$

The wind convection heat transfer coefficient is given as

(Duffie and Beckman 2013):

$$h_w = 5.7 + 3.8V_w \tag{3}$$

Where, V_w is the wind velocity given as 2 m/s (UR2).

The back and edge heat losses can also be determined as (Duffie and Beckman 2013):

$$U_b = \frac{k_b}{t_b} \tag{4}$$

$$U_e = \left(\frac{k_e}{t_e}\right)\frac{A_e}{A_c} \tag{5}$$

Where k_e and k_b are thermal conductivities of the back and edge insulation respectively, A_e is the edge surface area, t_e and t_b are thickness of edge and back insulations respectively.

The useful energy output is given as (Duffie and Beckman 2013)

$$Q_u = \dot{m}C_p\left(T_{out} - T_{in}\right) \tag{6}$$

$$Q_u = A_c\left[I_T\left(\tau\alpha\right) - U_L\left(T_{abs} - T_{amb}\right)\right] \tag{7}$$

Q_u can also be written by replacing the absorber temperature with the fluid inlet temperature and also introducting the heat removal factor (Duffie and Beckman 2013).

$$Q_u = F_R A_c\left[I_T\left(\tau\alpha\right) - U_L\left(T_i - T_{amb}\right)\right] \tag{8}$$

Where A_c, $(\tau\alpha)$, T_i and T_{amb} are the collector surface area (m^2), optical efficiency, fluid inlet and ambient temperatures (K) respectively.

The heat removal factor F_R from Eq. (8) is defined as (Duffie and Beckman 2013):

$$F_R = \frac{\dot{m}C_p}{A_c U_L}\left[1 - \exp\left(\frac{-U_L F' A_c}{\dot{m}C_p}\right)\right] \tag{9}$$

Where the collector efficiency factor F′ is defined (Duffie and Beckman 2013):

$$F' = \frac{1/U_L}{W\left[\dfrac{1}{\left[U_L\left(D+(W-D)F\right)\right]+\dfrac{1}{C_b}+\dfrac{1}{\pi D_i h_{fi}}}\right]} \tag{10}$$

The fin efficiency F is also defined as (Duffie and Beckman 2013):

$$F = \frac{\tanh\left[m(W-D)/2\right]}{m(W-D)/2} \tag{11}$$

Where $m = \sqrt{\dfrac{U_L}{k_c \delta_c}}$

Internal heat transfer coefficient (h_{fi})

$$h_{fi} = \frac{Nu\, k}{D_i} \tag{12}$$

For water as the working fluid, the Gnielinski correlation is used to calculate the Nusselt number (Gnielinski,1976, Cengel et al. 2015)

$$Nu = \frac{\left(\dfrac{f}{8}\right)(\mathrm{Re}-1000)\mathrm{Pr}}{1+12.7\left(\dfrac{f}{8}\right)^{0.5}\left(\mathrm{Pr}^{\frac{2}{3}}-1\right)} \qquad 0.5 \leq \ \mathrm{Pr} \leq \ 2000 \tag{13}$$

For nanofluid as the working fluid, Xuan and Li correlation for estimating the Nusselt number is used $0 \leq \phi \leq 2$ (Xuan and Li, 2003, Khin et al. 2017).

If the flow is laminar ($\mathrm{Re}_{nf} < 2300$)

$$Nu_{nf} = 0.4328\left(1+11.285\phi^{0.754}\left(\mathrm{Re}_{nf}\times\mathrm{Pr}_{nf}\right)^{0.218}\right)\mathrm{Re}_{nf}^{0.333}\,\mathrm{Pr}_{nf}^{0.4} \tag{14}$$

If turbulent flow ($Re_{nf} \geq 4000$)

$$Nu_{nf} = 0.0059\left(1 + 7.6286\phi^{0.6886}\left(\mathrm{Re}_{nf} \times \mathrm{Pr}_{nf}\right)^{0.001}\right)\mathrm{Re}_{nf}^{0.9238}\,\mathrm{Pr}_{nf}^{0.4} \tag{15}$$

Where Re, Pr stands for Reynolds and Prandtl numbers respectively and are given below

$$\mathrm{Re} = \frac{4\dot{m}}{\pi D_i \mu} \tag{16}$$

$$\mathrm{Pr} = \frac{\mu C_p}{k} \tag{17}$$

There are many correlations given to calculate the thermal conductivity of nanofluids among which is the relation given by (Yu and Choi 2003).

$$k_{nf} = \left[\frac{k_p + 2k_w + 2\left(k_p - k_w\right)\left(1+b\right)^3\phi}{k_p + 2k_w - \left(k_p - k_w\right)\left(1+b\right)^3\phi}\right]k_w \tag{18}$$

Brinkman 1952 suggested an equation to calculate the viscosity of the Nano-fluid as (Duangthongsuk and Wongwises 2010):

$$\mu_{nf} = \frac{1}{\left(1-\phi\right)^{2.5}}\mu_w \tag{19}$$

Pak and Cho 1998 correlation is used to calculate the nanofluid density and specific heat (Duangthongsuk and Wongwises 2010):

$$\rho_{nf} = \phi\rho_p + \left(1-\phi\right)\rho_f \tag{20}$$

$$C_{p,nf} = \frac{\rho_w C_{p,w}\left(1-\phi\right) + \rho_p C_{p,p}\phi}{\rho_{nf}} \tag{21}$$

All these calculations are done so as to obtain the outlet temperature and the efficiencies but as it’s seen above to calculate U_t and U_L the value of T_{abs} which is unknown have to be determined first. To do that, an initial guess value for T_{abs} has to be assumed, through which the values of U_L and Q_u are obtained. The T_{abs} value is calculated by the relation below and the guessed value is corrected by an iterative approach (Mahian et al. 2014).

$$T_{abs} = T_{in} + \frac{Q}{A_c F_R U_L}\left(1 - F_R\right) \tag{22}$$

$$\left| \frac{\left(T_{abs}\right)_{guess} - \left(T_{abs}\right)_{calculated}}{\left(T_{abs}\right)_{calculated}} \right| \leq 10^{-8} \tag{23}$$

The outlet temperature is obtained as follow (Duffie and Beckman 2013)

$$T_{out} = T_{in} + \frac{Q_u}{\dot{m} C_p} \tag{24}$$

The thermal efficiency as (Genc et al. 2018):

$$\eta_{en} = \frac{Q_u}{A_c I_T + Pumping\ Power} \tag{25}$$

3.2. The Second Law Analysis:

Thermal analysis is not enough to show the optimum operating conditing of a collector (Suzuki 1988). A more useful and clear evaluation must include the second law which may give better understanding of the system.

Exergy is the maximum work potential of a system or the maximum output that can be attained by a system relative to environment temperature. The second law analysis is based on the procedure given by Farahat et al. 2009, Suzuki 1988.

The general exergy equation is given as (Farahat et al. 2009, Suzuki 1988):

$$\dot{E}x_{in} + \dot{E}x_{out} + \dot{E}x_s + \dot{E}x_l + \dot{E}x_d = 0 \tag{26}$$

Where: $\dot{E}x_{in}$ is the inlet exergy rate, $\dot{E}x_s$ the stored exergy rate, $\dot{E}_{out}$ outlet exergy rate, $\dot{E}x_l$ lost exergy rate, $\dot{E}x_d$ destroyed exergy rate.

The inlet exergy rate is the summation of fluid flow exergy rate and absorbed solar radiation exergy rate and is given as (Farahat et al. 2009, Suzuki 1988):

$$Ex_{in} = \dot{E}x_{in,f} + \dot{E}x_{in,Q} \tag{27}$$

Where:

$$\dot{E}_{in,f} = \dot{m}C_p\left(T_{in} - T_{amb} - T_{amb}\ln\left(\frac{T_{in}}{T_{amb}}\right)\right) + \frac{\dot{m}\Delta P}{\rho} \tag{27a}$$

$$\dot{E}_{in,Q} = A_c\eta_o I_T\left(1 - \frac{T_{amb}}{T_s}\right) \tag{27b}$$

At steady state $\dot{E}x_s$=0;

The outlet exergy rate can be obtained from the relation given as (Farahat et al. 2009, Suzuki 1988).

$$\dot{E}x_{out,f} = -\dot{m}C_p\left(T_{out} - T_{amb} - T_{amb}\ln\left(\frac{T_{out}}{T_{amb}}\right)\right) + \frac{\dot{m}\Delta P}{\rho} \tag{28}$$

The lost exergy rate is given as (Farahat et al. 2009 and Suzuki 1988):

$$\dot{E}x_l = -U_L A_c\left(T_{abs} - T_{amb}\right)\left(1 - \frac{T_{amb}}{T_{abs}}\right) \tag{29}$$

And the destroyed exergy rate is given as (Farahat et al. 2009, Suzuki 1988):

$$\dot{E}x_d = \dot{E}x_{d,\Delta T_s} + \dot{E}x_{d,\Delta P} + \dot{E}x_{d,\Delta T_f} \tag{30}$$

Where:

$$\dot{E}x_{d,\Delta T_s} = -\eta_o I_T A_c T_{amb}\left(\frac{1}{T_{abs}} - \frac{1}{T_s}\right) \tag{30a}$$

$\dot{E}x_{d,\ \Delta Ts}$ is the destroyed exergy rate as a result of temperature difference between the sun and the absorber.

$$\dot{E}x_{d,\Delta P} = -\frac{\dot{m}\Delta P}{\rho}\left(\frac{T_{amb}\ln\left(\frac{T_{out}}{T_{amb}}\right)}{\left(T_{out} - T_{in}\right)}\right) \tag{30b}$$

$\dot{E}x_{d,\Delta P}$ pressure drop in the collector and working fluid flow in the collector

$$\dot{E}x_{d,\Delta T_f} = -\dot{m}C_p T_{amb}\left(\ln\left(\frac{T_{out}}{T_{in}}\right) - \left(\frac{T_{out} - T_{in}}{T_{abs}}\right)\right) \tag{30c}$$

$\dot{E}x_{d,\Delta Tf}$ the temperature between the fluids and plate absorber respectively which are given by the relations below as (Farahat et al. 2009, Suzuki 1988).

The total entropy generation (Bejan 1996):

$$\dot{S}_{gen} = \dot{m}C_p \ln\frac{T_{out}}{T_{in}} - \frac{\dot{Q}_s}{T_s} + \frac{\dot{Q}_o}{T_{amb}} \tag{31}$$

$$\dot{Q}_s = I_T \eta_o A_c \tag{31a}$$

$$\dot{Q}_o = \dot{Q}_s - \dot{m}C_p\left(T_{out} - T_{in}\right) \tag{31b}$$

Where $\dot{Q}_s$ and $\dot{Q}_o$ are the solar energy absorbed (W) by the collector surface and heat loss to the surrounding (W) respectively.

The exegetic efficiency is given as (Alim et al. 2013):

$$\eta_{ex} = 1 - \frac{T_{amb}\dot{S}_{gen}}{\left(1 - \frac{T_{amb}}{T_s}\right)\dot{Q}_s} \tag{32}$$

3.3. The Pressure Drop

In order to calculate the pressure drop, firstly, the major and minor losses are to be determined. The major loss is as a result of fluid flow in pipes whereas the minor is due to fittings, fluid entering and existing etc.

The total head loss h_L is the summation of the major and minor losses given as (Cengel and Cimbala, 2014):

$h_L = h_{l,\,major} + h_{l,\,minor}$

$$h_L = \frac{8\dot{m}^2}{\rho^2 g \pi^2 D_i^4}\left(f\frac{L}{D_i} + \sum K \right) \tag{33}$$

K is the loss coefficient assumed equals to 2 (Mahian et al. 2014) and f is the frictional factor.

A correlation is given by Goudar-Sonnad (2008) to obtain the frictional factor f which is non-iterative, more accurate and valid for all ranges of Reynolds numbers and relative roughness (Asker et al. 2014).

$$\frac{1}{\sqrt{f}} = a\left[\ln\left(\frac{d}{q}\right) + \delta_{CFA} \right] \tag{34}$$

Where: $a = \frac{2}{\ln(10)}$, $\quad b = \frac{\varepsilon/D}{3.7}$, $\quad d = \frac{\ln(10)}{5.02}\mathrm{Re}$, $\quad S = bd + \ln(d)$

$q = S^{\left(S/(S+1)\right)}$, $\quad g = bd + \ln\left(\frac{d}{q}\right)$, $\quad z = \left(\frac{q}{g}\right)$, $\quad \delta_{LA} = \frac{g}{g+1}z$

$$\delta_{CFA} = \delta_{LA}\left[1 + \frac{z/2}{(g+1)^2 + (z+3) + (2g-1)} \right]$$

Where, Re and ε/D is the Reynolds number and relative roughness respectively.

The pressure drop is calculated as (Shamshirgaran, 2018):

$$\Delta P = \left[f\frac{L}{D_i}\left(\rho\frac{V^2}{2}\right) \right]_{in/out\,header} + \left[\rho g\left(L\sin(\beta) + h_L \right) \right]_{riser+fittings} \tag{35}$$

Where:

$$V = \frac{4\dot{m}}{\rho \pi D_i^2} \tag{36}$$

3.4. Pumping Power

It is an active system. Therefore, a pump is required to mingle nanofluids in the system which would require electric power. It’s very vital to undertand the energy the pump needs to maintain constant flow in the collector. A relation is given to obtain the pumping power as (Cengel and Cimbala, 2014):

$$Pumping\ \ Power = \frac{\dot{m}}{\rho}\Delta P \tag{37}$$

Where:

$\dot{m}$, ΔP and ρ are the mass flow rate, pressure drop and density of the working fluid respectively.

Table 3.1. Thermopysical properties of Nanoparticles

Particles	Weight fraction (%)	Particle size (nm)	Specific heat (J/kg.K)	Thermal cond. (W/mK)	Density (kg/m3)	References
Al_2O_3	0.1-3	20	880	30	3600	Hawwash et al., 2018
	0-4	25	765	40	3970	Mahian et al., 2014
	0-6	-	765	40	3970	Bellos and Tzivanidis, 2017.
	1-4	-	773	40	3960	Alim, 2014
CeO_2	0-6	30	460	12	7220	Sharafeldin et al., 2018
Cu	0-2	100	385	401	8933	Bellos and Tzivanidis, 2018
	0-4	25-100		400		Shamshirgaran et al., 2018
	0-6	-		400		Bellos and Tzivanidis, 2017.
CuO	0-6	-	532	77	6000	Bellos and Tzivanidis, 2017.
	0-6		551	33	6320	Toghyani et al., 2016
	1-4		551	33	6000	Alim et al., 2014
MWCNT	0.06-0.25wt	1-2	711	3000	2100	Tong et al., 2015
SiO_2	0.2-0.6	7-70	703	1.4	2200	Hawwash et al., 2018
	0-4	25	745	1.4	2220	Mahian et al., 2014.
	0-6	-	765	36	3970	Toghyani et al., 2016
	1-4	-	765	36	3970	Alim et al., 2014
TiO_2	0-4	25	686	8.9	4250	Mahian et al., 2014
	0-6	21	692	8.4	4230	Toghyani et al., 2016
	0-6	-	686	8.95	4250	Bellos and Tzivanidis, 2017
	1-4	-	692	8.4	4230	Alim et al., 2014

Table 3.2. Collector specifications (Dawit et al., 2017, Ehsan et al., 2015)

Collector parameters	unit
Length of collector	1.8 m
Width of the collector	1.2 m
Length of absorber plate	1.65 m
Width absorber plate	1 m
Collector tilt angle β	37^0
Plate thickness δ_c	0.0005m
Optical efficiency $(\tau\alpha)$	0.962
Center distance between tubes, W	0.1125 m
Number of cover	1
Diameter of riser pipes	0.0125
Diameter of header pipes	0.025
Apparent sun temperature T_s	4350K
Thickness of back insulation, t_b	0.04
Emissivity of absorber plate ε_p	0.07
Emissivity of glass cover ε_g	0.88
Thermal conductivity of plate, k_p	386
Thermal conductivity of insulation material, k_p	0.044

4. RESULTS AND DISCUSSION

In this chapter, the results obtained by solving Eqs. 1-37 are discussed. The first part presents the validation of this work by comparing it with previous studies and experiment in the literature whereas the second part illustrates the parametric study.

4.1. Validations

As seen from figures 4.0-4.3, a comparison between an experimental values for the thermal efficiency, outlet temperature and absorber temperture conducted by (Bellos and Tzivanidis, 2018) as well as a computation by (Duffie and Beckman 2013) and this work using water as working fluid is done to show realiability of the study.

Fig. 4.0 the collector effiency factor versus center distance between two risers tubes; Fig. 4.1 shows the result of the thermal efficiency with reduced temperature; Fig. 4.2 the outlet temperature against reduced temperature; Fig. 4.3 the absorber temperature against reduced temperature. From fig. 4.0 it can be seen that increasing the distance between risers results to a decrease in the collector efficiency factor.

It can be seen from the comparison of all the figures, a very good agreement is found between all the results with minimum error which makes the thesis work reasonable.

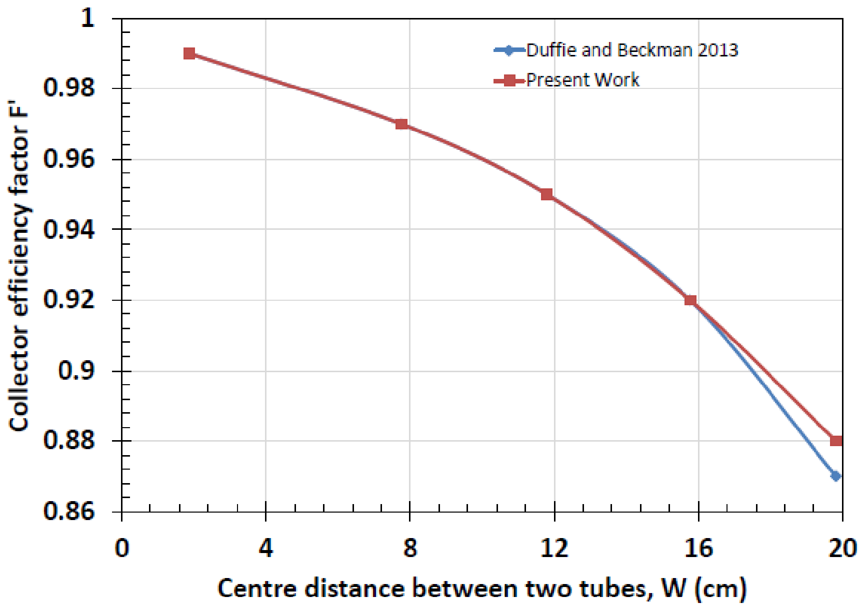


Figure 4.1. Collector efficiency factor variations with distance between risers.

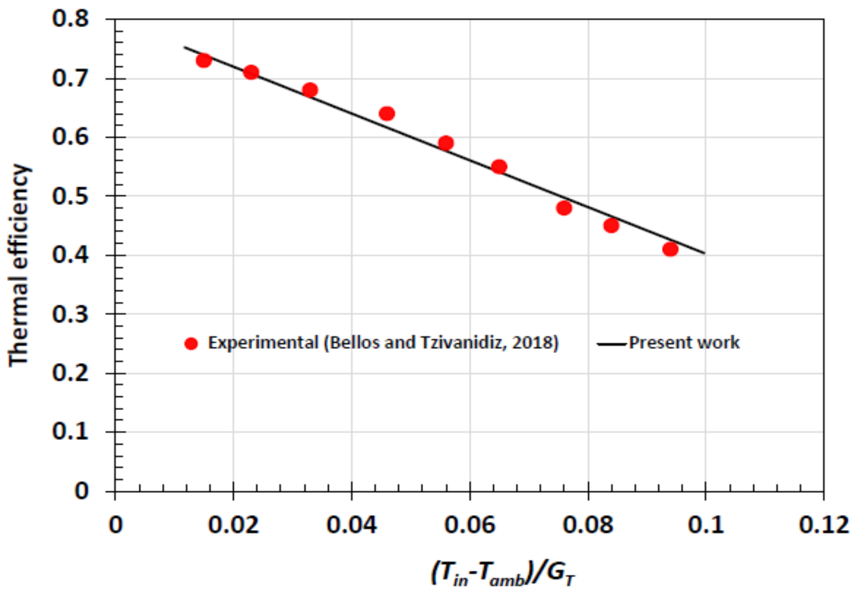


Figure 4.2. Themal efficiency variation with $(T_{in}\text{-}T_{amb})$ /G_T

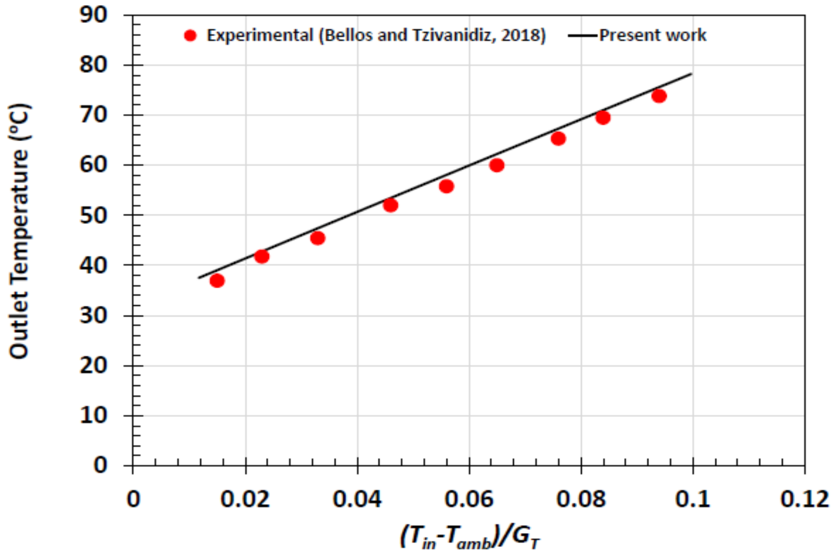


Figure 4.3. Outlet temperature variation with (Tin-Tamb) /GT

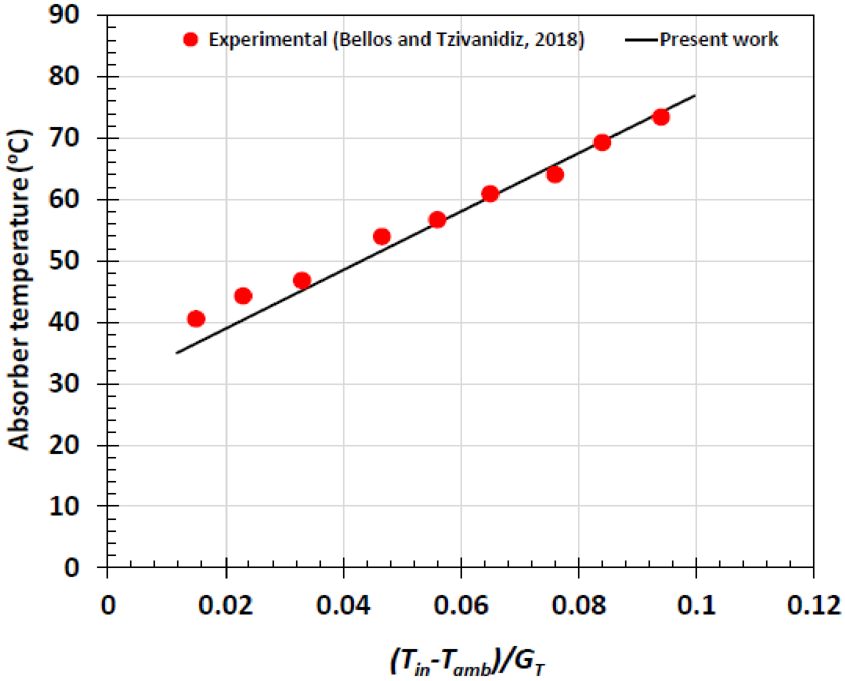
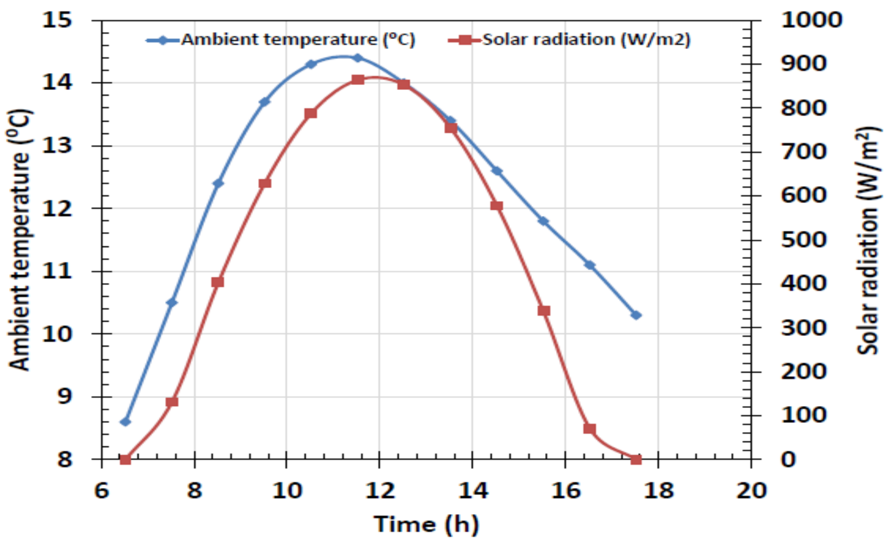


Figure 4.4. Absorber temperature variation with (Tin-Tamb) /GT

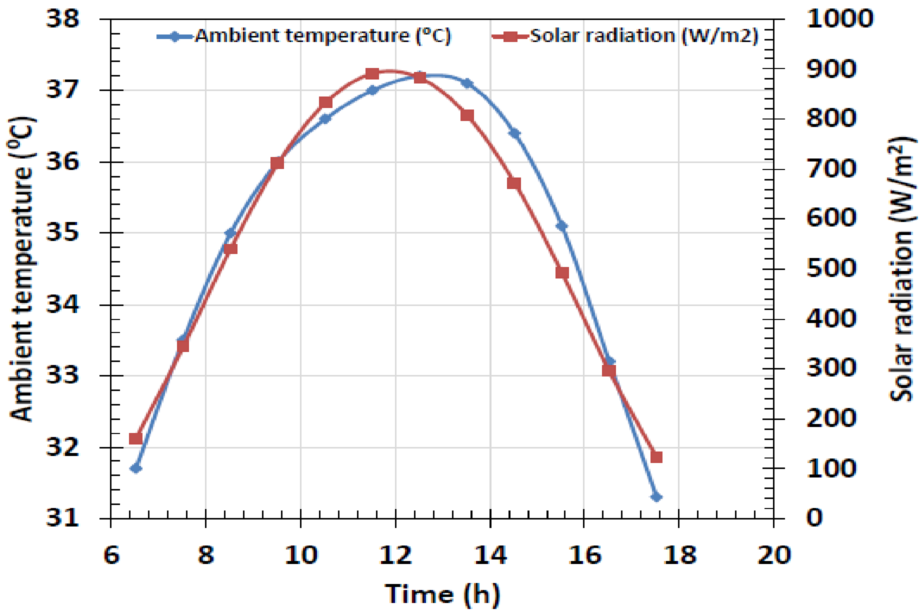
4.2. Parametric Study

Despite the differences in thermophysical properties of nanofluids and procedure, the results obtained are inline with others from the literature.

For this analysis, the coldest, January and hottest, July, months of the year are selected to evaluate the performmance of the FPSC with five different nanofluids. An average solar irradiation and ambient temperature are defined according to the monthly average daily weather data of Aydin city, Turkey as shown in Fig. 4.5 (a) and (b) (UR3).



(a)



(b)

Figure 4.5. Variations of daily solar radiation and ambient temperature (a) January

(b) July

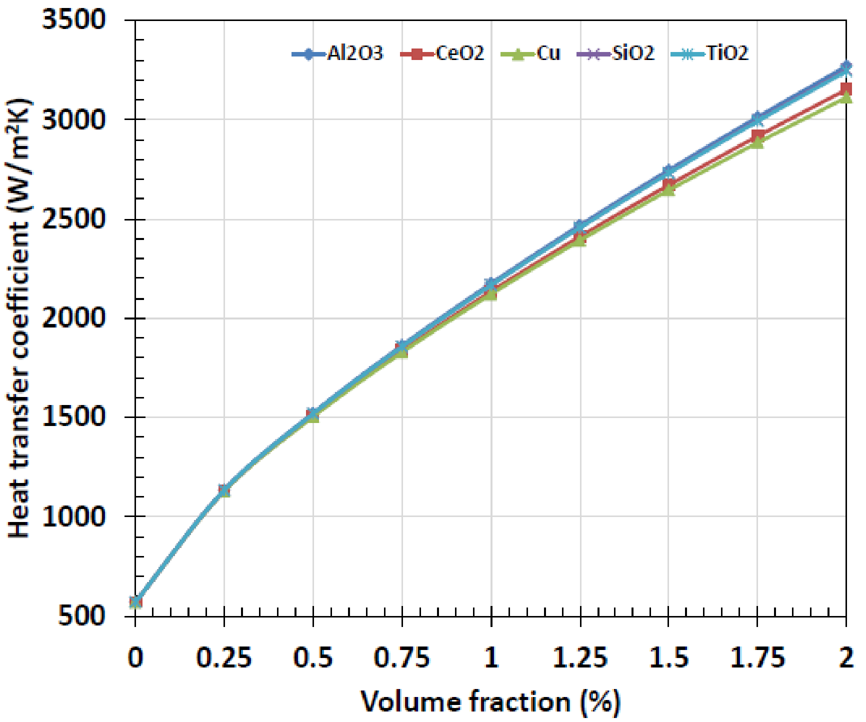
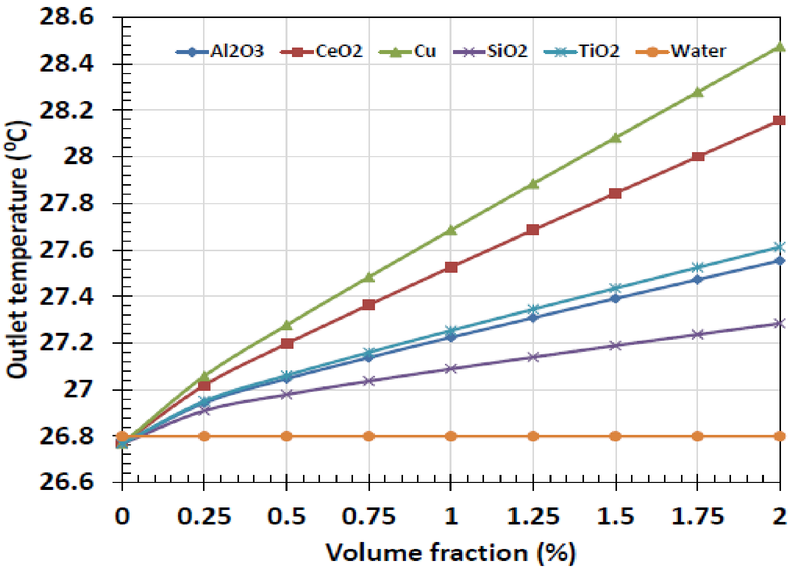
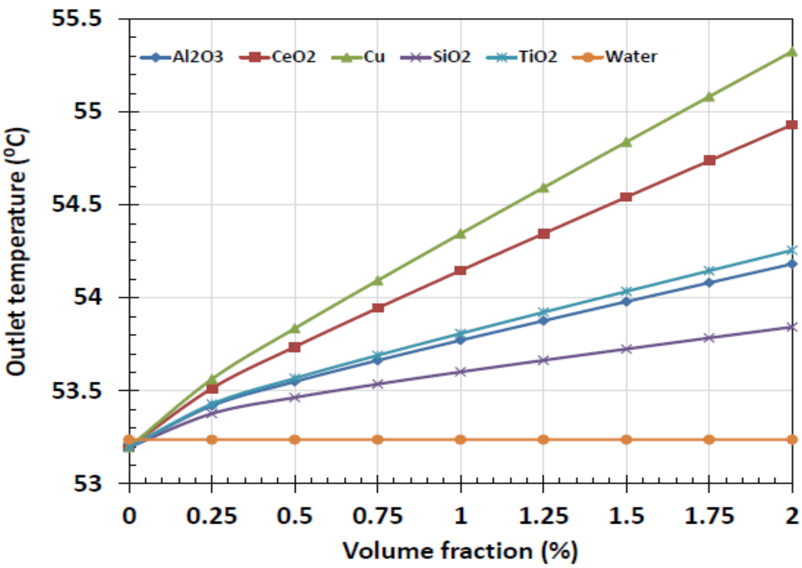


Figure 4.6. Heat tranfer coefficients versus volume concentration for different nanofluids at 0.02kg/s in January

Fig. 4.6 shows the effect of particle volume concentration increase and its influence on the heat transfer performance. Based on Eq. 12 the heat transfer coefficient is proportional to both Nusselt number and thermal conductivity. It can be seen that heat transfer coefficient increases as the volume fraction increases with maximum increase observed at volume fraction of 2% and constant flow rate of 0.02kg/s for all the nanofluids for a given solar radiation of 450W/m^2. This is obvious, because during particle loading, both the thermal conductivity and viscosity of the base fluid are enhanced. However, increase in thermal conductivity results to better heat transfer performance whilst increase in viscosity results to increase in boundary layer thickness. For the volume fractions used, the effect of thermal enhancement is higher than that of viscosity. Therefore, the heat transfer increases. For a volume fraction of 2% the highest heat transfer enhancement is observed in Al_2O_3, TiO_2, SiO_2, CeO_2 and Cu respectively.



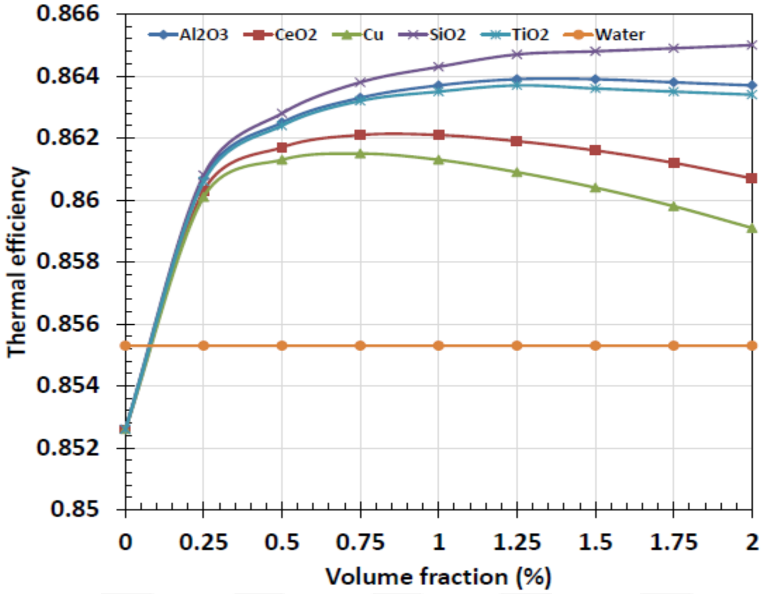
(a)



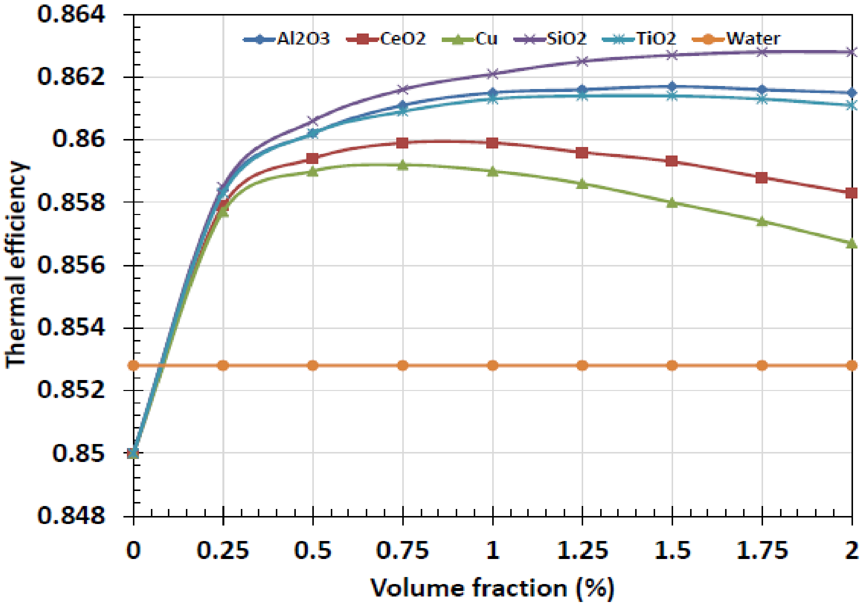
(b)

Figure 4.7. Outlet temperatures versus volume concentration for different nanofluids at 0.02kg/s in (a) January (b) July

The variation of outlet temperature with concentration of nanfluids is shown in Fig. 4.7 at a mass flow rate of 0.02kg/s in (a) January with a solar radiation of 450W/m^2 and (b) July with a solar radiation of 562W/m^2. It can be seen that Cu nanofluid provides the maximum outlet temperature whereas SiO_2 nanofluid shows the smallest value. Based on Eq. 24, the outlet temperature is inversely proportional to the heat capacity. By defintion, specific heat is the heat required to raise the temperature of a unit mass of a substance by one unit of temperature i.e. the smaller the heat capacity the higher the outlet temperature. Other factors such as density and thermal conductivity also determine higher outlet temperature. Al_2O_3 shows higher outlet temperature than SiO_2 despite having less heat capacity. The reason is clear, for a constant mass flow rate, a nanofluid with higher density results to lower velocity which makes it easier to absorb higher thermal energy. Also Al_2O_3 having higher thermal conductivity might be the reason. The maximum outlet temperature is observed on Cu, CeO_2, TiO_2, Al_2O_3 and SiO_2 respectively for months and volume fraction of 2% for both months. However, in January, the maximum outlet temperature is about 28.47^{0}C at 2% volume fraction of Cu nanofluid and 0.02kg/s whereas in July, the maximum outlet temperature is 55.32^{0}C at both same flow rate and volume fraction of Cu. This is due to metrological data of Aydin city, Turkey selected.



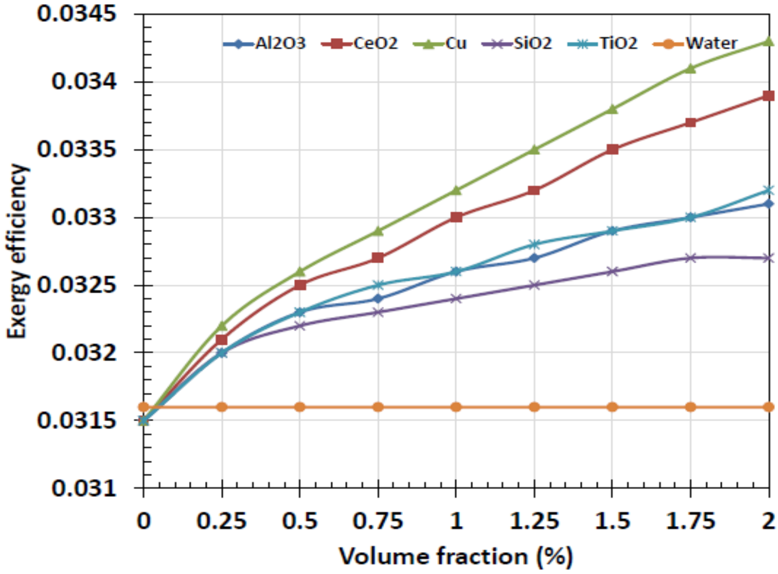
(a)



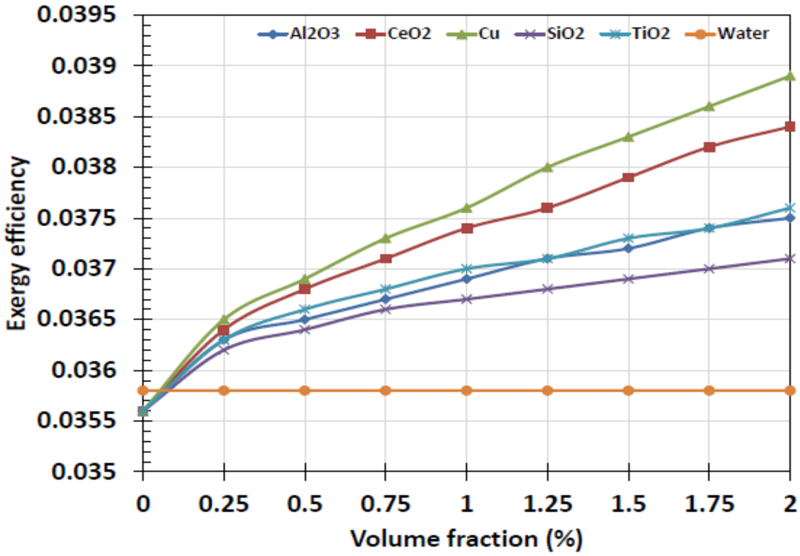
(b)

Figure 4.8: Thermal efficiency versus concentration for different nanofluids at 0.02kg/s in (a) January (b) July

Fig. 4.8 (a) with solar radiation of 450W/m^2 and (b) with solar radiation of 562W/m^2 shows the variations of thermal efficiency with volume fraction at flow rate of 0.02kg/s. The figures follows an opposite trend to the outlet temperature with SiO_2 nanofluid providing the highest efficiency whereas Cu nanofluid the smallest. This happened because among all the nanofluids, Cu provides the highest absorber plate temperature and according to Eq. 7 the absorbed energy will be minimized. Therefore, the efficiency reduced. The figures show that the thermal efficiency is a function of volume fraction to a certain limit. The maximum efficiency enhancement is “between” 0.75% to 2% for all the working fluids. For a constant flow rate of 0.02kg/s and volume fraction of 2% the maximum efficiency efficiency is obsorbed in SiO_2 by 10% in both months.



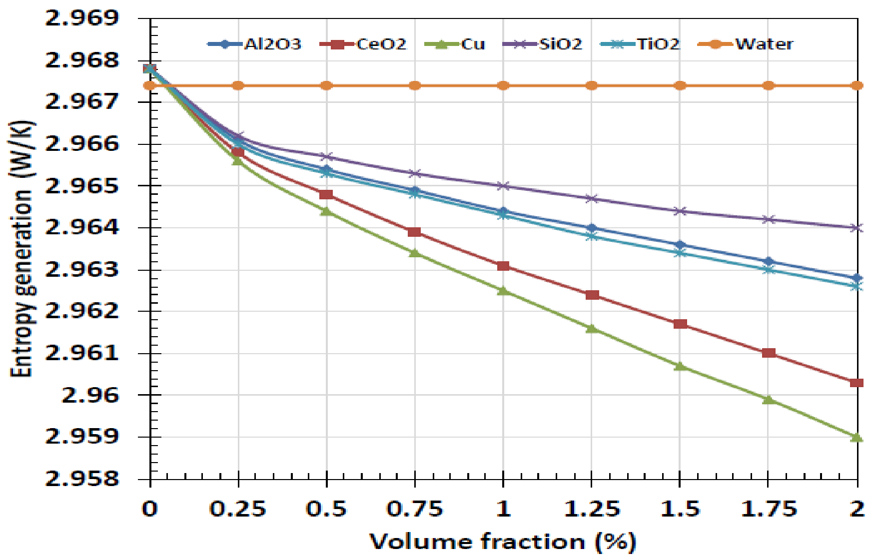
(a)



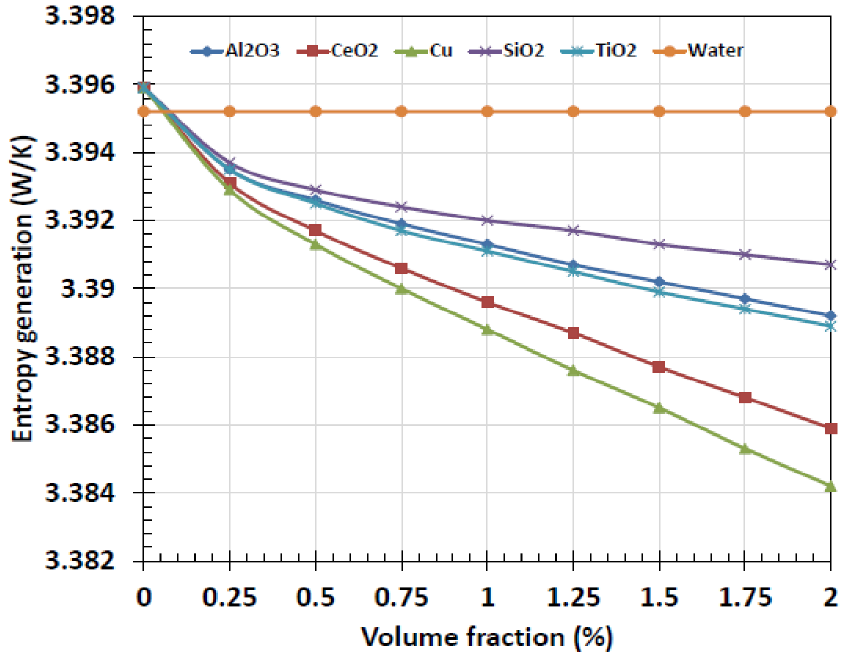
(b)

Figure 4.9: Exergy efficiency variation with volume fraction for different nanofluids at 0.02kg in (a) January (b) July

Exergy and Entropy complements each other. Fig. 4.9 (a) with solar radiation of $450W/m^2$ and (b) with solar radiation of $562W/m^2$ presents the variations of the exegetic efficiency with volume fraction at a constant mass flow rate 0.02kg/s. It can be seen that the exergy increases with increase in volume fraction. Also, exergetic efficiency increases with in solar radiation as seen in (b). The maximum exergy enhancement is observed in Cu, in January and July by 2.7% and 3.1% respectively at 4% volume concentration and flow rate of 0.02kg/s.



(a)



(b)

Figure 4.10. Variations of entropy generation with concentration for different nanofluids at 0.02kg/s in (a) January (b) July

To develop an efficient thermal system, entropy generation analysis will play a vital role. From Fig. 4.10 (a) with solar radiation of 450W/m^2 and (b) with solar radiation of 562W/m^2, it can be seen that for a constant flow rate of 0.02kg/s as well as varying the volume concentration, the entropy generation is less than that of water. This is because; addition of nanoparticles makes the working fluid to absorber and transfer solar radiation efficiently. Also, the thermal conductivity enhances with increase in volume fraction which results to higher heat transfer and thus reduces the irreversibility generated in the system. The minimum drop in entropy generation is observed in Cu, followed by CeO_2, then TiO_2, Al_2O_3 and lastly SiO_2 in both months.

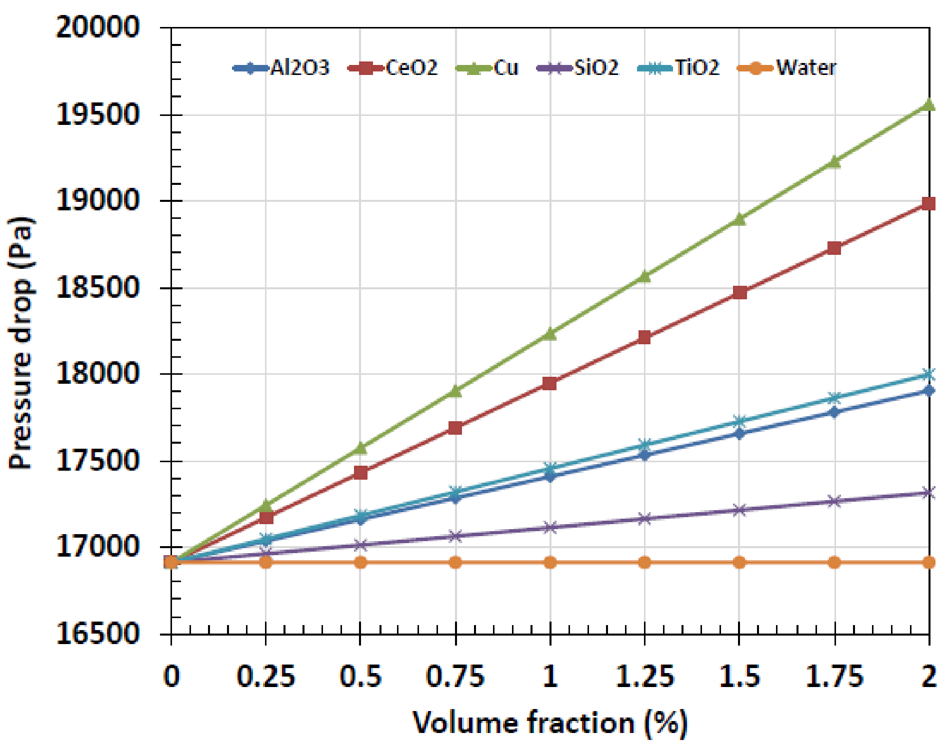


Figure 4.11. Variations of pressure drop with concentration for different nanofluids at 0.02kg/s in January with solar radiation of 450W/m2

Fig. 4.11 illustrates the variation of pressure drop with volume fraction for different nanofluids at constant flow rate of 0.02kg/s. The result show that frictional factor of the nanofluids are close to that of water and the pressure drop increases with concentration. It is obvious addition of nanoparticles into the base fluid enhances its viscosity and thermal conductivity which results to increase in frictional factor. Therefore, the pressure drop increases.

5. CONCLUSIONS

In this study, a steady state analysis of a flat plate solar collector is performed to investigate the effect of using five different nanofluids which includes Al_2O_3, CeO_2, Cu, SiO_2 and TiO_2 for different volume fractions and constant flow rate at different climatic conditions. The following are the findings of the study summarized below:

- Al_2O_3 shows highest heat transfer cofficient whereas Cu the smallest.
- Cu provides the highest outlet temperature followed by CeO_2, TiO_2, Al_2O_3 and SiO_2 as second, third, fourth and fifth, in that order for a constant flow rate of 0.02kg/s in both months.
- Cu shows the maximum outlet temperature of 55.32^{o}C at a volume fraction of 2% in July.
- The entropy generation decreases with increase in volume fraction for a constant flow rate with maximum drop observed in Cu, CeO_2, TiO_2, Al_2O_3 and SiO_2 respectively in both months.
- The pressure drop increases with increase in volume fraction at a constant flow rate with maximum drop seen in Cu, CeO_2, TiO_2, Al_2O_3 and SiO_2 respectively.
- SiO_2 showed the highest energetic efficiency, followed by Al_2O_3, TiO_2, CeO_2 and lastly Cu for a flow rate of 0.02kg/s and particle volume concentration “between” 0.75% to 2% in both months.
- SiO_2 provides higher energetic efficiency enhancement by up to 10% compared to water at 0.02kg/s and volume fraction of 2% in both months.
- Cu provided the highest exegetic efficiency, followed by CeO_2 then TiO_2, Al_2O_3 18% and lastly SiO_2 at a constant flow rate of 0.02kg/s and volume fraction of 2% in both months.

- SiO_2 provides higher exergetic efficiency enhancement in January and July by 2.7% and 3.1% respectively compared to water at 0.02kg/s and volume fraction of 2%.

For future work, experiments and more numerical studies are needed to improve the thermal performance of the collector. Moreover, CeO_2 needs further improvement because to my knowledge very few researchers perform an experiment with it as the working fluid.

REFERENCES

Ahmed M. S., Gyula G., Mahian, O., 2017. Experimental study on the performance of a flat plate collector using WO_3/Water nano fluids. 141: 2436–2444

Alima M.A., Abdin Z., Saidur R., Hepbasli A., Khairul M. A., Rahim N. A., 2013. Analyses of entropy generation and pressure drop for a conventional flat plate solar collector using different types of metal oxide nanofluids. ***Energy and Buildings*** 66: 289–296.

Ali J. M., Mahmood F., Mahmood S., Monireh H., 2014. Effects of CuO nanofluid on the efficiency of a flat-plate solar collector. ***Experimental Thermal and Fluid Science*** 58: 9–14.

Asker, M., Oguz E. T., Mustafa T. C., 2014. A review of non-iterative friction factor correlations for the calculation of pressure drop in pipes. ***Bitlis Eren Univ J Sci and Technol*** 4 (1),: 1-8

Balaji, K., Iniyan, S., Swami, M. V, 2018. Exergy, economic and environmental analysis of forced circulation fl at plate solar collector using heat transfer enhancer in riser tube. ***Journal of Cleaner Production*,** 171: 1118–1127.

Bejan, A., 1996. Entropy Generation Minimization: the Method of Thermodynamic Optimization of Finite-size Systems and Finite-time Processes. CRC Press.

Bellos, E. and Tzivanidis, C., 2018. Performance analysis and optimization of an absorption chiller driven by nano fl uid based solar fl at plate collector. ***Journal of Cleaner Production***, 174: 256–272.

Brinkman H.C., 1952. The viscosity of concentrated suspensions and solution, J. Chem. Phys. 20: 571

Carbonell, D., Cadafalch, J., Consul, R., 2013. Dynamic modelling of flat plate solar collectors . Analysis and validation under thermosyphon conditions. ***Solar Energy***, 89: 100–112.

Cengel, Y., and Ghajar, J. 2015. Heat and Mass Transfer: Fundamentals and Applications, fifth ed. 496-517, New York.

Cengel, Y., and Cimbala, 2014. Fluid Mechanics: Fundamentals and Applications, third edi., New York.

Dawit G. G., Pinakeswar M., Robi, P.S., 2017. CFD and experimental investigation of flat plate solar water heating system under steady state condition. ***Renewable Energy*** 106: 24-36

Diego-Ayala, U. and Carrillo, J.G., 2016. Evaluation of temperature and efficiency in relation to mass flow on a solar flat plate collector in Mexico. ***Renewable Energy,*** 96: 756–764.

Duffie J. and Beckman W., 2013. ***Solar Engineering of Thermal Processes, 4th ed.,*** 163: 236-319, New Jersey

Ehsan S., Farzad V., Ahmad K., 2015. Exergy efficiency investigation and optimization of an Al_2O_3/water nanofluid based Flat-plate solar collector. ***Energy and Buildings*** 101: 12–23

En, M.E.N.O.F., 1996. Solar Water Heating.

Erden, M., Karakilcik, M., Dincer, I., 2017. Performance investigation of hydrogen production by the flat-plate collectors assisted by a solar pond. ***International Journal of Hydrogen Energy,*** 42(4): .2522–2529.

Farahat, S., Sarhaddi, F., Ajam, H., 2009. Exergetic optimization of flat plate solar collectors. ***Renewable Energy,*** 34(4): 1169–1174.

Genc, M. A., Mehmet A. E., Alpaslan T., 2018. Thermal performance of a nanofluid-based flat plate solar collector: A transient numerical study. ***Applied Thermal Engineering*** 130: 395–407.

Gnielinski V., 1979. New equations for heat and mass transfer in turbulent pipe and channel flow, ***Int. Chem. Eng***. 16: 359.

Goudar C. T., Sonnad J.R., 2008. Comparison of the iterative approximations of the Colebrook-White equation. ***Hydrocarb Process*** 87: 79-83.

Hajabdollahi, Z. and Hajabdollahi, H., 2017. Thermo-economic modeling and multi-objective optimization of solar water heater using flat plate collectors. ***Solar Energy,*** 155: 191–202.

Hanane D., Ahmed O., Michela R., Roberto S., 2011. Thermal analysis and performance optimization of a solar water heater flat plate collector: Application to Tetouan (Morocco)"; ***Renewable and Sustainable Energy Reviews*** 15: 630–638

Hawwash A. A., Ali K. A., Nada S. A., Ookawara S., 2018. Numerical Investigation and Experimental Verification of Performance Enhancement of Flat Plate Solar Collector Using Nanofluids. ***Applied Thermal Engineering,*** 130: .363–374.

Helvaci, H.U. and Khan, Z.A., 2015. Mathematical modelling and simulation of multiphase flow in a flat plate solar energy collector. ***Energy Conversion and Management,*** 106: 139–150.

Hussain, S. and Harrison, S.J., 2015. ScienceDirect Experimental and numerical investigations of passive air cooling of a residential flat-plate solar collector under stagnation conditions. ***Solar Energy,*** 122: 1023–1036.

Hyeongmin K., Jinhyun K., Honghyun C., 2017. Experimental study on performance improvement of U-tube solar collector depending on nanoparticle size and concentration of Al_2O_3 Nanofluid, ***Energy*** 118: 1304-1312.

Javaniyan J. H., Saedodin S., Zamzamian A., Eshagh N. M., Wongwises S., 2017. Effects of porous material and nanoparticles on the thermal performance of a fl at plate solar collector : An experimental study. ***Renewable Energy,*** 114: 1407–1418.

Jeon, J., Park, S., Jae, B., 2016. Analysis on the performance of a flat-plate volumetric solar collector using blended plasmonic nanofluid. ***Solar Energy,*** 132: 247–256.

Julian D. O, Alejandro R., Philibert G., Sam Y., Rob H., Juan C. O., 2017. Integration of transparent insulation materials into solar collector devices. ***Solar Energy,*** 147: 8–21.

Khin N. C. S., Choudhury I. A., Masjuki H. H., Aoyama H., 2017. Theoretical analysis to determine the efficiency of a CuO-water nanofluid based-flat plate solar collector for domestic solar water heating system in Myanmar. ***Solar Energy,*** 155: 608–619.

Koholé, Y.W. and Tchuen, G., 2018. Experimental and numerical investigation of a thermosyphon solar water heater. ***International Journal of Ambient Energy,*** 0(0): 1–11.

Lukic, N., 2015. Theoretical and experimental investigation of the thermal performance of a double exposure flat-plate solar collector. 119: 100–113.

Mahian, O., Ali K., Ahmet Z. S., Somchai W., 2014. Performance analysis of a minichannel-based solar collector using different nanofluids. ***Energy Conversion and Management,*** 88: 129–138.

Murari, K. and Chaurasiya, R., 2017. A review on analysis and development of solar flat plate collector. ***Renewable and Sustainable Energy Reviews,*** 67: 641–650.

Naghrehabadi, A., Ebrahim H., Mojtaba M., 2016. Experimental investigation of efficiency of square flat-plate solar collector using SiO_2 nanofluid. ***Case Studies in Thermal Engineering*** 8: 378–386.

Pak, B.C. and Cho Y. I., 1998. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. ***Exp. Heat Transfer*** 11: 151.

Qinbo H., Shequan Z., Shuangfeng W., 2015. Experimental investigation on the efficiency of flat-plate solar collectors with nanofluids. ***Applied Thermal Engineering*** 88: 165-171.

Sabiha M.A., Saidur, R., Hassani, S., Said Z., Saad M., 2015. Energy performance of an evacuated tube solar collector using single-walled carbon nanotubes nanofluids. ***Energy Conversion and Management*** 105: 1377–1388.

Said, Z., Saidur, R., Sabiha, M.A., Hepbasli, A., Rahim N. A., 2016. Energy and exergy efficiency of a flat plate solar collector using pH treated Al_2O_3 nanofluid. ***Journal of Cleaner Production*** 112: 3915-3926.

Said Z., Sajid M.H., Alim M.A., Saidur R., and Rahim N.A., 2013. Experimental investigation of the thermophysical properties of AL_2O_3-nanofluid and its effect on a flat plate solar collector. ***International Communications in Heat and Mass Transfer*** 48: 99–107.

Said Z., Sabiha M. A., Saidur R., Hepbasli A., Rahim N.A., S. Mekhilef, and Ward T.A., 2015. Performance enhancement of a Flat Plate Solar collector using Titanium dioxide nanofluid and Polyethylene Glycol dispersant. ***Journal of Cleaner Production*** 92: 343-353.

Sami W., Kazi, S.N., Badarudin, A., 2015. ScienceDirect A review of studies on using nanofluids in flat-plate solar collectors. ***Solar Energy,*** 122: 1245–1265.

Sharafeldin M. A. and Gyula G., 2018. Experimental investigation of flat plate solar collector using CeO_2 nanofluid. ***Energy Conversion and Management*** 155: 32–41.

Shamshirgaran S., Morteza K. A., Hussain H. Al – Kayiem, Korada Viswanatha Sharma, 2018. Energetic and Exergetic Performance of a Solar Flat-Plate Collector Working with Cu.

Suzuki, A., 1988. General theory of exergy-balance analysis and application to solar collectors. Energy vol. 13, no. 2: 153-160.

Tang, R., Yanbin C., Maogang W., Zhimin L., Yamei Y., 2010. Experimental and modeling studies on thermosiphon domestic solar water heaters with flat-plate collectors at clear nights. ***Energy Conversion and Management,*** 51(12): 2548–2556.

Toghyani, S., Ehsan B., Ebrahim A., 2016. Thermodynamic analysis and optimization of an integrated Rankine power cycle and nano-fluid based parabolic trough solar collector. ***Energy Conversion and Management*** 121: 93–104.

UR1 http://docplayer.net/20850734-Ministry-of-power-energy.html

UR2 https://www.mgm.gov.tr/

UR3 http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

Verma, S.K., Tiwari, A.K., Chauhan, D.S., 2017. Experimental evaluation of flat plate solar collector using nanofluids. ***Energy Conversion and Management,*** 134: 103–115.

Weerapun Duangthongsuk and Somchai Wongwises, 2010. An experimental study on the heat transfer performance and pressure drop of TiO_2 nanofluids flowing under a turbulent flow regime. ***International Journal of Heat and Mass Transfer*** 53: 334–344.

Xuan Y. and Li, Q., 2003. Investigation on convective heat transfer and flow features of nanofluids. ***ASME J. Heat Transfer*** 125: 151

Yousefi, T., Farzad V., Ehsan S., Sirus Z., 2012. An experimental investigation on the effect of MWCNT/H_2O nanofluid on the efficiency of flat-plate solar collectors. ***Experimental Thermal and Fluid Science*** 39: 207–212.

Yu W. and Choi, S.U.S., 2003. The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwell model, J. Nanoparticle Res. 5: 167.

Zhang, D., Jinping L., Zhangwei G., Linjun W., Junhu N., 2016. Thermal performance investigation of modified flat plate solar collector with dual-function. ***Applied Thermal Engineering,*** 108: 1126–1135

Zhou, F., Jie J., Jingyong C., Bendong Y., 2017. Experimental and numerical study of the freezing process of flat-plate solar collector. ***Applied Thermal Engineering,*** 118: 73–784

RESUME

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