Indoor investigation for improving the hybrid Photovoltaic /Thermal system performance using Nanofluid (AL_2O_3-Water)

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Abstract

Hybrid Photovoltaic/Thermal system (PV/T) were designed and implemented to investigate the improving of the electrical and thermal efficiency by using nanofluids. The electrical efficiency reduced due to the significant reduction in the maximum power of the photovoltaic panel under rising temperature, for this reason, the payback period of the PV system is extended and the lifespan of the PV module may also be shortened. In order to resolve this problem, cooling technique can be utilized effectively dissipate the heat from PV module. An experimental rig is designed which is consisting of heat exchanger and working fluid circulating pipes are placed at PV rear surface. Forced cooling using (AL_2O_3-Water) nanofluid with different concentration ratios tests is utilized to reduce the operating temperature of PV.

The results indicated that using base fluid, the temperature of the PV module was (79.1^{o}C) and a conversion efficiency of about (8 %.).While using nanofluid at different concentration ratios (0.1- 0.5 step 0.1) % at constant mass flow rate (0.2 l/s), the temperature is more dropped significantly to (42.2^{o}C) at concentration ratio (0.3%) and led to increase in the efficiency of solar panel to (12.1%), but when increasing of concentration ratios more than (0.3%) that led to increase PV temperature to (52.2^{o}C) and led to a decrease of PV efficiency to (11.3%). The heat which was extracted from the PV module by the cooling nanofluid can contribute to the overall energy output of the system.

Keywords : PV cooling; Temperature effect; Nanofluids; Improving efficiency.

دراسة مختبرية لتحسين اداء المنظومة الحرارية الكهروضوئية الهجينة باستخدام مائع اوكسيد الالمنيوم النانوي

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الخلاصة

المنظومة الهجينة (PV/T) صممت ونفذت للتحقق عمليا من امكانية تحسين كفاءتها الكهربائية والحرارية باستخدام تقنية التبريد بالمواد النانوية . ان الكفاءة الكهربائية تنخفض نتيجة ارتفاع درجة الحرارة في اللوح الشمسي ولهذا السبب فان فترة الاسترداد للنظام وعمر اللوح الشمسي قد تقل . تقنية تبريد اللوح الشمسي بالماء استخدمت لحل هذه المشكلة لتبديد الحرارة من اللوح الشمسي . تقنية التبريد عمليا تكونت من مبادل حراري وانابيب ماء وضعت على السطح الخلفي للوح الشمسي وبتبريد قسري باستخدام اوكسيد الالمنيوم النانوي وبتراكيز مختلفة تم تحضيرها واستخدمت لتقليل درجة الحرارة .

النتائج بينت بدون استخدام اوكسيد الالمنيوم النانوي مع الماء فان درجة حرارة اللوح الشمسي كانت (79.1^{o}C) والكفاءة الكهربائية لاتتعدى تقريبا 8% بينما عند استخدام اوكسيد الالمنيوم النانوي وبتراكيز مختلفة (0.1- 0.5 step 0.1)% وبثبات جريان المائع عند (0.2L/s) فان درجة الحرارة انخفضت الى درجة (42.2^{o}C) عند نسبة تركيز (0.3%) مما ادى الى زيادة بالكفاءة الكهربائية للمنظومة بقيمة اكثر من (12.1%) ولكن عند زيادة نسبة التركيز اكثر من (0.3%) فان درجة الحرارة قد ازدادت الى (52.2^{o}C) وقلت الكفاءة الى (11.3%) . الحرارة التي بددت من اللوح الشمسي باستخدام تقنية التبريد باستخدام النانو بامكانها ان تزيد الطاقة الكلية الخارجة من المنظومة الهجينة .

الكلمات المفتاحية :- تبريد اللوح الشمسي , تاثير درجة الحرارة ,موائع نانوية , تحسين كفاءة.

NOMENCLATURE

A= Area of the PV module (m^2).
Ac= Area of collector (m^2).
C_p=Specific heat capacity (kJ/kg.c).
C_{pf} = Heat capacity of the base fluid (kJ/kg.c).
C_{pnf} = Heat capacity of the nanofluid (kJ/kg.c).
C_{pp} = Heat capacity of the nanoparticles (kJ/kg.c).
G = Irradiation and it is defined as (1000W/m^2) for standard condition.
I_{mp}= PV current at maximum power point(A).
K_f = Base fluid thermal conductivity (W/m.c).
K_{nf} = Thermal conductivity of the nanofluid (W/m.c).
K_ρ= Thermal conductivity of the nanoparticle (W/m.c).
$\dot{m}$ = Mass flow rate (kg/s)
MPPT = Maximum power point tracer.
ϕ= Volume concentration of the nanoparticles.
T_c = Cell temperature (^{o}C)
T_{in} = Inlet temperature of the cooling fluid (^{o}C),
T_o = Temperature of standard condition (25^{o}C),
T_{out} = Outlet temperature of cooling fluid (^{o}C),
V_{mp}= PV voltage at maximum power point (V)
V_{NP} = Volume of the nanoparticles (m^3)
V_T =Total volume (m^3)
β = Temperature coefficient of silicon cell(β=0.0045 $^o C^{-1}$).
η_o = Nominal electrical efficiency under standard condition.
μ_{nf} = Nanofluid viscosity (kg/m.s).
μ_w = Water viscosity(kg/m.s).
ρ_f = Density of the base fluid(kg/m^3).
ρ_{nf} = Density of the nanofluid (kg/m^3).
ρ_p = Density of the nanoparticles(kg/m^3).

INTRODUCTION

The PV/T system refers to a system that extracts heat from the panel with using heat transfer fluid. There are several reasons which motivate the development of the PV/T system .One of the main reasons is that PV/T system can provide higher efficiency than individual PV and thermal collector system. With increased the efficiency, the payback period of the system can also be shorten. The electrical efficiency reduction of PV modules due to their temperature increase can be partially avoided by water or air heat extraction. PV heating is mainly the result of the absorbed solar radiation that is not converted into electricity and PV cooling is considered necessary to keep electrical efficiency at a satisfactory level. The usual mode of PV cooling by water is the circulation of it through a heat exchanger in thermal contact with the PV module rear surface, to avoid pressure and electrical problems [1].

The application of a nanofluid in solar collectors leads to a homogeneous temperature distribution inside the receiver. In addition, greater light absorption, a high absorption at visible wavelengths and a low emissivity at infrared wavelengths can be achieved, and sunlight can be directly converted into useful heat [2].

Advantages of nanofluids compared to conventional solid-liquid suspensions for heat transfer intensifications, properly engineered thermal nanofluids possess the following advantages:

- High specific surface area and therefore more heat transfer surface between particles and fluids.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.
- Adjustable properties, including thermal conductivity and surface wet ability, by varying particle concentrations to suit different applications.

Industrial processes require heating at different temperature levels. Low quality heat, at temperatures less than ($95^{o}C$), can be provided via flat-plate solar collectors or from hybrid PV/T systems. These collectors are used broadly to increase the working fluid temperature in the range of (30^{o} to $100^{o}C$) above the ambient temperature. Its operation depends on the absorption of solar radiation; the absorbed energy is conducted to a working fluid circulating inside the tubes of the collector [1]. This working fluid may be water, ethylene glycol or a mixture of water and propylene glycol [2-3], but these fluids have low thermal conductivities. For instance, the thermal conductivity of water is (0.685 W/m K) at ($120^{o}C$) while that of ethylene glycol is (0.236 W/m.K) at ($100^{o}C$). Since the emergence of nanofluids [2], which show higher thermal conductivities than the corresponding base fluids, research work has investigated the potential of nanofluids as the working fluids of collectors, nanofluids have attracted attention as a working fluid for solar collectors because of their predicted capability to enhance the thermal performance of collectors, and thus energy and cost savings can be achieved [4].

The main goal of this work is to improve the PV performance by using nanofluids through: -

A – Design and construct a cooling water technique to solve the problem of rising temperature inside a PV module and to improve the electrical and thermal efficiency of a PV/T system.

B- Study the effect of nanofluid on the electrical and thermal efficiency of a PV/T system.

Methodology

Physical Properties of the Working Fluid

The physical properties of the working fluid are changed due to effect of the nanoparticles. For conventional fluids, these properties can be attained from standard tables or equations [5]. However, for nanofluids, the properties depend on parameters such as the nanoparticle concentration [6]. Herein, the properties are considered temperature dependent, and the correlations given by Azmi et al. [7] can be used. The model target is to compare the performance of the collector using a nanofluid relative to base fluid (water) under the same temperature conditions.

Drew and Passman [8] suggested the well-known Einstein′s equation for calculating viscosity, which is applicable to spherical particles in volume fractions less than (5.0 vol%), and is defined as follows:

$$\mu_{nf} = (1 + 2.5\phi)\mu_w \qquad \ldots(1)$$

An alternative formula for calculating the thermal conductivity was introduced by Yu and Choi [9], which is expressed in the following form:

$$k_{nf} = [\frac{k_p + 2k_f - 2(k_f - k_p)\phi}{k_p + 2k_f - (k_f - k_p)\phi}]k_f \qquad \ldots(2)$$

The density of the nanofluid can be calculated according to the mixing theory as developed by Pak and Cho [10]. The experimental results of Sommer and Yerkes [11] demonstrate the applicability of the formula.

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \qquad \ldots(3)$$

The specific heat is calculated from Xuan and Roetzel [12] as:

$$(\rho Cp)_{nf} = (1-\phi)(\rho Cp)_f + \phi(\rho Cp)_p \qquad \ldots(4)$$

The volume concentration of the nanoparticles is defined as follows[12]:

$$\phi = \frac{V_{NP}}{V_T} \qquad \ldots(5)$$

Electrical and Thermal efficiency of Hybrid PV/T System

The theoretical cell electrical efficiency (η_e) defined as [1] :-

$$\eta_e = \eta_o\left[1-\beta(T_c - T_o)\right] \quad \ldots(6)$$

Where

$$\eta_o = \frac{V_{mp} I_{mp}}{GA} \quad \ldots(7)$$

$$\eta_e = \frac{\int VIdt}{A_c \int G(t)dt} \quad \ldots(8)$$

$$\eta_{th} = \frac{m^{\bullet} Cp \int (T_{out} - T_{in})}{A_c \int G(t)dt} \quad \ldots(9)$$

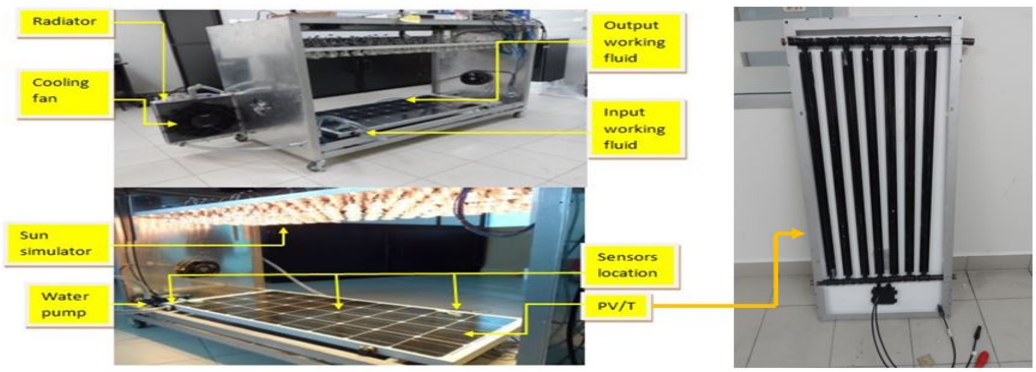
$$\eta_{total} = \eta_{th} + \eta_e = \frac{m^{\bullet} C_p \int (T_o - T_i)dt + \int VIdt}{A_c \int G(t)dt} \quad \ldots(10)$$

The thermal and electrical efficiencies are presented in Eqs. (9) and (10). It can be seen that the solar irradiation is a function of time and those parameters which are affected by the solar irradiation, such as inlet and outlet temperatures, PV voltage and PV current, are also functions of time.

Experimental Set-up

Description of the PV/T System

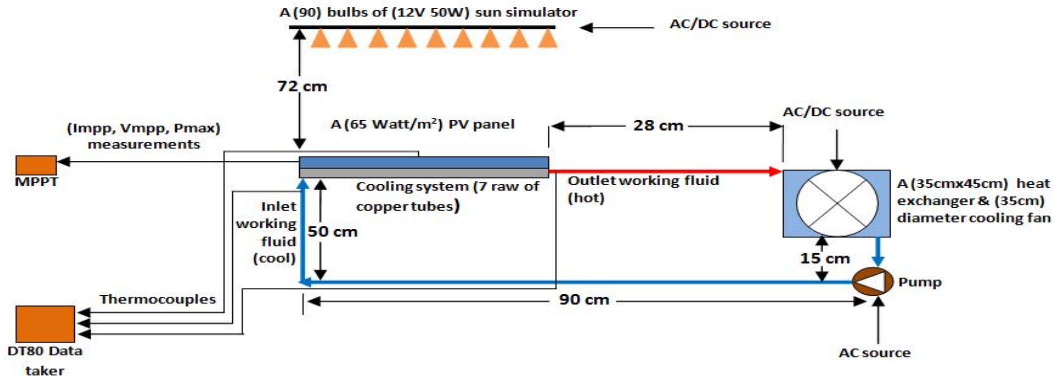
A test setup was designed to investigate the thermal and electrical performances of the Photovoltaic thermal system. This system was built in the building of UM POWER ENERGY DEDICATED ADVANCED CENTER (UMPDAC) at the University of Malaya in Malaysia. The photograph of the setup is shown in fig.1; a schematic diagram of the complete experimental set-up is shown in fig. 2.



Figure(1) Photograph of cooling of PV/T system which is built in this study

A mono-crystalline solar panel was used in this experiment to generate the electricity. During the operation, a maximum power point tracker (MPPT) was used to modulate the power output from solar panel to be the maximum value.

Solar irradiation was measured by the pyranometer, fixed at same level as the solar panels. In this experiment, the working fluid mass flow rate was measured by 1/2" Nominal Threaded and the temperature of working fluid and PV module was obtained by using three k-type thermocouple directly connected to the data taker type DT80. The voltage and current of the solar panels were directly recorded by the data taker as shown in fig.2.



Figure(2) Schematic diagram of cooling of PV/T system which is built in this study

Preparing of Nanofluid

In the experience after the screening process cooling water and its impact on increasing the efficiency of solar cells we prepare (4) liters nanofluid of aluminum oxide - water with a five concentration ratios (0.1%, 0.2%, 0.3%, 0.4%, 0.5%), the AL_2O_3 is used with particles size of (30nm) and the statement of its impact on the cooling process and improve the efficiency of solar cells have been prepared in the laboratories of University Malaya/ Malaysia

Figure(3) five samples of (AL_2O_3-Water) nanofluid

Experimental Measurements Accuracy

1- The accuracy of pyranometer is (±0.05%).
2- The accuracy of DT80 data taker is (±0.01%).
3- The accuracy of MPPT data taker is (±0.03%).
4- The accuracy of K-type thermocouples is (±0.4%).
5- The accuracy of working fluid mass flow rate is (±0.5%).

Results and discussion

All physical properties of working fluid changed such as viscosity, thermal conductivity, density, specific heat, according to equations (1, 2, 3, and 4), all these properties depend on concentration ratio of nanoparticles on base fluid (water) in experiment, and for this reason made five concentration ratios of nanofluid to take the better case of concentration ratio for experiment.

Fig.4 shows the effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on thermal efficiency. An increasing in the thermal gain with increasing of concentration ratio of nanofluid because the thermal conductivities of nanofluid is increased when concentration ratios of nanofluid increased according to equation (2) and that led to increasing of thermal efficiency of PV/T system.

Fig.5 shows Effect of nanofluid concentration ratios at mass flow rate (0.2 l/s) on PV panel temperature .The value of (0.3%) concentration ratio give good cooling for PV panel because of increasing thermal conductivities of working fluid and led to more absorption of heat from PV panel, and when it increase more than (0.3%) the PV temperature will increase because the density and viscosity will be increasing with rising of concentration ratio according to equations (1&3) and this led to inverse effect for this enhancement.

Fig.6 shows the effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on PV panel maximum power.When PV temperature decreased with using of nanofluid the maximum power generated will be increased.

Fig.7 shows the effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on Impp of PV panel. The better maximum power generated at (0.3%) nanofluid concentration ratio because this ratio give good cooling for PV panel. Fig.8 shows the, effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on Vmpp of PV panel. The enhancement in Impp & Vmpp with using nanofluid shows that at (0.3%) concentration ratio.

Fig.9 shows the effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on electrical efficiency of PV system .The results show that the electrical efficiency was increased when using nanofluid to (0.3%) concentration ratio and it will decreased when it will be up to (0.3%) because the PV temperature will be increasing as the increasing of concentration ratio up to (0.3%).

Fig.10 shows the MPPT trace at end of testing the effect of rising temperature on PV performance without cooling and fig.11 shows MPPT trace at end of testing the effect of water cooling at (0.2 l/s) on PV performance.

Figs, 12, 13, 14, 15 and 16 show the MPPT trace at end of testing the effect of nanofluid cooling at (0.1, 0.2, 0.3, 4, and 0.5 % concentration ratio) on PV panel performance. The improvement in PV/T system performance due to decease in temperature of PV by using nanofluids and the best concentration ratio was (0.3%) because it gives good cooling for PV while more than (0.3%) the PV temperature will increase because the density and viscosity will increase.

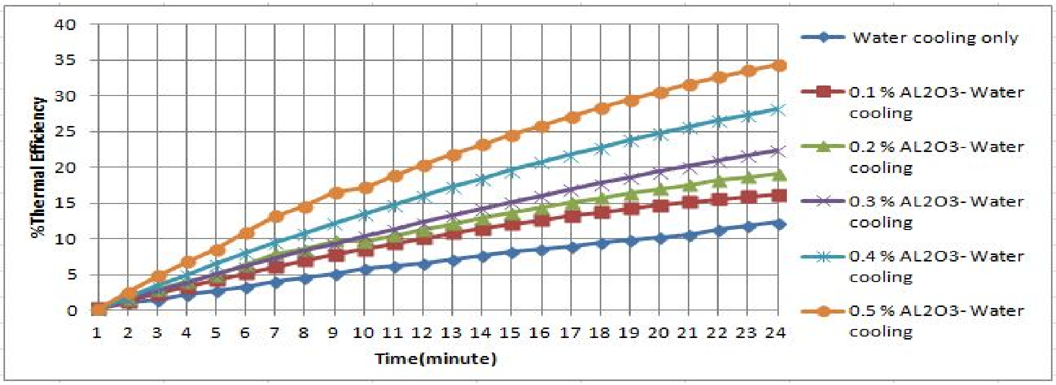
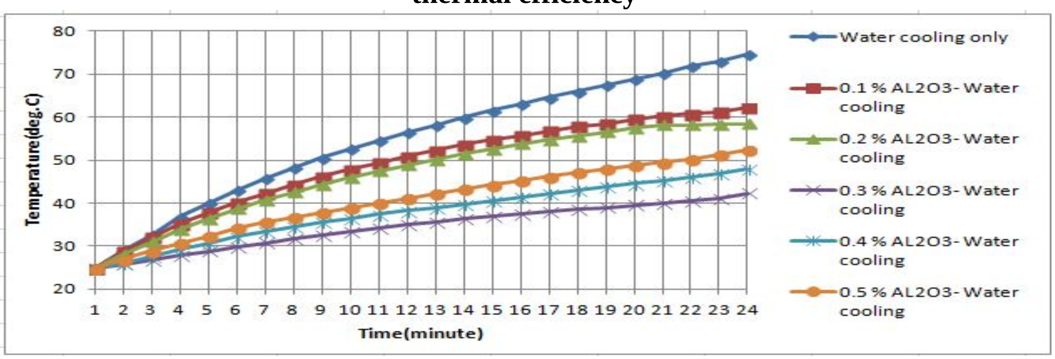
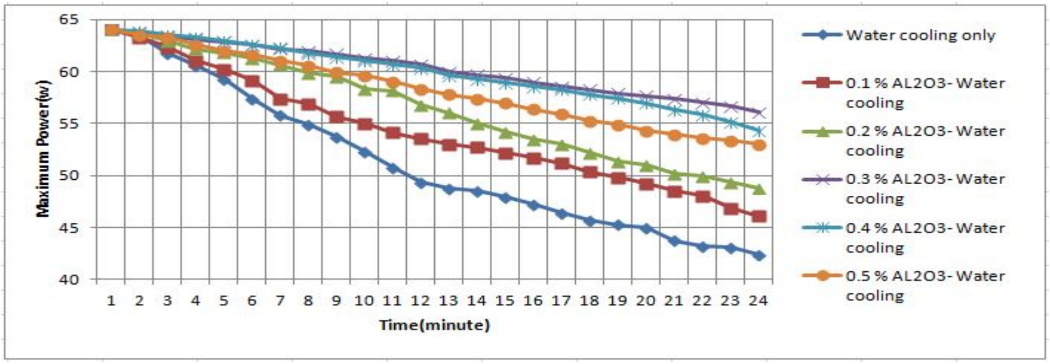


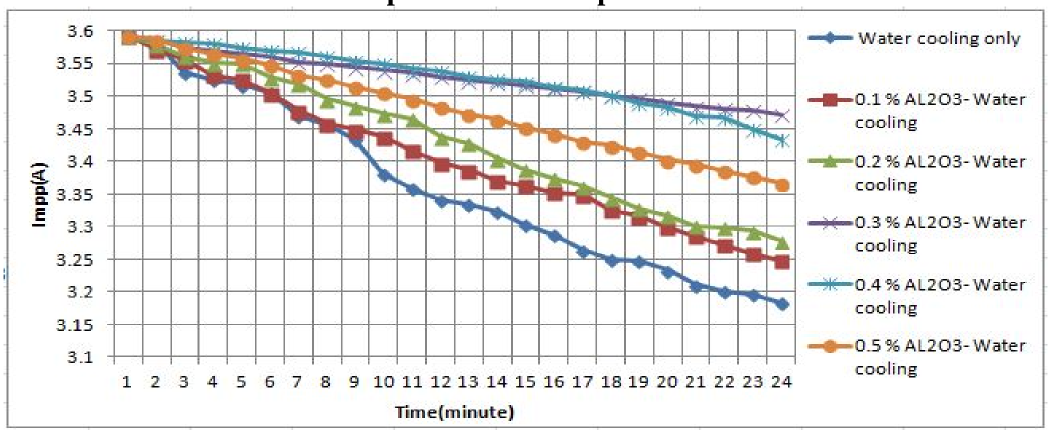
Figure (4) Effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on thermal efficiency



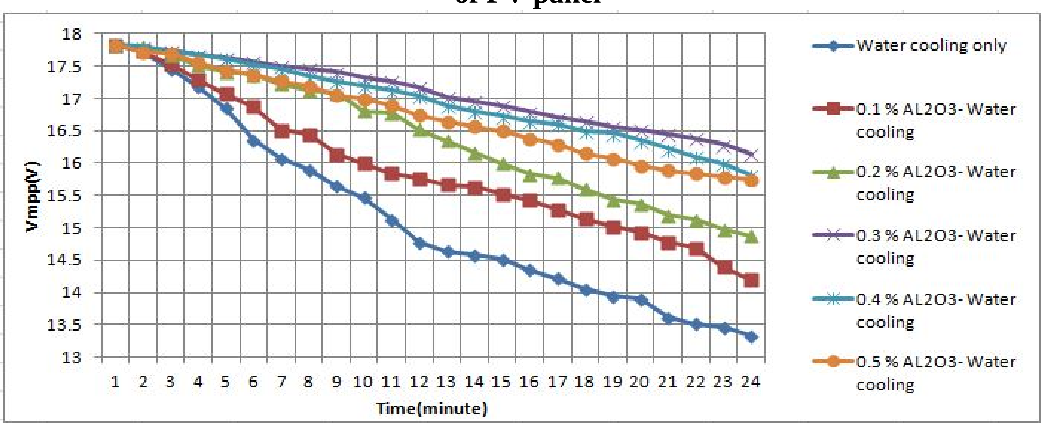
Figure(5) Effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on PV panel temperature



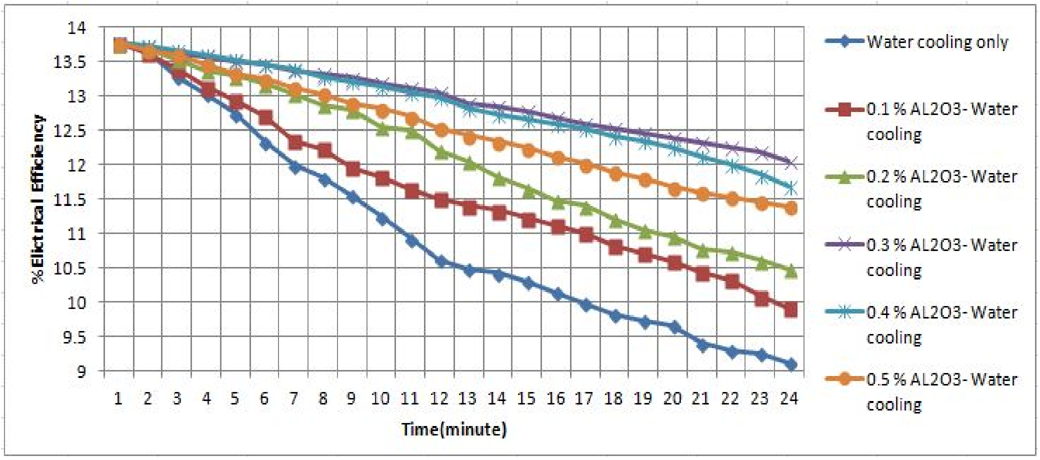
Figure(6) Effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on PV panel maximum power



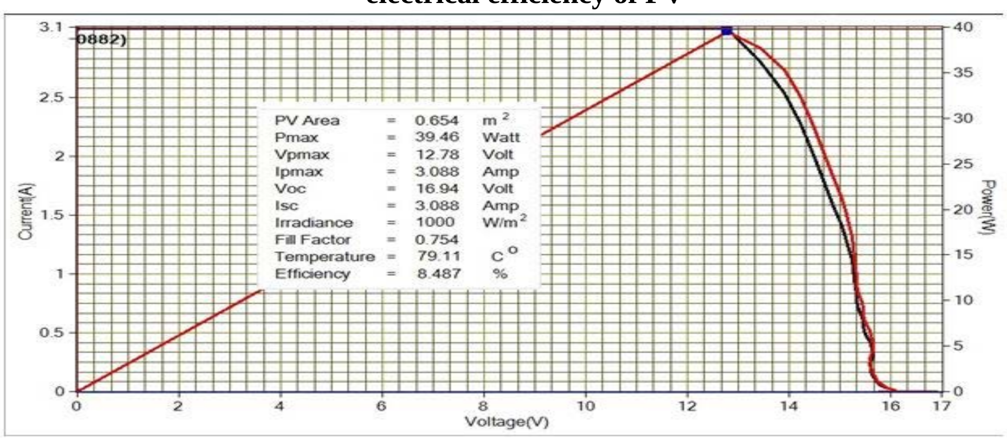
Figure(7) Effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on Impp of PV panel



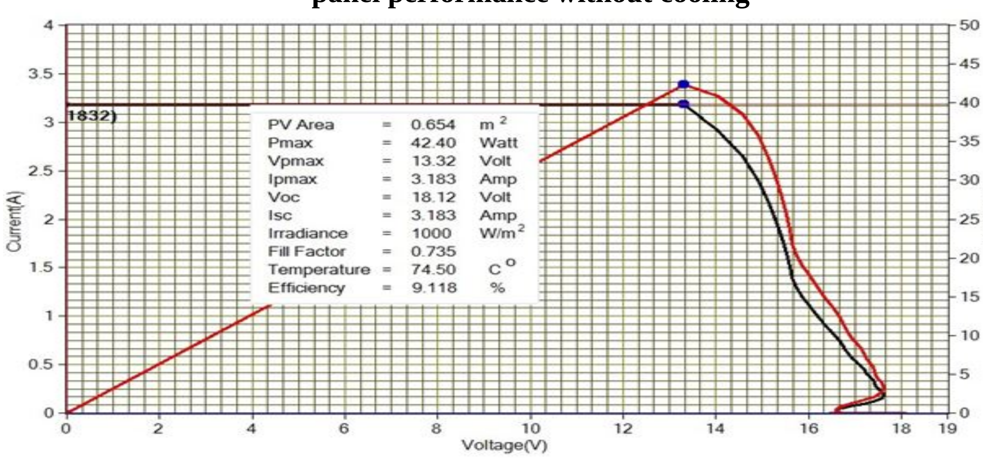
Figure(8) Effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on Vmpp of PV panel



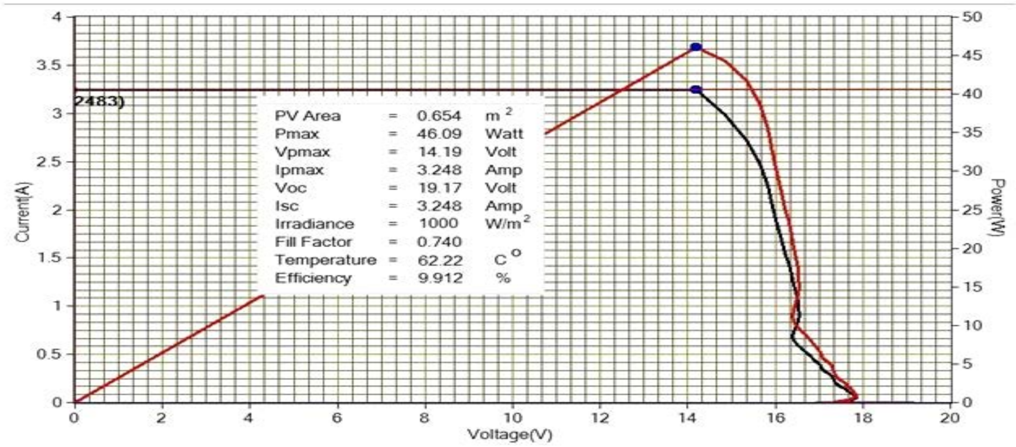
Figure(9) Effect of nanofluid concentration ratio at mass flow rate (0.2 l/s) on electrical efficiency of PV



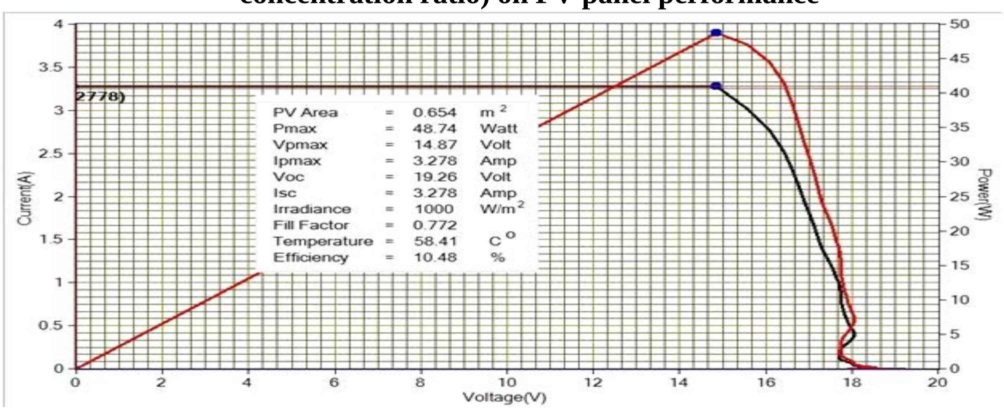
Figure(10) MPPT trace at end of testing the effect of rising temperature on PV panel performance without cooling



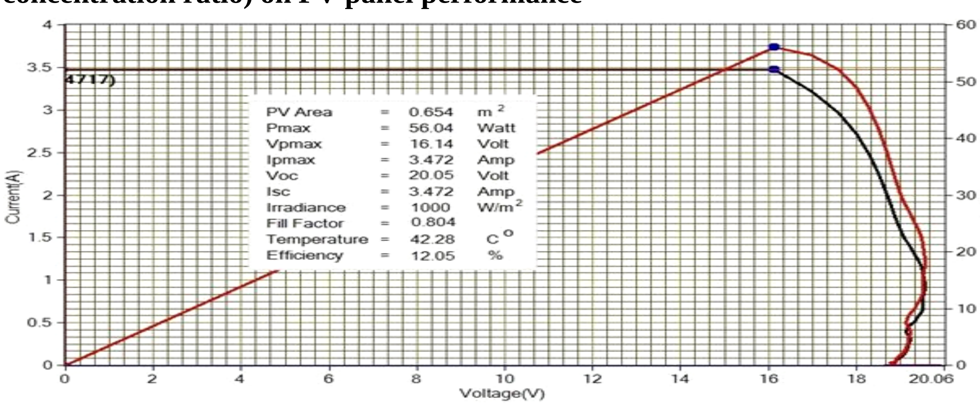
Figure(11) MPPT trace at end of testing the effect of water cooling at (0.2 l/s) on PV panel performance



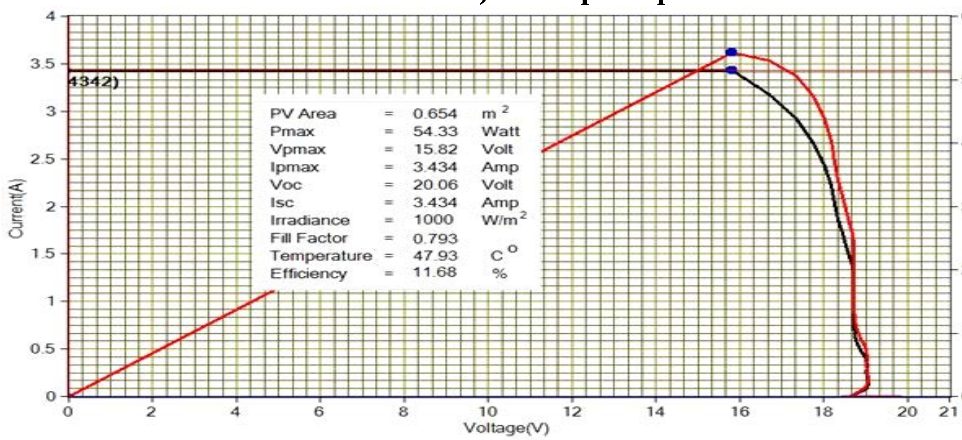
Figure(12) MPPT trace at end of testing the effect of nanofluid cooling at(0.1% concentration ratio) on PV panel performance



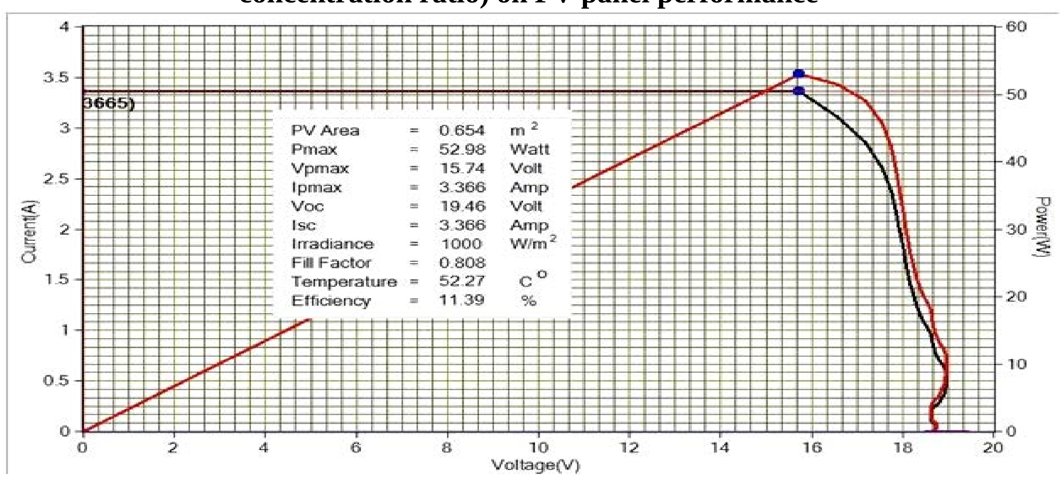
Figure(13) MPPT trace at end of testing the effect of nanofluid cooling at(0.2% concentration ratio) on PV panel performance



Figure(14) MPPT trace at end of testing the effect of nanofluid cooling at(0.3% concentration ratio) on PV panel performance



Figure(15) MPPT trace at end of testing the effect of nanofluid cooling at(0.4% concentration ratio) on PV panel performance



Figure(16) MPPT trace at end of testing the effect of nanofluid cooling at (0.5% concentration ratio) on PV panel performance

Conclusions

The effect of different concentrations ratio of (AL_2O_3) nanofluid with water base was examined on PV/T performance for different mass flow rates. The results indicated that when used nanofluid (AL_2O_3) at different concentration ratios (0.1, 0.2, 0.3, 0.4, 0.5) % at mass flow rate (0.2 l/s), the temperature is more dropped significantly from (79.1^{o}C) to (42.2^{o}C) at optimum concentration ratio of nanofluid (0.3%), this led to increase in the electrical efficiency of solar panel to (12.1%) and the thermal efficiency increased to (34.4%).

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