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Enhancement of the photovoltaic thermal system performance using dual cooling techniques

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The aim of this work is to enhance the photovoltaic / thermal system performance by dissipating the high heat stored inside the PV panels. A new design of front and back cooling systems has been made based on spraying water on the front surface and circulation of a Nanofluid (AL_2O_3 – H_2O) in the back cooper pipes with a small heat exchanger. Deionized water and Nanopowder AL_2O_3 are mixed homogenously to be the working fluid and used as a cooling fluid in the back closed system. Concentration ratios of Nanopowder are (0.1,0.2, 0.3,0.4, and 0.5) % with a different mass flow rates of water are applied. The thermal and electrical performance of PV/T was recorded as a function of solar irradiation intensity and temperature on the PV panel surface. The temperature of PV panel dropped from 76℃ to 64℃ with front and back cooling by water. This dropping in temperature led to increase the average electrical PV efficiency to (7.5) % at an optimum flow rate of (2L/min.). When using Nanofluid ($AL_2O_3 - H_2O$), the temperature dropped significantly to (45℃) at a concentration ratio of (0.3%) causing an increment in the PV efficiency of (10.9) %.

Keywords: PV performance; PV cooling; Nanofluids applications; Water pumping system.

NOMENCLATURE

A : Area of the PV module (m2).
Ac : Area of collector (m2).
C_P : Specific heat capacity of fluid (J/K_g. °C)
G : Solar radiation (W/m2)
Im : Maximum current of PV module.
Q : Heat transfer rate (J/s)
To : Temperature of standard condition (25 °C)
T_i : Inlet temperatures of fluid in PVT (°C)
In PVT (°C) T_o : Outlet temperatures of fluid
Pvt: Photovoltaic thermal
V_m : Maximum voltage of PV module
β : Temperature coefficient of silicon cell i.e ($\beta = 0.0045°C^{-1}$)
Ø : Nanoparticles volume fraction
η_0 : Nominal electrical efficiency
η_{th} : Thermal efficiency
μnf: Nanofluid viscosity (kg/m.s).
μw: Water viscosity(kg/m.s).
ρf : Density of the base fluid(kg/m3).
ρnf: Density of the Nanofluid (kg/m3).

1. INTRODUCTION

As the world is confronting the issue of global warming, energy shortfall and the retrogradation of environment and energy sources, there is a requirement for an alternate energy to asset generating power instead of using fossil fuels. The energy consumption all over the world , especially in the industrialized countries, has been growing at an alarming rate. Most of the world's energy, (86%) of supply originates from the fosil fuels [1]. It is estimated that the world energy demand will increase by 45% between 2006 and 2030. The rate of expansion is 1.6% per year. An exciting alternative to diminish these negative effects is an expansion of the renewable energy utilizations. Solar energy is one of the most promising sources among renewable energy because it is clean, available and inexhaustible. Solar energy can be used in different wayes such as, thermal field using thermalcollectors or electricity generation through solar Photovoltaic (PV) cells. A PV cell is a semiconductor device that generates electricity when light falls on it. The physical process in which a PV cell or solar cell converts sunlight into electricity is known as the photovoltaic effect [2]. The performance of a photovoltaic (PV) system not just relies upon its basic electrical characteristics: maximum power, maximum power voltage, maximum power current, maximum system voltage, open-circuit voltage (Voc), short-circuit current (Isc), but is also adversely affected by several impediments for example ambient temperature, duststorms, suspension in air, global solar radiation intensity, spectrum and angle of irradiance [3,4]. The main factor which plays an essential role in the performance of solar cells is surface temperature of the solar cells. A small increment in the temperature of the solar cell decreases the output of the solar cells significantly [5,6]. PV-T technology is a hybrid system that combines PV panels with solar thermal collectors and capitalizes on the untapped heat energy of the PVsystem. Hybrid Photovoltaic/Thermal (PV/T) system is one of the most prominent strategies for cooling the photovoltaic panels nowadays, by extracting heat from it using heat transfer fluid. The higher efficiency can be provided by the PV/T system as compared with the conventional PV and thermal collector systems, therefor it was developed. A PV cell transforms only a small part (less than 20 %) of the irradiance into electrical energy, thus PV heating is the result of the absorbed solar radiation that is not converted into electricity [7]. Furthermore, the increased temperature can likewise bring structural harm to the module if the thermal stress stays for a protracted period, thus cooling the PV is essential to keep the electrical efficiency at an acceptable level and achieves expectations level [8]. For solar collectors, Nanofluids have attracted attention as a working fluid due to their anticipated ability to improve the thermal performance of the collectors and the energy and cost savings can be achieved. In this work Nanofluid was used as the working fluid to increase heat transfer from the rear surface of PV/T. Nanofluids have the following advantages as compared to conventional fluids which make them suitable for different applications involving heat exchange:- improvement in efficiency of heat transfer systems because of the suspended Nanoparticles that enhance the thermal conductivity and the suspended nanoparticles increased the surface zone and the heat capacity of the fluid because of the very small size of the particles . Reduced pumping power compared to pure liquids to achieve equivalent heat transfer is proper for various applications. Its properties can be changed by varying the concentricity of the Nanoparticles [8,9].

Salih Mohammed Salih et al (2015) [10] have presented experimentally the performance enhancement of PV array based on sprayed cooling water on the front side of the panel to dissipate heat and keep the panel cooling at minimum temperatures. The results of this study showed that the performance of PV panel had been increased and the cooling rate for 5 min.was 4 ºC/min in midday and the average value of efficiency of spraying system along one day was about 17.8 %. Dorobanțu et al (2013) [11] have evaluated PV panels front water-cooling methodology. They concluded that the open voltage of the panel risies when its temperature diminishes and because of the lower operating temperature, the life cycle can be increased. Chao-Yang et al (2012) [12] have evaluated a hybrid Photovoltaic thermal system (PV/T) which involved polycrystalline PV cells, water pump, controller, water tank. The PV/T collector was erected with copper tube and copper sheet settled on the rear of PV panel. The consequences of this research demonstrated that the thermal efficiency of the thermal unit can reach 35.33% and the electrical effectiveness of PV panel achieved was 12.77%. Sardarabadi et al.(2014) [13] have presented an experimental work to study the impact of utilizing Al_2O_3

Nanofluid as a working fluid in a PVT system to improve its thermal and electrical efficiencies. The Al_2O_3 Nanofluid utilized in this work was1% and 3% by weight (wt %). From the outcomes, it was observed that the thermal efficiency of the PVT collector for the two cases of 1wt% and 3 wt% of nanofluids increased by 7.6% and 12.8%, respectively.
The fundamental objectives of this work are: 1- to enhance the thermal and electrical performance of the photovoltaic / thermal system (PV/T), 2- to solve the problem of rising temperature by design and construct a cooling water technique in the front and back surfaces of the PV panel, 3- study the effect of utilizing Nanofluid (Al_2O_3- water) as a working fluid in the circulating pipes and, 4- study the effect of cooling the heat exchanger by splashing it with water.

2. METHOD OF ANALYSIS

2.1.1- Thermal and electrical performance of the PV/Tsystem

Thermal efficiency is a function of the solar radiation (G), the input temperature of fluid (T_i), and the output temperature (T_o). The thermal efficiency is estimated by the following equation [14, 15, 16, 17, and 18]:

$$\eta_{th} = \frac{m^{\cdot} cp\ (T_o - T_i)}{A_c G} \tag{1}$$

The nominal electrical efficiency (η_o) of a PV module can be calculated by the following formula for different incident solar irradiations

$$\eta_0 = \frac{V_{mp} I_{mp}}{GA} \tag{2}$$

The electrical efficiency (η_{elec}) as a function of PV temperature is:-

$$\eta_{elec} = \eta_0 [1 - \beta (T_c - T_0)] \tag{3}$$

2.1.2-Thermo physical properties of the working fluid
The Thermophysical properties of the working fluid change due to the influence of the nanoparticles. These properties of conventional fluids can be found from standard tables or equations [14, 17]:-

$$\rho_{nf} = (1\text{-}ø)\ \rho_f + ø\ \rho_p \tag{4}$$

$$(\rho\ Cp\ )_{nf} = (1 - ø)(\rho\ Cp\ )_f +$$

$$\text{ø}\,(\rho\ Cp\,)_p \tag{5}$$

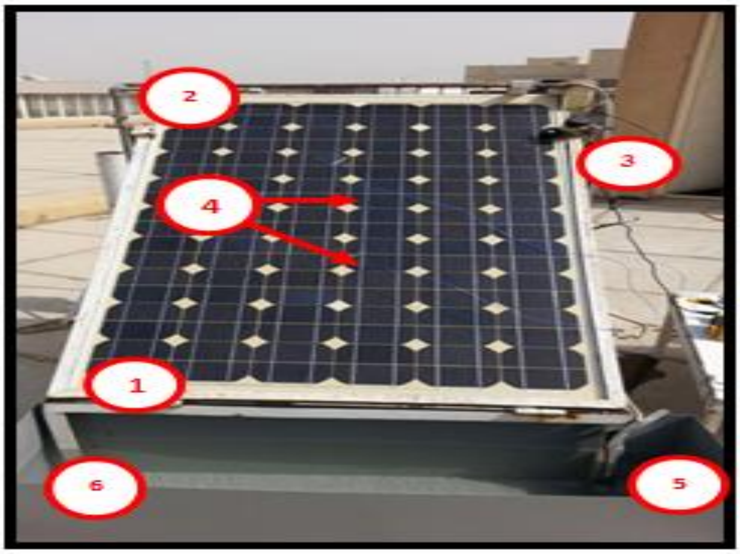
$$\mu_{nf} = (1{+}2.5\ \text{ø}\,)\ \mu_w \tag{6}$$

$$K_{nf} = \left[\frac{K_f + 2K_f - 2(K_f - K_p)\text{ø}}{K_p + 2K_f - (k_f - K_P)\text{ø}}\right]K_f \tag{7}$$

$$\phi = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{m_p} + \frac{m_f}{\rho_f}} \tag{8}$$

2.2 -Experimental procedure

Figure. (1) Shows the experimental setup developed to investigate the thermal and electrical performances of the Photovoltaic thermal system. This system was built-on site of Electromechanical Engineering Department, University of Technology. The experimental setup consists of SR-100S PV panel made from Monocrystalline semiconductor, charge controller, battery, DC-DC boost converter, PMDC motor used as pumping system load, copper pipes, radiator with fan and circulation pump for cooling hot water. Figure. (2) Presents a schematic diagram of PV/T.



1-Photovoltaic Panel, 2-copper Pipe, 3- thermostat, 4- Thermocouples, 5-Dc Pump 6-water tank

Figure 1 PV panel and cooling system used during the experiment

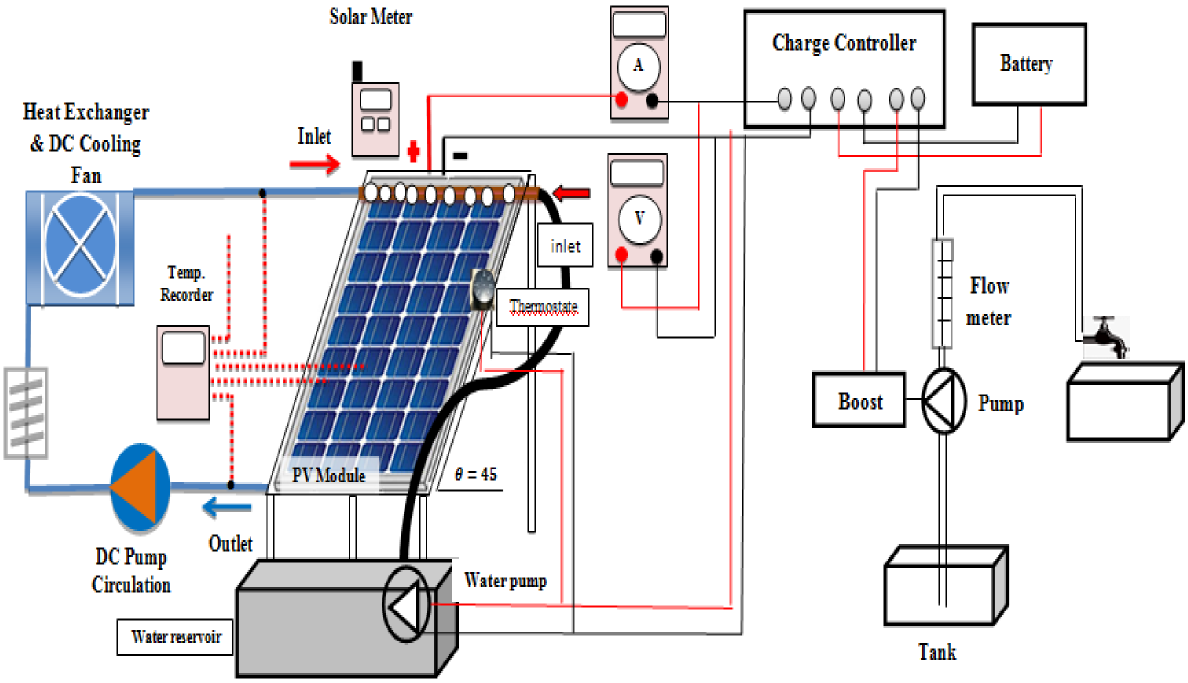


Figure 2 Schematic representation of PV/T system

The main element in the preparation of the experiment is a photovoltaic panel which produces direct current (DC) electricity. The SR-100S PV panel made from Monocrystalline semiconductor was used in this experiment. The photovoltaic module consists of (9 x 6 cells). The PV generates 100 watt as a maximum power under Standard Test Conditions (STC) and at maximum solar radiation it generates a max. Power current (Impp) nearly equals to (5.8A).

This experimental study included three steps to cool the system which led to enhance the performance of the PV cell. First , front cooling with a thin continuo as film of water flowing on the front surface of the panel, the second cooling the rear surface of PV using working fluid circulation pipes and third, cooling the heat exchanger by water spraying.

2.2.1 Front cooling system

The front cooling system as shown in Figure 3 consists of a copper pipe, thermostat, feed pump and reservoir. To produce a film of water on the photovoltaic panel, a cribriform pipe has been fixed at the top edge of the panel with (16) holes each of (65 mm) in diameter, for the water flow. The thermostat is an instrument used to control the temperature of the solar panel. It is regulated to keep the temperature of PV under 50C° so that when the temperature of PV exceed 50C° the front cooling system will be operated. It was fixed on the right edge of the panel. The water pump was put in the reservoir and when the surface temperature of the panel exceeds 50C° it starts pumping water from the reservoir to the surface panel. The reservoir is of dimensions (1, 0.3, and 0.4) m made from iron and used to store and collect water. This cycle is repeated.

Figure 3 Front cooling (film of water)

2.2.2 Back cooling system

The back-cooling system of the PV consists of a copper sheet (2mm) in thickness and pipe (11mm) inner diameter. The copper sheet and the piping are tied up directly to the rear side of PV panel. Copper material has been used for its high thermal conductivity. Thermal sink was used between the PV panel and the 2mm copper plate to maximize heat transfer. The copper pipes are linked using a welding machine. The welding method is 40% tin and 60% silver. The storage capacity of the piping system is 1.5 liters welded to the copper sheet along its height and length, then fixed on the rear surface of the PV panel. The copper pipes have at least one inlet and one outlet to allow working fluid to enter and exodus from it respectively. Working fluid enters the pipes with low temperature and leaves as hot fluid. The size of the copper pipes was calculated accord to the size of PV panel utilized in this experiment. The dimension of the thermal collector design is shown in Figure. (4a, b).

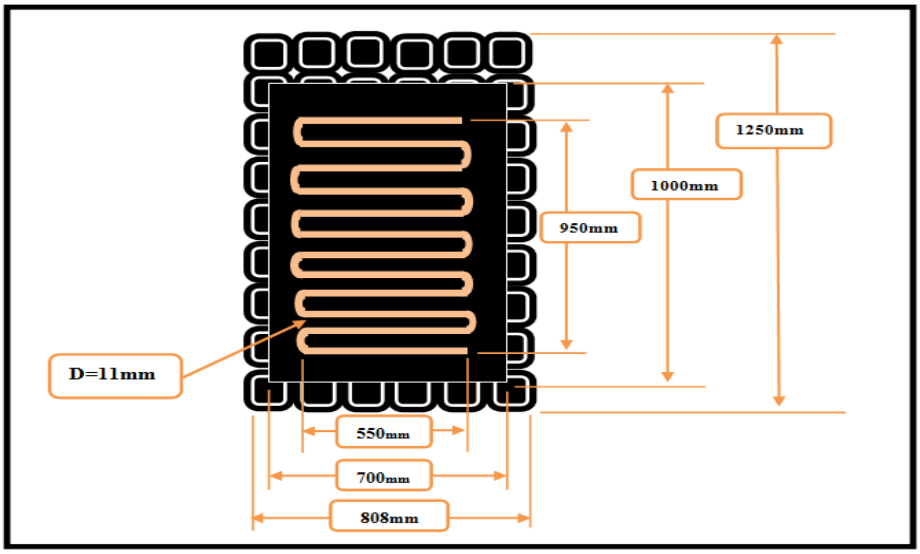


Figure 4a Dimensions of thermal collector mounted on the back side of PV panel

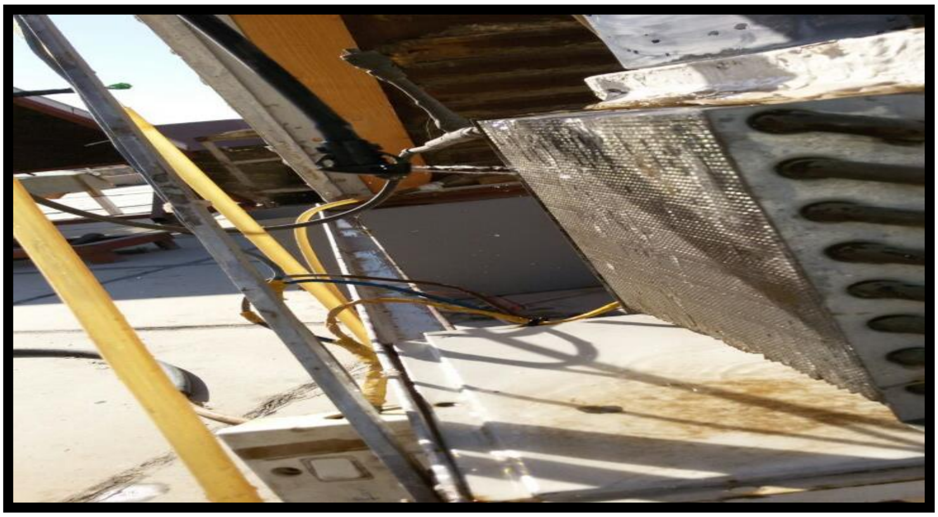


Figure 4b Spraying water over the heat exchanger

2.3 Preparing the Nanofluid

Nanofluid has been prepared in the corrosion laboratory of the Materials Engineering Department at the University of Technology. Nanopowder type of AL_2O_3 nanoparticles with a particle size of (30 nm) was used. Then water has been ionized and the powder added to the deionized water and diskrbed by a magnetic mixer type (LMS-2003D) with 650 W for 3 hours, after that the mixture has been treated by ultrasonic homogenizer type KQ3200E with (220 Volt, 50KHz, 150 W) for about 20 minutes to disperse the small particles in the liquid so that they become equally distributed. After studying the impact of water-cooling technique on the performance of PV/T system, (Al_2O_3 - water) Nanofluid was prepared at five concentration ratios (0.1, 0.2, 0.3, 0.4, and 0.5) % by mixing the particles with 1.5 liters of ionized water. Figure. (5) Shows different samples of (Al_2O_3 –water) Nanofluid concentrations.

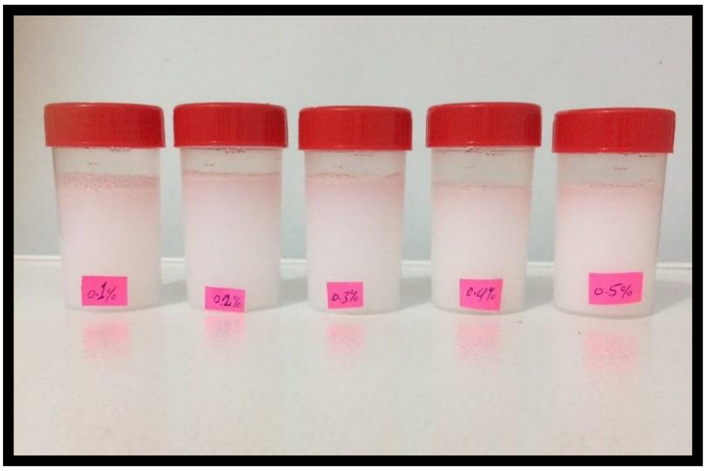


Figure 5 Five samples of (AL_2O_3-Water) Nanofluid

3. RESULTS AND DISCUSSION

3.1 Effect of solar radiation and temperature on the performance of PV module

Solar radiations have a significant effect on the electrical efficiency of the PV module. The solar radiations cause an increase in a cell operating temperature as shown in Figure 6. This increase in surface temperature leads to a reduction in the electrical efficiency of the system**.**

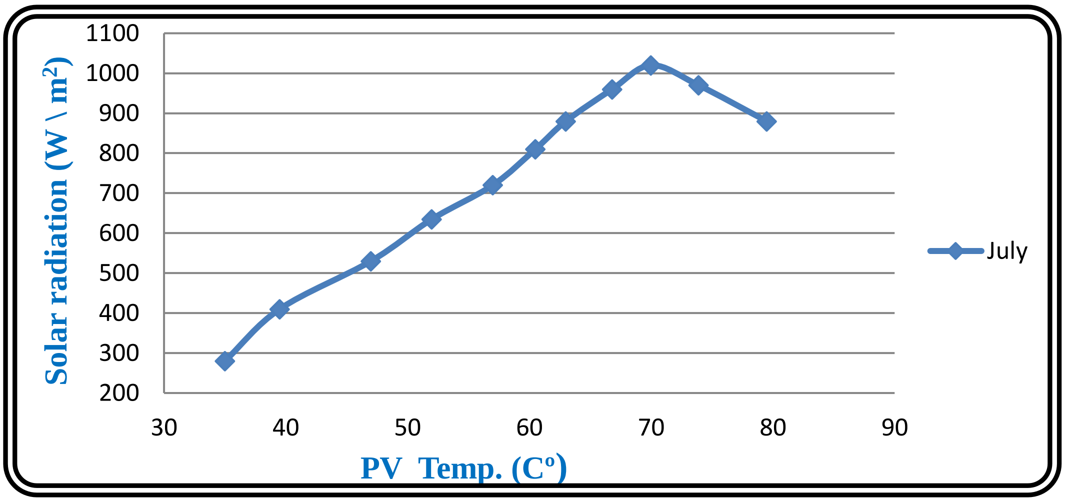


Figure 6 Solar radiation and PV Temperature in July

3.2 PV performance with cooling technique

The raising temperature of the solar cell has a large effect on the performance of the cell. This problem can be resolved by cooling the solar panels. As a result of the cooling process the temperature of the PV panel will be dropped and the performance will be enhanced. The thermal performance of PV/T system is shown in Figures. (7) to (13) with flow rates (1, 1.5, 2) l/min. respectively. Figure. (7) Shows the temperature difference of the PV/T. The temperature difference between inlet and outlet is almost linear with the solar radiation at changing value of radiation from 200 W / m^2 to 1020 W / m^2. From Figure 7 it is observed that flow rate increase causes a decrease in the output temperature and then decrease the temperature difference. But the decrease in flow rate leads to increase output temperature and then increases the temperature difference and then get the best thermal gain. This is because the fluid needs a long time to absorb heat from the surface of PV module. The cooling processes have a significant effect on the PV temperature, it was observed that (2L/min) flow rate gives the best performance in reducing the PV temperature. The reduction in the PV cell temperature reflects on the performance of the cell and thus affects the current and voltages for PV module as shown in Figures. (9 and10). From Figures. (11and 12) indicate that the results of the cooling process for all flow rates give improvement in the power generated from PV module and the best one at (2l/min) flow rate because more heat is dissipated in (radiator) with increasing flow rate of circulating working fluid. The effect of flow rate on the electrical efficiency is shown in Figure. (12). It is observed that the electrical efficiency of the PV module increases with increasing flow rate of the fluid. The best electrical efficiency was obtained at the optimum flow rate (2 L/min), because all the performance is improved at this rate. Figure. (13) Presents the effect of the module cooling on the fill factor. It can be noted that the fill factor is inversely proportional to the module surface temperature and it increases for the module with cooling rather than without cooling.

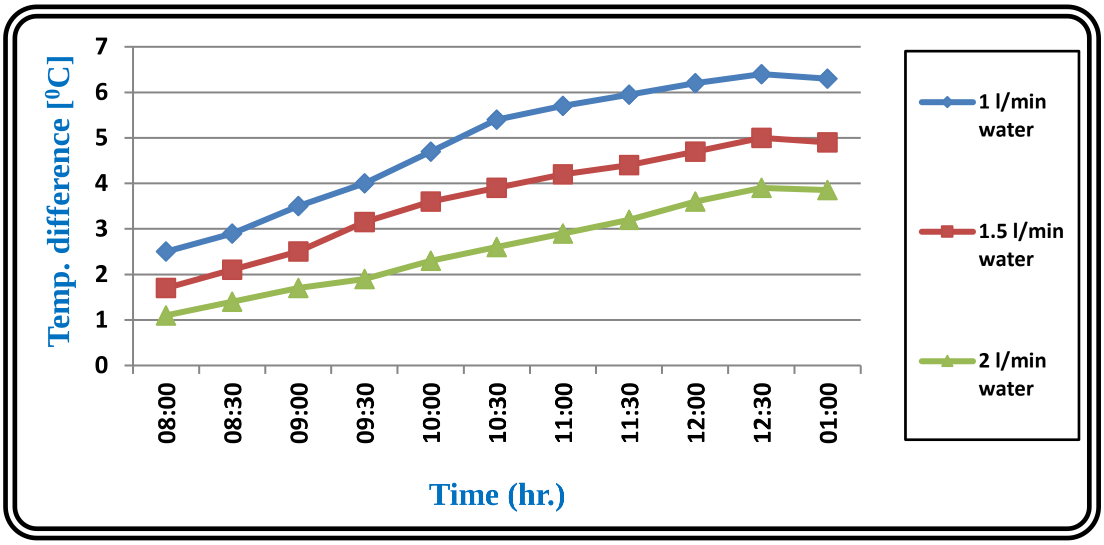


Figure 7 Effect of mass flow rates of water on the temperature difference.

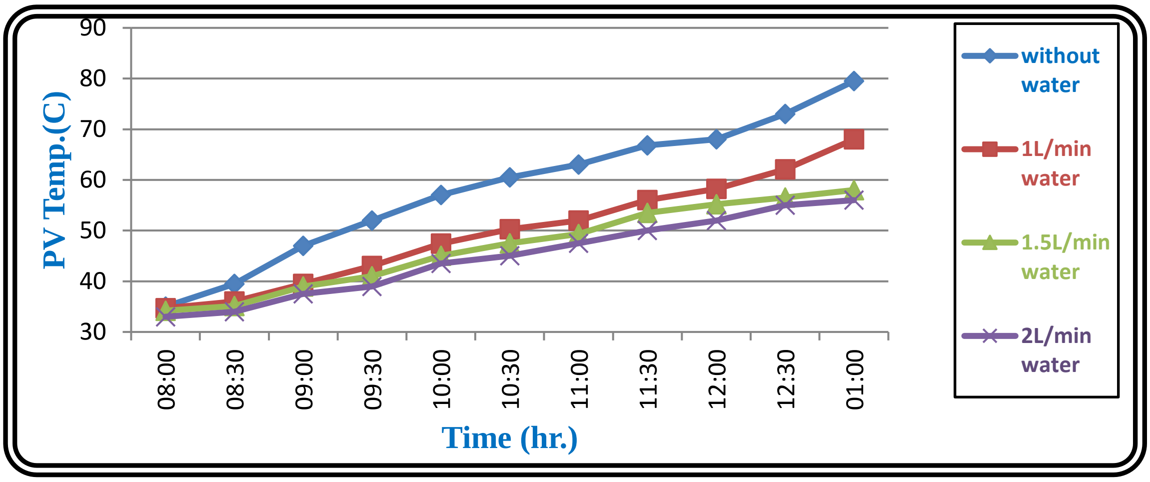


Figure 8 Effect of mass flow rates on the PV temperature.

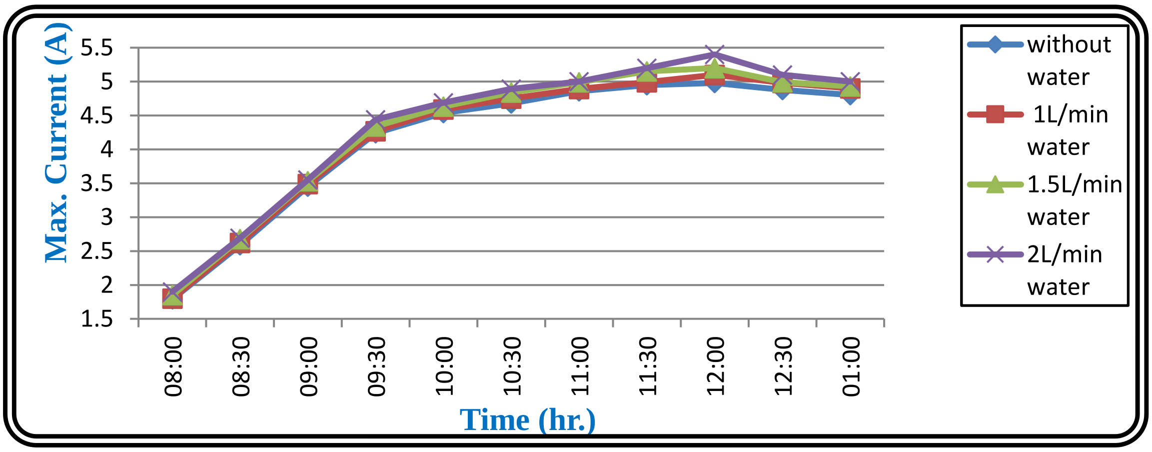


Figure 9 Effect of mass flow rates on max. current.

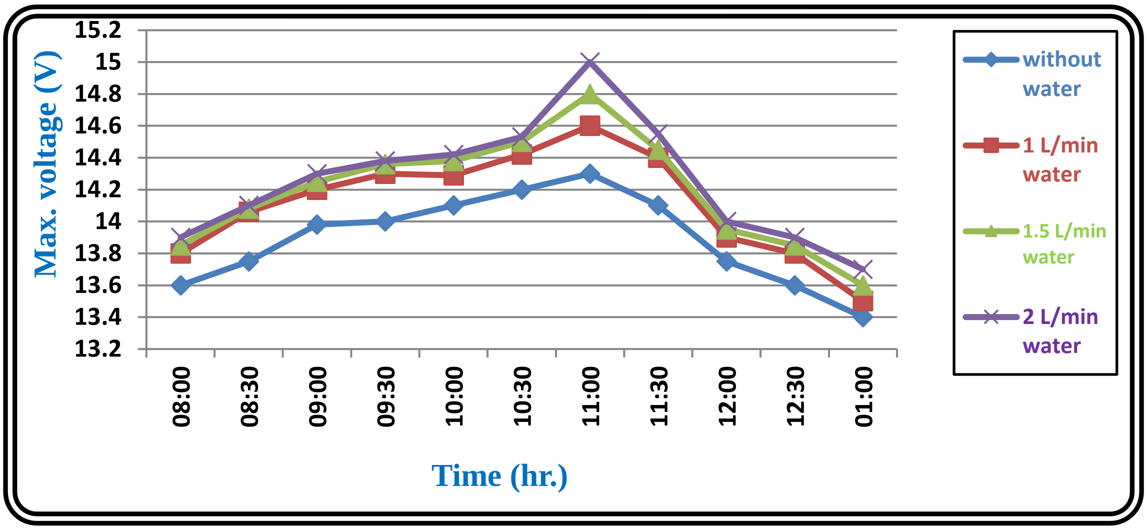


Figure 10 Effect of mass flow rates on max. voltage.

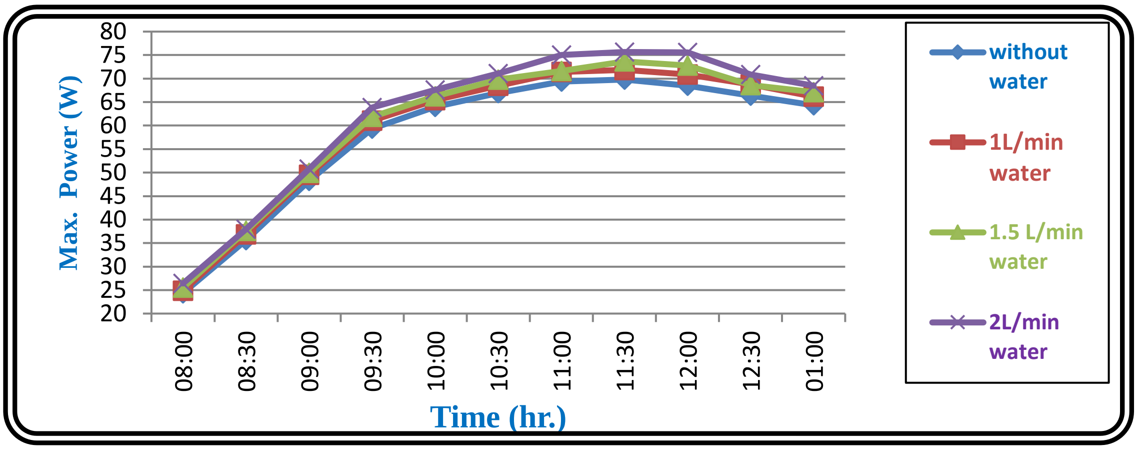


Figure 11 Effect of mass flow rates on max. power.

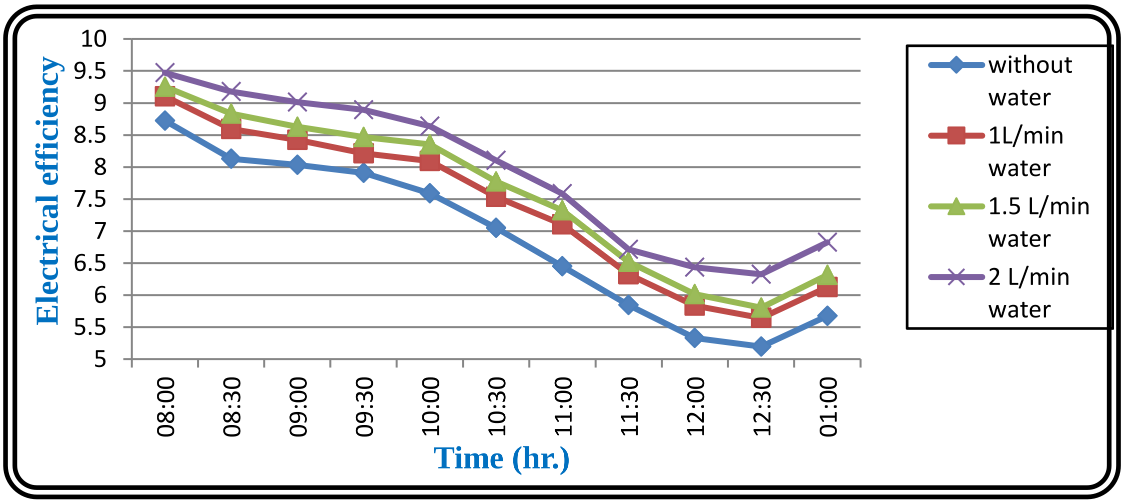


Figure 12 Effect of mass flow rates on the electrical efficiency.

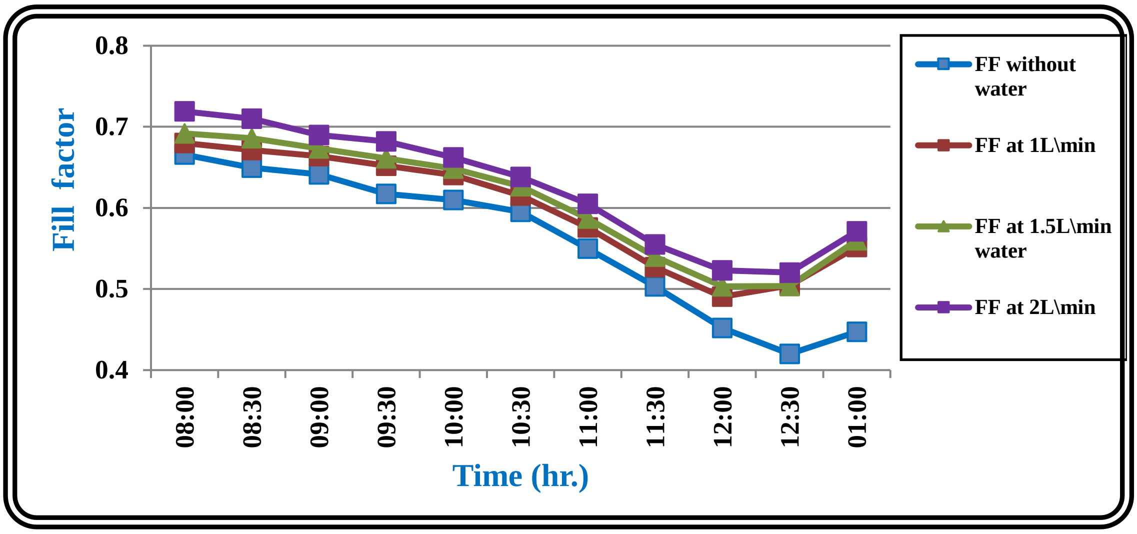


Figure 13 Effect of mass flow rates on the fill factor.

3.3 The performance of PV/T system with (AL_2O_3- water) Nanofluid

All physical properties of the working fluid change with Nanofluid concentration such as viscosity, thermal conductivity, density and specific heat. All these properties depend on concentration ratio of Nanoparticles in base fluid (water). Five concentration ratios of Nanofluid were used to take the best case of concentration ratio. Figure. (14) Shows the impact of Nanofluid concentration ratios on the mass flow rate of (0.2 l/s) on PV panel temperature. The value of (0.3%) concentration ratio gave a good cooling for PV panel by increasing the thermal conductivities of the working fluid. This led up to more absorption of heat from PV panel, and when it increases more than (0.3%) the PV temperature will increase because the density and viscosity will be increasing with rising of concentration ratio. This gives an inverse effect on the performance of PV. And, when the PV temperature decreases by using Nanofluid as a working fluid, the maximum power generated from the PV module will increase too as shown in Figure. (15) A better maximum power is generated at (0.3%) Nanofluid concentration ratio because this volume ratio gives better cooling for PV module. Aso with (0.3%) Nanofluid concentration ratio the Imax &Vmax will be improved as shown in Figures. (16 and 17). From Figures.(18 and 19) it is observed that the maximum electrical efficiency and thermal efficiency respectively were at (0.3%) concentration ratio and it will decreases when the concentration ratio will up to (0.3%) because the PV temperature will be increasing . Figure. (20) Presents the impact of Nanofluid concentration ratios at a constant mass flow rate of (2 L/min) on the fillfactor. It can be noted that the best value of fill factor at (0.3%) nanofluid concentration ratio because this volume ratio gives a good cooling.

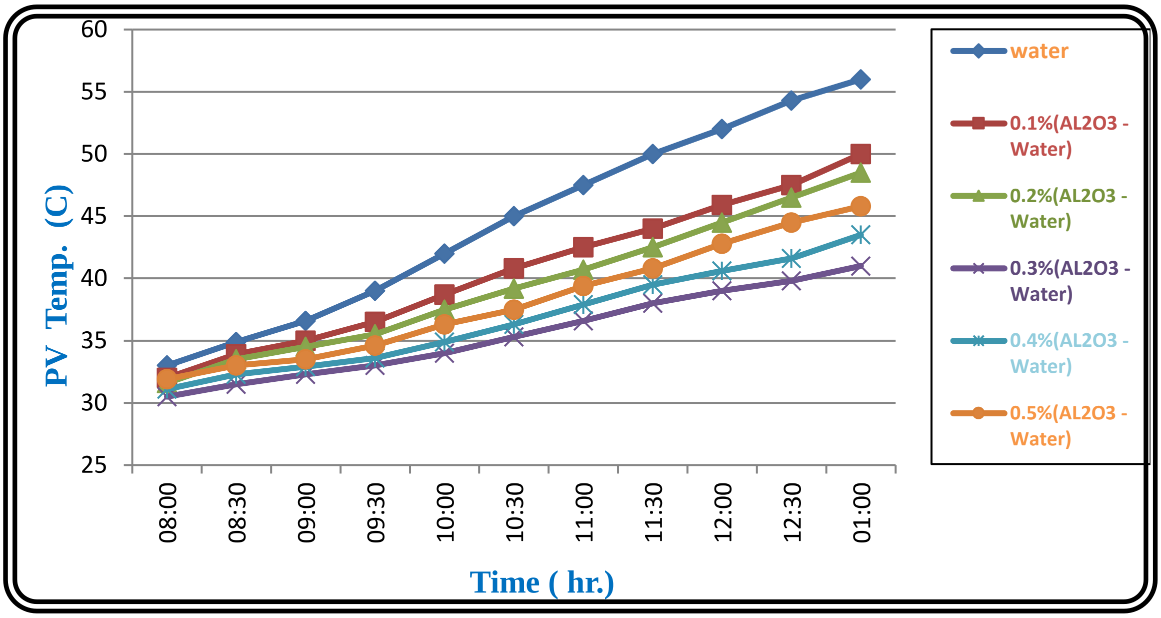


Figure 14 Effect of Nanofluid concentrations ratio at constant mass flow rate (2 L/min.) on the PV temperature.

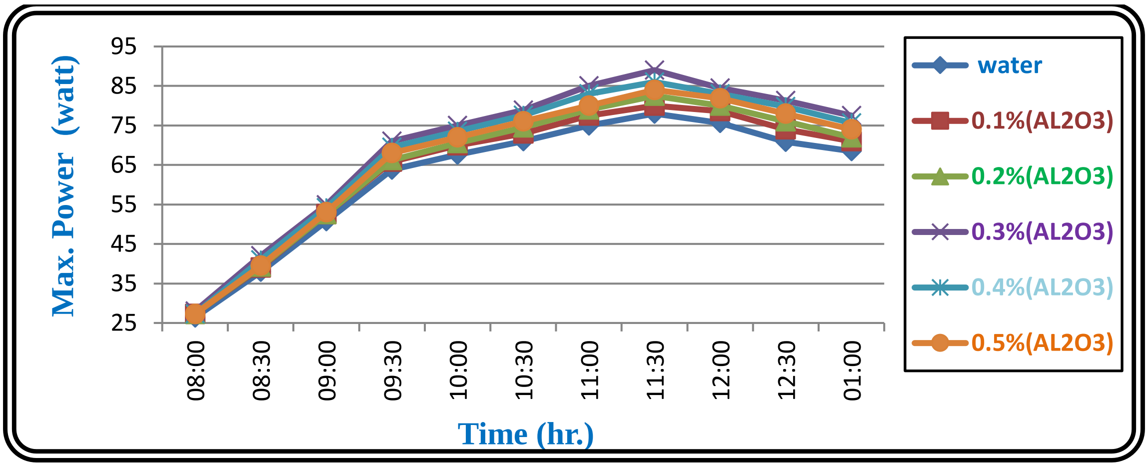


Figure 15 Effect of Nanofluid concentrations ratio at constant mass flow rate (2L/min.) on max. Power.

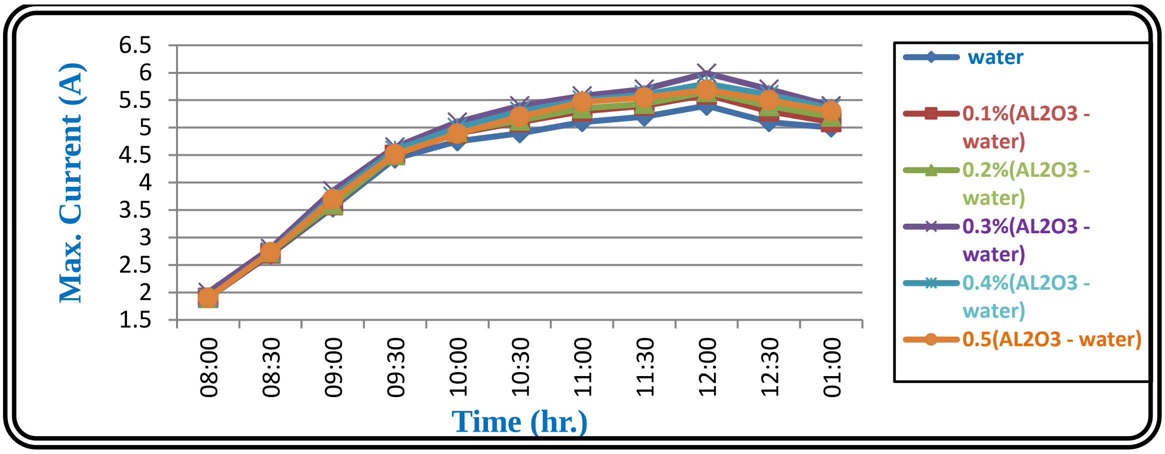


Figure 16 Effect of Nanofluid concentrations ratio at constant mass flow rate (2 L/min) on max. current.

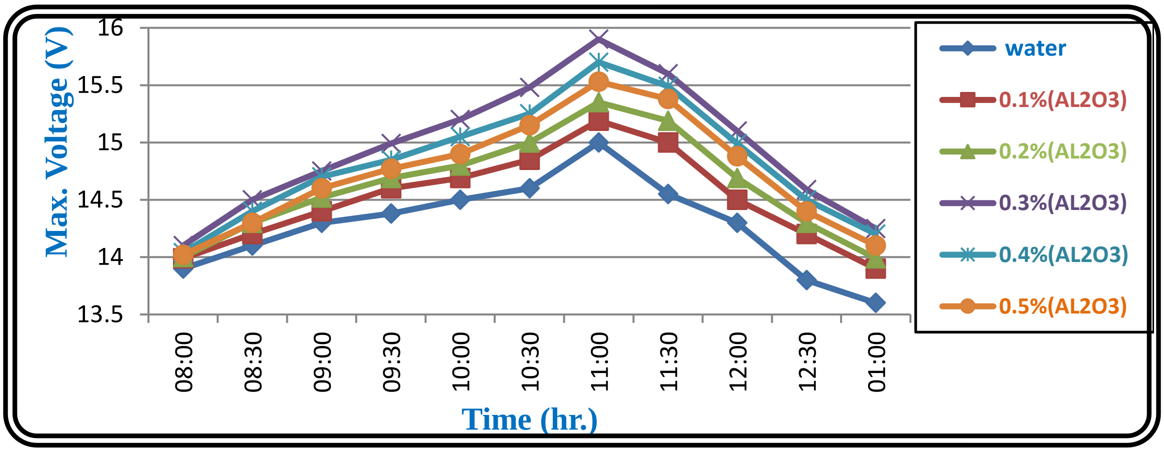


Figure 17 Effect of Nanofluid concentrations ratio at constant mass flow rate (2 L /min.) on max. voltage.

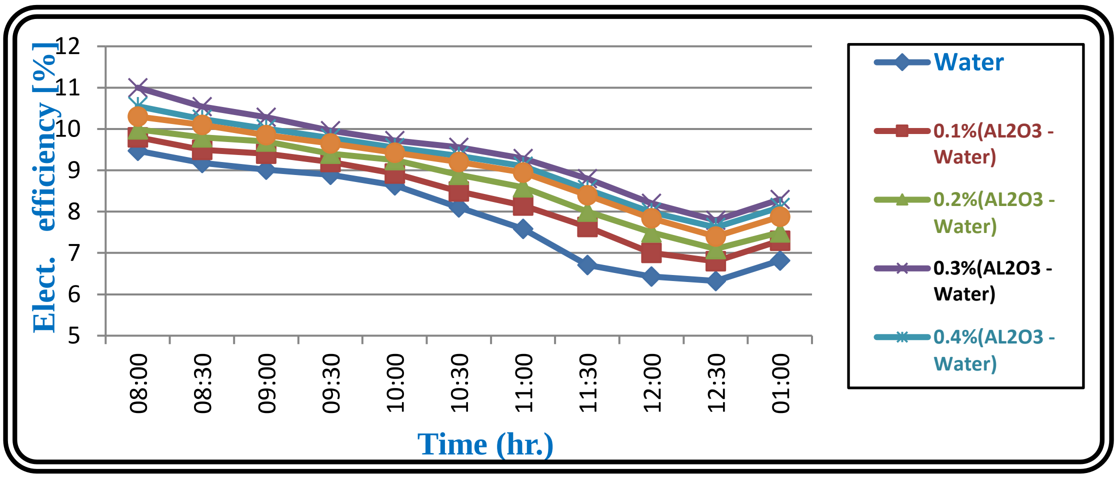


Figure 18 Effect of nanofluid concentrations at constant mass flowrate (2L/min.) on the electrical efficiency.

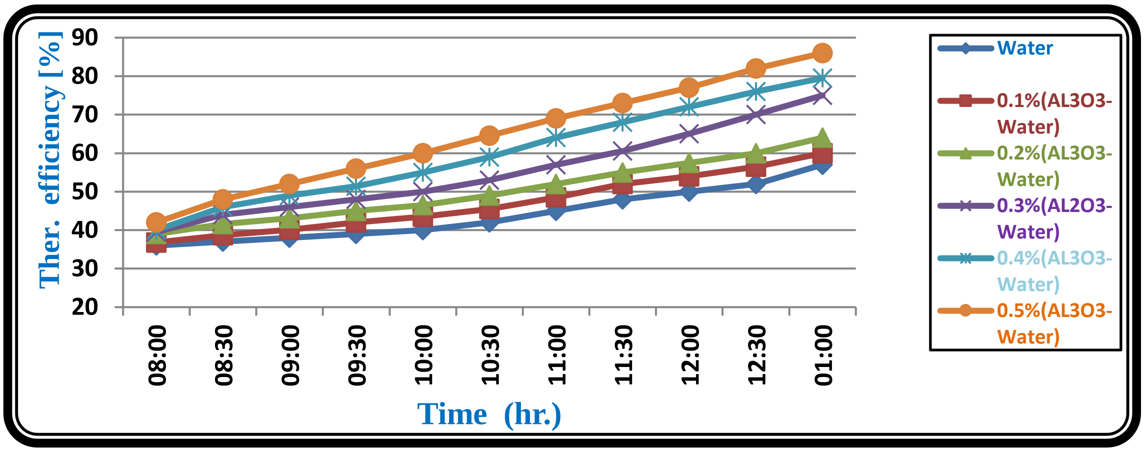


Figure 19 Effect of nanofluid concentrations at constant mass flow rate(2L/min.) on the thermal efficiency.

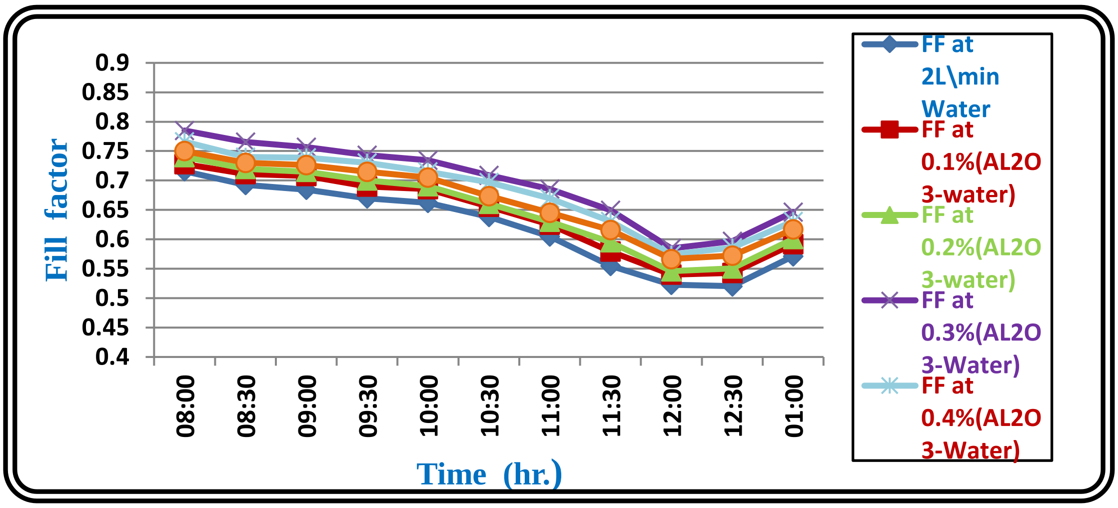


Figure 20 Effect of nanofluid concentrations at constant mass flow rate (2L/min.) on the fill factor.

3.4 The performance of PV water pumping system

The objective accomplished through this study is the investigation of the effect of solar radiation changing on the pumping system performances. From the results, it's observed that the increase of solar radiation led to increase the pump flow. The speed of running motor was affected by the value of the voltage, therefore when the PV module was operating at high temperatures the generated voltage was decreased. Which led to decrease the output of the DC pump whereas the output of DC pump increased with e increased the generated voltage. It is inferred that making a film of water on the front side of the PV panel and circulating the working fluid through pipes at the rear side of the PV panel led to substantially enhanced performance of the system due to the sizable increase of the received power by improving performance of PV module as shown in Figures. (21and 22).

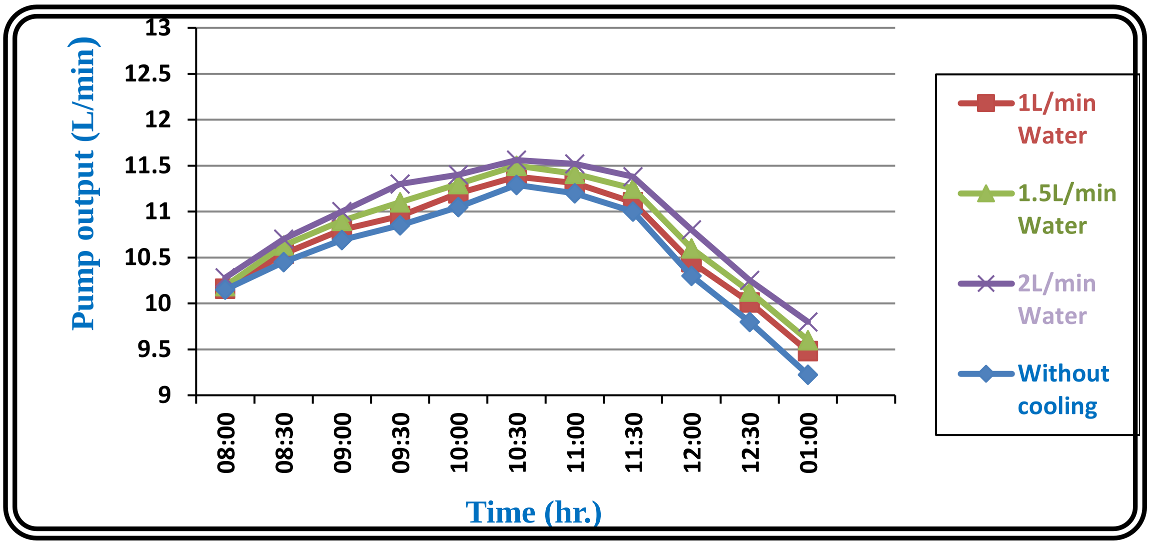


Figure 21 Pump output at different mass flow rates of Water.

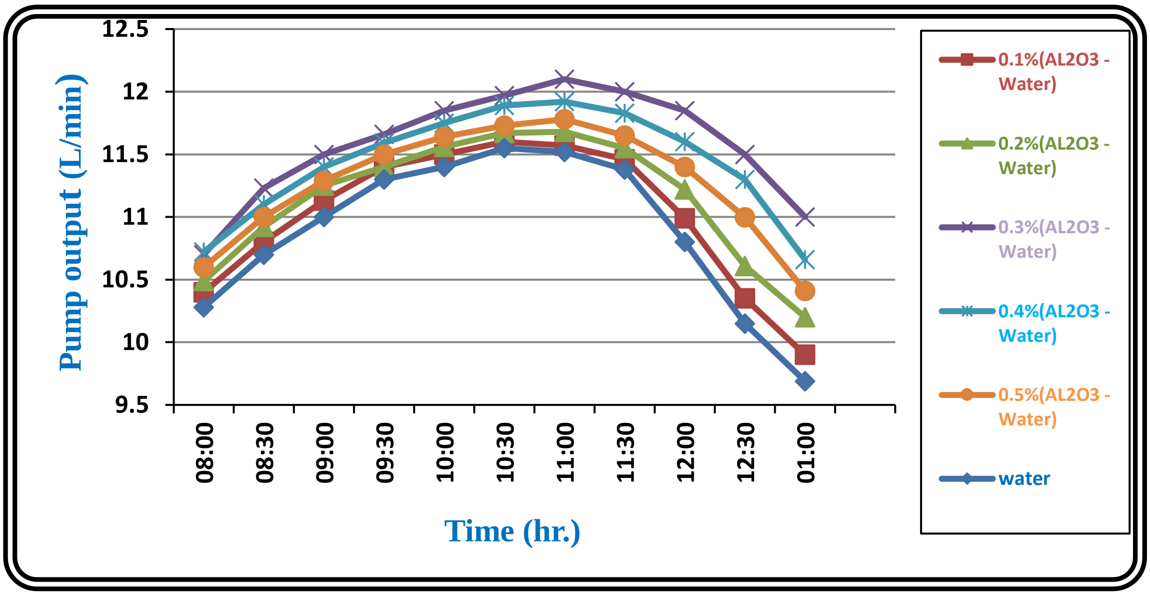


Figure 22 Pump output at constant mass flowrate (2 l /min.) with different concentration ratios.

4. CONCLUSIONS

The electricity generated by solar pane l increased with the increase in solar radiation, but the efficiency of solar panel decreases when the operating temperature of panel increases. In this experimental study, a hybrid PV/T system was used to enhance the electrical efficiency of PV panel and improve its performance. Multi methods were used for cooling the PV panel: a thin film of water running on the front surface of the panel, spraying water in the heat exchanger and circulating water on the back side, a different mass flow rates of water. The electrical and thermal efficiencies of a hybrid system increased with increasing the mass flow rate of water and the optimum value was 2 L/min. Using a film of water and spraying water in a heat exchanger with back cooling decreased the PV temperature by about (28%) when the results are compared with back cooling only. When using Nanofluid, the effect of different concentration ratios of (AL_2O_3) Nanofluid with water were examined on PV/T performance for different mass flow rates. The results indicated that the use of Nanofluid (AL_2O_3) at different concentration ratios (0.1, 0.2, 0.3, 0.4, and 0.5) % at a mass flow rate of (0.2 L/min) caused the temperature is more drop significantly from (76 C°) to (45C°) at an optimum concentration ratio of Nanofluid of (0.3%) . This led to increase the electrical efficiency of the solar panel to (10.9 %).

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