

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 7, Issue 8, August 2018

## Performance Evaluation of Photovoltaic Water Pumping System Using Booster Reflector and Spray Water Cooling

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**ABSTRACT:** The effects of booster reflector and spray water cooling on the performance of photovoltaic (PV) water pumping system was investigated for Makurdi located on latitude 7° 44' and longitude 8° 32'. The efficiency, power output and discharge rate were studied at the different Phases of the experimentation viz; PV alone inclined at 30° (Phase 1), PV inclined at 30° and spray water cooling alone (Phase 2), PV inclined at 30° and booster reflector inclined at 45° alone (Phase 3) and PV inclined at 30° with water spray cooling and booster reflector inclined at 45° (Phase 4). It was observed that the mean efficiency of the Phases was 44.85, 51.60, 48.14 and 59.64% respectively for Phases 1,2,3 and 4. The mean power output and water discharge rate for the various Phases were 234.17, 255.32, 238.80 and 265.99W and 1229.29, 1678.39, 1505.77 and 1893.52 liters/hour for Phases 1, 2, 3 and 4 respectively. It was observed that Phase 4, with the combined effect of booster reflector and spray cooling on the PV panel cells recorded highest improvement on the water pumping system with remarkable improvements of 14.79, 13.95 and 54.03 % for efficiency, power output and water discharge rate respectively. The study concluded that applying these modifications on the PV water pumping system significantly improved its performance.

**KEYWORDS:** Booster reflector, Photovoltaic panel, Spray cooling, Power output, Discharge rate, Efficiency, System performance.

### I. INTRODUCTION

In the contemporary society, the world market for photovoltaic (PV) solar panel technology is expanding rapidly. This increasing market for PV panels indicates the fact that increasing demand for a clean, reliable energy solution are being sought for. For these reasons, PV panels may be the method of choice for supplementing today's global energy needs. Although PV solar panel production is rising, PV panels are still a relatively new and high priced technology. Solar energy is the most increasing and promising source that plays a vital role in meeting the demand and saving for the depleted fossil resources. The rapid consumption of fossil fuels to meet the increasing energy demand leads to environmental pollution and the depletion of fossil fuels is prompting the search for alternative energy resources to actualize sustainable development. There remains the need for a commercially viable, cost effective method of implementing residential-scale photovoltaic systems for consumer homes. PV panels convert incoming irradiance into electricity. However, not the full spectrum of the solar radiation is converted due to the band gap of solar cell materials (Silicon poly-crystalline and amorphous). The unwanted radiation (UV and IR) enhances the operational temperature rise as a consequence of which a considerable drop in the performance of the PV cells output efficiency is observed. To increase the efficiency of the PV system, it is necessary that the system works at low temperature. However, working in the exposure to sunlight for long duration makes it difficult to achieve such low temperatures. Cooling methods therefore need to be incorporated with the system so as to extract the heat of the system, thus lowering temperature of the operational condition. The most effective way to generate electrical energy from PV at lower costs requires the reduction in the size (number) of PV panels used in a given power demand and the use of PV cooling methods and reflectors offer

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great potential in actualizing this. It was proved by [7] that, the use of cooling PV cells with water film and increasing irradiance with booster reflector on a PV water pumping system was able to reduce the cost of the installation from three to two PV panels. The use of PV panels as power source for pumping water is one of the most promising areas in photovoltaic applications. Because of the high average temperature (33°C) in Makurdi necessitated by high solar insolation (3.5kWh/m<sup>2</sup>/day) [8], operation conditions of PV panels used for water pumping and other applications are expected to be unfavorable for achieving desired efficiencies, power outputs and discharge rates. This paper intends to study the effects of booster reflectors and water cooling on the performance of a water pumping system.

## II. LITRRATURE SURVEY

Use of solar collectors and booster reflectors under non-satisfactory conditions for high latitudes was reported by [1]. He showed that using booster reflectors for solar collectors leads to an increase of 30 percent in annual performance with only a 10 percent increase in the installation cost for the solar collector system. [2] investigated the performance of photovoltaic modules with planar booster reflectors with variable lengths and tilts for Swedish conditions. They reported that a flat stationary booster reflector can increase the annual output of the module in the order of 20-25 percent. [3] used commercial PV modules and low concentration planar reflectors. The concentrating module described in their paper, increased generation power density and is expected to increase electricity delivered by 1.5 compared to conventional modules. [4] studied PV modules with and without a tilted plan reflector. They indicated that the planar booster reflectors can improve the yearly energy output of PV modules by about 22 %. [5] developed a V-trough concentrator system for different types of tracking modes: seasonal, one axis north-south, and two axes tracking. [6] investigated photovoltaic thermal (PV/T) collector without reflectors and with reflectors. They showed that energy saving efficiency for PV/T collector without reflectors is 60.1 %, which is above the conventional solar thermal collector, whereas the energy-saving efficiency for PV/T collector with reflectors in optimal position is 46.7 %, which is almost equal to the values for conventional thermal solar collector. [7] optimized the PV pumping system to improve its efficiency and reduce the cost of installation. The use of photovoltaic panels as the power source for pumping water is one of the most promising areas in photovoltaic applications. Photovoltaic water pumping systems are particularly suitable for water supply in villages and remote locations where no electricity supply is available.

## III. METHODOLOGY

In order to evaluate the performance of a PV water pumping system installed with booster reflector and active water cooling, an experimental outdoor system was set up. The experimental set-up was done in Makurdi, the capital city of Benue state. It was carried out within the months of January to April 2017. The set-up consisted of two poly-crystalline photovoltaic (PV) panels (2 X 300 W) with a surface area of 3.9004 m<sup>2</sup>, inclined at an angle with the booster reflector and facing each other to maximize the irradiance. The PV panels were connected in series so as to get the required amount of energy needed to power the DC pump. The booster reflector was made of aluminum foil due to its high reflective characteristics, availability, low cost, and eases of handling. The booster reflector height was constructed to have equal size with PV panel in order to receive uniform distribution of the solar radiation on the panel surface as seen in Plate 1. The PV panels tilt angle and direction was set considering the location of Makurdi (latitude 7° 44' and longitude 8° 32'). The PV panels were installed south facing. The tilt angle of the PV panels was varied from 0 - 60° with increments of 15°. The booster reflector inclination was varied from 15 – 60° with increments of 15°. The variations of the angle of the PV panel and that of the booster reflector was done to determine the optimum tilt angle of the PV panels in tracking the isolation and optimum angle at which the booster reflector focuses maximum suns energy on the PV panels. The use of booster reflector ensures that while the suns irradiance is yet to focus on the PV panels directly, the rays are directed to it from the booster reflector thus sustaining the power demand of the installation. The PV panels were connected to the solar pump through a maximum power point tracking (MPPT). Measurements of voltage, current, temperature and flow rate was done with use of the instrument control system shown in Plate 2.

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Plate 1: Picture showing the Inclination of the PV Panels and the Booster Reflector



Plate 2: Instruments Control System Measuring Voltage, Current, Temperature and Discharge Rate.

## IV. RESULTS AND DISCUSSION

In phase 1 the effect of PV panel tilt angle alone was studied to determine which tilt angle gave the optimum efficiency, power output and water discharge rate. In figure 1, the weekly average efficiency against time. It was obtained when then PV panel was tilted from the angles of 0, 15, 30 and 45° and readings of voltage, current and insolation taken hourly from 9 am to 5 pm without the effects booster reflector and water cooling. Efficiency was the calculated and plotted against time.

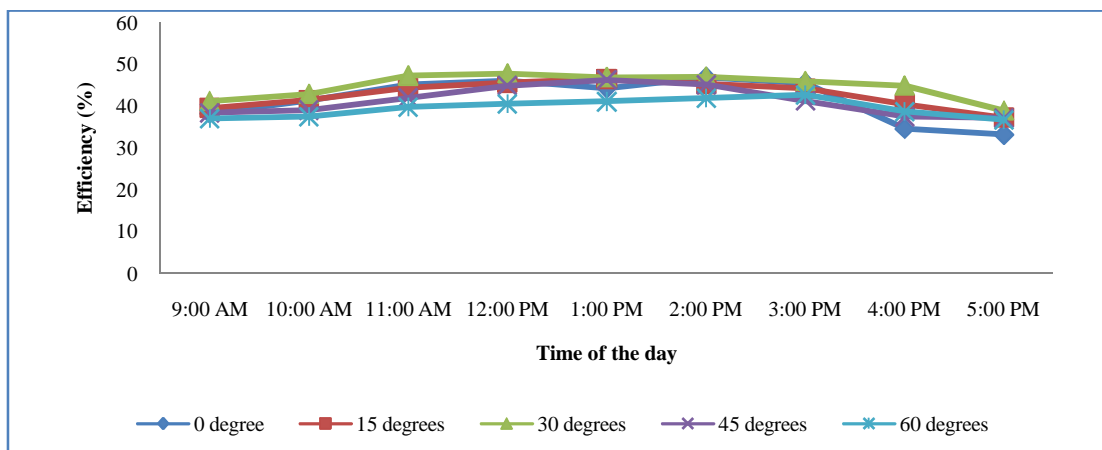


Figure 1: Weekly Average Efficiency against Time of the Day when PV Panel Tilt was 0°, 15°, 30°, 45° and 60°

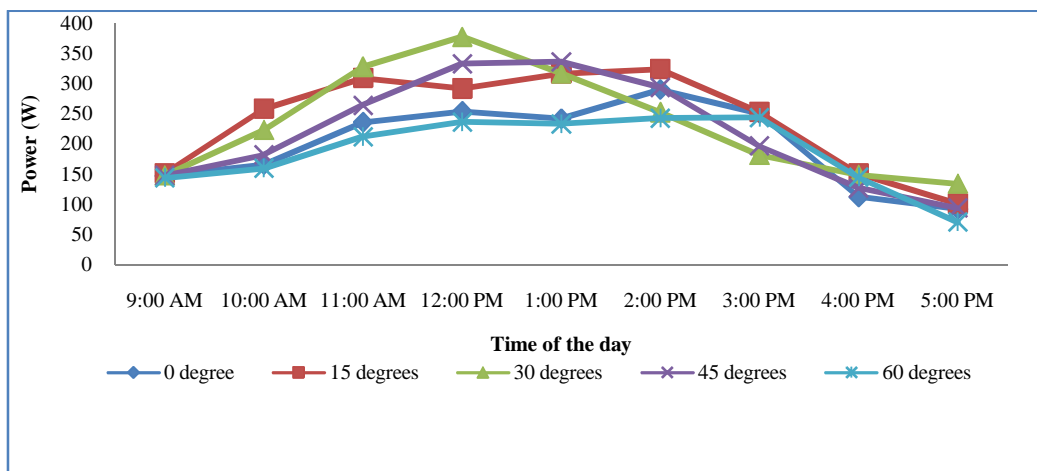
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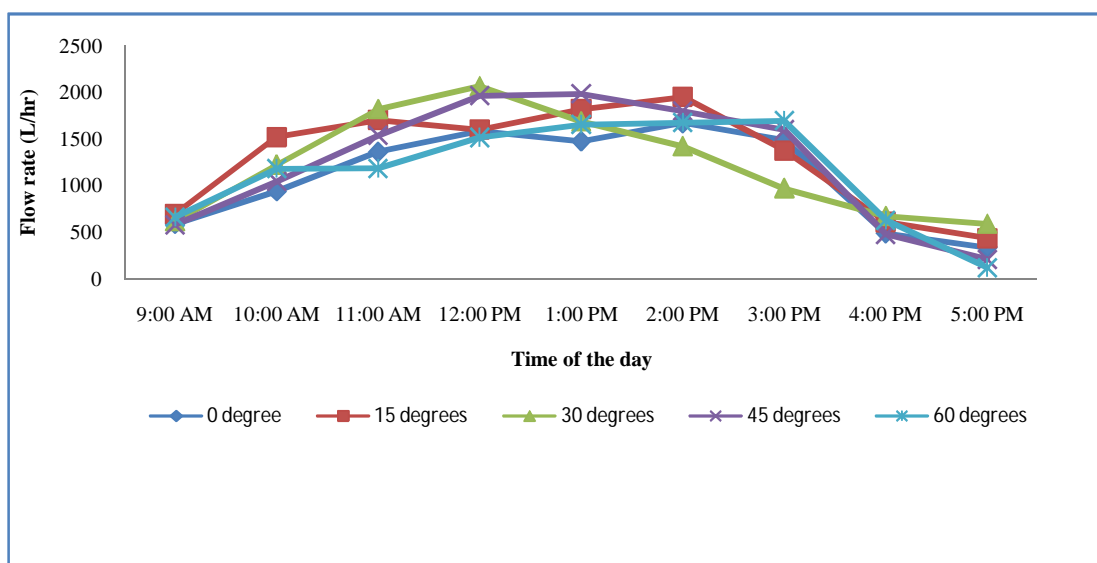
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It was observed that at all tilt angles; the efficiency was highest between 12 noon to 3 pm after which a gradual drop was observed. However, the PV panels inclined at 30° gave a slightly higher efficiency compared to the others. Similar trend was observed for power output and discharge rate.



**Figure 2: Weekly Average Power against Time of the Day when PV Panel Tilt was 0°, 15°, 30°, 45° and 60°**

Figure 2 shows the weekly average power obtained against time of the day for all the tilt angles used (0, 15, 30 and 45°) taken from the hour of 9 am to 5 pm. It generally shows an increase in power from the hours of 11 am to 2 pm then begins to fall for all the tilt angles. However, the power output, at 12noon, power output was highest for 30° tilt. This was perhaps due to the direct effect of the sun on the PV panels. This was perhaps due to the fact that at this tilt angle, as the position of the PV panel could attract maximum rays from the sun.



**Figure 3: Weekly Average Flow Rate against Time of the Day when PV Panel Tilt was 0°, 15°, 30°, 45° and 60°**

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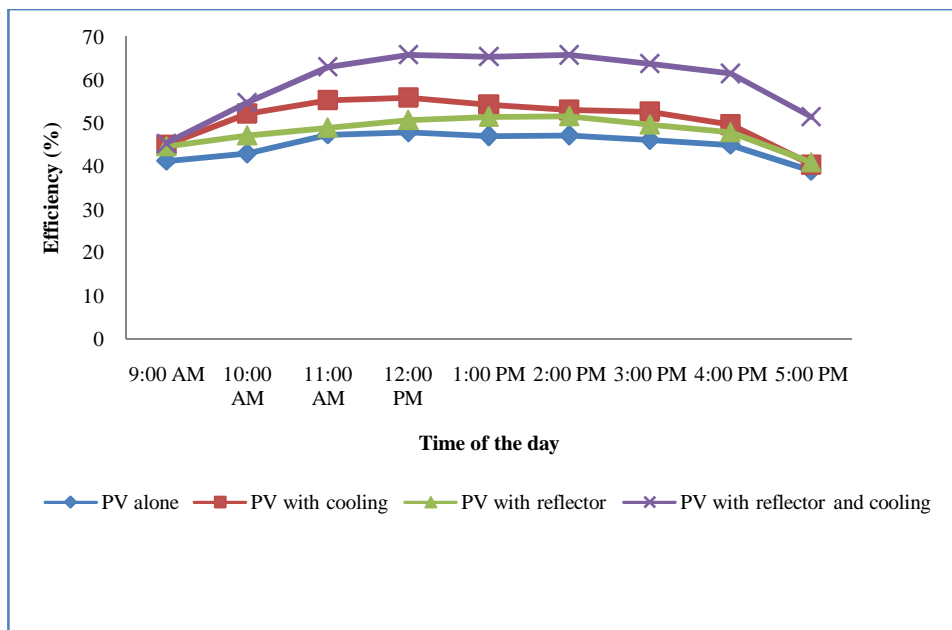
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Figure 3 shows the weekly average discharge rate obtained against time of the day for all the tilt angles used (0, 15, 30 and 45°) taken from the hour of 9 am to 5 pm. It generally shows an increase in discharge rate from the hours of 11 am to 2 pm then begins to fall for all the tilt angles. For all the Phases, it was generally observed that, all the parameters (efficiency, power output and discharge rate) begin to increase from 11 am and tend to drop between the hours of 2 and 3 pm. The inclination of PV panel at 30° gave the optimum power and discharge rate of 377.20 W and 2062.90 liters/hour respectively as seen in Figures 2 and 3. In Phase 1, the PV panels alone were inclined at the determined angle of 30° and the effects on efficiency, power output and water discharge rate were generally observed to be lower compared to subsequent phases as seen in Table 1.

In Phase 2, water spray cooling was now used, maintaining the inclination at 30° on the PV panel and generally similar observation was noted for efficiency, power and discharge rate as seen in Figures 4, 5 and 6. However, for the power output and discharge rate, it was observed that beyond 2 pm, when the temperature begins to drop and the effect of water spray cooling begins to have adverse effects on temperature needed to sustain the operation of the system, the effect of the booster reflector provided the additional power to sustain water pumping operation.



**Figure 4: Effect of various Phases on Efficiency when PV Panel was Inclined at 30° and Reflector at 45°**

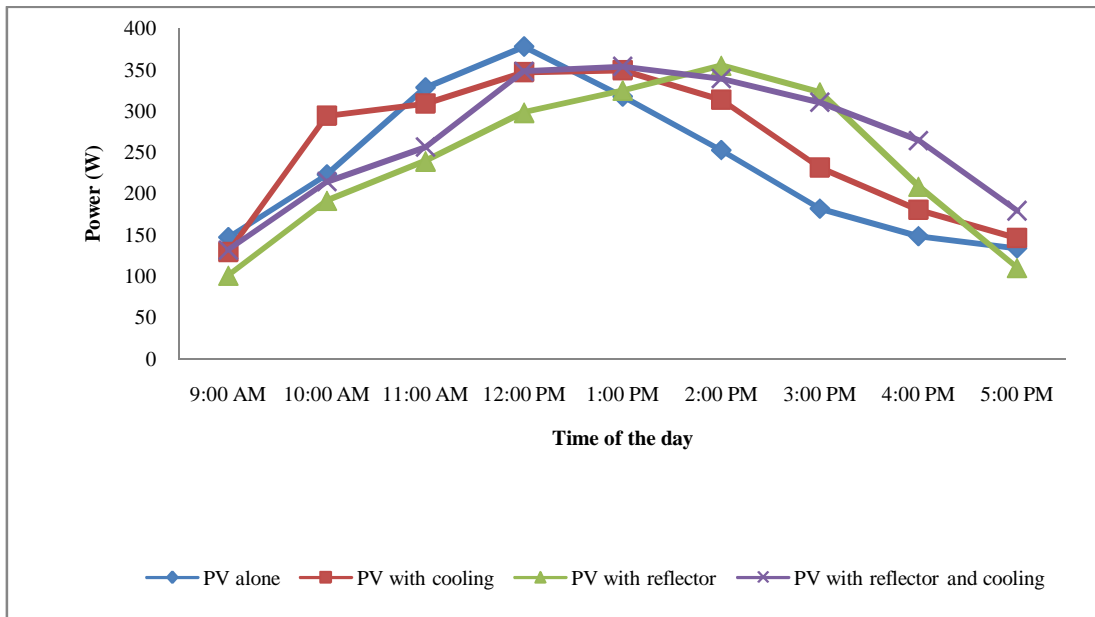
Figure 4 shows the plot of efficiency against time of the day for all the phases (PV panel alone, PV panel with spray cooling alone, PV panel with booster reflector alone and PV panel with spray cooling and booster reflector).

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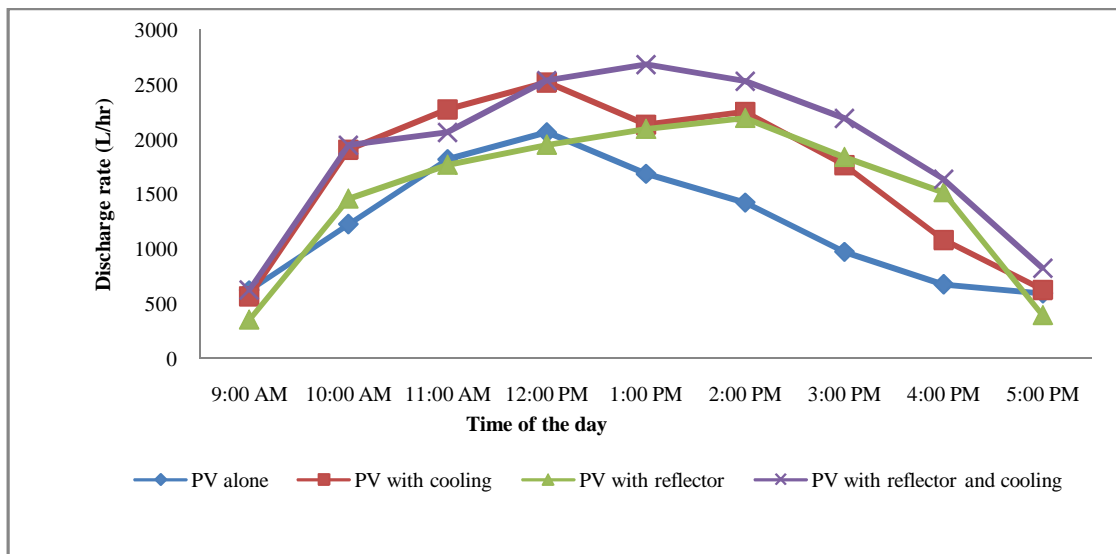
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**Figure 5: Effect of various Phases on Power when PV Panel was Inclined at 30° and Reflector at 45°**

Figure 5 shows the plot of power output against time of the day for all the phases (PV panel alone, PV panel with spray cooling alone, PV panel with booster reflector alone and PV panel with spray cooling and booster reflector).



**Figure 6: Effect of various Phases on Discharge Rate when PV Panel was Inclined at 30° and Reflector at 45°**

Figure 6 shows the plot of water discharge rate against time of the day for all the phases (PV panel alone, PV panel with spray cooling alone, PV panel with booster reflector alone and PV panel with spray cooling and booster reflector).



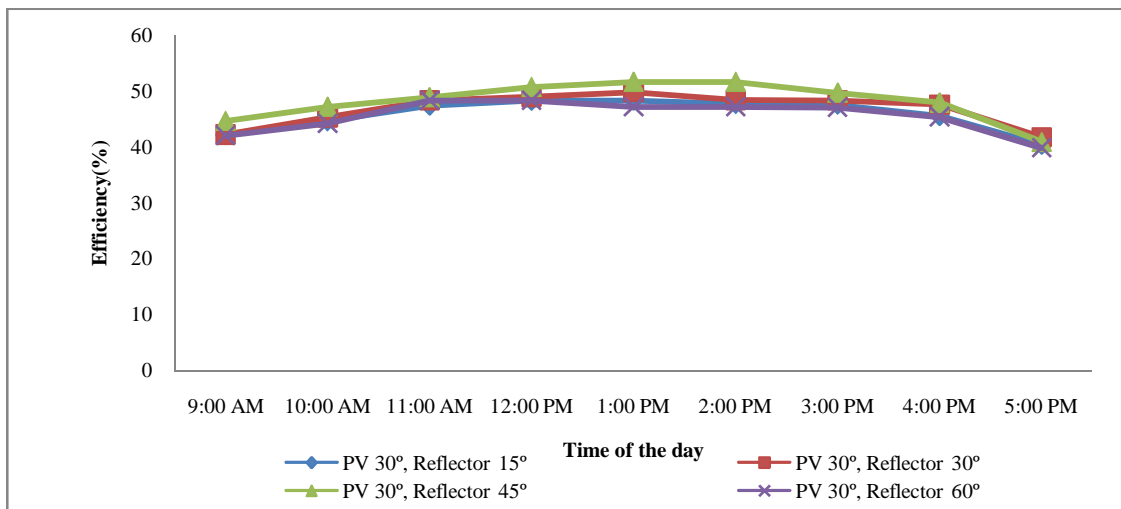
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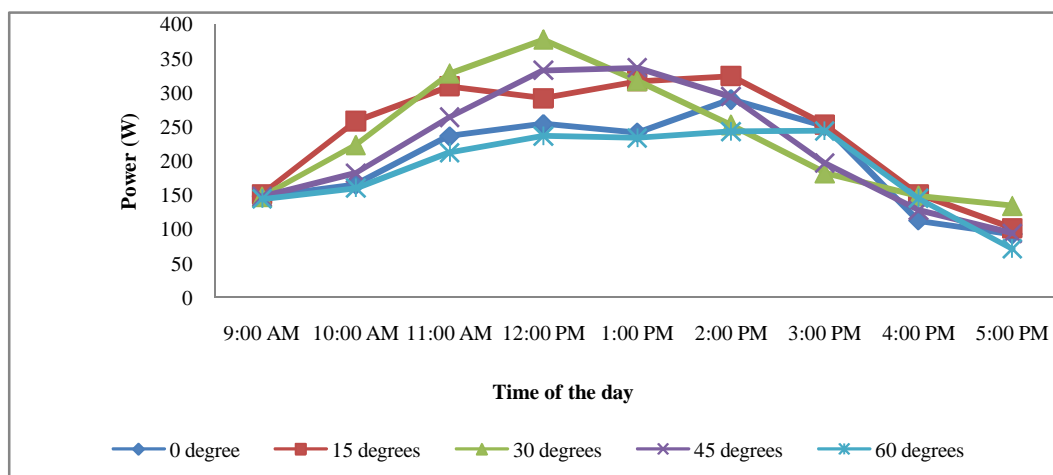
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In Phase 3, the booster reflector was integrated with the system to study its effects on efficiency, power and discharge rate. The effect of inclination of the booster reflector to the PV panel was studied to determine the optimum tilt of the booster reflector as it affects the efficiency, power output and discharge rate as seen in Figures 7, 8 and 9 respectively.



**Figure 7: Weekly Average Efficiency against Time of the Day for PV Panel Tilted at 30° and Booster Reflector Tilt Angles of 15°, 30°, 45° and 60°**

The best booster reflector inclination position with already determined position of the PV panel was studied to fine the optimum efficiency, power and water discharge rate as shown in Figure 7, 8 and 8. The inclination of booster reflector at 45° gave a better efficiency.



**Figure 8: Weekly Average Power against Time of the Day for PV Panel Tilted at 30° and Booster Reflector Tilt Angles of 15°, 30°, 45° and 60°**

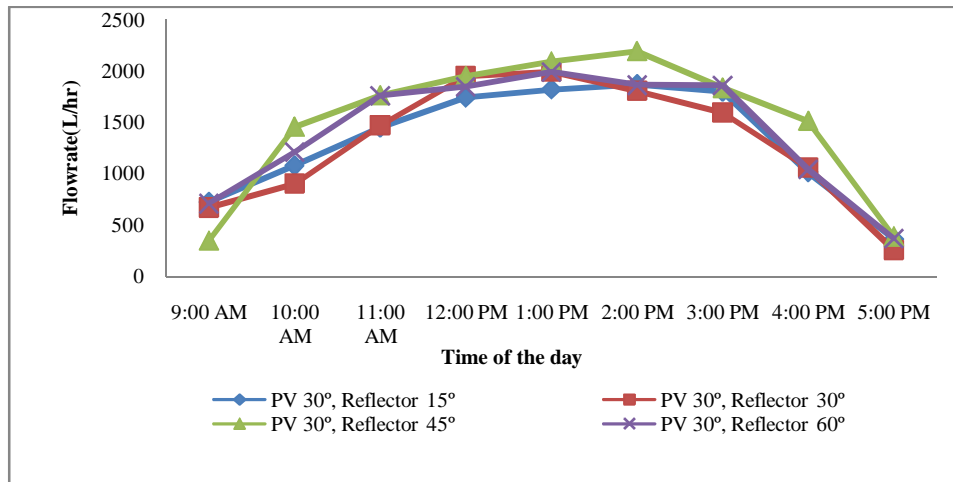
For the power output in Figure 8, the inclination of booster reflector at 45° still gave optimum result between the hours of 11am and 12noon.

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**Figure 9: Weekly Average Flow Rate against Time of the day for PV Panel Tilted at 30° and Booster Reflector Tilt Angles of 15°, 30°, 45° and 60°**

Also in Figure 9, the booster reflector inclination at 45° gave better results for discharge rate compared to the inclinations at 15, 30 and 60°. So 45° inclination of the booster reflector was used in Phases 3 and 4 the results of which are presented in Figures 4, 5 and 6 for efficiency, power output and discharge rate respectively. In Figure 4, it was observed that with the reflector and PV alone, the efficiency increased only slightly above the efficiency of PV alone at all hours. Perhaps, this was due to additional temperature increment from the use of the reflector. The efficiency of the system is the fraction of solar energy falling on the panel that is converted into electricity and it depends on the temperature. Higher solar irradiance possibly increases the output power. But their effect is counter balanced by the PV panel temperature which reduces the efficiency [9]. For power output in Figure 5, the effect of reflector was lowest until 2- 3 pm, when higher temperatures were experienced, power output was maximum. This was perhaps due to the fact that between these hours of the day, it was obviously that more rays were redirected to the PV panels. For discharge rate in Figure 6, the effect of the booster reflector (Phase 2) gave better discharge rate than when PV alone (Phase 1) especially between the hours of 1- 2 pm.

The inclination of the booster reflector at 45° was subsequently used in Phase 4 which now included the effects of PV panel/booster reflector inclination and water spray cooling. From Figures 4,5 and 6, it was observed that Phase 4 gave the highest performance compared with the other Phases in terms of the studied parameters especially beyond 1pm when the effect of redirecting the irradiance are mostly felt. Perhaps before this time the effect of played a predominant role thus having adverse effect on operation temperatures. It was then considered that the inclinations of 30° and 45° for PV and booster respectively and water spray cooling gave optimum performance of the PV water pumping system. Similar observation was reported by [7], they also reported that 45° inclination of the reflector with the PV panels gave the optimum power when they investigated the effect of reflector inclination on power at Kerman on latitude 30° 17' and longitude 57° 50' despite the difference in the location of the two cities. However, [10] reported an inclination of 60° of reflector with the PV panel inclined at 45° to the horizontal when they studied the effect of angle orientation of flat mirror concentrators on solar panel system output in Baghdad. Perhaps the discrepancy could arise from the location (Baghdad location, 33°18' N and 44°21' E), type of PV panels and nature of reflectors used, they considered mirror as the reflector. Similarly in Table 1, when the booster reflector was introduced without spray cooling, the electrical efficiency of the system dropped. This observation was also in line with an earlier position of [11], that the electrical efficiency of the PV was much dependent on the ambient temperature. When the temperature increases, like in the introduction of the booster reflector, the efficiency reduces. Increasing the temperature reduces the band gap of a semi conductor affecting most semiconductor materials. The parameter most affected by increasing the temperature is the open circuit voltage. According to [12] low temperature operation is necessary for PV modules. As temperature increases, the dark saturation current of the PV is increased and this leads to drop in open circuit voltage. Also the band gap of the photovoltaic material decreases which leads to an



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increase in photo current. The first effect is more than the second, so there is generally a net decrease in the solar conversion efficiency with increasing temperature. Temperature affects how electricity flows through an electrical circuit by changing the speed at which electrons travel. This is because increasing temperature causes increase in resistance of the circuit and vice-versa. So determining the right temperature for optimum performance becomes critical. For this work, 45° inclination of booster reflector provided the optimum operational conditions for the water pumping system. According to [13], only 20 % of incident solar radiation that falls on PV panel is converted to electricity. The remaining major part is converted to heat. As a consequence, the accumulated heat energy increases the PV panel operating temperature, hence leads to a drop in its electrical efficiency. Also, [9] posited that elevated temperature leads to voltage decrease but slightly increases the output current. The increase of output current with decreasing output voltage results in low production of electrical efficiencies of PV panels. As observed in Table 1, water spray cooling increased the performance of the system. This observation was in line with many other researchers, they concluded that cooling the PV panel by covering the cells' surface with a film of water was to improve the PV system operating at higher temperature. In the present work, with only the cooling Phase (Phase 2), the efficiency, power output and discharge rate were observed to be higher than when the system operated with only the reflector (Phase 3). However, the combination of both booster reflector and cooling (Phase 4) experienced higher system performance with improvements of the system to 14.79, 13.59 and 54.03 % respectively for efficiency, power output and discharge rate. According to [7], an improvement in the mean daily power of 50.4 % when the effect of both booster reflector and cooling was used was recorded. And that with only reflector, the power improvement was only 14.0 % while with only water cooling, the power output improvement was 17.80 %. A flowing water film practically absorbs the heat generated by the array and reduces the cells reflection during the day. Due to the film of water and additional cooling by evaporation, the cells operational temperature has been significantly reduced as compared to that not equipped with cooling but with booster reflector [7]. Same observation was reported by [7] using booster reflector and cooling array. They reported that using a film of water over the cells significantly decreased the cells temperature to 36 °C while the ambient temperature was 35 °C, the temperature of PV array without reflector was 59 °C while that of PV array with booster reflector was 71 °C and PV array with reflector and water film simultaneously was 39 °C. The evaporating water further decreased the temperature of the cells and therefore results in increased electrical yield. Water spray cooling, an intermediate layer of water with  $n = 1.33$  (refractive index) reduces the reflected fraction of an incoming perpendicular ray from 4.4 – 2.0 % and therefore improves the optical transmittance of the PV cells [14]. Moreover, use of flowing purified water over the cells enhances cleaner cells [7]. The use of water film over panels can be useful in most PV applications operating at high temperature climate.

**Table 1: Mean output, efficiency and water discharge rate for all the Phases and corresponding improvement**

Phase 1 (PV alone at 30°)	Phase 2 (PV with cooling)	Phase 3 (PV with reflector)	Phase 4 (PV with reflector and cooling)
Mean Phase Power Output(Watt)	234.17	255.32	238.80 265.99
Improvement		9.03%	1.98% 13.59%
Mean Phase Discharge Rate (l/hr)	1229.29	1678.39	1505.77 1893.52
Improvement		36.53 %	22.49 % 54.03 %
Mean Phase Efficiency (%)	44.85	51.60	48.14 59.64
Improvement		6.75 %	3.29 % 14.79 %

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## V. CONCLUSION

The increasing temperature as a result of increased irradiance has been a drawback in the performance PV panels when used alone or coupled with booster reflectors. The extra solar radiation from the booster reflector had adverse effects on the system as the cell temperature increased. This was noticed in the drop in the efficiency, power output and discharge rate. When cooling of the PV cells was adopted, significant improvement of the system was observed. The performance got better with the simultaneous use of booster reflector and water cooling of PV cells. The water film cooling counterbalances these drawbacks reasonably. The present study focused on improving the performance of water pumping system designed with water spray cooling and booster reflector for lowering and balancing the temperature of the cells. It was concluded that the use of booster reflector and water spray cooling of the PV cells simultaneously significantly improved the performance of the system.

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