Enhancing Photovoltaic Efficiency through Engine Oil Coatings: A Comparative Analysis of New, Partially Used, and Degraded Oils

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Abstract: The efficiency of photovoltaic (PV) systems is significantly influenced by surface conditions, including contamination, which impairs light absorption and reduces overall power output. This study investigates the effects of coating a PV panel with Mobil engine oil in various states and compares the results with those of a clean reference panel. The experiments utilized a 300 mm x 200 mm PV panel with a nominal power rating of 10 W, coated with 0.2 liters of oil to ensure uniform coverage. The oil samples included new oil (O1), halfway-used oil (O2), and fully degraded oil (O3). Measurements of power output, temperature, and solar irradiance were recorded hourly from 8:00 AM to 6:00 PM. The clean panel exhibited power outputs ranging from 9.02 W to 9.56 W. Coating with O1 resulted in the most significant enhancement, with power output increasing by up to 4.29% at peak irradiance (9.97 W at 2:00 PM). The O2 coating provided moderate improvements, with a maximum increase of 1.56% (9.68 W at 2:00 PM). Conversely, the degraded oil (O3) generally reduced power output, with a maximum decrease of 1.91% (9.23 W at 5:00 PM). The findings indicates that a uniform application of fresh Mobil oil can reduce light reflection and improve light absorption, enhancing PV panel performance. However, the benefits diminish as the oil degrades, underlining the importance of oil quality for sustained performance gains.

Keywords: Light Absorption, Degraded Oil, Engine Oil Coatings, Photovoltaic (PV) Efficiency, and Solar Panel Performance

تعزيز كفاءة الخلايا الكهروضوئية من خلال طلاء زيت المحرك: تحليل مقارن للزيوت الجديدة والمستعملة جزئيًا والمتدهورة

الملخص: تتأثر كفاءة الأنظمة الكهروضوئية بشكل كبير بـ الظروف السطحية، بما في ذلك التلوث، الذي يضعف امتصاص الضوء ويقلل من إجمالي الناتج من الطاقة. تبحث هذه الدراسة في آثار طلاء لوحة PV بزيت محرك Mobilفي حالات مختلفة وتقارن النتائج بنتائج لوحة مرجعية نظيفة. استخدمت التجارب لوحة PV مقاس 300 مم × 200 مم مع تصنيف طاقة اسمي يبلغ 10 وات، مطلية بـ 0.2 لتر من الزيت لضمان التغطية الموحدة. تضمنت عينات الزيت زيتًا جديدًا (O1) وزيتًا نصف مستعمل (O2) وزيتًا متدهورًا بالكامل .(O3) تم تسجيل قياسات خرج الطاقة ودرجة الحرارة والإشعاع الشمسي كل ساعة من الساعة 8:00 صباحًا إلى 6:00 مساءً. أظهرت اللوحة النظيفة مخرجات طاقة تتراوح من 9.02 وات إلى 9.56 وات. أدى الطلاء بـ O1 إلى التحسين الأكثر أهمية، مع زيادة خرج الطاقة بنسبة تصل إلى 4.29٪ عند ذروة الإشعاع (9.97 وات في الساعة 2:00 مساءً). وقد أدى طلاء O2 إلى تحسينات معتدلة، مع زيادة قصوى قدرها 1.56% (9.68 واط في الساعة 2:00 مساءً). وعلى العكس من ذلك، أدى الزيت المتدهور (O3) عمومًا إلى تقليل خرج الطاقة، مع انخفاض أقصى قدره 1.91% (9.23 واط في الساعة 5:00 مساءً). تشير النتائج إلى أن التطبيق الموحد لزيت موبيل الطازج يمكن أن يقلل من انعكاس الضوء ويحسن امتصاصه، مما يعزز أداء الألواح الكهروضوئية. ومع ذلك، تتضاءل الفوائد مع تدهور الزيت، مما يؤكد أهمية جودة الزيت لتحقيق مكاسب أداء مستدامة.

1. Introduction

Photovoltaic (PV) systems, a cornerstone of renewable energy technologies, have become an important component in the transition toward sustainable energy solutions. However, the efficiency of these systems is highly sensitive to external environmental factors, including surface contaminants and dust accumulation, which can significantly degrade their performance. Surface contamination impedes light absorption by the PV panels, leading to reduced power output and efficiency [1-2]. PV system performance can still be hampered by a number of operational and environmental issues even with major developments in technology [3]. The accumulation of oil on photovoltaic surfaces is one of such issue, and it can happen in areas where there is a lot of oil production, transportation, or use [4]. However, limited research has been conducted on the effect of engine oils, in various stages of degradation, as potential coatings for PV surfaces. Engine oils are known to possess unique physical properties, including viscosity and film formation capabilities, which could offer protection against dust accumulation, moisture ingress, and other surface contaminants.

Previous studies have explored various coatings, such as hydrophobic films and anti-soiling agents, to reduce the accumulation of dust and other environmental particles [5-7]. The distribution and size of dust particles play a crucial role in shading and reducing PV efficiency. The distribution and deposition of dust are influenced by factors such as composition, size, shape, weight, and external environmental conditions, including temperature, wind speed, humidity, and dirtiness. Additionally, human activities, vehicle emissions, and natural events like volcanic eruptions contribute to increased dust accumulation on PV panels [8-9]. Smaller particles cover a larger surface area compared to coarser particles, diminishing radiation absorption and negatively affecting PV performance [10-11]. Fine particles exhibit greater stability and concentration on surfaces than coarse ones [12-13], resulting in increased light diffusion, particularly at shorter wavelengths, and higher radiation loss [14]. This degradation is exacerbated in high-humidity conditions, where microscopic dust particles adhere to surfaces, forming sticky films that are resistant to removal by natural forces such as wind [15].

Several studies have investigated the factors that result to lower solar PV energy production, while some examined the effect of oil coating in enhancing the PV output, among them are; Khatib et al. investigated the effects of five air pollutants—red soil, ash, sand, calcium carbonate, and silica—on the performance degradation of multicrystalline PV modules. Their findings revealed that reductions in PV voltage and power are directly linked to the type and quantity of deposited pollutants. Among these, ash caused the most significant voltage reduction, reaching 25%, followed by red soil, calcium carbonate, silica, and sand [16]. Kalogirou et al. observed that dust and pollution reduce irradiation on PV panel surfaces, causing a power output decline that can exceed 43% [17]. Boyle et al. conducted a natural study to examine bulk dust settlement and its impact on light transmission, reporting a distributed soiling ratio of 1 to 50 mg/day, which varied based on time, angle, and location [18]. Laarabi et al. identified a positive correlation between dust density and light transmission loss, noting that the type of soiling further exacerbates the reduction in light transmission [19]. Kazem et al. reported that PV panel efficiency decreases due to dust accumulation, ranging from 16% to 8% over a 45-day period in desert regions [20].

In Saudi Arabia, PV panels tilted at 26° accumulated 5 g/m² of dust in 45 days, leading to a conductivity reduction of approximately 20% [21]. Similarly, in Kathmandu, accumulated dust on PV panels over five months reached 9.67 g/m², resulting in a productivity decline of about 29.76% [22].

The coating of fresh oil to photovoltaic (PV) surfaces forms a thin layer that minimizes solar radiation reflection, potentially enhancing PV efficiency by capturing more radiation and improving energy conversion [23]. However, the physical and chemical properties of oil change as it is used. Partially used oil, containing particles, combustion byproducts, and impurities, can increase opacity, further reducing light transmission. This diminishes the PV system's efficiency while altering the interaction between the oil and the PV surface [24].

Because oil coating has a major effect on the efficiency of solar energy conversion, it has been extensively researched in relation to photovoltaic (PV) systems. Mustapha et al. [25] addresses the general ideas behind how light transmission obstruction and localized heating caused by surface impurities, such as oil, might lower PV performance. Surface contamination, especially with fresh oil, can drastically reduce photovoltaic performance because of its high refractive index, which enhances solar reflection and scattering [26]. The methods by which oil pollution, even in trace levels, can obstruct light absorption and raise surface temperatures, resulting in rapid material degradation were studied in [27]. Research conducted by Adinoyi et al. [28] emphasizes the unique difficulties caused by oil residues from industrial pollutants, pointing out that even a thin layer of new oil can cause a 30% reduction in PV cells' energy production. In a similar vein, Cristaldi et al. [29] found that oil pollution in cities can significantly reduce photovoltaic panel efficiency, requiring frequent cleaning to preserve performance. As Mani et al. [26] highlight, partially used oil further lowers light transmission and raises the danger of thermal stress on PV cells due to its mixture of combustion byproducts and particles. The impacts of used oil on photovoltaic performance were studied by Sanjeev et al. [30], who discovered that the presence of carbonaceous particles can cause significant efficiency losses as well as thermal degradation. Pareek et al. [31] investigated how completely degraded oil, which has a high level of impurities, significantly lowers optical clarity and creates stains that are difficult to remove. The long-term impacts of such oil as highlighted in [32] present film which require more thorough cleaning techniques and raise maintenance costs. Lastly, Al-Housani et al. [33] proposed that improving the durability of PV materials and creating efficient cleaning methods are critical to reducing the negative impacts of oil contamination on PV systems.

While many of the existing studies consider the effects of various soil, dust, and shading on PV output, few have examined the impact of oil coating, and none have considered the effect of oil in respect of its state of degradation. This study contributes to the feasibility of using engine oil coatings to enhance PV efficiency, focusing on a comparative analysis of three distinct types of oils: new (O1), halfway-used (O2), and completely degraded (O3). Experimenting and analysing the impact of coating the Mobil engine oil in these three states to the surface of PV panels make this study novel. The study compares the power output of PV panels with engine oil coatings to that of uncoated, reference panels to determine whether these oils can provide a viable solution for improving PV system efficiency.

2. Material and methods

A. Materials Employed

A 10W, 22.05V, 0.63A photovoltaic (PV) panel is one of the materials used in this study to assess how dirt and oil coatings affect solar PV performance. To guarantee an accurate estimation of sun exposure, solar irradiance is measured by a solar power meter. A digital multimeter is used to measure electrical properties like voltage, current, and power output. While a fine and uniform oil coating is produced using a bottle sprayer.

Furthermore, in order to comprehend the effects of heat on PV performance, non-contact temperature measurements of the PV panels and the surrounding environment are provided using a Model GP-200 infrared thermometer. Among other things, Table 1 summarised the equipment employed in this study and Figure 1 shows the items utilized in this experiment.

Table 1. List and Specification of the equipment used

ent	**ations**	**nal Information**
oltaic Panel	**num Power (P_max):** 10W	**ype:** Polycrystalline/Monocrystalline
	Circuit Voltage (V_oc): 22.05V	**erature Coefficient (Voltage):** -0.36
	Circuit Current (I_sc): 0.63A	**nsions:** (300mm x 200mm)
	Tolerance: ±5%	**t:** Approx. 1.2kg
	ency: Around 15%-18%	**ne:** Aluminum alloy for durabili ight
d Thermometer	**l:** GP-200	**urement Range:** -50°C to 550°C (-)
	acy: ±1.5% or ±1.5°C	**ution:** 0.1°C
	ivity: Adjustable (0.1–1.0)	**nce-to-Spot Ratio (D:S):** 12:1 (for a s from a distance)
	nse Time: <500ms	**y Type:** Typically uses 9V battery
ower Meter	**urement Range:** 0–1999 W/m²	**acy:** ±5%
	ution: 1 W/m²	**y Type:** Digital LCD
	r Type: Silicon photodiode	**Supply:** 9V battery
Multimeter	**ge Measurement Range:** 0–1000V (D AC)	**ent Measurement Range:** 0–10A (
	r Measurement Range: Calculated b and current ranges	**acy:** Typically ±0.5% for voltage, ±
	y Type: Digital LCD	**y Type:** 9V
	ional Features: Continuity buzzer, diode ce measurement	**gory Rating:** CAT III/CAT IV ds for measuring high-energy circuits)
prayer	Manual trigger sprayer	**e Type:** Adjustable (mist, stream)
	ial: Plastic (HDPE or PET)	**ity:** 500mL–1L
	Uniformity: Produces fine and consisten	**cations:** Used to apply uniform coat ed experimental conditions

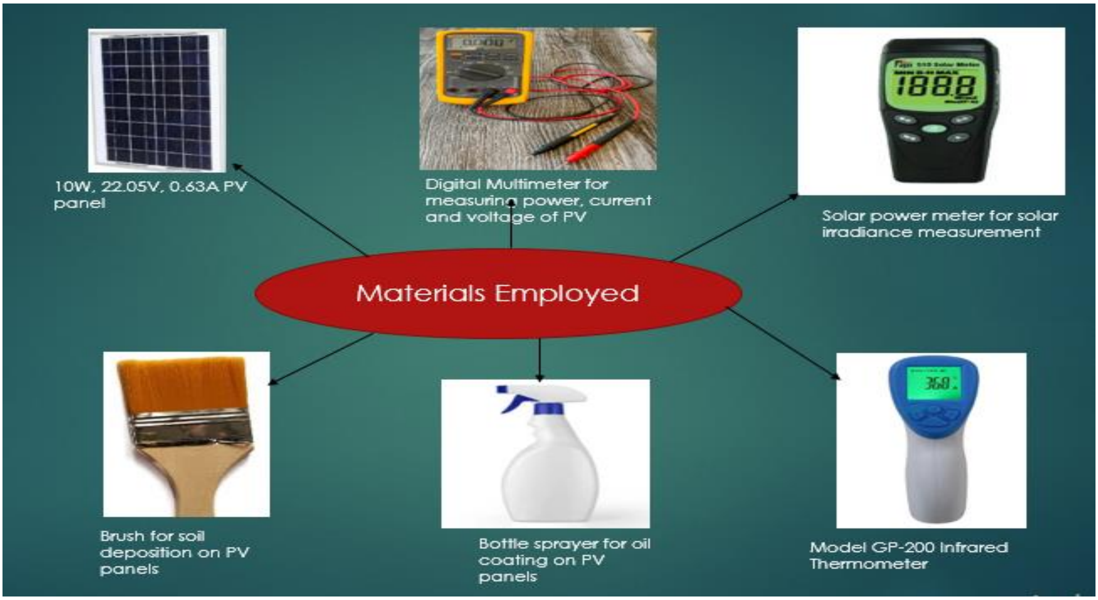

Figure 1: Materials used

B. Experimental Setup

1) *Photovoltaic panel:* In this study, we utilized photovoltaic (PV) panels with specific characteristics designed to provide consistent and reliable performance. Each panel has a maximum power output of 10W, a short circuit current (I_sc) of 0.63A, and an open circuit voltage (V_oc) of 22.05V. The power tolerance is ±5%, indicating that the actual power output can vary by up to 5% from the specified maximum power. A total of four PV panels were used in the experiment, divided into two groups to assess the impact of different oil coating on their performance. The installation of the PV panels was conducted at Mewar University, located at coordinates 25.0328° N latitude and 74.6366° E longitude. This location offers a conducive environment for solar energy experiments due to its ample sunlight exposure throughout the year. To optimize the solar energy capture, the panels were installed at a tilt angle of approximately 25 degrees, corresponding to the latitude of the location which is ideal for maximizing sunlight exposure during peak hours [34].

The effective solar irradiance that reaches the PV cells is decreased when oil contamination occurs on PV surfaces. Reduction factor (R o) can be used to model the effect of oil pollution by taking into account the transmissivity loss caused by oil. The kind and degree of oil deterioration determine this component.

$$G_{eff} = G \times (1 - R_0) \tag{1}$$

Where G_{eff} is the effective solar irradiance; Ro is the oil contamination reduction factor, which varies depending on the kind and degree of degradation of the oil. Empirical evidence from [26] demonstrates how effective solar irradiation decreases as oil content and deterioration rise.

The incident solar radiation can also be impacted by the reflectance of the PV surface, which is altered by oil pollution. Given reflectance, the effective solar radiation is determined by:

$$G_{eff,ref} = G \times (1 - R_0)\left(1 - R_f\right) \quad (2)$$

Where R_f is the reflectance factor due to oil, which varies based on the oil's optical properties.

When these variables are combined, the oil-contaminated PV module's output power can be written as follows:

$$P_{out} = G_{eff,ref} \times (1 - R_0) \times A \times \eta(T) \quad (3)$$

Where P_{out} is the output power of PV, $G_{eff,ref}$ is the effective reflectance solar radiation, A is the area of PV, $\eta(T)$ is the efficiency of the PV module at temperature T.

2) *Oil Samples:* Three types of Mobil engine oil were selected to study their varying impacts on PV panel performance: A **New Mobil Engine Oil sample (O1)** was obtained by purchasing a new container of Mobil engine oil, representing oil in its pristine, unused state. Moreover **Half-used Mobil Engine Oil sample (O2)** was taken as the second sample after the oil had been used in a generator for four days with each day 12 hours of operation. At this halfway point, the oil had started to accumulate impurities, making it a representative sample of oil in mid-usage. Finally **completely Used Mobil Engine Oil sample (O3)** was the final sample which was collected after the oil had been used for eight days with each day 12 hours of operation, aligning with its typical lifespan in the generator. This sample represents oil that is heavily contaminated and turns dark at the end of its usable life. The oil samples are shown in figure 2 and their properties are summarised in Table 2.

Figure 2: Various Mobil oil samples used for PV coating

Table 2: Summary of the Mobil oil samples properties with respect to degradation [35]

Property	**New Mobil Engine Oil (O1)**	**Half-used Mobil Engine Oil (O2)**	**Completely Used Mobil Engine Oil (O3)**
Source	Purchased new	Collected after 4 days of generator use	Collected after 8 days of generator use
Appearance	Clear, amber	Slightly darker, with impurities	Dark, with visible impurities and sludge
Viscosity	High	Medium	Low
Oil Condition	Pristine, no contaminants	Moderate level of contaminants	High level of contaminants
Oxidation Level	Low	Moderate	High
Wear Metals Content	None	Low to moderate	High
Additive Depletion	None	Moderate	Significant
pH Level	Neutral	Slightly acidic	More acidic
Water Content	None	Low	Moderate
Acid Number	Low	Moderate	High
Lubricity	Excellent	Reduced	Poor
Smell	Mild petroleum smell	Slightly burnt smell	Strong burnt smell
Usage Impact	Fresh and clean	Shows signs of usage and degradation	Heavily degraded, nearing end of life

C. Experimental Procedure

After setting up the materials, the procedure of this work starts by isolating a reference panel that was left uncontaminated. In order to correctly evaluate the impact on solar PV performance, an even and controlled layer of oil coating was applied to the PV panels in this investigation using a brush. Applying paint precisely while preserving uniform thickness and dispersion throughout the panel surface is made possible by the brushing technique. This control is essential because uneven application could result in inconsistent shading effects, making it more difficult to isolate the performance impact of the oil layer [36]. Using a brush, oil samples O1, O2, and O3 were carefully applied to the PV panels. Lastly, the combined effects of oil pollutants on solar PV performance were examined using an oil-coated PV panel; the brush ensured a consistent base layer and a uniform application.

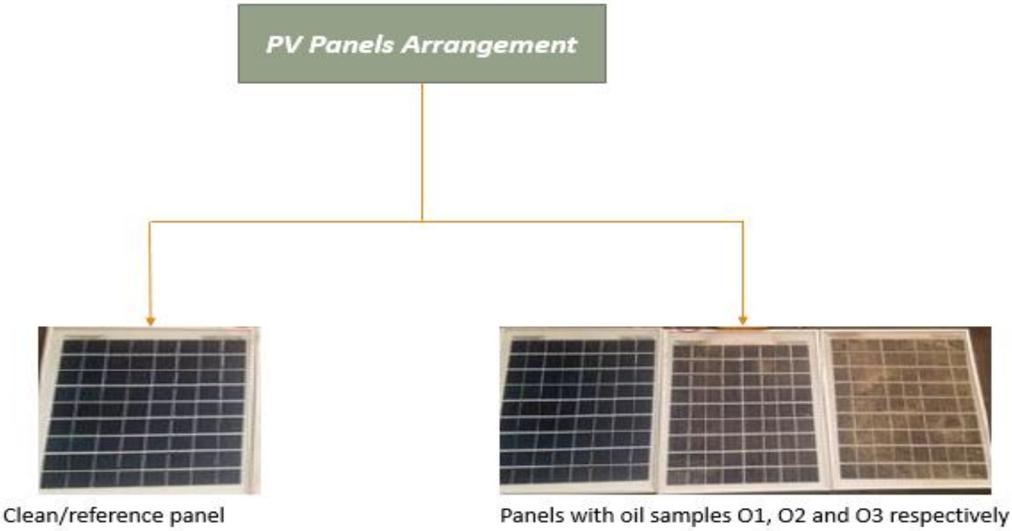

Figure 3: Experimental procedures

For the experimental grouping, the 4 PV panels were categorized as follows: one panel was kept clean and uncontaminated to serve as the control. Another three panels were coated with Mobil oil with various degradation levels and their impacts were assessed. This arrangement allowed for a comprehensive analysis of how Mobil oil with different degradation levels affects PV panel performance. The performance of the contaminated panels was compared against the control panel to quantify the efficiency losses attributable to each type of contaminant. Furthermore, the quantity of oil samples used was precisely measured to ensure consistency and reliability in the experimental results. For the oil coating, 0.2 liters of oil were applied uniformly to three separate panels. Oil samples (O1, O2, and O3) each with 0.2 liters were distributed across three panels respectively.

D. Performance Measurement

The performance of the PV panels was monitored hourly from 8:00 AM to 6:00 PM daily. During each hour, the power output was measured and recorded using a multimeter, solar irradiance was measured using a solar power meter, and temperature was measured with a Model GP-200 Infrared Thermometer. This experiment was conducted over a period of 30 days, and the average values of the measured variables were determined and presented in this work.

The percentage change in the power output of the PV was calculated using the following equations, and the results are presented in this study:

$$\%\Delta P_O = \frac{P_{with\ oil} - P_{clean}}{P_{clean}} \times 100\% \qquad (4)$$

Equations 1, 2 and 3 represent the percentage change in power of PV when the samples are applied, where $\%\Delta P_O$ is the percentage change in power of PV with soil samples, with oil samples and with oil-soil samples respectively. And also P_{clean} and $P_{with\ oil}$ are the power output of the reference PV and that with oil respectively.

3. Result and discussion

A. Result of the PV Clean/reference Output Power

As shown in Table 3, the 10W PV panel experiment demonstrated a strong correlation between temperature, solar irradiation, and the panel's performance. Both temperature and irradiance climbed between 8:00 and 18:00, reaching their maximums at 14:00 with values of 1250 W/m2 and 42°C, respectively. In accordance with this, at 14:00 the power production peaked at 9.56 W, little less than the 10 W specified, most likely as a result of inefficiencies due to manufactures and real world uncertainties. It is evident that the PV panel exhibited good efficiency and dependability in a range of daytime situations, as it maintained a consistent power production near its peak capacity despite the fluctuations.

Table 3: Operating conditions of the PV system and its power output

Operating conditions			Clean PV	
Time (Hrs)	Temp. (^{0}C)	Irrad. W/m^2	I_{SC} (A)	P_O (W)
8	31	225	0.38	9.02
9	32	307	0.39	9.12
10	34	477	0.42	9.26
11	35	510	0.45	9.34
12	36	783	0.49	9.43
13	39	1081	0.51	9.49
14	42	1250	0.54	9.56
15	40	1129	0.52	9.52
16	37	974	0.50	9.47
17	35	622	0.48	9.41
18	33	349	0.40	9.22

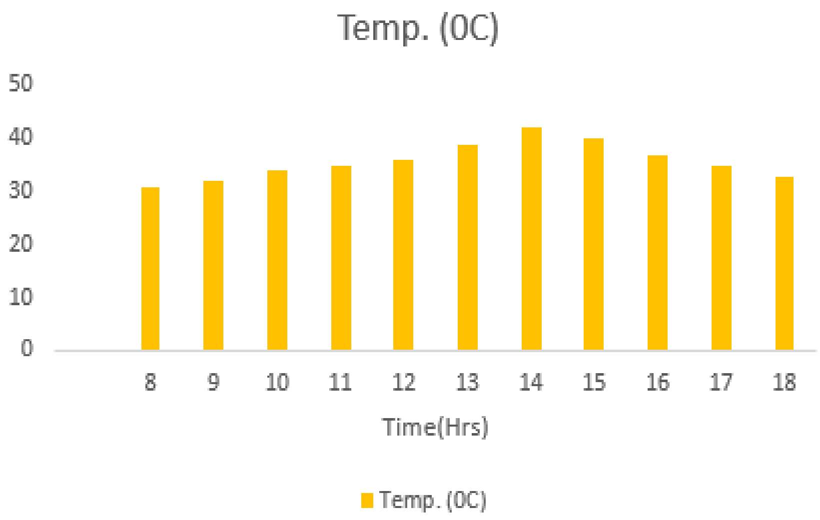

Figure 4: Average temperature variation per hours in a day

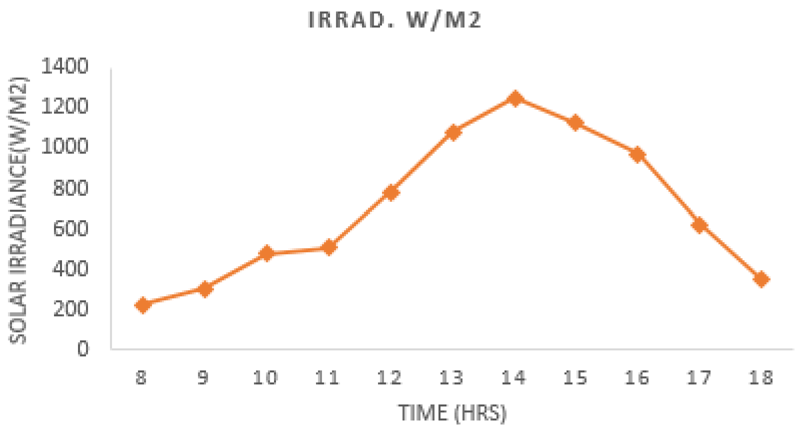

Figure 5: Average solar irradiance variation per hours in a day

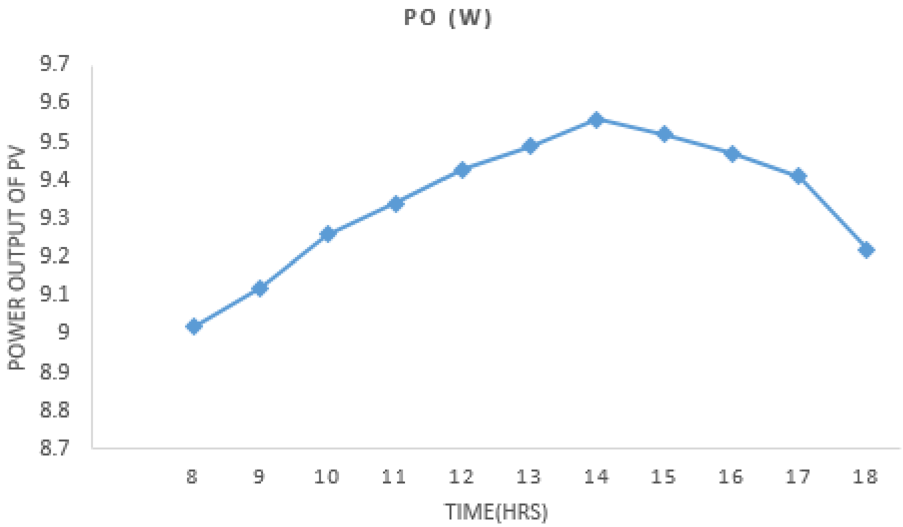

Figure 6: Average power output of clean PV per hour

The clean PV system's operational parameters and accompanying power output are shown in Table 3. By 8 AM, the temperature is 31°C; by 2 PM, it reaches its highest point of 42°C; by 6 PM, it has dropped down to 33°C. In a similar vein, solar irradiance peaks at 1250 W/m² at 2 PM, falls to 349 W/m² by 6 PM, and begins at 225 W/m² at 8 AM. With a range of 9.02 W from 8 AM to 9.56 W at 2 PM. The average hourly temperature fluctuation is shown in Figure 4, which also shows the normal daily temperature profile with a peak in the early afternoon and a decrease in the evening. Understanding this temperature profile is crucial to comprehending the PV system's thermal properties and how they affect efficiency. The average hourly variation in solar irradiance is depicted in Figure 5, where a bell-shaped curve peaks at midday. This variance has a direct impact on the PV system's energy input, which in turn determines the power output. The clean PV's average power output per hour is shown in Figure 6, which shows that even in the face of temperature and irradiance variations, the power output is largely constant. This demonstrates how well the PV system performs in transforming solar energy that is readily available into electrical power. The data in **Table 1** indicate that both temperature and solar irradiance significantly influence the power output of PV panels. The highest power output corresponds to the periods with the highest temperature and irradiance, confirming that optimal PV performance is closely linked to these environmental conditions.

B. Pearson Correlation Analysis of the effect of Temperature and Irradiance on PV output

To calculate the Pearson correlation coefficient (γ) between variables, we use the following formula:

$$\gamma = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \times \sum(y_i - \bar{y})^2}} \tag{5}$$

Where: x_i and y_i are individual data points of variables X and Y.

$\bar{x}$ and $\bar{y}$ are the means of X and Y, respectively.

Now the Pearson correlation coefficients for the relationships between the following were calculated and the results are summarized in T:

1. Temperature (°C) and Power Output (PO):
2. Irradiance (W/m²) and Power Output (PO):
3. Temperature (°C) and Irradiance (W/m²):

Table 4: Summary of the Pearson correlation coefficients

Parameter Pair	**Pearson Correlation Coefficient (r)**	**Interpretation**
Temperature (°C) and Power Output (W)	0.931	Strong positive correlation
Irradiance (W/m²) and Power Output (W)	0.938	Strong positive correlation
Temperature (°C) and Irradiance (W/m²)	0.979	Very strong positive correlation

stronger as shown in Table 4. This make irradiance as the dominant factor influencing PV performance, as it directly determines the energy available for conversion into electricity. The near-linear relationship confirms that within the tested range, power output scales proportionally with irradiance. From a comparative standpoint, the relationship between irradiance and power output is more direct and predictable than the relationship between temperature and power output. Irradiance is the dominant parameter, as indicated by its slightly higher correlation coefficient, suggesting that efforts to optimize PV system performance should prioritize maximizing irradiance exposure.

Conversely, the very strong correlation between temperature and irradiance reflects the challenges of disentangling these effects in performance analysis, as their combined influence can complicate the assessment of each factor's independent impact.

While both temperature and irradiance positively correlate with power output, irradiance demonstrates a slightly stronger and more consistent influence. The very strong correlation between temperature and irradiance further confirms their interdependence in natural operating conditions. These emphasize the importance of addressing both irradiance optimization and thermal management to achieve maximum PV efficiency. The coefficient of 0.979 between temperature and irradiance demonstrates a very strong positive correlation. This reflects the inherent link between these two environmental parameters, as higher irradiance typically leads to increased ambient temperatures. This strong association underscores the role of irradiance as the primary driver of thermal effects observed in the PV system. Such insights are critical for accurately modeling environmental influences on PV performance.

C. Result and Discussion of PV Output Power with Oil Samples

Table 5: power output of PV for various oil samples

Operating conditions			Clean PV	Oil samples (10g) each					
				O1	O2	O3	O1	O2	O3
Time (Hrs)	Temp. (^{0}C)	Irrad. W/m^2	P_O (W)	P_{O1} (W)	P_{O2} (W)	P_{O3} (W)	P_{O1} (%)	P_{O2} (%)	P_{O3} (%)
8	31	225	9.02	9.35	9.15	8.96	3.66	1.44	-0.67
9	32	307	9.12	9.43	9.21	9.00	3.40	0.99	-1.32
10	34	477	9.26	9.48	9.27	9.11	2.38	0.11	-1.62
11	35	510	9.34	9.52	9.35	9.16	1.93	0.11	-1.93
12	36	783	9.43	9.61	9.46	9.26	1.91	0.32	-0.02
13	39	1081	9.49	9.86	9.53	9.37	0.45	0.41	-1.26
14	42	1250	9.56	9.97	9.68	9.50	4.29	1.56	-0.63
15	40	1129	9.52	9.90	9.57	9.41	3.99	0.53	-1.16
16	37	974	9.47	9.74	9.49	9.31	2.85	0.21	-1.69
17	35	622	9.41	9.58	9.43	9.23	1.81	0.21	-1.91
18	33	349	9.22	9.50	9.30	9.14	3.04	0.87	-0.87

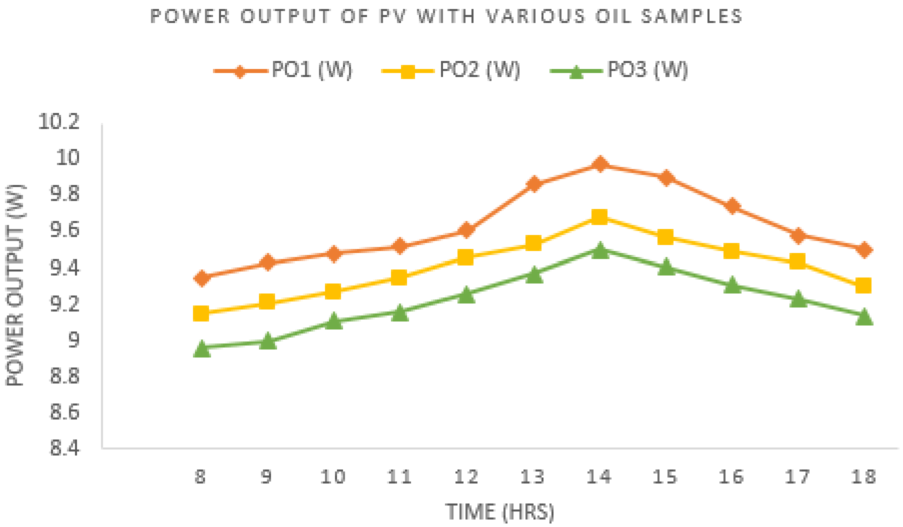

Figure 7: Power output of PV with various oil samples

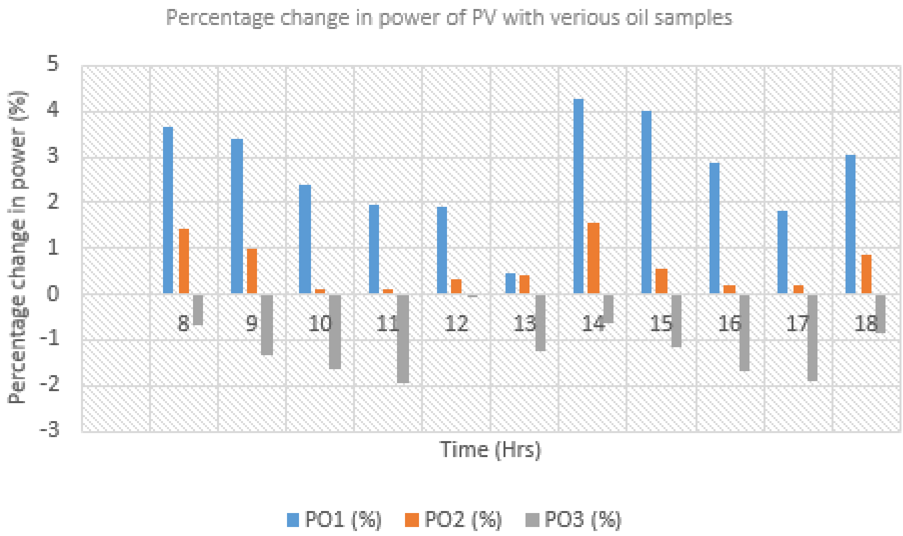

Figure 8: Percentage change in power output of PV with various oil samples

The results, presented in Table 5 and visually detailed in Figures 7 and 8, illustrate the nuanced effects of these oils on the energy conversion efficiency of PV panels. At 8:00 AM, under relatively low irradiance (225 W/m²) and moderate temperature (31°C), the clean PV panel generated 9.02 W. Applying new oil (O1) increased the output by 3.66% to 9.35 W, attributable to its ability to form a thin, uniform layer that enhances light absorption by reducing surface reflection. The halfway-used oil (O2) increased power output by 1.44% (9.15 W), indicating the retention of some beneficial optical properties. However, degraded oil (O3) slightly decreased the output by 0.67% (8.96 W), likely due to impurities and reduced transparency. At midday (12:00 PM), under heightened irradiance (783 W/m²) and temperature (36°C), the clean panel produced 9.43 W. New oil (O1) further improved output by 1.91% to 9.61 W, while halfway-used oil (O2) yielded a marginal increase of 0.32% (9.46 W). The degraded oil (O3) produced a negligible change (-0.02%) at 9.26 W. These results suggest that higher irradiance amplifies the impact of oil properties, with new oil maintaining its advantage while degraded oil demonstrates minimal benefit.

At peak irradiance (2:00 PM), under extreme conditions (1250 W/m², 42°C), the clean panel output was 9.56 W. New oil (O1) exhibited its maximum effectiveness, enhancing power output by 4.29% to 9.97 W, underscoring its ability to optimize light absorption during peak sunlight hours. The halfway-used oil (O2) increased output by 1.56% to 9.68 W, while degraded oil (O3) led to a slight decrease of 0.63% (9.50 W), reflecting its diminished efficacy under intense conditions. By 6:00 PM, as irradiance dropped to 349 W/m² and temperature decreased to 33°C, the clean panel produced 9.22 W. The new oil (O1) maintained a positive impact, increasing output by 3.04% (9.50 W). The halfway-used oil (O2) provided a modest boost of 0.87% (9.30 W), whereas degraded oil (O3) caused a slight reduction of 0.87% (9.14 W).

New Mobil oil (O1) consistently improved power output across all conditions, with a maximum increase of 4.29% during peak irradiance. This improvement is attributed to its optical properties, such as reduced surface reflection and enhanced transmission of sunlight to the PV cells.

The halfway-used oil (O2) exhibited moderate improvements, retaining some of the properties of new oil but with reduced efficacy due to impurities. Degraded oil (O3), characterized by opacity and uneven coverage, generally reduced power output, especially under high irradiance, highlighting its counterproductive impact on PV efficiency.

The observed power changes due to oil coatings (4.29%, 1.56%, and -1.91%) fall within the ±5% power tolerance of the PV panels; however, the consistency and reproducibility of these changes across varying irradiance levels and temperatures strongly suggest that the effects are attributable to the oil coatings rather than measurement inaccuracies. The instrumentation used, including calibrated solar power meters and multimeters, ensured high measurement precision, while repeated tests under controlled conditions confirmed the trends. Additionally, while used oil (O2 and O3) may contain contaminants such as metal particles from engine wear, which could affect the optical properties of the coating, these represent realistic environmental conditions for areas exposed to oil residues.

D. Real-Time Applications

This study has significant implications for real-world scenarios. The findings suggest that applying new or moderately used engine oil to PV panels could serve as an inexpensive, temporary method to enhance performance in areas with less dust or dirt accumulation. For instance, in arid or industrial regions, where frequent cleaning is impractical, such coatings could improve energy yield without requiring advanced maintenance solutions. However, the diminished effectiveness of degraded oil underlines the importance of using clean, high-quality materials to avoid counterproductive results. Furthermore, these insights are valuable for optimizing PV systems in hybrid configurations, such as microgrids, where maintaining high efficiency is critical for balancing energy supply and demand. Policymakers and renewable energy developers can use these findings to develop cost-effective strategies for improving PV performance in challenging environments, ultimately contributing to greater energy security and sustainability.

4. Conclusion

In conclusion, this study demonstrates that applying Mobil engine oil as a coating on photovoltaic (PV) panels can influence power output, with new oil (O1) enhancing performance by up to 4.29%, partially used oil (O2) showing moderate improvements, and degraded oil (O3) leading to slight reductions. These effects are attributed to the optical properties of the coatings, which impact light absorption and reflection. While the observed changes fall within the PV panel's ±5% power tolerance, the consistent trends confirm the coatings' role in modulating performance. This research confirms the potential of thin-film coatings to enhance PV efficiency and underscores the importance of mitigating environmental contaminants like oil and dust that can degrade performance. Future research should investigate the combined effects of oil and particulate matter on PV efficiency under realistic field conditions, explore advanced coatings with self-cleaning or anti-reflective properties, and develop automated maintenance systems to ensure optimal panel performance in diverse environments.

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