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The Effect of Fluid Type and Volume on Concentrated Solar Sphere Power Generation

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Abstract - Because of the rising need for renewable energy sources, several innovative systems that use natural resources to create energy and deliver power have emerged. The solar sphere system (a container) is a novel system that gathers and focuses solar energy emitted by the sun at a focal point on a multijunction device. The multijunction device is made up of a high-efficiency solar cell that transforms sunlight into energy.

Many aspects/parameters in the solar sphere system influence the quantity of power generation and the related efficiency, resulting in increased overall system performance. The factors are the fluid medium inside the container/sphere and the volume or the amount of the fluid oil inside the sphere. In our previous research paper, the size, thickness, fluid medium, and some shapes were investigated. It was confirmed that the oil is the best fluid medium, and the sphere is the best shape to generate the highest efficiency and highest output power. As a result, the purpose of this work is to explore and investigate the possible kind of fluid oil, and the volume/amount of the oil inside the sphere to determine the influence of these factors on the performance of the solar sphere. The results of the trials revealed that these factors have a substantial impact on power output and system efficiency.

From the results, it is found that the fluid oil type and the effect of fluid oil volume/amount inside the solar sphere significantly change the value of the output power. Hence, in order to improve the efficiency of the solar sphere, cooking oil (sunflower coconut, corn oil) is the best. Moreover, the acrylic sphere should be filled with oil completely in order to generate the highest output power and higher efficiency.

***Keywords*:** solar, concentrated energy, thickness, power.

1. Introduction

Worldwide, societies are battling a variety of risks, including those related to the environment, food, and water. Technological advancements and improvements have arisen to assist these cultures in surviving these risks. Studies over the last decade have shown that research efforts in the energy industry have grown exponentially, and a large energy peak is projected between 2016 and 2040 [1-3].

Organizations at the worldwide and national levels are investigating many energy concerns, including challenges connected to energy generation, conservation, and storage. On top of these issues, the greatest difficulty remains the creation of energy capable of meeting the world's energy demand. Most of this energy demand is directed towards the supply of electricity which is currently being supplied by conventional nonrenewable sources. Hence, the challenge to meet the rise in energy demand is also coupled with the challenge of providing the same with renewable resources [4-6].

In theory, the many renewable energy sources available can meet the world's increasing energy demand in the next years. The negative impact and depletion of nonrenewable energy sources will be lessened as a result, as will the cost of energy generation. Among the several renewable sources, solar energy, which is easily gathered from the sun, is one that is accessible to many locations and can be the answer to cover and maintain the present rate of power consumption [7-10].

Various improvements in solar energy collecting and conversion to electricity have been presented since the discovery of the idea of solar energy collection. The solar sphere is one of these advances since this new inventive method has been shown to be more efficient than traditional solar panels. Aside from its better efficiency, the solar sphere can immediately transform the energy received from the sun into electrical energy. It can also solve the limitations of traditional solar panels, such as the enormous surface area required for installation and the necessity for a sun tracking device to guarantee the panel is constantly facing the sun, especially as the angles of the sun's light beams vary during the year. As a result, the solar sphere system may overcome the constraints and limits of traditional solar panels [11-12].

In a nutshell, the solar sphere system fills a sphere with liquid, which is then kept in direct sunshine. The gathered solar energy is then focused by a unique lens arrangement into a spot over a high-efficiency solar cell, which transforms the concentrated energy into electricity. A multimeter is used to measure the electrical energy created, while a pyranometer is used to measure the incoming solar irradiation.

Many components of the solar sphere system, including the sphere parameters and liquid parameters, were tested with and described in prior published research. The sphere parameters comprised various forms, designs, and sizes, while the liquid parameters included various fluid media and volumes within the spherical itself. The various characteristics were tested under various situations throughout the year, and the efficiency and output power were compared with the traditional solar panel. The findings of these studies confirmed that the solar sphere system can create electrical power more efficiently than traditional solar panels. The following is a summary and conclusion of the prior experiments:

1- Form/shape: The entire spherical was the optimum shape for this criterion, producing four times more output power for the same area.

2- Size: It was also proved that as the size of the sphere rose, so did the output power and efficiency.

3- Fluid medium: Among the various fluids tested, oil produced one and a half times more output power than alcohol. Alcohol, on the other hand, was able to create double the output power of water, with air producing the least output power [13-17].

Liquid-filled spherical applications are already in use in a variety of technical sectors and applications. To finish the analysis of the solar sphere system, the influence of sphere thickness on overall system performance should be investigated. As a result, the parameters that have a degree of influence on the operation of the solar sphere system should be tested [18-34].

The goal of this research is to determine the impact of the following factors/parameters on the performance of the solar sphere. The factors include the type of fluid oil and the volume of oil inside the sphere. In addition, the influence on power output. Furthermore, to clearly increase the system's performance in generating power and then optimizing its efficiency.

2. Experimental Apparatus And Methods

Figure 1 depicts a schematic illustration of the experimental setup for the solar sphere system. Plexiglas acrylic was selected to make the sphere because it has the highest potential to gather solar energy. Furthermore, the best liquid based on prior trials was utilized, which was frying oil. A stainless-steel platform is used to elevate and support the sphere from the ground surface so that the multijunction device may be placed beneath it.

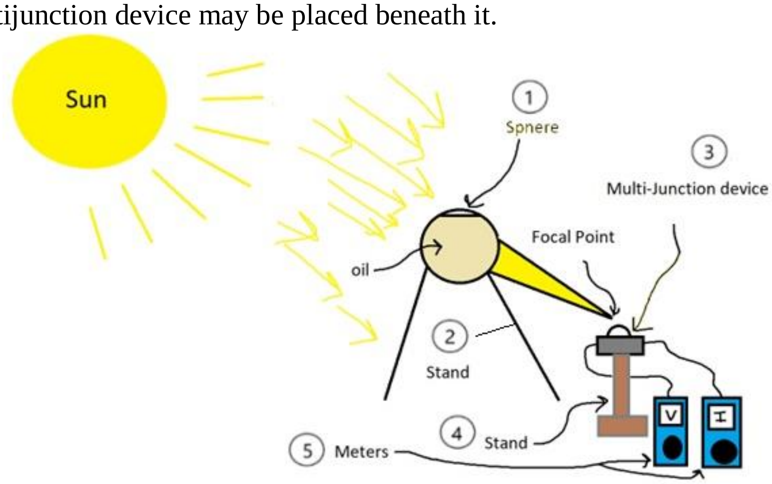

Fig. 1. The Solar sphere system experiment's setup

The multijunction device is additionally supported by a tiny stainless-steel platform that can be adjusted and rotated to capture the focus point at different solar radiation angles. The multijunction device is also linked to a multimeter, which measures voltage and current. After gathering solar energy and focusing it on the focal point of the multijunction device, these two measured parameters will be utilized to compute the power output of the solar sphere system. The solar radiations collected by the sphere will be focused on the multijunction device at the special lenses' configuration, which consists of layered junctions that maximize energy collection from light and aid in further concentration of the solar energy on the concentrated solar cell attached to a heat sink. This sort of multijunction device was employed in the solar sphere system experiment because it can withstand high temperatures caused by focusing sun radiation. Figure 2 depicts the separate components of the solar sphere system in addition to the whole experimental setup of Figure 1.

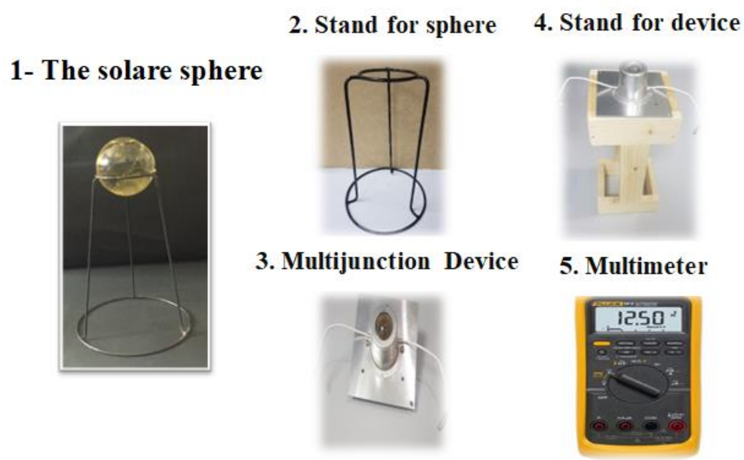

Fig. 2. Individual solar sphere experiment components

Figure 3 depicts further details about the multijunction device, such as the main optic, secondary optic, multijunction photovoltaic cell, and better thermal performance for cooling the system. Figure 4 depicts the real outdoor experimental setup utilized to conduct this experiment.

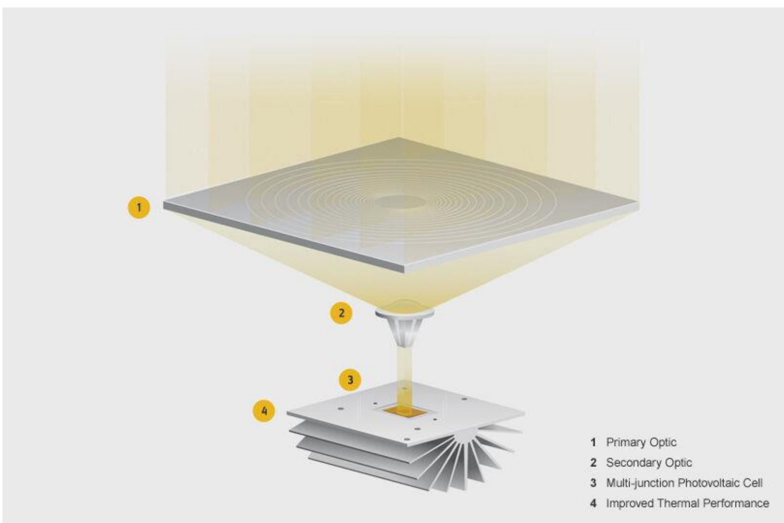

Fig. 3. Internal multijunction component diagram.

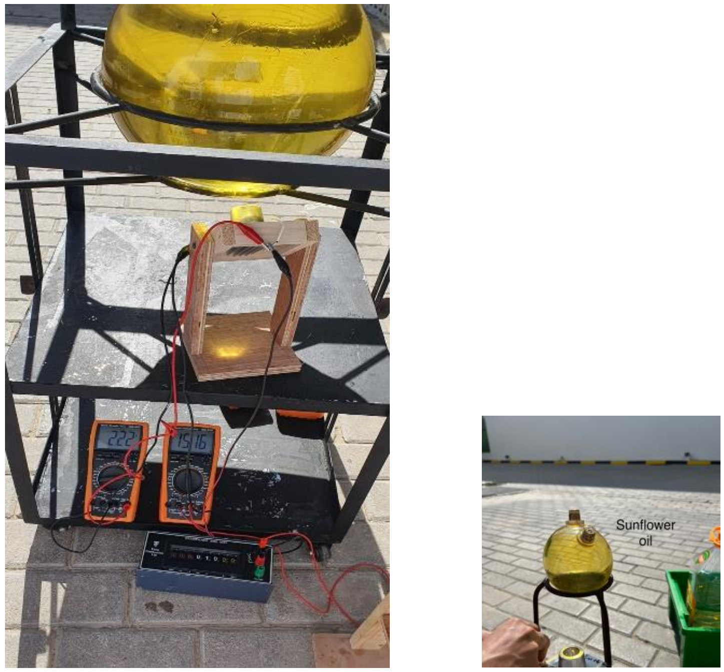

Fig. 4. The genuine outdoor testing setup.

2.1. Results and Data Analysis

Many experiments are carried out for a sphere with diameters of 10, 15, and 30 cm to investigate the effect of fluid oil type and the effect of fluid oil volume/amount inside the acrylic container/solar sphere and to measure the power output and efficiency.

As illustrated in Figures 1 and 4, the sphere is placed on the stand above the multijunction device, which is coupled to the voltage and current ampere meter. The focus point was discovered beneath the sphere and set to be directly above the lens of the multijunction device by managing the multifunction device's stand, which can be modified and controlled by moving it in all directions and levels. The trials were then carried out for each mentioned sphere. For all of these experiments and instances, the voltage and current ampere were measured. The following equations are used to compute the power output of the solar cell (w):

$$P_{out} = I \times V \quad (1)$$

Where I and V are the current and voltage detected by the multimeter, respectively.

Normal photovoltaic solar panel (PV) efficiency is often defined by a panel's capacity to convert sunlight into useful energy for human consumption. Knowing a panel's efficiency is critical for selecting the right panels for a solar system. Due to space limits, more efficient panels are required for smaller roofs.

$$\eta_{max} = \frac{P_{max}}{E_{s,y} \times A_c} \quad (2)$$

Where η_{max} is the maximum efficiency.

P_{max} is the maximin power output.

$E_{s,y}$ is the incident radiation flux.

A_c is the area of the collector.

The incident radiation flux is more accurately defined as the quantity of sunlight that strikes the earth's surface in W/m^2. Manufacturers utilize an expected incoming radiation flux of 1000 W/m2 under standard test conditions (STC). However, the standard test conditions STC incorporate various assumptions and are region dependent.

In contrast, the generated power of concentrated sphere systems such as ours is more than that of typical solar systems. The solar collector directs more sunlight to the receiver, which in our setup is the solar cell. Some parameters are provided to be employed in the following equations to gain an overview of how much solar radiation is focused on and the power input of the solar forms.

The geometrical concentration ratio (CR) is the quantity of solar radiation impacting the receiver calculated from the collector and receiver area. As a result, the geometrical concentration ratio is the ratio of the collector and receiver regions (CR) [35].

$$CR = \frac{A_{collector}}{A_{receiver}} \tag{3}$$

The optical concentration ratio is defined as the ratio of light intensities at the collector to those at the receiver. The optical concentration ratio is smaller than the geometrical concentration ratio because it incorporates light intensity losses (solar radiation). The higher the concentration ratio in concentration technologies, the better the system.

$$CR_{optical} = \frac{A_{collector} \times I_{collector}}{A_{receiver} \times I_{receiver}} \tag{4}$$

The sun radiation on the receiver, which is our system's multi-junction solar cell, is as follows:

$$G_r = G \times CR\ (W/m^2) \tag{5}$$

Where G is the solar radiation (W/m2) and Pin is the solar cell's input power.

$$P_{in} = Gr \times A_{cell} \tag{6}$$

Electrical efficiency:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{I \times V}{G_r \times A_{cell}} \tag{7}$$

Furthermore, the efficiency of each experiment was calculated.

1- The effect of fluid oil type:

Different types of oil were tested in order to find out the best oil. The types of oil are sunflower, corn oil, coconut oil, palm oil, sesame oil, olive oil, and engine oil. Table 1 shows the specification of these types of oil.

Table 1 Oil Types and properties/specifications

oil	**Density** kg/m^3	**reflective index**	**Viscosity** kg/ms	**Power output**	**color**
sunflower	918.8	1.474	0.0492	26.44	Clear and slightly/Bright Gold
corn	922.3	1.470	0.0349	25.22	Pale yellow
coconut	924.3	1.430	0.0550	25.79	Slightly yellow
palm	904.0	1.458	0.0430	15.25	Reddish orange
olive	895.0	1.470	0.0400	2.37	Dark green
sesame	899.0	1.472	0.0349	5.92	Dark reddish-brown

Figure 5 demonstrates samples of the current-voltage characteristics for several types of oil for a 10 cm diameter sphere. While doing the experiments the engine oil did not give any power out point as it was difficult to find the focal point over the multijunction device hence this kind of oil was eliminated directly. The current is nearly 10 amps at short-circuit (zero circuit resistance/zero voltage potential between multijunction terminals). Up to 2.5 V, the current is steady. Then, when the voltage rises, it decreases to zero Amps at 2.8 V. (open circuit). The best operating point is at the highest power point, which is comparable to V = 2.5 V. Figure 6 illustrates the relationship between oil type and output power compared to PV. While figure 7 demonstrates the relationship between oil types and the efficiency compared to PV. It is clear from these figures that the best oil that has the higher power output and higher efficiency is in order sunflower oil, coconut oil, corn oil, palm oil, sesame oil, and at end olive oil.

Moreover, the used oil of corn oil and sunflower oil was tested compared to the pure new oil that is not used and the results were impressive in that the used oil in both cases was better than the new unused oil.

When looking at the oil properties and specifications, it seems that the viscosity and the reflective index do not play a significant role in the results. While the density and the color are important factors that affect the results. The higher the density, the highest the power generation hence higher efficiency. And the clear and light color, the highest power generation hence higher efficiency.

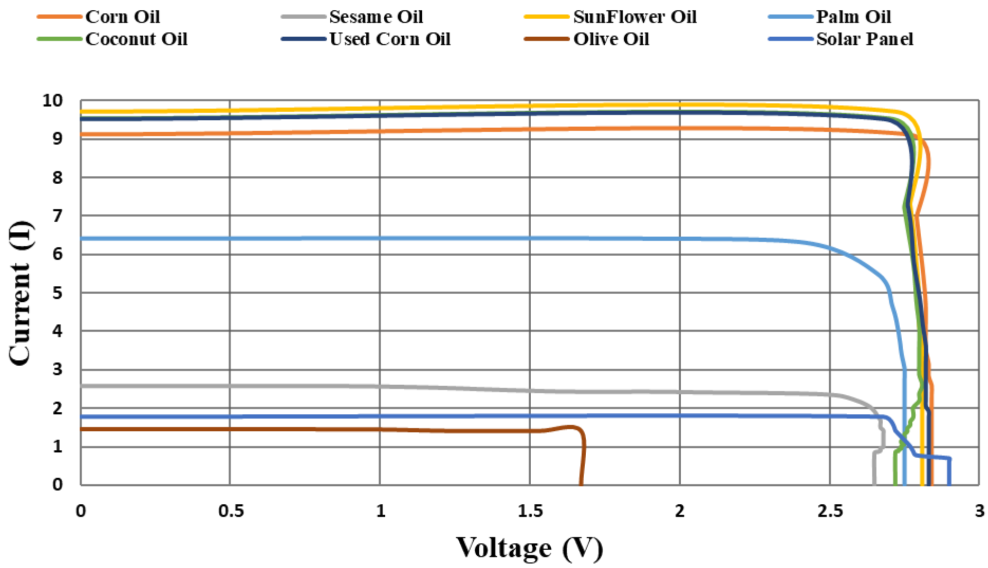

Figure 5 I-C curve for different types of oil

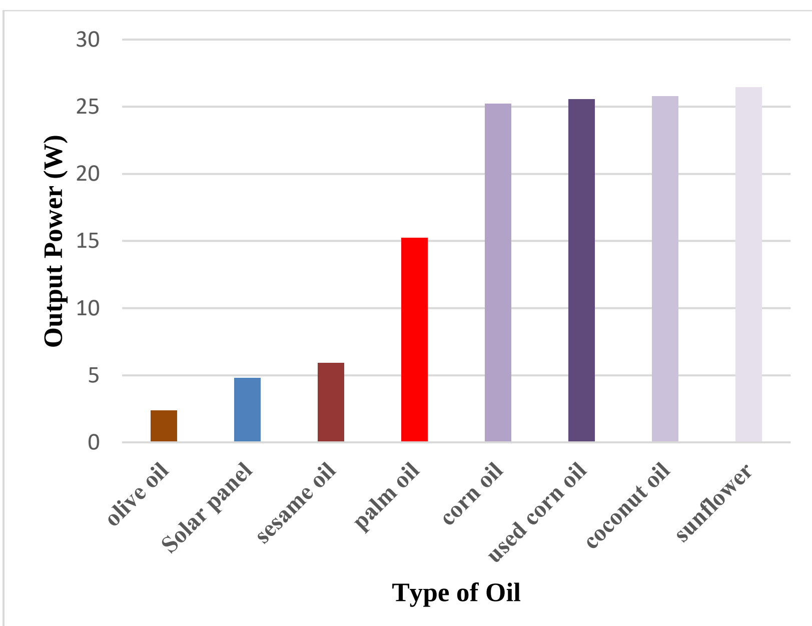

Figure 6 The relationship between oil type and output power compared to PV

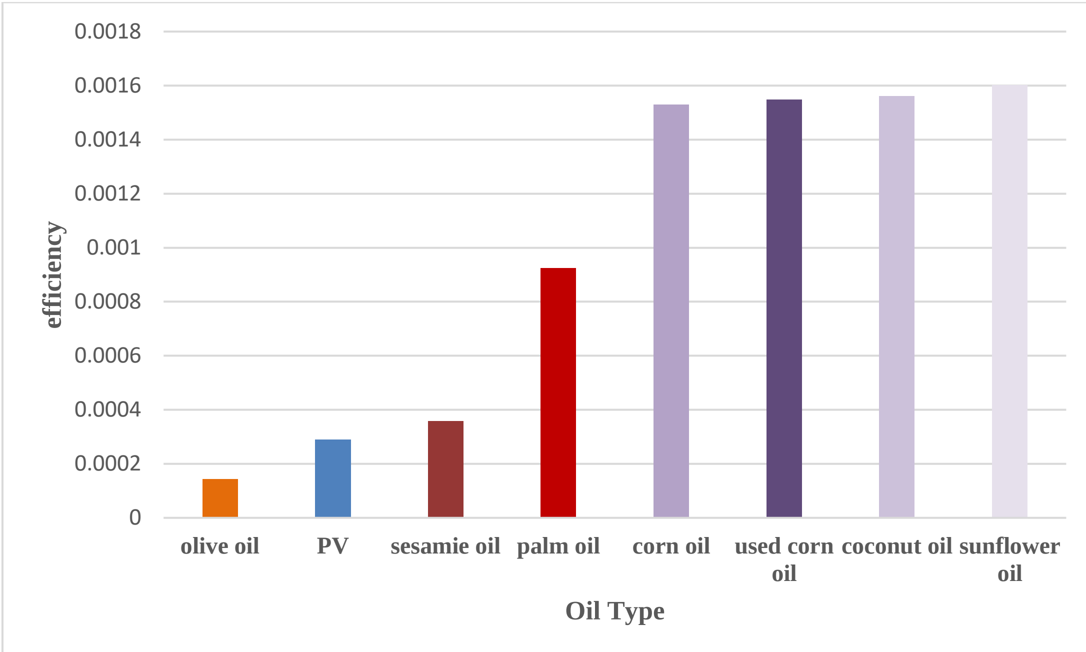

Figure 7 The relationship between oil type and efficiency compared to PV

2- The effect of fluid oil volume/amount inside the sphere:

In order to test the effect of volume or the amount of the fluid oil inside the sphere, different fluid volumes/amounts were tested as shown in Table 2. The fluid oil used for these experiments is sunflower oil as it is conferment to be the best oil in the previous section. Where the first column of Table 2 shows the oil percentage filled in the sphere (%) while the second column illustrates the equivalent volume/amount of oil inside the sphere (Litter).

Table 2 Oil volume inside the sphere

Percentage of oil filled in the sphere %	Equivalent volume/amount of oil inside the sphere (Litter)
25	2.375
50	4.75
60	5.7
70	6.65
100	9.5

Figure 8 demonstrates samples of the current-voltage characteristics for the above-mentioned volume/amount of oil inside the sphere of several types of sunflower oil for a 10 cm diameter sphere. The maximum current is nearly 170 amps at short-circuit (zero circuit resistance/zero voltage potential between multijunction terminals). Up to 3 V, the current is steady. Then, when the voltage rises, it decreases to zero Amps at 3 V. (open circuit). The best operating point is at the highest power point, which is comparable to V = 3 V. Figure 9 illustrates the relationship between the percentage of sunflower oil filled in the sphere (that is the equivalent volume/amount of oil inside the sphere) and output power.

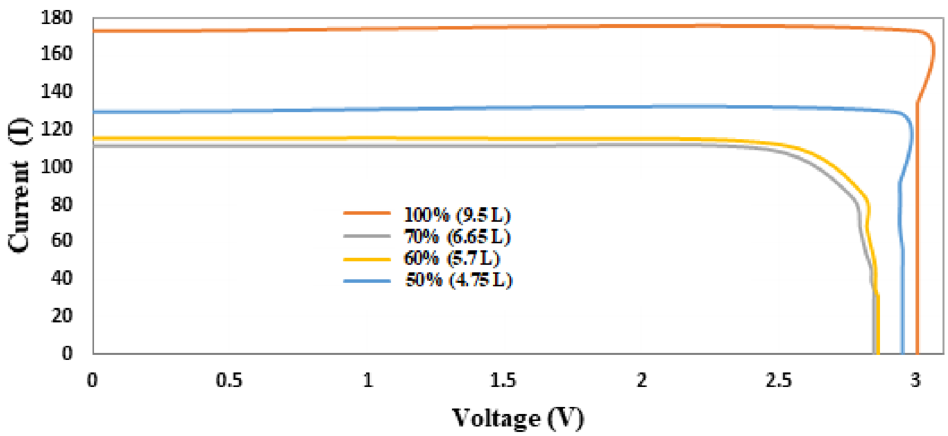

Figure 8 I-C curve for different volumes of oil

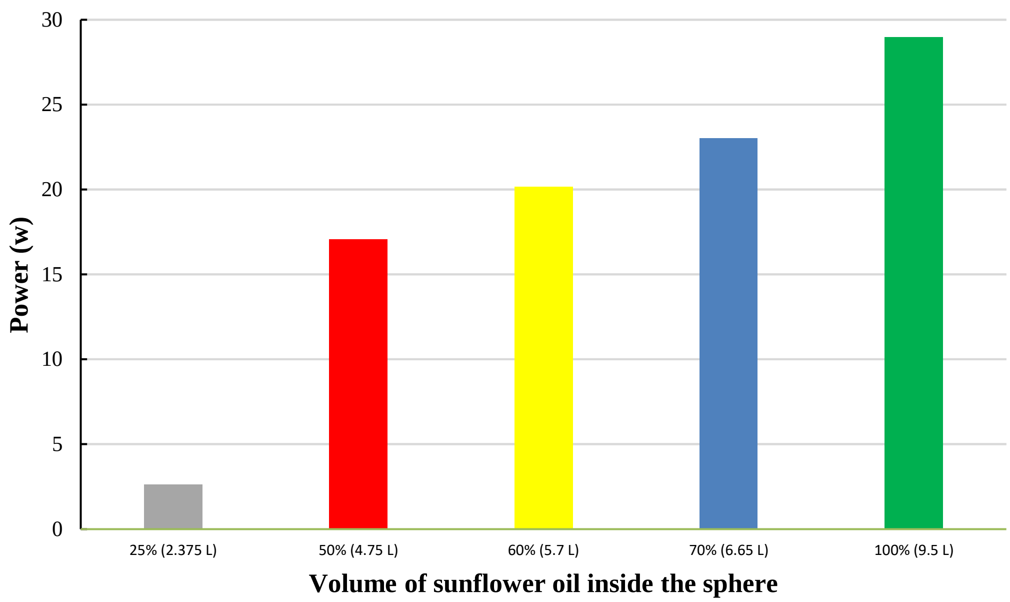

Figure 9 The relationship between oil volume and output power

From the above figures, it is clear that the sphere filled with 100% oil gives a higher output power.

Furthermore, it is obvious that the output power of this system (the concentrated acrylic solar sphere) is about four times that of a standard solar panel PV with the same cross-sectional area. This type of compression is critical because it leads to the conclusion that this system does not require more installation space than the area required to install the solar panel. It will cut the installation space by 25% to 50%. Furthermore, this finding is consistent with that demonstrated in our past study works [13-17].

In conclusion, the effect of fluid oil type and the effect of fluid oil volume/amount inside the acrylic solar sphere is examined in order to achieve better performance for the power generation hence, in order to improve the performance of the system and optimize its efficiency. The results showed that fluid oil type and the effect of fluid oil volume/amount inside the solar sphere significantly change the value of the output power. Hence, in order to improve the efficiency of the solar sphere, cooking oil (sunflower coconut, corn oil) is the best. Moreover, the acrylic sphere should be filled with oil completely in order to generate the highest output power and higher efficiency.

4. Conclusion

The effect of fluid oil type and the effect of fluid oil volume/amount of the acrylic solar sphere filled with oil fluid is carried out in order to improve the applicability of the power generation. The results illustrate a significant effect of fluid oil type and the fluid oil volume/amount on the output power hence the efficiency. The main conclusions can be summarized as follows:

1. The obtained output power was increased by increasing the amount of oil inside the acrylic solar sphere. Thus, the sphere should be filled with oil completely in order to generate the highest output power.
2. The calculated efficiency was increased by increasing the amount of oil inside the acrylic solar sphere. Hence, the sphere should be filled with oil completely in order to generate the highest output power.
3. The used oil of the corn oil and the sunflower oil was tested compared to the pure new oil (that is not used) and the results were impressive that the used oil in both cases was better than the new unused oil.
4. While comparing different kind of oil, the results reveal that cooking oil (sunflower, coconut, and corn oil) generate the highest output power hence the highest efficiency.
5. The output power of our system (the concentrated acrylic solar sphere) is almost about 4 times more than the conventional solar panel having the same cross-sectional area. This conclusion is the same conclusion shown in our previous research papers [13-17].

Finally, the concentrated acrylic solar sphere system requires less installation area compared to installing the conventional solar panel. The reduction of the installation area is around 25-50%. This conclusion is the same as the ones shown in our previous research papers [13-17].

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References

[1] H. Abdulmouti, K. Ali, A. Ali, M. Ali, S. Abdullah, R. Abdalla, “Smart Innovation Applications for a GreenHouse Using Sustainable and Renewable Energy in the UAE,” Publisher: IEEE. DOI: 10.1109/ICASET.2018.8376782, Electronic ISBN: 978-1-5386-2399-2, Print on Demand (PoD) ISBN: 978-1-5386-2400-5, IEEE Xplore Digital Library: 11 June 2018.

[2] H. Abdulmouti, Z. Skaf, and S. Alblooshi, "Smart Green Campus: The Campus of Tomorrow," 2022 Advances in Science and Engineering Technology International Conferences (ASET), 2022, pp. 1-8, DOI: 10.1109/ASET53988.2022.9735087, Publisher: IEEE. Date Added to IEEE Xplore: 18 March 2022.

[3] Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., & Matschoss, P. (Eds.). (2011). Renewable energy sources and climate change mitigation: special report of the intergovernmental panel on climate change. Cambridge University Press. [Accessed 15 March. 2017].

[4] H. Abdulmouti, A. Bourezg and R. Ranjan, "Exploring the Applicability of Agrivoltaic System in UAE and Its Merits," *2023 Advances in Science and Engineering Technology International Conferences (ASET)*, Dubai, United Arab Emirates, 2023, pp. 1-6, doi: 10.1109/ASET56582.2023.10180741.

[5] Hassan Abdulmouti, Zakwan Skaf, Wasif Minhas, Saeed Almheiri. Aquaponics System Display at Sharjah Campuses-The Campus of Tomorrow. 5th Advances in Science and Engineering Technology multi- conferences (ASET 2023). The International Conference on Renewable and Sustainable Energy. 20-23 Feb. 2023.

[6] Green Facts. (2016). Forests & Energy: 2. What are the trends and prospects of energy supply and demand? [Accessed 3 March. 2017].

[7] H. Abdulmouti, "Innovative Environment-Friendly Systems for a Modern Town," 12th International Conference on Sustainable Energy & Environmental Protection (SEEP'19), 18-21 Nov. 2019, UOS, Sharjah, UAE.
[8] Cooper, H. M. (2000). Organizing knowledge syntheses: a taxonomy of literature review. Knowledge Society, 1, 104–126[Accessed 3 March. 2017].
[9] Maria-Lluïsa Marsal-Llacuna, Joan Colomer-Llinàs, Joaquim Meléndez-Frigola,Lessons in urban monitoring taken from sustainable and livable cities to better address the Smart Cities initiative,Technological Forecasting and Social Change,Volume 90, Part B,2015,Pages 611-622.
[10] Volker Quaschning. Renewable Energy and Climate Change. Berlin University of Applied Systems HTW, Germany. (Translator) Hedy Jourdan. A John Wiley & Sons, Ltd., Publication, 2010.
[11] Green Rhino Energy. Concentrating Photovoltaics Solar Power. Retrieved May 06, 2016. http://greenrhinoenergy.com/solar/technologies/pv_concentration.php
[12] Fluke Corporation Fluke 83V and 87V detailed specifications. What is a digital multimeter. Retrieved May 12, 2016. http://enus.fluke.com/training/training-library/measurements/electricity/what-is-a-digitalmultimeter.html.
[13] H. Abdulmouti, "An Experimental Innovative Solar Sphere Design to Generate Electricity," 5th International Conference on Renewable Energy and Development (ICRED 2019), 20- 23 September 2019, Okinawa, Japan.
[14] H. Abdulmouti, A. Ahmed Aljasmi, M. Ali Almarzooqi, H. Alyasi, M. Jassim Khair, Y. Mohamed Almulla, A. Ahmed Almulla, "Generating Power from Innovative Solar Sphere," DOI: 10.1109/ICASET.2019.8714441, ISBN Information: Electronic ISBN: 978-1-5386-8271-5, Print on Demand (PoD) ISBN: 978-1-5386-8272-2, Date of Publisher: 16 May 2019, Publisher: IEEE Xplore.
[15] H. Abdulmouti, Producing Electricity by Concentrated Solar Energy," The 2nd International Conference on Advances in Energy Research and Applications (ICAERA'21), November 24 - 26, 2021, Seoul, South Korea.
[16] H. Abdulmouti, S. Alblooshi, Z. Skaf and S. Abdulnaser, "Exploring the Flow of Solar Sphere Using PIV," *2023 Advances in Science and Engineering Technology International Conferences (ASET)*, Dubai, United Arab Emirates, 2023, pp. 1-6, doi: 10.1109/ASET56582.2023.10180584.
[17] Hassan Abdulmouti, PIV of Flow Convection Induced by Solar Sphere to Generate Power. ENERGY 2023: The Thirteenth International Conference on Smart Grids, Green Communications, and IT Energy-aware Technologies, (ICNS 2023), Copyright (c) IARIA, 2023, ISBN: 978-1-68558-054-4, March 13-17, 2023, pp. 5-12, Barcelona, Spain.
[18] H. Abdulmouti, "Numerical Simulation of Bubble Convection in Two-phase Stratified Liquids," Multiphase Science and Technology by Begell House, Inc "USA", Volume 31, Issue 2, pp.:133–149 (2019), The Home for Science and Engineering, DOI: 10.1615/MultScienTechn.2019029995.
[19] H. Abdulmouti, "Experimental Measurement for Surface Flow Characteristics Generated by a Bubble Plume," The Journal of Flow Visualization and Image Processing, 22 (1–3), 39–58, 2015, Begell House "USA", The Home for Science and Engineering.
[20] H., Abdulmouti, "The Measurements of Bubble Plume Structure Parameter," International Journal of Fluid Mechanics Research, Begell House "USA", The Home for Science and Engineering, 44(3): 1–19, 1064–2277/17/$35.00, 2017.
[21] H. Abdulmouti, "Measurements of Thermal Effect on Bubble Parameter," The 3rd Thermal and Fluids Engineering Conference (TFEC), March 4-7, 2018, Fort Lauderdale, FL, USA.
[22] H. Abdulmouti, "Measurement of Flow Structures Induced by a Bubbly Plume Using Visualization, PIV, and Image Measurement," Scholar's Press, Saarbrücken, Germany, ISBN-13: 978-3-639-51490-2, 7, June 2013.
[23] H. Abdulmouti and M. Shinneeb, "Investigation of Free-Surface Flow Induced by a Bubbly Plume Using PIV," 2020 (ASET), Electronic ISBN: 978-1-7281-4640-9. ISBN: 978-1-7281-4641-6. Print on Demand (PoD), pp. 1-5, DOI: 10.1109/ASET48392.2020.9118203, Publisher: IEEE. Added to IEEE Xplore: 16 June 2020.
[24] H. Abdulmouti, and T. Mohamed Mansour. "The Technique of PIV and Its Applications," 10th International Congress on Liquid Atomization and Spray Systems (ICLASS-2006), 27 Aug.-1 Sept. Kyoto, Japan.
[25] H. Abdulmouti, "Bubbly Two-Phase Flow: Part II- Characteristics and Parameters," DOI: 10.5923/j.ajfd.20140404.01 American Journal of Fluid Dynamics, Volume 4, Number 4, 4(4): 115-180, December 2014, (Scientific and Academic Publishing).
[26] H., Abdulmouti, "Bubbly Two-Phase Flow: Part I- Characteristics, Structures, Behaviors and Flow Patterns," American Journal of Fluid Dynamics, Scientific and Academic Publishing, vol. 4, no. 4, 4(4), pp. 194-240. DOI: 10.5923/j.ajfd.20140404.03. December, 2014a.
[27] H. Abdulmouti, "Particle Imaging Velocimetry (PIV) Technique: Principles, the typically used methods, classification and applications," Scholar's Press. ISBN-13: 978-3-639-51249-6, 6 March 2013.

[28] H., Abdulmouti, “2D- numerical simulation of surface flow velocity and internal flow structure generated by bubbles,” Multiphase Science and Technology, Begell House (USA), the Home for Science and Engineering, 28 (2): 153–171, 0276–1459/16/$35.00 © 2016, DOI: 10.1615/MultScienTechn.2017018926, 2016.
[29] H. Abdulmouti and E. Jassim, “Visualization and Measurements of Bubbly Two-Phase Flow Structure Using Particle Imaging Velocimetry (PIV),” European Scientific Journal (ESJ), /special/ edition No.3, ISSN: 1857 – 7431, pp. 197-208, June 2013.
[30] H. Abdulmouti. “Particle Imaging Velocimetry (PIV) Technique: Principles and Application,” Yanbu Journal of Engineering and Science, 2.1, pp. 50-67, 2021.
[31] H. Abdulmouti, Y. Murai, J. Ohta, and F. Yamamoto, “Measurement of Bubble Plume Generated Surface Flow Using PIV,” Journal of the Visualization Society of Japan, Vol. 21, No. 2, pp. 31-37, 2001.
[32] H. Abdulmouti, Y. Murai, J. Ohta, and F. Yamamoto, “PIV Measurement of Bubbly Flow Interaction with Water Surface,” Journal of the Visualization Society of Japan, Vol. 19, No. 2, pp. 209-210, 1999.
[33] H. Abdulmouti, Y. Murai, J. Ohta, and F. Yamamoto, “PIV Measurement of Surface Flow Induced by Bubble Curtain,” Journal of the Visualization Society of Japan, Vol. 19. No. 1, pp. 239~242, 1999.
[34] H. Abdulmouti, Y. Murai, J. Ohta, and F. Yamamoto, "PIV Measurement and Numerical Analysis of Flow around Bubble Curtain," Japanese Society of Mechanical Engineer (JSME), No. 987-1, pp. 83-84, 1998.
[35] Solanki, C. (2013). Solar Photovoltaics Fundamentals, Technologies and Applications (2nd ed., p. 237). Delhi: PHI Learning Private Limited, Rimjhim House, Patparganj Industrial Estat