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DIRECT CONVERSION OF SOLAR ENERGY
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# Performance Analysis of Photovoltaic Thermal System Using Silicone Oil Spectrum Filter[1]

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**Abstract**—The paper reports use of silicone oil as spectrum filter and heat absorber for photovoltaic thermal systems. The terrestrial solar spectrum is in the wavelength range of 0.25 to 2.5 μm. The response range of C-Si solar cell is 0.75 to 1.125 μm. In the current study, the feasibility of Silicone oil (Transformer oil) as spectrum filter cum heat absorber for C-Si solar cell is investigated. The spectroscopic analysis of 1 cm thick Silicone oil sample with UV-VIS-NIR spectrophotometer is carried out. This analysis concludes that the Silicone oil is transparent to the response range of C-Si solar cell. Also, it shows a significant absorption for UV and IR part of the spectrum. A glass container with 1 cm thick Silicone oil layer is mounted on the C-Si PV module. The performance of the system is analyzed using solar simulator at irradiance of 1000 W/m$^2$, AM 1.5 G and in natural sunlight at Nagpur (21.10 N, 79.090 E). The experiments were performed for the entire year for time period of one hour in the noon. With Silicone oil spectrum filter, the average electrical efficiency of the PV module was found increase marginally. However, for 10 W module, 27 W average heat gain was recorded. In this study, the surface area of PV module (30 × 35 cm = 0.105 m$^2$) was very small. In actual practice, for large scale installations, significant heat gain is possible. The experimentation and significant outcomes are discussed in this article.

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## INTRODUCTION

The terrestrial solar radiations are in the wavelength range of 0.25 to 2.5 μm [1]. This solar energy is used separately in photovoltaics and in thermal systems. In photovoltaics, the photon with higher or lower energy than the band gap of PV material remains unused and causes losses in the PV systems. The response range of C-Si solar cell is 0.75–1.125 μm wavelength of the incident solar spectrum [2]. The photons with higher energy than the materials' band gap, causes Thermalization losses in the solar cell. The output voltage of the C-Si solar cell reduces by 2.3 mV/°C temperature rise of the solar cell [3]. Thus, it is always desirable to keep the low operating temperature of the PV cells in the module. To address this issue, different techniques have been proposed in the past. Many of these studies include combined photovoltaic thermal systems (PVT), where the PV module is allowed to expose the entire solar spectrum, and heat from the PV module is extracted by means of circulating fluids, thereby improving the electrical performance of the system. Also, the collected heat is used in separate applications. Many researchers explored the PVT systems with the use of air [4–6], water [7–9], a combination of air and water [10–12]. The exhaustive review of such several techniques has been reported in the literature [13–15]. Spectrum filtration is another technique of PVT system. In this technique the solar spectrum is filtered using optical filters. The desirable part of the spectrum is allowed to fall on the PV module and the undesirable part is collected and used separately as heat. These systems are referred as beam split PVT system (BSPVT) in the subsequent text. This concept is suggested in 1955 [16]. The first experimental work of this concept is reported in 1978 [17]. The comprehensive summary of the experimental and theoretical work of such systems carried out by many researchers is documented in the recent review papers [18, 19]. The optically selective liquids with good heat capacities can be used for BSPVT. Since a decade, use of liquids for spectrum filtration for PVT applications is being explored by some researchers around the world. Use of nanofluids [20], water [21–23], therminol and heat transfer oils [24] for BSPVT systems are reported in the recent past. The present research work is focused upon the investigation of easily available and inexpensive liquid for spectrum filtration suitable for BSPVT.

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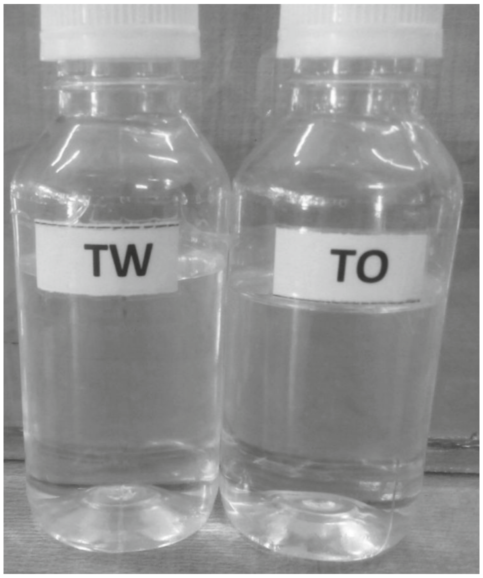

**Fig. 1.** Actual photograph showing sample of Silicone oil (TW: Tap Water, TO: Silicone oil).

## EXPERIMENTAL

The following considerations are important for the selection of liquid for BSPVT.

- It should be transparent to the response range of solar cell material;
- It should be opaque for all other wavelengths (in most of the cases UV and IR);
- Its thermo physical and the optical properties must be stable at all the temperatures. It should be non volatile, should have low viscosity and high heat capacity.
- It should be easily available and inexpensive.

For the above mentioned considerations, 'water' is suggested as the best choice by many investigators [21–23]. However, there are some liquids which show better performance than water. The feasibility of silicone oil, glycerin, and edible oils for BSPVT is reported recently [25]. In the present study, use of 'Silicone oil' as spectrum filter for BSPVT is explored.

## SPECTROSCOPIC ANALYSIS

The absorption spectrum of (1cm thick) Silicone oil sample was analyzed using UV-VIS-NIR spectrophotometer for 200 to 2500 nm wavelength with scanning rate of 600 nm/min and scanning interval of 1.0 nm. Figure 1 shows the actual photograph of sample of Silicone oil (TO in Fig. 1). The Silicone oil is clear liquid like tap water (TW in Fig. 1) Fig. 2 shows the absorption spectrum of the Silicone oil.

As shown in Fig. 2, the Silicone oil is transparent to the response range of C-Si solar cell. In addition, it has significant absorption of UV and IR.

## PERFORMANCE ANALYSIS USING SOLAR SIMULATOR

The electrical performance of the solar cell (A poly crystalline Si solar cell, 2 V, 150 mA, 4 × 4 cm) was investigated under the influence of Silicone oil spectrum filter using a solar simulator as shown in Fig. 3.

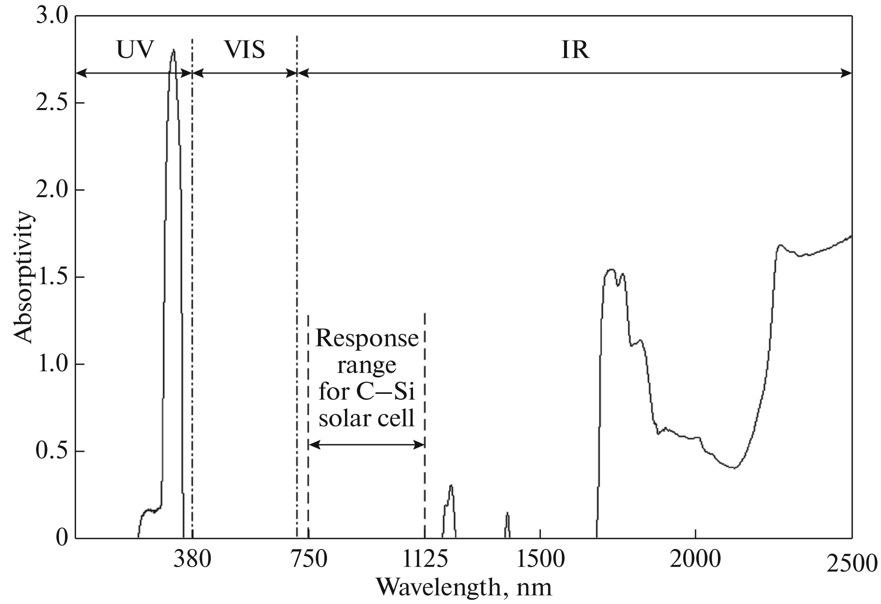

**Fig. 2.** Absorption spectrum of silicone oil.

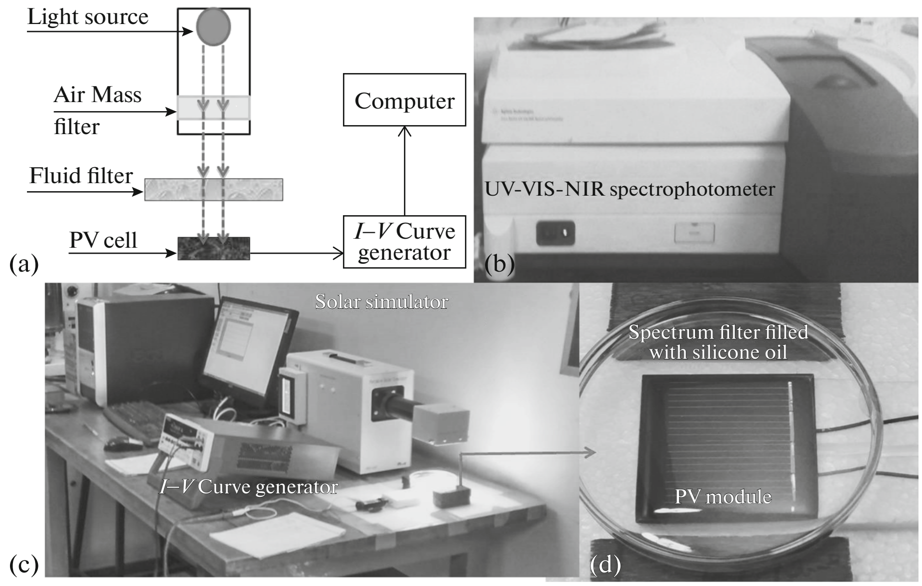

**Fig. 3.** Experimental set up for solar simulator experiments.

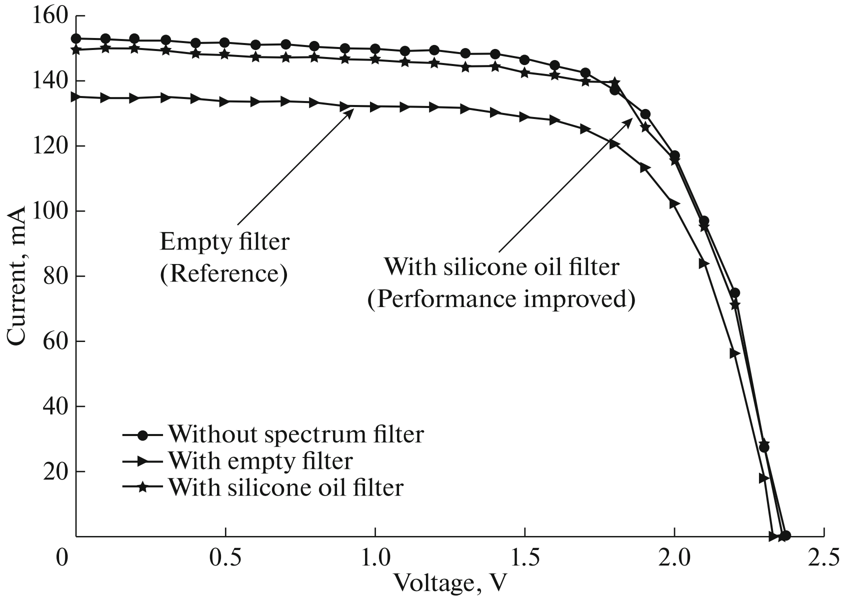

**Fig. 4.** Electrical performance of the Solar cell using solar simulator.

The artificial light source is fixed at 1000 W/m$^2$, and using an air mass filter, the input irradiation is maintained equivalent to AM 1.5 throughout the tests. A borosilicate glass case containing 1cm layer of Silicone oil is placed above the solar cell attenuating the beam of solar simulator. The solar cell is attached with cooling fans at the bottom to maintain the constant cell temperature.

As shown in Fig. 4, there is no significant effect on the electrical performance of the solar cell with and without Silicone oil spectrum filter. During this experimentation, the temperature of the module was kept constant. However, in natural sunlight, as the irradiation increases, the temperature of the PV module would increase. The Silicone oil spectrum filter attenuates some of the undesired incoming solar radiations, which helps to keep the PV module at lower temperature as compared to the module temperature without filter. This prediction proved true in the experimentation in natural sunlight described in the subsequent text.

**Table 1.** Instruments used for experimentation

| No. | Component | Specification |
|---|---|---|
| 1 | PV modules | Make: Waaree Solar India, $P_{\max} = 10$ W, $V_{oc} = 21$ V, $I_{sc} = 0.62$ A, Temp. coefficient for power = –0.47%/k |
| 2 | Glass containers | Glass Make:AIS Stronglass, Refractive index:1.5, thickness: 2 mm |
| 3 | Pyronometr | Make: Kipp and Zonen, Range: 0–2000 W/m$^2$ |

## EXPERIMENTATION IN NATURAL SUNLIGHT

For the experimental purpose, two photovoltaic modules of Poly C-Si were selected. Both the modules were mounted facing due south, tilted at an optimum tilt angle of 21.1° and were exposed to equal solar radiations. The container made up of low iron solar glasses was used to contain the Silicone oil. To measure the incident solar radiations, a well calibrated Pyranometer was used. The 1 cm thick Silicone oil container (spectrum filters) is mounted on the PV modules 5 cm above it. The insulated fixtures were used to mount the filter container above the PV modules. Due care is taken to thermally separate the PV modules and the liquid containers. Thermocouples were attached to measure the temperature of the module surfaces and the liquid inlet/outlet. Both the modules were attached to the *I*–*V* curve generator. The components and other related data is given in Table 1. Figure 5 shows the schematic diagram and actual photographs of the experimental arrangement.

The assembly was mounted on the roof top at Nagpur (India). During experimentation, the mass flow rate in the filter was kept constant 5 LPH. The radiation intensities above and below the filters, inlet and outlet temperatures of the Silicone oil, temperature of PV module were recorded. The monthly average data is considered for the analysis.

## RESULTS AND DISCUSSIONS

The experiments were performed for the entire year for time period of one hour in the noon. The electrical performance of the system was analyzed by drawing the *I*–*V* curves. Following relations were used to calculate the electrical and thermal efficiency of the system. Electrical efficiency of the *PV* module:

$$\eta_{\text{ele}} = \frac{P_{\max}(\text{W})}{IG(\text{W})} = \frac{V_{\text{mp}} \times I_{\text{mp}}}{IG(\text{W})}.$$

Termal efficiency of the filter

$$\eta_{\text{th}} = \frac{Q_{\text{gain}}(\text{W})}{IG(\text{W})} = \frac{mC_{\text{p}}(T_{\text{in}} - T_{\text{out}})}{IG(\text{W})}.$$

Figure 6 shows the radiation intensity above and below the filter.

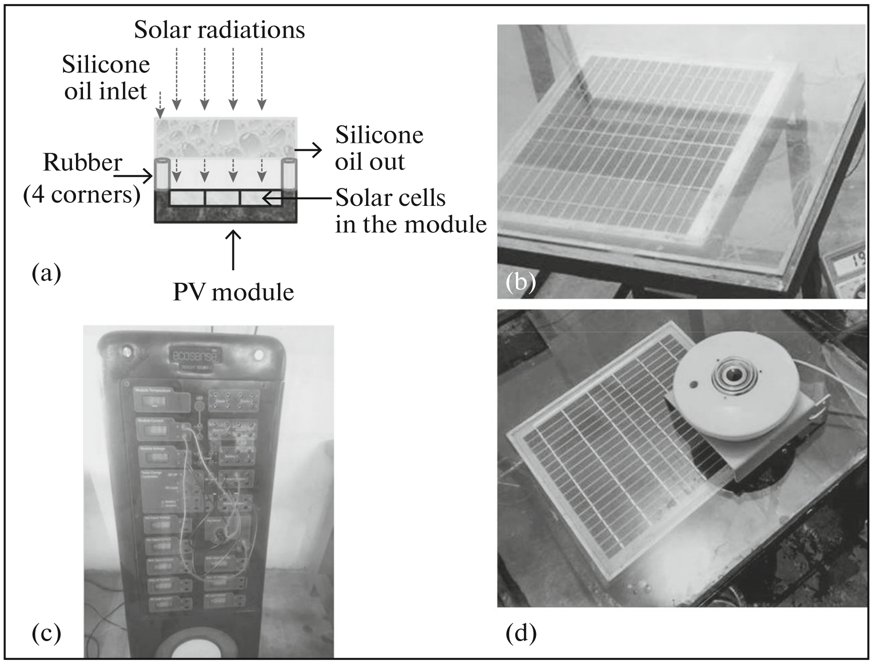

**Fig. 5.** (a) Schematic diagram showing position of filter, (b) actual photograph showing filter mounted on PV module, (c) actual photograph showing display unit, (d) pyranometer.

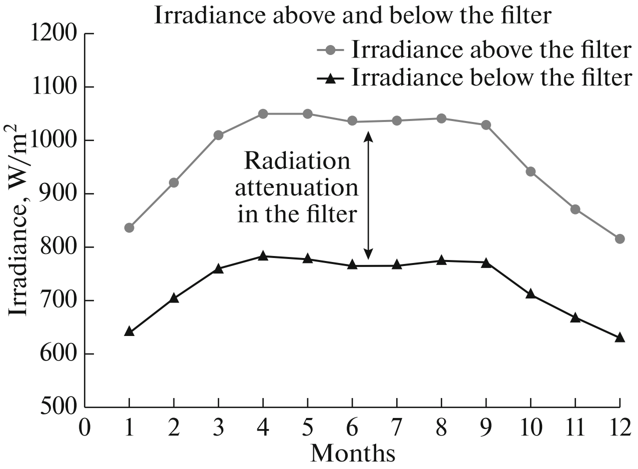

**Fig. 6.** Radiation intensity above and below the filter.

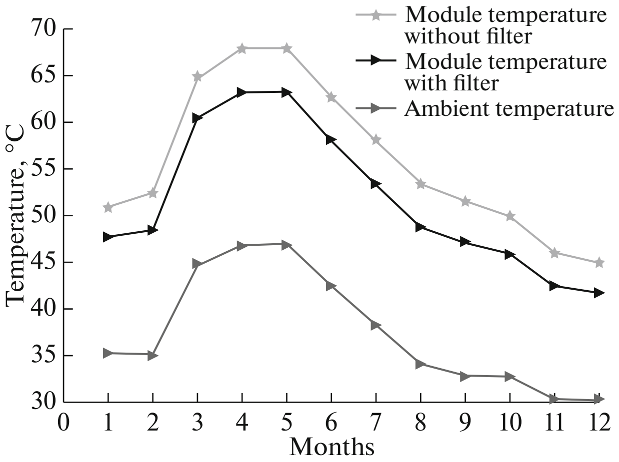

**Fig. 7.** Temperature of PV module with and without filter.

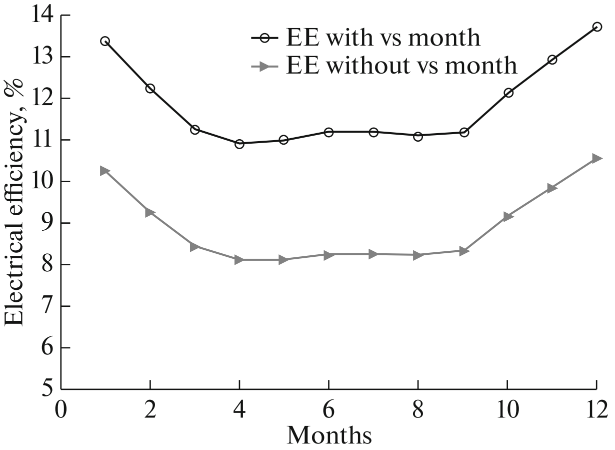

**Fig. 8.** Electrical efficiency of the module with and without filter.

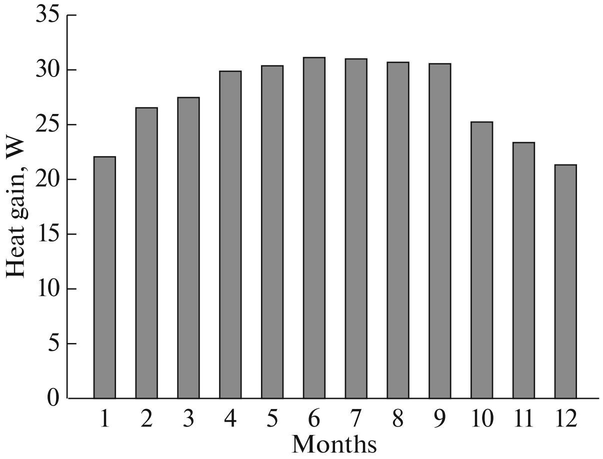

**Fig. 9.** Heat gain in the spectrum filter.

As shown in Fig. 6, on an average 239 W/m$^2$ of radiation intensity is attenuated by the Silicone oil spectrum filter. It involves the attenuation by two glasses of the containers and attenuation by 1cm thick Silicone oil layer. Figure 7 shows the module temperature with and without spectrum filter.

As shown in Fig. 7, the average module temperature with filter is less as compared to its temperature without filter. This reduction in the operating temperature of PV module surely improves its performance.

Figure 8 shows the electrical efficiency with and without filter. As shown in Fig. 8 the electrical efficiency of the PV module with spectrum filter is always higher as compared to the efficiency without filter. Figure 9 shows the average heat gain from the filter.

As shown in Fig. 9, average 27 W heat is collected in the spectrum filter. For experimental purpose, A 10 W *PV* module with surface area of (30 × 35 cm = 0.105) m$^2$ was used in this study. In actual practice, for large scale installations, significant heat gain is possible.

## CONCLUSIONS

In the current study, the performance of a photovoltaic thermal system using Silicone oil spectrum filter is analyzed with solar simulator and in natural sunlight. The Silicone oil is easily available, inexpensive and it is transparent for the response range of C-Si solar cell i.e. 0.75–1.125 μm wavelength of terrestrial solar spectrum. The spectrum filter improves the electrical performance of the PV module marginally. However, on an average 239 W/m$^2$ of undesired part of solar spectrum is attenuated by 1 cm thick Silicone oil spectrum filter. This trapped heat can be used separately. In this study, the experiments were performed with a 10 W PV module with non concentrated radiations. It is strongly suggested to explore the feasibility of BSPVT system with concentrating radiations by flat reflecting mirrors. In such systems, the heat gain can be improved by extracting heat from the rear surface of the PV module.

## REFERENCES

1. Sukhatme, S.P. and Nayak, J.K., *Solar Energy Principles of Thermal Collection and Storage,* 3rd ed., New Delhi: Tata McGraw-Hill, 2008.
2. Taylor, R.A., Otanicar, T., and Rosengarten, G., Nanofluid-based optical filter optimization for PV/T systems, *Light: Sci. Appl.,* 2012, vol. 1, p. e.34.
3. Skoplaki, E. and Palyvos, J.A., On the temperature dependence of photovoltaic module electrical performance: a review of efficiency/power correlations, *Solar Energy,* 2009, pp. 614–624.
4. Hegazy, A.A., Comparative study of the performances of four photovoltaic/ thermal solar air collectors, *Energy Convers. Manage.,* 2000, vol. 41, pp. 861–81.
5. Bambrook, S.M. et al., Maximising the energy output of a PVT air system, *Solar Energy,* 2012, vol. 86, pp. 1857–1871.
6. Tingting Yang and Athienitis, A.K., A study of design options for a building integrated photovoltaic/thermal (BIPV/T) system with glazed air collector and multiple inlets, *Solar Energy,* 2014, vol. 104, pp. 82–92.
7. Kalogirou, S.A. and Tripanagnostopoulos, Y., Hybrid PV/T solar systems for domestic hot water and electricity production, *Energy Convers. Manage.,* 2006, vol. 47, pp. 3368–3382.
8. Hosseini, R., Hosseini, N., and Khorasanizadeh, H., An experimental study of combining a photovoltaic system with a heating system, in *Proceedings of World Renewable Energy Congress, 2011,* pp. 2993–3000.
9. Wei He, Yang Zhang, and Jie Ji, Comparative experiment study on photovoltaic and thermal solar system under natural circulation of water, *Appl. Therm. Eng.,* 2011, vol. 31, pp. 3369–3376.
10. Assoa, Y.B. et al., Study of a new concept of photovoltaic-thermal hybrid collector, *Solar Energy,* 2007, vol. 81, pp. 1132–1143.
11. Dubey, S. and Tiwari, G.N., Thermal modeling of a combined system of photovoltaic thermal (PV/T) solar water heater, *Solar Energy,* 2008, vol. 82, pp. 602–612.
12. Dubey, S. and Tiwari, G.N., Analysis of PV/T flat plate water collectors connected in series, *Solar Energy,* 2009, vol. 83, pp. 1485–1498.
13. Chow, T.T., A review on photovoltaic/thermal hybrid solar technology, *Appl. Energy,* 2010, vol. 87, pp. 365–379.
14. Charalambous, P.G., Maidment, G.G., Kalogirou, S., and Yiakoumetti, K., Photovoltaic thermal (PV/T) collectors: a review, *Appl. Therm. Eng.,* 2007, vol. 27, pp. 275–286.
15. Tyagi, V.V., Kaushik, S.C., and Tyagi, S.K., Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology, *Renewable Sustainable Energy Rev.,* 2012, vol. 16, pp. 1383–1398.
16. Jackson, E.D., Areas for improvement of semiconductor, solar energy convertors, in *Proceedings of the Conference on Use of Solar Energy, 1955,* pp. 122–126.
17. Moon, R.L., James, L.W., and vander Plas, H.A., Multigap solar cell requirements and the performance of AlGaAs and Si cells in concentrated sunlight, in *Proceedings of the 13th Photovoltaic Specialists Conference,* 1978, pp. 859–867.
18. Imenes, A.G. and Mills, D.R., Spectral beam splitting technology for increased conversion efficiency in solar concentrating systems: a review, *Sol. Energy Mater. Sol. Cells,* 2004, vol. 84, pp. 19–69.
19. Mojiri, A., Taylor, R., Thomsen, E., and Rosengarten, G., Spectral beam splitting for efficient conversion of solar energy – a review, *Renewable Sustainable Energy Rev.,* 2013, vol. 28, pp. 654–663.
20. Robert Taylor, A. et al., Nanofluid optical property characterization: towards efficient direct absorption solar collectors, *Nanoscale Res. Lett.,* 2011, vol. 6, p. 225.
21. Rosa-Clot, M., Rosa-Clot, P., and Tina, G.M., TESPI: thermal electric solar panel integration, *Solar Energy,* 2011, vol. 85, pp. 2433–2442.
22. Rosa-Clot, M., Rosa-Clot, P., Tina, G.M., and Ventura, C., Experimental photovoltaic-thermal Power Plants based on TESPI panel, *Solar Energy,* 2016, vol. 133, pp. 305–314.
23. Lanzafame, R. et al., Field experience with performances evaluation of a single-crystalline photovoltaic panel in an underwater environment, *IEEE Trans. Ind. Electron.,* 2010, vol. 57, pp. 2492–2498.
24. Taylor, R.A., Otanicar, T., and Rosengarten, G., Nanofluid-based optical filter optimization for PV/T systems, *Light: Sci. Appl.,* 2012, vol. 1, p. 34.
25. Joshi, S.S., Dhoble, A.S., and Jiwanapurkar, P.R., Investigations of different liquid based spectrum beam splitters for combined solar photovoltaic thermal systems, *J. Solar Energy Eng., ASME Trans.,* 2016, vol. 138, pp. 021003-1-6.