Research & Reviews: Journal of Pure and Applied Physics

e-ISSN:2320-2459
p-ISSN:2347-2316

Performance Evaluation of a Concentrator Photovoltaic System Cooled by an Optical Liquid Filter

Afef Jannen[1*], Monia Chaabane[1], Hatem Mhiri[1], Philippe Bournot[2]

[1]Laboratory of Thermal and Thermodynamic Industrial Processes, Department of Energy Engineering, National Engineering School of Monastir, Monastir University, Tunisia

[2]Aix Marseille University, CNRS, IUSTI, Marseille, France

Research Article

Received date: 16/06/2021

Accepted date: 12/07/2021

Published date: 22/07/2021

***For Correspondence**

Laboratory of Thermal and Thermodynamic Industrial Processes, Department of Energy Engineering, National Engineering School of Monastir, Monastir University, Ouardanine road, 5000 Monastir, Tunisia

E-mail: afef.jannen@hotmail.fr

Keywords: Concentrating Photovoltaic System (CPVS), CFD simulations, PV cooling, Optical liquid filter, OWF, Performance optimization

ABSTRACT

This paper presents a numerical investigation of a novel Optical Water Filter (OWF) integration in a Concentrator Photovoltaic System (CPVS). The OWF consists of a water layer placed on top of the PV module that serves as a solar spectrum splitter and a heat absorber. The water layer transmits the visible and a part of the infrared radiation, while filtering the ultraviolet and some of the infrared radiation which are not used by the PV cells. In this paper, numerical simulations were carried out for different filter's nature and dimension. Five water layers are considered, respectively 1 cm, 2 cm, 3 cm, 4 cm and 5 cm. Results showed the significant effect of the water layer thickness on the PV cell temperature and proved that the best total efficiency is obtained for the water thickness range of 3 cm to 5 cm for which it exceeds 50%. The article pointed out the effects of the inclination of CPVS and the solar irradiation for the different water thicknesses. It is shown that the filter does not change the known results of the CPVS but it influences the gain in electrical efficiency which can reach an average value of about 3%. Moreover; a comparison of the performance of different working fluids (propylene glycol, ethylene glycol, water and coconut oil) for the optical filter was performed and the results showed that water and coconut oil are found the best filters. The study presents also the concept of energy-saving efficiency to evaluate and to provide criterion for checking the overall performance of PVT systems. It is found that the energy-saving efficiency of optical filters with coconut oil exceeds 0.7 for higher thickness layers than 2 cm.

INTRODUCTION

As Researchers now a day are increasingly attracted to new sectors like photovoltaic energy; which has been found as the most appropriate alternative to meet the growing energy demands of the modern world. Despite the advantages of this technology, the temperature rises of the solar cells remain its major disadvantage as it causes a significant decrease of the system's efficiency. Moreover, the high operating temperature causes an irreversible degradation of PV cells in the long term. In recent years, a substantial amount of research has been dedicated to the investigation of new techniques presenting a better PV performance without the potential risk of cell damage.

Different solutions for reducing the operating temperature were proposed by specialized researchers who studied various cooling methods and systems. Arpin and Zhu discussed techniques to reduce the operating surface temperature of a PV model and proposed to integrate a transparent coating (photonic crystal cooling) placed on the top surface of the PV cells [1,2]. This topping is capable of reflecting the heat generated by PV cells in the form of infrared light back into space. Consequently, the PV cells are cooled as more photons are absorbed by the PV module. A PV panel cooled by transparent coating is so found as an economical solution that doesn't require an additional space for cooling unless the heat reflected into space is wasted and could be so used for other applications. Many authors like Huang, Sardarabadi and Hachem have discussed another technology which consists of using Phase Change Materials (PCMs) [3-5]. This process can reduce the operating temperature helping to reach a higher electrical efficiency. The hybrid solar photovoltaic/thermal panels are also a solution for cooling by the use of air or water as heat transfer fluid. Other investigations like Tiwari, Cao, Saygin and Kasaeian were interested to hybrid photovoltaic-thermal systems cooled by forced air circulation [6-9]. In this solar system; the heat produced by the PV panel is transferred to the air by convection which reduces the operating temperature of the PV module. Although the heated air is useful for building heating, water cooling is fund more effective than air cooling in hot climatic conditions. Wang have proposed other cooling techniques by coupling the PV conversion systems with a thermo-electric model (PV/TE) cooled by the heat sink [10]. The power collected from the module is dissipated in a resistance and stored in a battery. The experience results showed that this technology can reduce the PV temperature and that an important part of the waste heat can be used. Alrobaian studied the performance of the PV module by using geothermal cooling. Using this method, the PV surface temperature dropped up to 24.5% [11].

Water cooling technique or water immersion cooling has drawn the attention of many researchers in recent decades not only because of its high efficiency and cost effectiveness but also due to its environmental friendliness [12-16]. With this technique, a PV module is placed in a large water recipient, such as rivers, oceans, lakes, canals, etc. Water is used as an immersion fluid, which absorbs heat from the PV module and maintains the surface temperature of the PV module. Therefore, when the water absorbs the heat from the PV module the electrical efficiency increases. However, the analysis of its performance showed that its efficiency is very low; mainly during cloudy days.

The major problem resulting from the PV cell heating is that they can't convert all the incident solar radiation into electricity and an important part of the incoming radiation is so converted into heat. There are three types of solar radiation spectra Qahtan divided as follow: 8% of Ultraviolet UV (0.2 µm-0.38 µm), 36% of Visible VIS (0.38 µm-0.78 µm), and 46% of Infra-red IR (0.78 µm-2.5 µm) [17]. Silicon PV cells can only convert the visible and same of the infrared radiation into electricity; the rest of the spectrum is converted into heat. Chendo and Borden proposed the spectral beam splitting technology (method) to improve the performance of PV panels [18,19]. This process involves the decomposition of sunlight into discrete wavelength bands by a diachronic filter and showed that PV cell responds better and gives a higher efficiency.

Al-Shohani developed a new Optical Water Filter (OWF) placed on the top of the PV model and used it as a wave splitter [20]. An OWF, as its name suggests, is a filter which reflects, absorbs or and transmits in each wavelength. It can avoid the overheating of the photovoltaic cells by absorbing the waves outside of the interval (0.38 µm to 1.18 µm) and forming a window for incident radiation absorption by the PV cells.

In this paper; we present a numerical study of a novel optical water filter for a concentrator photovoltaic system CPVS. The novelty of this work is that this is a first CFD simulation of an optical filter in a real system. In addition, we propose a parametric study helping to evaluate the optimum filter' nature and dimension.

MODELING AND SIMULATION

Geometric Description and Meshing

In this paper, we propose an optimization of a concentrating photovoltaic system CPVS' performance by the addition of an optical filter. The numerical model is developed using the CFD package Ansys Fluent 16.0. For the CFD model validation; we are based on our CPVS experimental study of CPVS [21]. The CPVS consists of PV panel and a concentrator. **Figure 1** presents a description of the CPVS. The concentrator is made of stainless steel; it is 3.64 m long and 2 m wide. The PV panel is an STP020S12/cb panel of 18 single crystalline silicon solar cells. Based on previous experimental tests, the same dimensions, materials and properties of the experimentally investigated CPVS system are introduced for the CFD simulation [22]. The mesh generated in the entire field of this system, which is presented in **Figure 2**, consists of hexahedral cells. A grid independent study was also carried out and the optimum mesh size which was obtained with 960864 cells.

Numerical Simulation

Mathematical modeling

For the CPVS' simulation, the governing equations of mass, momentum and energy are solved. These equations can be written as follows:

- **The continuity equation:** $\frac{\partial \rho}{\partial t} + div(\rho \upsilon) = 0 \qquad (1)$
- **The momentum conservation equation:** $\frac{\partial(\rho \upsilon)}{\partial t} + \vec{\nabla}.(\rho \upsilon \upsilon) = -\vec{\nabla} P + \vec{\nabla}.\overline{\overline{\tau}} + \rho.g + F \qquad (2)$
- **The energy conservation equation:**

$$\frac{\partial(\rho.E)}{\partial t} + \vec{\nabla}.(\upsilon(\rho E + P)) = \nabla.(K_{eff} \nabla T - \sum_j hjJj + (\overline{\overline{\tau}}_{eff}.\upsilon)) + S_h \qquad (3)$$

Where ρ is the fluid density, υ is the vector of velocity in its 3D coordinates, P is the static pressure, $\overline{\overline{\tau}}$ is the stress tensor, (ρ.g) is The gravitational force, E is the energy transfer term, K_{eff} is the effective conductivity, F isthe external body force, h_j is the enthalpy of the species j, $\overline{\overline{\tau}}_{eff}$ is the viscous stress tensor, and S_h is the volumetric heat source, J_j is the diffusion flux of the species j. $Y_M + S_K$

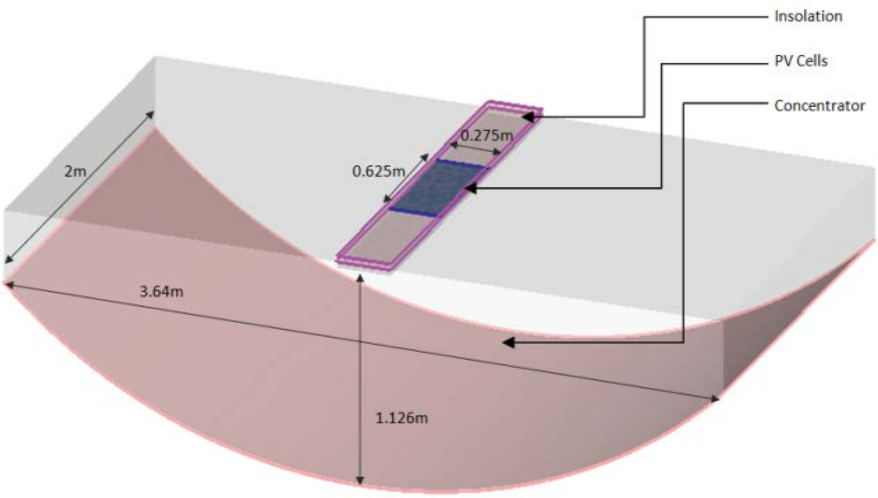

Figure 1. Description of the CPVS.

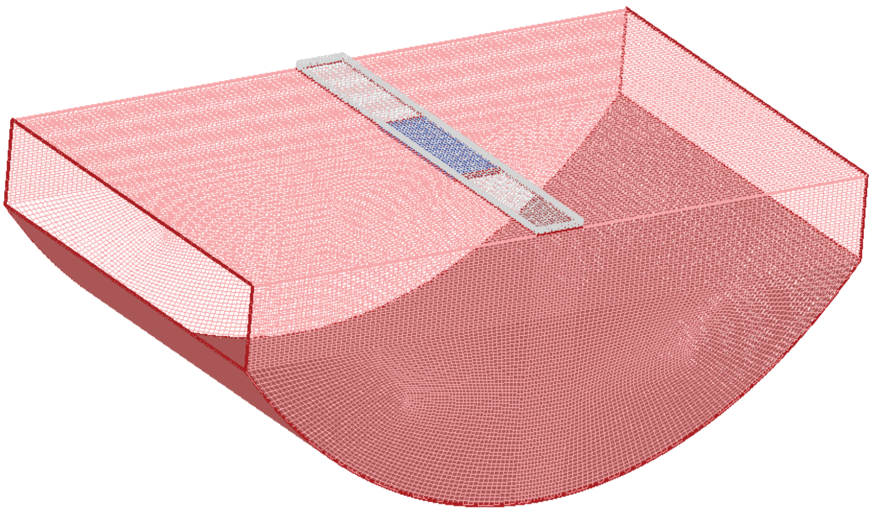

Figure 2. The gr id generated for the CPVS system.

Turbulence equations: The turbulence model used for closing this problem is the first order k-ε model. The turbulence kinetic energy and dissipation rate equations are written as follows:

$$\frac{\partial}{\partial t}(\bar{\rho}k)+\frac{\partial}{\partial x_i}(\bar{\rho}k\tilde{u}_\imath)=\frac{\partial}{\partial x_i}[(\bar{\mu}+\frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}]+G_k+G_b-\bar{\rho}\in+Y_M+S_K \quad (4)$$

$$\frac{\partial}{\partial t}(\bar{\rho}\varepsilon)+\frac{\partial}{\partial x_i}(\bar{\rho}\varepsilon\tilde{u}_\imath)=\frac{\partial}{\partial x_j}[(\bar{\mu}+\frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_j}]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\bar{\rho}\frac{\varepsilon^2}{k}+S_\varepsilon \quad (5)$$

where G_k is the generation of turbulence kinetic energy due to the mean velocity gradients, Gb is the generation of turbulence kinetic energy due to buoyancy, Y_M is the contribution of fluctuating dilatation in compressible turbulence to the overall dissipation rate, S_K, S are the source terms. The turbulence viscosity μ_t is computed by combining K and ε as follows:

$$\mu_t=\rho C\mu\frac{k^2}{\varepsilon} \quad (6)$$

- **The DO Model Equation**

The DO model considers the radiative transfer equation in the direction $\vec{s}$ as a field equation:

$$\frac{dI(\vec{r},\vec{s})}{ds}=-(a+\sigma_s)I(\vec{r},\vec{s})+a\left(\frac{\sigma T^4}{\pi}\right)+\frac{\sigma s}{4\pi}\int_0^{4\pi}I(\vec{r},\vec{s})\Phi(\vec{S},\vec{S}')d\Omega' \quad (7)$$

Here λ is the wavelength and a_λ is the spectral absorption coefficient.

Assumptions and Boundary Conditions

For the numerical resolution; The CFD package ANSYS is based on a finite volume method for these three-dimension equations resolution.

To solve these equations, the simplifying assumptions considered in this work are as follows:

- The fluid is incompressible
- Climatic conditions corresponding to fair weather conditions
- In the analysis of natural convection flaws, the fluid properties can be assumed constant except for the density change with temperature, which is considered for air

It is described by the Bossiness approximation and expressed as follows:

$$(\rho\text{-}\rho_{\circ}) = -\rho_{\circ}\beta(T - T_{\circ}) \quad (8)$$

The boundary conditions introduced in the CFD simulation are defined by the ambient temperature and solar radiation evolution. These parameters are taken from the experiments which have been conducted for a Tunisian Saharan climate, in the city of Tozeur, on the 31st of May 2012. The CPVS was south facing and 34° titled above the horizontal.

- The concentrator is defined as adiabatic wall: heat flux=0 w/m²
- The PV cells are defined as coupled which allows introducing both convective and radiant transfer in this surface
- The glass covering the PV cells is defined as mixed in order to take into account the convection and radiation heat transfer at this surface
- The external covering surface is defined as pressure outlet

Based on the cell temperature results it was possible to have different temperatures on the photovoltaic cells and to calculate the numerical efficiency using the photovoltaic efficiency formula defined by Swapnil Dubey [23]. Equation 9 represents the traditional linear expression for the PV electrical efficiency.

$$\eta_{pv} = \eta_{Tref}[1\text{-}\beta_{ref}(T_{pv}\text{ - }T_{ref})] \quad (9)$$

With: η_{pv} =Photovoltaic efficiency

T_{ref} =Reference temperature at the STC defined for a solar radiation of 1000 W/m². It is equal to 25°C.

η_{ref} =Photovoltaic performance at T_{ref}

$\beta_{ref} = 1/(T_{\circ} - T_{ref})$; $T_{\circ}$ is the temperature at which the electrical performance of the module falls to zero. For monocrystalline silicon, this temperature is chosen as $T_{\circ} = 270°C$.

NUMERICAL RESULTS

CFD Model Validation

Figure 3 shows a comparison between numerical and experimental results of the temporal evolution of the electrical efficiency of the CPVS. The results show a satisfactory agreement between numerical results and the experimental data, justifying

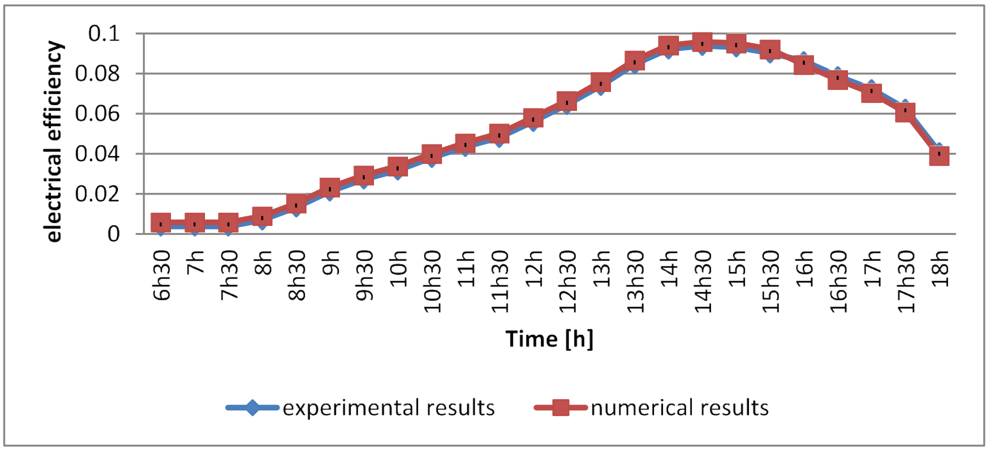

Figure 3. Numerical and experimental results of the temporal evolution of the electrical efficiency of the CPVS.

this model use to perform a parametric study. The next step consists on the CPVS' optimization by discussing different parameters' effect [22].

Investigation of a Concentrating Photovoltaic System CPVS with OWF

Based on the good agreement between our CFD results and the experimental data of the concentrating photovoltaic system CPVS; we propose a numerical investigation for this solar system performance' improvement. We study CPVS with an optical filter and discuss the effect of this layer addition on this solar system electrical efficiency.

The modeled optical water filter OWF consists of a glass tank with a cover having the same length and width as the PV module. The tank and cover are made of glass of 3 mm thickness and 91% transmittance. The width of water in the tank was also changed and the studied values are of 1 cm, 2 cm, 3 cm, 4 cm and 5 cm. In order to conclude the effect of the OWF on the solar cells temperature, the simulation was carried out with and without the optical filter under Standard Testing Conditions (STCs) (ambient temperature: Tamb=25°C, solar radiation: G=1000 W/m^2).

When we are using an non-gray radiation model like the DO, "The Gray-Band Absorption Coefficient" and "The Gray-Band reflection index" allow us to specify a different absorption coefficient and reflection Index in the materials panel for each one of the gray-bands previously defined. In this paper, we defined both the absorption coefficient and the reflection Index of the water with the help of values given by Hale and Buiteveld [24,25].

In order to compare the performance of cooled PV cell with the base PV system, relative percentage of cell temperature reduction was calculated as proposed by Baloch [25]:

$$\%T_{cell\ reduction} = (T_{cell,with\ cooling} - T_{cell,uncooled}) / T_{cell,uncooled} \quad (10)$$

The thermal efficiency η_{th} of the OWF system is computed as a function of solar radiation G, the initial temperature of the liquid in the spectrum filter Ti and the final temperature of the selected liquid in the spectrum filter T_f:

$$\eta_{th} = [m \times Cp \times (T_f - T_i)]/(G \times A) \quad (11)$$

Where A is the surface area of the filter (0.275 × 0.625) m^2 and Cp is the specific heat of the liquid at mean temperature and m is the mass flow rate of the liquid in kg/s.

Many researchers used the total efficiency η_{tot}, which is the summation of the thermal and electrical efficiencies respectively noted η_{th} and η_{pv} for evaluating PVT systems. It can be expressed as presented in reference Society [26]:

$$\eta_{tot} = \eta_{th} + \eta_{pv} \quad (12)$$

It is also known that electric energy is a high-grade form of energy since it is converted from thermal energy. Huang defined the energy-saving efficiency η_f as [27]:

$$\eta_f = \frac{\eta_{pv}}{\eta_{power}} + \eta_{th} \quad (13)$$

Where η_{power} is the electrical efficiency of a conventional power plant and its value can be taken as 0.38. The evaluation of energy-saving efficiency indicator also considers the quantity and the quality of the energy converted by PV/T system into solar energy. It has been fund by Huang that the daily efficiency for most solar hot water heaters with an low initial water temperature is around 0.50 [28]. This value provides a criterion for checking the overall performance of a PV/T system. It is expected that the energy saving efficiency for a PV/T system should exceed 0.50 in order to prove its effectiveness relatively to the conventional solar hot water system.

Effect of Filters with Different Water Layer Thicknesses on the CPVS with Different Water Layer Thicknesses

By following the similar numerical procedure than that considered for the CFD model validation, we investigate the effect of the water filter thicknesses on the CPVS's performance.

The PV performance (electrical efficiency, thermal efficiency, total efficiency and energy-saving efficiency) without and with the OWF is presented in **Figure 4**. It's remarkable that the performances of the CPVS are enhanced with the optical filter due to the avoidance of the negative impact of temperature on PV cells. Numerical result of the electrical efficiency without OWF shows a value if 12.55%, while the electrical efficiency of the PV with OWF of 1 cm, 2 cm, 3 cm, 4 cm and 5 cm water layer thickness is fund of 13.4%, 14.21%, 14.78%, 14.84%, and 14.89%, respectively. This rise in electrical efficiency, with the use of the OWF, is due to the reduction of the negative effect of the PV temperature on the system efficiency. This system presents also the advantage of an important thermal efficiency, which is fund of 22.5%, 25.6%, 28.02%, 29.9%, and 31.1% for the water layer thickness of 1 cm, 2 cm, 3 cm, 4 cm and 5 cm, respectively. **Figure 4** also shows the energy-saving efficiency of the OWF which takes the values of

e-ISSN:2320-2459
p-ISSN:2347-2316

45.44%, 53.84%, 63.39%, 64.42%, and 66.5% for water layer thickness of 1 cm, 2 cm, 3 cm, 4 cm, and 5 cm, respectively. The analysis of this figure results also shows that the Energy-saving efficiency for a PV collector with an OWF and a water thickness of more than 3 cm exceeds 60%, which is higher than the value obtained with a conventional solar thermal collector.

The temperature contours are also presented in **Figure 5** for across section and near the studied OWF system. The analysis of these contours shows that the OWF use results in a decrease of PV temperature; mainly for high thicknesses and allows a more uniform temperature profile.

Effect of the Inclination on the Performance of CPVS with OWF

In this part of the paper, we study the influence of the inclination on the performance of the panel. The inclination is the slope of the module with respect to the horizontal (measured in °: a 90° angle means that the module is horizontal and an inclination of 0° means that the module is vertical). Actually, we model four slopes: 90°, 60°, 45° and 30°, for a radiation of 1000 W/m^2. **Figure 6** shows the positioning of the panel relative to the horizontal plane and the angle of the inclination.

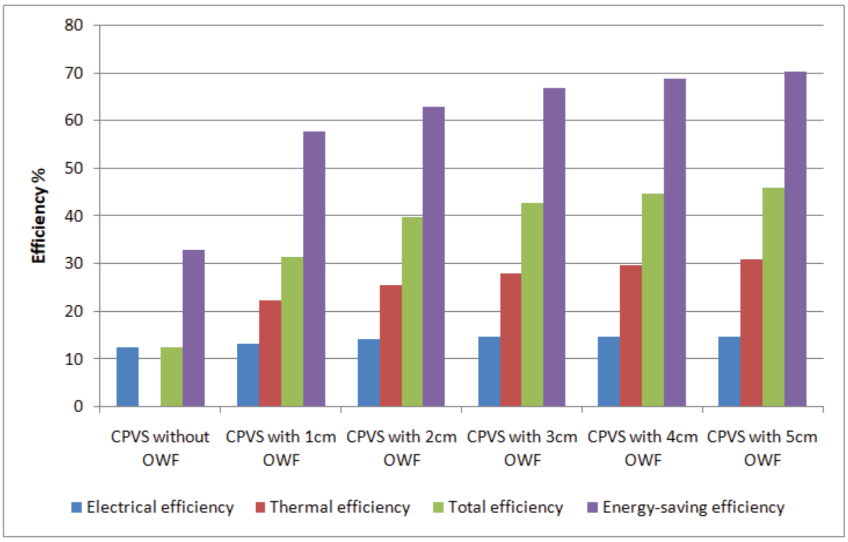

Figure 4. Numerical performance of the CPVS-OWF.

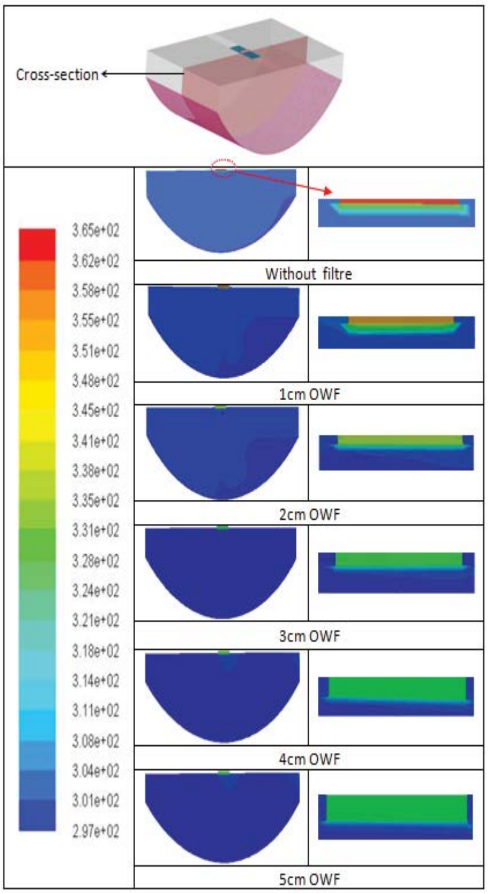

Figure 5. Temperature contours of the CPVS-OWF with different water layer thicknesses.

In **Figure 7**, we show the variation of the Electrical efficiency as a function of the inclination with different thickness of the optical filter. From these results, we note that the efficiency of photovoltaic cells is optimal when the plane of the photovoltaic cells is perpendicular to the sun: it is the case for the inclination of 90°. The inclination of the solar panels greatly influences the final yield since it is the factor on which the reception of the Sun's rays depends. For best performance, the angle of incidence should be 90°. Changing the inclination of the CPVS with the optical filter influences the gain, but the optimum thickness of OWF is still the same, corresponding to the highest value.

Effect of Filter with Different Solar Irradiation

Figure 8 presents numerical results of the variation electric efficiency with the solar global radiation and the thickness of the optical filter. The considered solar fluxes are 200 W/m², 400 W/m², 600 W/m², 800 W/m² and 1000 W/m². We note that the optimal electrical performance corresponds to a solar flux of 600 W/m². When solar radiation reaches 1000 Wm^{-2}, it causes an increase in temperature of the photovoltaic cells and consequently a remarkable decrease in photovoltaic efficiency. The analysis of the electrical efficiency of CPVS also shows that optical filter presents the best performance for higher thicknesses then 3 cm, expecting an average gain of 2.8% relatively to the solar system without filter.

Investigations of Different Liquid Optical Filters

It is required to use PVT systems with spectrum filters for their suitability in application where both the hot water and electricity are produced. The material choice has a vital role in the PVT system performance. There are many considerations while selecting the material for the filter. Water and air are the most popular candidates as cooling medium in PVT systems. Many phase change materials can also be used in PVT systems. Sathe described some of prominently used PCMs in PVT systems [29]. Filtering systems with optical spectrum filters are emerging nowadays. There is a wide scope for investigations of different liquids as spectrum filters and heat absorbers for optical liquid filter systems. Different nanofluids and heat transfer fluids are not that much explored in PVT systems yet. Taylor demonstrated that nanofluids are efficient, compact and potentially low-cost as spectrally

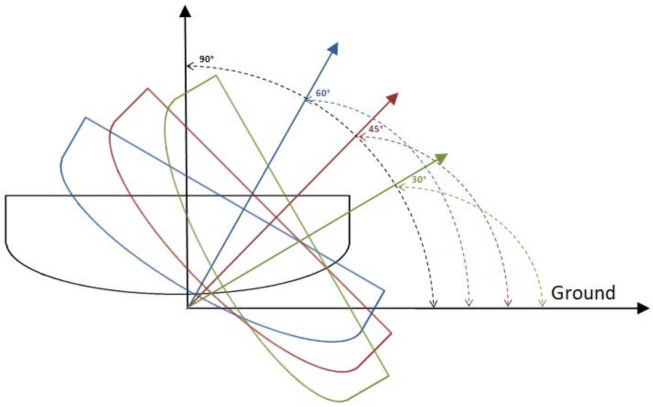

Figure 6. Positioning of the panel relative to the horizontal plane.

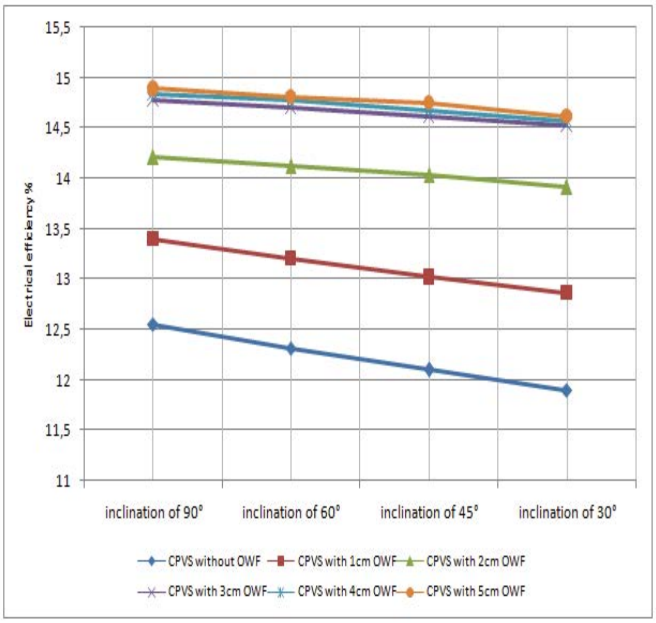

Figure 7. Electrical efficiency of the CPVS with different inclinations and thicknesses of OWF.

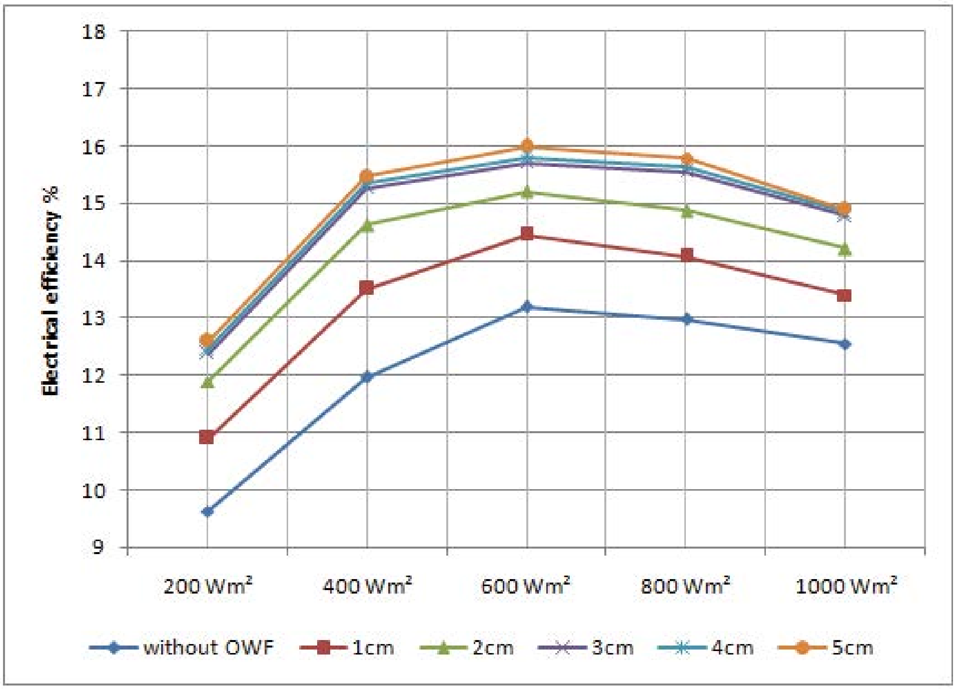

Figure 8. Electrical efficiency of the CPVS with different solar global radiation and thicknesses of OWF.

selective optical filters [30]. Otanicar studied optical properties of four liquids (water, ethylene glycol, propyleneglycol and therminol VP-1) commonly used in solar energy applications [31]. Joshi also suggested different ideas of systems with a selection of easily available transparent liquids (water, coconut oil, Al_2O_3 Nanofluid, siliconoil) [32].

To determine which filter should be constructed, we should take care offour aspects: optical properties (absorption spectrum, transmission spectrum), aging effect which is related to the effect of continuous exposure to sunlight, thermal properties (heat capacity, viscosity, flammability) and economical aspects (easily available, inexpensive for large-scale commercial application).

In the present work, we are studying a selection of 4 liquids: water, ethylene glycol, propylene glycol and coconut oil to act as a spectrum filter for the PV system, offering so a better electrical performance. In addition to being the first CFD simulation of such a solar system; this numerical study helps to evaluate the performance of these different fluids and to investigate which one is the most suitable for this type of applications. The corresponding fluid allows so extracting the heat from the PV cells and maintaining the operating temperature as low as possible. The thermo-physical properties of the selected fluids are presented in **Table 1**.

By following the similar numerical procedure than that considered for the CFD model validation, we investigate the effect of the liquid nature for the considered optical filter. The absorption coefficient and the reflection index of the different selected liquids introduced for the numerical simulation are those given by Hale, Buiteveld, Sani, Taylor and Joshi [23,24,30,33,34].

Numerical results of the temperature reduction of the selected liquids with different liquid layer thicknesses are presented in **Figure 9**. As shown in the first part of this paper, for all the considered liquids, there is a significant reduction in the PV cell's temperature when the filter thickness is varied from 1 cm to 3 cm. But for higher thickness layers more than 3 cm, 4 cm and 5 cm, we obtained practically the same effect on the temperature reduction. It can be seen that compared to the empty filter, the water and coconut oil filters show the best temperature reduction while a lower decrease is obtained with ethylene glycol and propylene glycol filters. This is mainly due to their particular thermo-physical properties like their high thermal conductivity which is an essential criterion for heat transfer enhancement as well as their important specific heat.

Electrical efficiency, thermal efficiency, total efficiency and energy-saving efficiency of the PV filter for all selected liquids with different water layer thicknesses are presented in **Figure 10**. The analysis of these results shows that the performances of Ethylene glycol and Propylene glycol PV filter are very similar to each other and their performance is lower compared to that of the other PV liquid filters. This can be explained by the low solar-weighted absorption coefficient of these two glycol fluid as well as their particular characteristics as they are visibly clear and absorb less energy in the visible band where the largest portion of solar energy is concentrated. On the other hand, coconut oil presents the best solar energy absorption potential because it absorbs heat in UV and IR regions, which is immensely desirable for PV cells. Which allow us to conclude the influence of the optical behavior of the fluid on the spectral beam filter for the entire solar illumination (PV band and thermal band) on the thermo-electric performance of the CPVS.

The present study introduces the concept of energy-saving efficiency to evaluate and provide criterion for checking the overall performance of PVT systems. The energy-saving efficiency of an optical filter with coconut oil exceeds 0.7 for high thickness layers (higher than 2 cm) which is higher than that of the other liquids (propylene glycol, ethylene glycol and water). These results

e-ISSN:2320-2459
p-ISSN:2347-2316

Table 1. Thermophysical properties of selected liquids.

Name of the fluid	Density [kg.m^{-3}]	Specific heat (Cp) [kJ. kg^{-1} K^{-1}]	Thermal conductivity [W.m^{-1}K^{-1}]
Water	998.2	4182	0.6
Ethylene glycol	1111.4	2415	0.252
Propylene Glycol	1.7	1440	0.0168
Coconut oil	916	3508	0.321

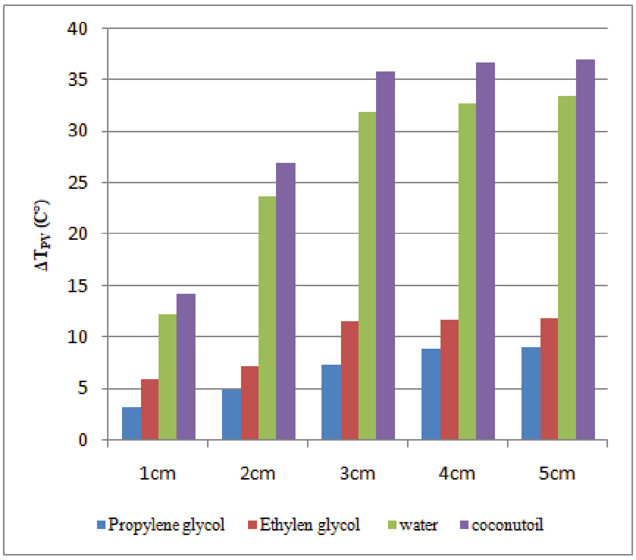

Figure 9. Temperature reduction in CPVS with selected optical liquids and liquid layer thicknesses.

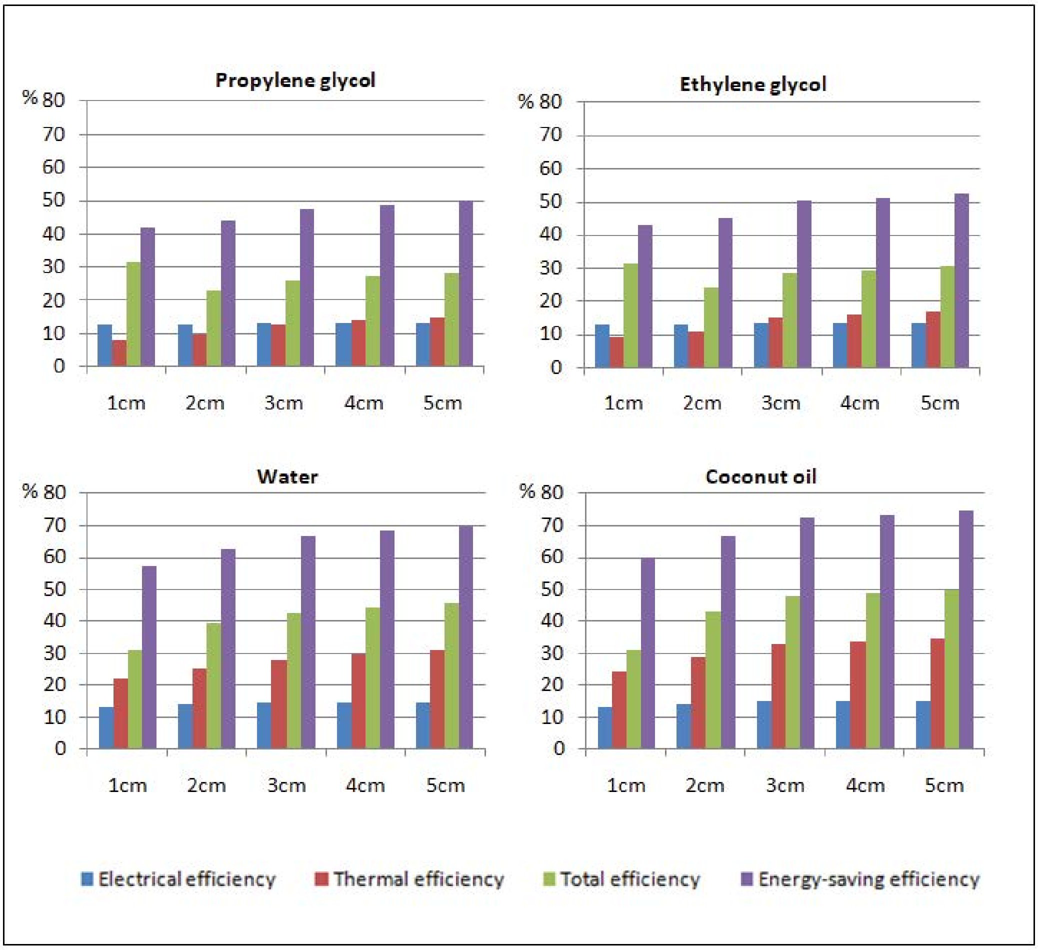

Figure 10. Performances of the CPVS for the selected optical liquids with different liquid layer thicknesses.

clearly show the advantages of this liquid choice as a filter for the PV system performance optimization.

From previous results, the propylene glycol and ethylene glycol are found less efficient as heat transfer fluids than water and coconut oil. But this can probably be modified by introducing nanoparticules in the liquid filter. In future work, we will look to demonstrate how the addition of nanoparticules to the optical liquid filter can enhance the performance of PVT systems.

CONCLUSION

This paper is devoted to the numerical investigation of an optical water filter used on a concentrator photovoltaic system. The simulations of the CPVS-OWF were carried out for different water thicknesses 1 cm, 2 cm, 3 cm, 4 cm and 5 cm. Results showed a significant decrease of the PV module's temperature for thicknesses up to 3 cm and a negligible reduction above this value. As per the PV's performance, the use of OWF proved to be extremely beneficial since it resulted in a rise of the electrical, thermal and energy-saving efficiencies.

The article pointed out different effects associated with the thickness of the OWF (inclination of CPVS, solar radiation). The filter does not change the known results of the CPVS but it influences the gain in electrical efficiency. Also investigations of different working fluids combined with different fluid layer thicknesses were proposed. Compared to the reference case (without filter), the best performance was obtained by using Coconut oil and water, which allowed the highest temperature reduction, providing so better electrical performance compared to ethylene glycol and propylene glycol.

REFERENCES

1. Arpin KA, et al. Three dimensional self-assembled photonic crystals with high temperature stability for thermal emission modification. Nat Commun. 2013;4:2630.
2. Zhu L, et al. Radiative cooling of solar cells. Optica. 2014;1:32-38.
3. Huang MJ, et al. Phase change materials for limiting temperature rise in building integrated photovoltaics. Sol Energy. 2006;80:1121-1130.
4. Sardarabadi M, et al. Experimental study of using both ZnO/water nanofluid and Phase Change Material (PCM) in photovoltaic thermal systems. Sol Energy Mater Sol Cells. 2017;161:62-69.
5. Hachem F, et al. Improving the performance of photovoltaic cells using pure and combined phase change materials-experiments and transient energy balance. Renew Energy. 2017;107:567-575.
6. Tiwari A, et al. Performance evaluation of photovoltaic thermal solar air collector for composite climate of India. Sol Energy Mater Sol Cells. 2006;90:175-189.
7. Cao C, et al. Research on PV/T-air source heat pump integrated heating system in severe cold region. Procedia Eng. 2016;146:410-414.
8. Saygin H, et al. Performance evaluation of a modified PV/T solar collector: A case study in design and analysis of experiment. Sol Energy. 2017;141:210-221.
9. Kasaeian A, et al. Effects of forced convection on the performance of a photovoltaic thermal system: An experimental study. Exp Therm Fluid Sci. 2017;85:13-21.
10. Wang R, et al. Parameterization investigation on the microchannel heat sink with slant rectangular ribs by numerical simulation. Appl Therm Eng. 2018;133:428-438.
11. Abdulrahman A, et al. Performance of PV panel coupled with geothermal air cooling system subjected to hot climatic. Appl Therm Eng. 2019;148:1-9.
12. Abrahamyan Yu A, et al. The efficiency of solar cells immersed in liquid dielectrics. Solar energy materials and solar cells. 2002;73:367-375.
13. Xiang H, et al. 3D numerical simulation on heat transfer performance of a cylindrical liquid immersion solar receiver. Energy Convers Manag. 2012;64:97-105.
14. Clot MR, et al. Submerged PV solar panel for swimming pools: SP3. Energy Procedia. 2017;134:567-576.
15. Sun Y, et al. Direct liquid-immersion cooling of concentrator silicon solar cells in a linear concentrating photovoltaic receiver. Energy. 2014;65:264-271.
16. Han X, et al. Electrical and thermal performance of silicon concentrator solar cells immersed in dielectric liquids. Appl Energy. 2011;88:4481-4489.
17. Qahtan A, et al. The effectiveness of the sustainable flowing water film in improving the solar-optical properties of glazing in the tropics. Energy Build. 2014;77:247-255.
18. Chendo MA, et al. Analysis of spectrally selective liquid absorption filters for hybrid solar energy conversion. Opt Mater Tech Energy Eff Sol Energy Conver. 1985;160:160-165.
19. Borden PG, et al. Design and demonstration spectrum splitting photovoltaic concentration module. Sandia Report SAND. 1982.
20. Al Shohani WAM, et al. Reducing the thermal load of a photovoltaic module through an optical water filter. Appl Therm Eng. 2016;109:475-486.

e-ISSN:2320-2459
p-ISSN:2347-2316

21. Chaabane M, et al. Performance evaluation of concentrating solar photovoltaic and photovoltaic/thermal systems. Sol Energy. 2013;98:315-321.

22. Dubey S, et al. Temperature dependent Photovoltaic (PV) efficiency and its effect on PV production in the world: A review. Energy Procedia. 2013;33:311-321.

23. Hale GM and Querry MR. Optical constants of water in the 200 nm to 200 µm wavelength region. Appl Optics. 1973;12:555.

24. Buiteveld H, et al. 1994. Optical properties of pure water. SPIE Ocean Optics XII. 1994;2258:174-183.

25. Baloch AAB, et al. Experimental and numerical performance analysis of a converging channel heat exchanger for PV cooling. Energy Convers Manag. 2015;103:14-27.

26. International Solar Energy Society. ISES solar world congress 1987: Advances in solar energy technology. 1987.

27. Huang BJ, et al. Performance evaluation of solar photovoltaic/thermal systems. Sol Energy. 2001;70:443-448.

28. Huang BJ. Performance rating method of thermosyphon. Sol Energy. 1993;50:435-440.

29. Sathe TM and Dhoble AS. A review on recent advancements in photovoltaic thermal techniques. Renew Sustain Energy Rev. 2017;76:645-672.

30. Taylor RA, et al. Nanofluid based optical filter optimization for PV/T systems. Light Sci Appl. 2012;1:1-7.

31. Otanicar TP, et al. Optical properties of liquids for direct absorption solar thermal energy systems. Sol Energy. 2009;83:969-977.

32. Joshi SS, et al. Investigations of different liquid based spectrum beam splitters for combined solar photovoltaic thermal systems. J Sol Energy Eng. 2016;138:021003.

33. Joshi SS. Use of silicone oil and coconut oil as liquid spectrum filters for bspvt: With emphasis on degradation of liquids by sunlight. 2017;140:1-9.

34. Sani E and Dell'Oro A. Optical constants of ethylene glycol over an extremely wide spectral range. Opt Mater. 2014;37:36-41.