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Water cooling film design to reduce surface temperature of PV module

Rahool Rai[1,2] | Mahesh Kumar[1] | Asad A. Zaidi [1*] | Fareed Hussain Mangi[2] | Kashif Ahmed[1] | Ziaullah Khan[2]

[1]Department of Mechanical Engineering, Faculty of Engineering Sciences and Technology, Hamdard University, Karachi, 74600, Pakistan

[2]Department of Electrical Engineering Sukkur Institute of Business Administration (SIBA), Sindh, Pakistan

Correspondence
Asad A. Zaidi, Hamdard University, Karachi, Pakistan
Email: asad.zaidi@hamdard.edu.pk

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ABSTRACT. Solar energy is the most available solution being used worldwide but at present the commercial Photovoltaic (PV) module is only limited to 19% efficiency, this efficiency is further reduced to 10-16% due to rise in temperature at the mid-day time. Current study focuses on the reduction of the temperature of the PV module by using CFD analysis using water at the front surface of the PV module. For the simulation front glass specifications are considered with laminar flow of water. Different thickness of water film and varying Reynolds number has been analyzed. In this regard, 10 Reynolds number ranging from 5 to 50 and 10 different thicknesses ranging from 5mm to 50mm were studied. It was concluded that the maximum change in temperature was at the water film thickness of 5mm and Reynolds number 10.

keywords: PV Module Efficiency; water film thickness, optimum Reynolds number, CFD Analysis, temperature reduction.

RESUMEN. La energía solar es la solución más disponible utilizada en todo el mundo, pero en la actualidad el módulo fotovoltaico (PV) comercial solo tiene una eficiencia limitada al 19%, esta eficiencia se reduce aún más al 10-16% debido al aumento de la temperatura al mediodía. El presente estudio se centra en la reducción de la temperatura del módulo fotovoltaico mediante el análisis CFD utilizando agua en la superficie frontal del módulo. Para la simulación se consideran las especificaciones del vidrio frontal con flujo laminar de agua. Se analizó el espesor de la película de agua y la variación del número de Reynolds. Se concluyó que el máximo cambio de temperatura se produjo con un espesor de película de agua de 5 mm y un número de Reynolds de 10.

Palabras clave: Eficiencia del módulo fotovoltaico, espesor de la película de agua, número de Reynolds óptimo, análisis CFD, reducción de temperatura.

*Corresponding Author: asad.zaidi@hamdard.edu.pk

1 | INTRODUCTION

Pakistan is fronting a severe power scarcity, resulting in a forced blackout of 8 to 12 hours per day in metropolitan areas over the past decade, up to 18 hours in rural regions [1], [2]. The main motive for increasing gap in the supply and demand is the increase in electricity demand and the depletion of energy resources and economic constraints. For this scenario, the government has engaged various measures, including partial reformation of the power segment in accordance with the guidance of international financial institutions [3], [4]. Therefore, at present, apart from facing the severe challenges of meeting electricity demand, country is also confronting for ensuring energy security in the context of essence of global climate change concerns . However, as we face micro climate change and the speedy diminution of existing energy possessions, the energy literacy of all citizens is fundamental to far sight future trends and transformations [5]. To overcome this fatal problem, researchers are transforming to sustainable, reliable and pollution free resources. Utilization of Solar has replaced with coal based power plants to grasp its great potential [6].

Due to standard set for the maximum power output for a solar, set at 25 oC, 5% loss in the PV panel performance occur with the increase of 1 oC on the surface of PV Panel [7], [8]. Experimental analysis of a system, having parallel duct array with defined inlet and outlet for the distribution of airflow at the back of panel, was conducted and found the results with the relation whose trend was varying linearly between efficiency and temperature. The author found efficiency 8-9% without cooling and 12-14 % with cooling system [9], [10]. In a systematic study of PV Panel by introducing a Heat sink at the back of the PV module using Ansys (Fluent) for simulation. With the temperature of 56oC at the surface of the PV module only 86 % of the maximum power of standard was achieved. Besides with the reduction of 10oC temperature at surface of the PV module, 4 % efficiency was increased [11], [12].

Ashish Saxena *et al* [13] performed a laboratory based experiment, in which he allowed water to flow over the surface of (PV) panel with two different operations of pump: intermittently and continuously at multiple flow rates. He carried out intermittent cooling at 3 different flow rates which showcased a total gain of 18 % energy against no cooling. Moreover, He observed that for continuous cooling the temperature of water is assumed to be 25oC and flow is controlled at $0.6lit/min$ for low consumption of water and power. Since Martin Raju *et al* [14] in his paper have discussed in detail by proofs that optimum flow rate over the photovoltaic was $170L/h$. It was the flow where PV produced maximum electrical efficiency. He validated his model through experimental analysis and he found that volume fraction influences the efficiency of PV module.

The main objective of this study was to reduce the surface temperature and enhance the efficiency of photovoltaic module through Ansys Fluent Software for laminar flow. Geometry and meshing were created by using ANSYS Workbench R2019.By changing various Reynolds number, consequently varying thickness of flow Therefore, in the first a water film was decided with optimal thickness to achieve surface temperature around 20-25 oC. In the second an optimum flow parameter (i.e. Reynolds Number) was to be proposed for maximum heat transfer between water and the PV module glass.

2 | DESIGN AND METHODOLOGY

2.1 | Computational fluid dynamics (CFD)

Computational Fluid Dynamics, its acronym CFD, has become a rapidly adopted practice to solve complex problems in modern age of Engineering and Technology [15] [16], [17]. CFD has been driven from the discipline of heat transfer and fluid mechanics. It has reduced cost and optimized the operation of the equipment which has resulted in improved efficiency through computational simulation [18], [19], [20]. It is a multi-disciplinary tool which is evolved by fluid mechanics, mathematics and computer science. The dedication of CFD is only for the fluids that are in motion. Numerical simulations of any fluid flow falls under the umbrella of computational part [21].

2.2 | Geometrical Drawing and Meshing

All the models with different geometrical specifications are designed in space claim, a built in design tool in CFD (Fluent) to sketch the 3D drawing as shown in Figure 1. A thin plate (Glass) of the Photovoltaic (PV) panel was sketched with the thickness of 3.4mm. However, a duct like rectangle was also developed.

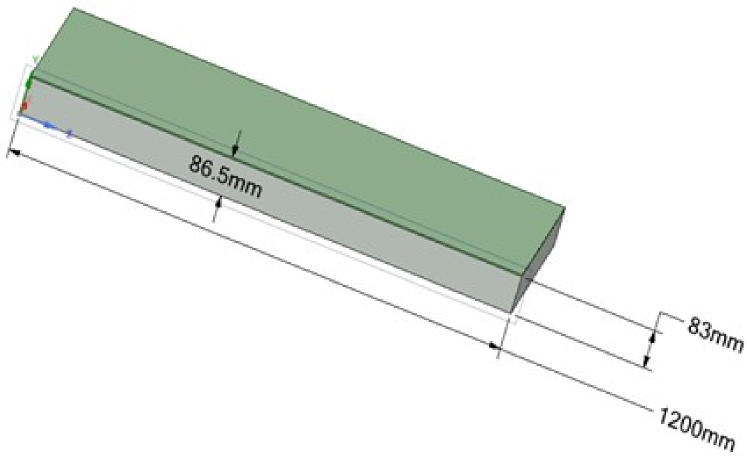

FIGURE 1 Solid Model of Glass with duct

2.3 | 3D Model Meshing

It is the most important step in CFD which comes after the geometry. In this phase basically, cells are designed on which the flow variables are calculated in a computational sphere. There exist different shapes of cells, such as (Triangle, Quadrilateral, tetrahedrons, hexahedron etc.) Fine mesh was adopted of 5mm. The structure mesh of 3D model is shown in Figure 2.

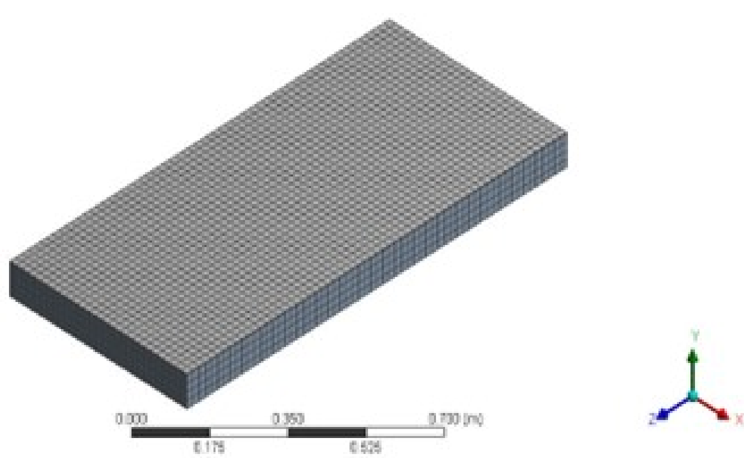

FIGURE 2 Structure Mesh of the 3-D model

Fourier's Law of Thermal Conduction (Eq. 1) and Newton's Law of Cooling (Eq. 2) were the basic equations to be considered for the heat transfer from PV module glass to water (Coolant) where k is thermal conductivity, A is area, T is temperature and h is the convective heat transfer coefficient. However, following parameters for the glass were considered as a standard to calculate heat transfer. Table 1 showing data for the glass.

$$q_k = -kA\frac{dT}{dx} \tag{1}$$

Eq. 1. Fourier's Law of Thermal Conduction.

$$q = hcA\Delta T \tag{2}$$

Eq. 2. Newton's Law of Cooling.

TABLE 1 Properties of Glass and Water [22]

Material	Thermal Conductivity (W/m·K)	Density ρ (kg/m^3)	Specific Heat Capacity (J/kg·K)	Temperature T (K)
Glass (solid)	1.8	3000	500	50
Water (liquid)	0.6	998.2	4182	25

2.4 | Input Variables

Velocity is considered as the most viable and changing input variable which is directly affected by the flow rate. Keeping in mind that the temperature at surface of the glass is constant, which is 323K. While Velocity is affected by the variation of Reynolds number. Therefore, velocity was taken as an input variable, calculated at different Reynold's number ranging from 5 to 50.

2.5 | Calculations

Meanwhile, considering the velocity as main input variable, it was observed that the glass and duct over the glass was rectangle. So, the hydraulic diameter was taken in the Reynolds number formula and calculations were calculated as given in Table 2 and these calculations were carried out by the equation (3).

$$D\neg h = \frac{2ab}{a+b} \tag{3}$$

Eq. 3. Work equation where "a" is the thickness of water film and "b" is width of the water film/ PV module.

2.6 | Numerical Analysis

The intended geometry was meshed and allowed for the simulation in Ansys Fluent Academic Version V19R2. For the current geometry Laminar flow was taken due to transparency over the PV module surface for maximum conversion of irradiance into electrical energy. So, the model was solved using Energy Equation Eq. (4) [23], [24] on steady state condition.

TABLE 2 Hydraulic Diameter

Dh (Hydraulic Diameter)	a	B
m	m	M
0.0918	0.05	0.56
0.08331	0.045	0.56
0.07467	0.04	0.56
0.06588	0.035	0.56
0.05695	0.03	0.56
0.04786	0.025	0.56
0.03862	0.02	0.56
0.02922	0.015	0.56
0.01965	0.01	0.56
0.00991	0.005	0.56

$$\begin{aligned}\frac{\partial}{\partial t}\left[\rho\left(e+\frac{V^2}{2}\right)\right]+\nabla\cdot\left[\rho\left(e+\frac{V^2}{2}\right)\vec{V}\right]\\ =\rho\dot{q}+\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)-\frac{\partial up}{\partial x}-\frac{\partial vp}{\partial y}-\frac{\partial wp}{\partial z}\\ +\frac{\partial u\tau_{xx}}{\partial x}+\frac{\partial u\tau_{xy}}{\partial y}+\frac{\partial u\tau_{zx}}{\partial z}+\frac{\partial v\tau_{yx}}{\partial x}+\frac{\partial v\tau_{yy}}{\partial y}+\frac{\partial v\tau_{yz}}{\partial z}+\frac{\partial w\tau_{zx}}{\partial x}\\ +\frac{\partial w\tau_{zy}}{\partial y}+\frac{\partial w\tau_{zz}}{\partial z}+\rho\vec{f}\cdot\vec{V}\end{aligned} \tag{4}$$

Eq. 4. Energy equation on steady state condition where e is the specific energy, p is pressure, u, v and w, are velocity components in the x ,y and z direction, respectively.

3 | RESULTS & DISCUSSION

3.1 | Maximum Heat transfer

The calculations were performed On ANSYS FLUENT software at different Reynolds number ranging from 5 to 45 as shown in Table 3. Geometry and meshing was done with the help of ANSYS workbench. Water was used as a fluid and solid was modeled as Glass of photovoltaic. The flow was modeled as laminar and incompressible. Because of incompressible flow the solver was used as pressure based in ANSYS fluent. Then calculations were run on various Reynolds numbers. It was observed that with the increase of Reynold number the change in temperature also increases. However, From $Re = 35$ the change in temperature becomes constant as clearly visible in Table 3. Therefore, the value of Reynold is suggested as 35 at hydraulic diameter 0.04786 for maximum heat transfer.

3.2 | Optimum Thickness of film

After calculating optimum Reynold number 35, for maximum heat transfer. Secondly the optimum thickness was calculated. For the calculation of optimum thickness, different values of thickness were taken ranging from 5 to 50 mm. On the basis of thickness hydraulic diameter was calculated. Change in temperature between inlet and outlet was calculated on different thickness values as shown in figure 3. It can be observed from

TABLE 3 Heat transfer Vs Reynolds number

Dh (Hydraulic Diameter)	Velocity (m/s)	ΔT (K)	Reynolds Number
0.0918	2.0202	2.2398	5
0.08331	4.040404	2.2405	10
0.07467	6.060606	2.2408	15
0.06588	8.080808	2.2409	20
0.05695	10.10101	2.241	25
0.04786	12.12121	2.241	30
0.03862	14.14141	2.2411	35
0.02922	16.16162	2.2411	40
0.01965	18.18182	2.2411	45

figure 3 that the maximum change in temperature occurs at 5 mm thickness of water. Moreover, as the value of thickness is increased the change of temperature is decreased. Which is also visible in contours as shown in Figures 4, 5 and 6. The maximum heat transfer occurs at $Re = 35$ and $thickness = 5mm$ in comparison to $Re = 30$, $thickness = 30mm$. Therefore, it has been selected as optimum value of Reynold and optimum value of thickness.

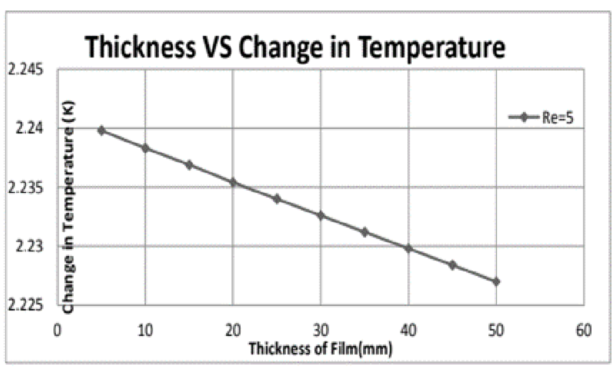

FIGURE 3 Thickness vs Change in temperature.

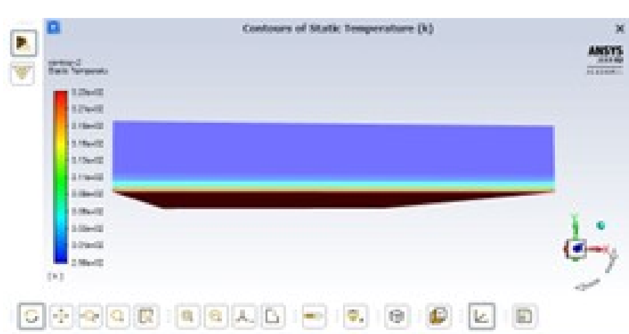

FIGURE 4 Contour at Re=30 a=30mm

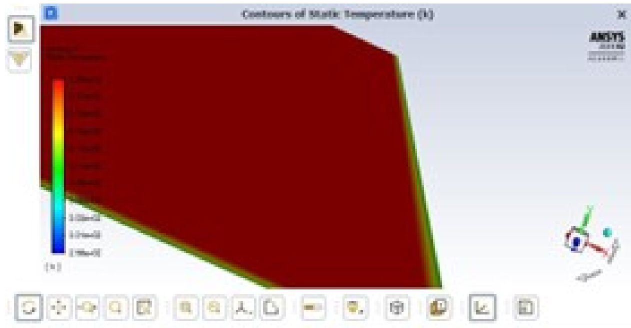

FIGURE 5 Contour at Re=35 a=5mm

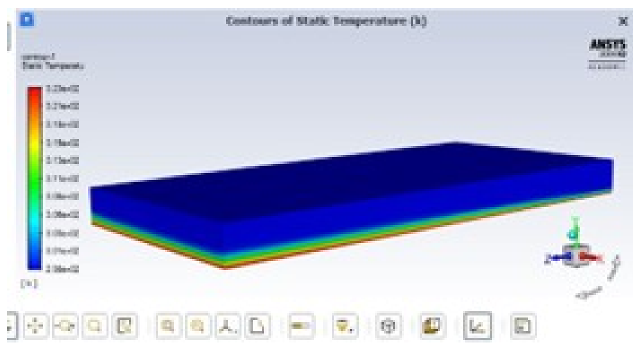

FIGURE 6 Re=5 a=35mm

4 | CONCLUSION

Cooling of PV module is taking place rapidly to increase its performance in general and electrical output in particular. While different methods are adopted to reduce its working temperature when operated in mid days at maximum temperature. Surface temperature (Heat generated from irradiance) is extracted by using water as a cooling opponent above its front transparent glass. The flow of water was controlled by using basic formula of Reynolds number and hydraulic diameter. Finally, it was observed that the maximum change in temperature was at Re = 35 and film thickness a = 5mm. Therefore, the film design is suggested for the thickness of 5mm and Reynolds number at 35.

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