AIR COOLING OF PHOTOVOLTAIC PANELS: A NUMERICAL APPROACH

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ABSTRACT: It is well known that high temperatures affect in a negative way the performance of PV Silicon modules. There are several ways of decreasing the modules temperature by external cooling, therefore increasing its performance: water and air cooling. Although we are interested in studying the way that the PV module transfers heat to the external cool water while it approaches its optimum working temperature, this work is a first step towards developing the digital tools to study water cooling of PV roof installations. The model, which is a fine modeling, studies the cooling of a PV panel by air in two different cases of convection: natural cooling in a cool environment and forced cooling with wind. The numerical simulations show the efficient heat transfer between the PV panel (modeled by a glass plate) and ambient air. We use the Navier-Stokes equations coupled with the heat equation, using the Boussinesq approximation to take into account the thermal variation of density. This allows us to take into account the varying parameters as temperature, wind speed and inclination of panel (gravity). The simulations show that the most efficient regime for free convection is when the module is not perpendicular to gravity direction. The efficiency increases with the wind speed. The most efficient case is obtained when the wind is parallel to the panel.
Keywords: Modelling, Heat transfer, Cooling, Silicon modules, Photovoltaic Panels

1 INTRODUCTION

The performance of a PV system depends on several parameters including temperature. It is well known, that the part of absorbed solar radiation that is not converted into the electricity converts into thermal energy and causes a decrease in electrical efficiency. This efficiency can be improved if panel temperature is reduced by cooling (i.e. Si-based PV modules can increase their power output by ~0.45%/K) [1-3]. This problem has been deeply studied in past years developing different cooling approaches to reduce the modules temperature to an optimal performance value. We can find, as examples, several previous studies where air or water was used as the cooling media [4-8].

This work is in the framework of a bigger project that aims to model and study heat transfer between water and Si-based PV modules, for the further optimizations in systems that use water cooling to increase performance of PV roof installations [9,10]. The work is a first step to developing the numerical tools to study the way that the PV module transfers heat to the external cool water while it approaches its optimum working temperature.

2 MODEL

The work involves two different axes. The first one is a conventional thermal study to provide orders of magnitude of various phenomena and to show the importance of the convection transfer coefficient in panel cooling. We explain the limits of this approach, making the numerical simulation essential for these physical systems. That is why the second axis bases the simulation on partial differential equations to describe the heat exchange between glass and air.

The global thermal analysis shows that the cooling of the panel is governed by convection. We perform numerical simulations based on the Navier-Stokes equations for velocities and pressure in the air. The thermal conduction in the panel and the thermal convection in the air are described by coupled heat equations. On the interface, temperature and heat flux are continuous.

The convection is due to the dilatation of the fluid associated with gravitation. The variation of density with temperature is taken into account by the Boussinesq approximation.

The overall coupled system is discretized by a stabilized finite element method.

The panel has been modelled by a glass and the interaction with air was modeled by partial differential equations justified by its physics (Fig.1). Several parameters as temperature, wind speed and inclination of panel (gravity) have been varied to study two different cases of convection: natural cooling in a cool environment (free convection) and forced cooling with wind (forced convection) [11].

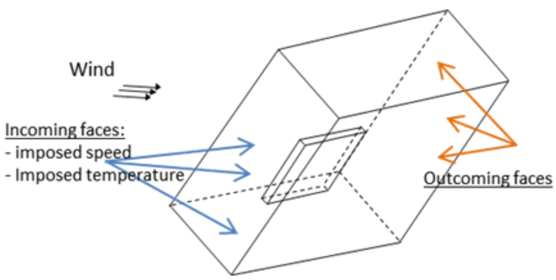

Figure 1: Computational domain

3 RESULTS

The results obtained for natural cooling (free convection) gives us the following values for dimensionless parameters, for a reference wind speed of $v_{\mathcal{L}}$=1 m.s^{-1}

$\mathcal{R}_e = 6\text{x}10^3$, $Pr = 6\text{x}10^4$ and $Gr = 5\text{x}10^9$

The value of the Reynolds number shows that this flow is low turbulent. As the Grashof number is very large, the force of gravity is predominant over the viscous forces, which leads to a strong convection, indicating a thermal turbulence. Moreover, the Peclet number confirms that heat exchange occurs essentially by convection.

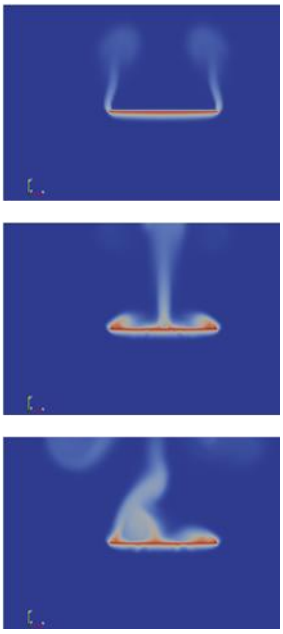

Figure 2: Free Convection. Heat transfer after 10, 50 and 100 s (panel horizontal).

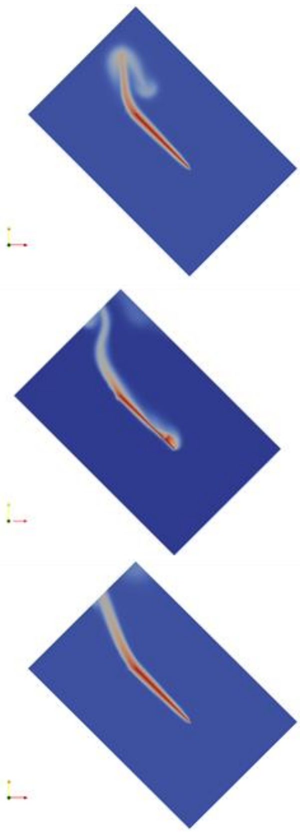

Figure 3: Free Convection. Heat transfer after 10, 50 and 100 s (panel oblique at 45º).

Figures 2 and 3 show the temperature of the free convection system for different orientations of the panel: horizontal and oblique at 45º. The heat transfer of the panel is shown after 10, 50 and 100 s. Figure 4 shows the vertical orientation, for free convection. In this case, the heat transfer of panel is shown after 5, 10 and 50s. When the module is horizontal, the formation of heat plumes is chaotic and the low speed allows air ripple effect. When the panel is no longer perpendicular to the direction of gravity, it appears a convection current that evacuates the heat through the stack effect. In these conditions, heat exchanges are more effective.

For wind cooling (forced convection), the following results are obtained for the dimensionless numbers:

- v_∞=1 m.s^{-1}: $\mathcal{R}_e$ = 6x10^3, Pr = 6x10^4

- v_∞=5 m.s^{-1}: $\mathcal{R}_e$ = 30x10^3, Pr = 30x10^4

When the speed of wind is 1 m.s^{-1} the thermal exchanges are similar to those of free convection. In the case of a wind speed of 5 m.s^{-1} the Reynolds and Peclet numbers are increased indicating a better efficiency in the convective heat transfer.

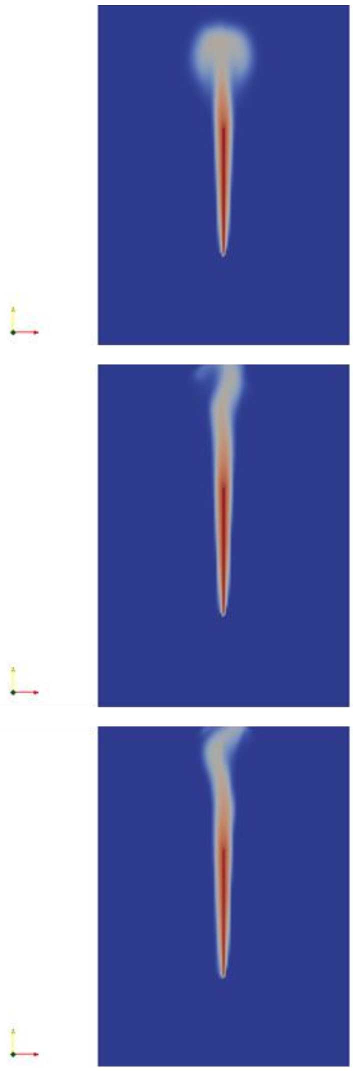

Figure 4: Free Convection. Heat transfer after 5, 10 and 50 s (panel vertical).

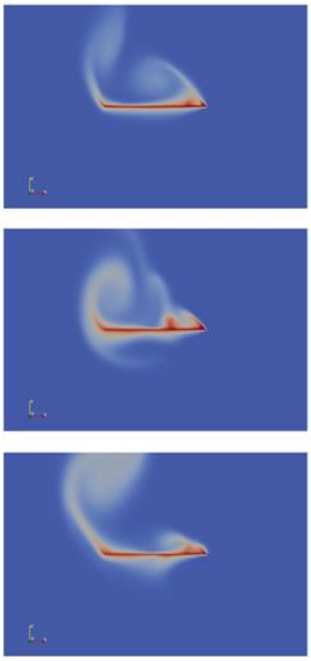

Figure 5: Forced Convection. Heat transfer after 5, 10 and 80 s for horizontal wind speed 1ms-1 (top), and 5ms-1 (bottom)

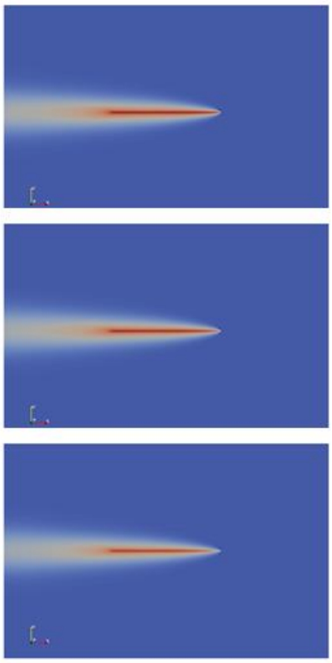

Figure 6: Forced Convection. Heat transfer after 5, 10 and 80 s for horizontal wind speed 1ms-1 (top), and 5ms-1 (bottom)

Figure 5 shows the glass panel placed horizontally with the wind direction parallel to it (from right to left) and a speed of 1 m.s^{-1}. The calculated speed v_L associated with free convection is the same magnitude as that of the wind v_∞ imposed. The thermal regime is called joint, that is to say intermediate between free convection and forced convection. Simulation results perfectly match with that behavior. We find that the heat plumes are partially blown by the wind.

On the contrary, with a wind speed of 5 m.s-1 (Fig. 6), we observe no formation of heat plumes, which corresponds to a forced convection regime.

In Figure 7 the wind direction is at 45o compared to panel's one, with a speed of 5 m.s-1. For a sufficiently long time, we find a close scenario to that of the forced convection configuration. It should be noted that heat is dissipated only from the upper face under the wind. On the underside face, the hot air cannot easily drain; heat accumulates which severely limits the heat exchange between the panel and the air. For a shorter time, there is an intermediate regime where we can see a few heat plumes appear.

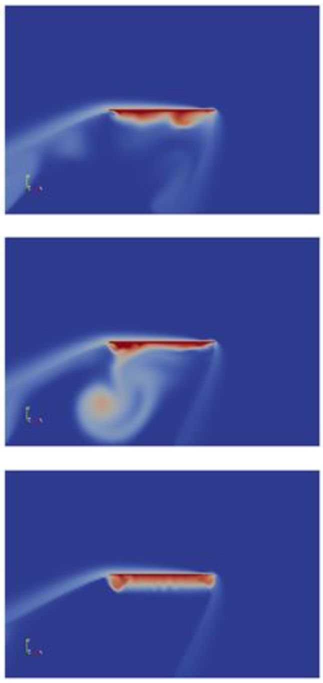

Figure 7: Forced Convection with wind speed of 5ms-1 at a direction of 45o. Heat transfer after 5, 10 and 100 s.

4 CONCLUSIONS

We have studied the cooling (heat transfer) of a PV panel by air. The panel has been modelled by a glass and the interaction with air was modeled by partial differential equations justified by its physics. Several parameters as temperature, wind speed and inclination of panel (gravity) have been varied to study two different cases of convection: free convection and forced convection.

The numerical simulations show that the most efficient regime for free convection is when the module is not perpendicular to gravity direction. The efficiency increases with the wind speed. The most efficient case is obtained when the wind is parallel to the panel.

This first numerical approach yields to results consistent with the physical approach. Our next steps in 2016 will be applying the model for water cooling and linking the model to sunlight irradiation.

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