Humidity Control in Planar Micro-Tracking CPV Modules by Means of Passive Solutions

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Abstract. CPV modules mostly contain air between lenses and cells that due to the water vapor content can end up condensing, being a potential problem not only of reliability of the interior components but also affects the transmissibility of the optical stage and therefore reduces energy yield. Among the passive humidity control options, the use of desiccants, the use of breathers and the formation of controlled condensation have been identified. On the one hand, the dynamic response of molecular sieves, zeolites and silica gel has been tested, showing that silica gel has a higher adsorption/desorption capacity than the rest. On the other hand, breathers based on Gore membrane and labyrinth structure have been compared, the latter having the best breathability. Finally, the suitability of using controlled condensation to prevent condensation from forming in the lens area has been validated. The procedure is based on the radiative cooling experienced by lenses exposed to the night sky, by using materials with higher emissivity in the spectral range of the atmospheric window.

INTRODUCTION

Most CPV modules contain air inside as a medium between the concentrator stage and the cell receiver. Therefore, unlike flat modules, they have the potential problem of internal condensation, since the air contains a quantity of water vapor that, depending on its temperature, can end up condensing.

High levels of humidity or liquid water have a significant impact on the performance and reliability of the module's internal components [1]. In addition, condensation on the lenses seriously affects the transmissivity of the lenses and significantly can reduce the final performance of the module and its energy yield.

The relative humidity (RH) content in a volume of air has been explained in detail in a previous work [2]. Basically, as soon as the dew point is reached (RH=100%), condensation forms, considering that the relative humidity (the moisture holding capacity of the air) increases as the air temperature decreases.

CONDENSATION REDUCTION

It is necessary to avoid condensation by reducing the moisture content in the air. If only passive methods are considered and hermetically sealing the module at a low humidity level is ruled out because of the stresses that would arise due to thermal shock, there are basically two options normally used. 1- the use of desiccants and 2- allowing ventilation, especially when having the module equalized, the interior humidity will vary according to the ambient humidity. These traditional methods will be explored in addition to a proposal based on controlled condensation.

Desiccants

In previous works [2], we had proved experimentally the viability of desiccants as a proper way of reducing the humidity content in planar micro-tracking CPV modules. In this work, we have explored the dynamics of the humidity adsorption/desorption for several desiccants: molecular sieves, zeolites, and silica gel. In Fig. 1 we can see the time evolution of the desiccants after dehydrating them for 2 hours after being stabilized at 40% RH and 24 ºC.

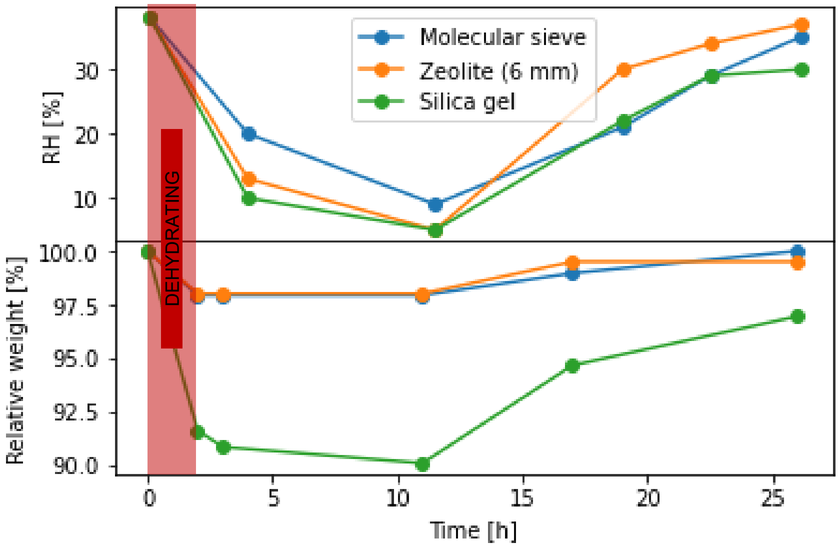

FIGURE 1. Desiccants (molecular sieve, zeolites, and silica gel) temporal evolution after stabilization at 40% RH and 23 ºC and a dehydrating process by heating in oven at 80 ºC for 2 hours. All of them take about 12 hours to reach the lowest level of humidity after dehydration and 12 hours more to recover the previous level of humidity. Silica gel performs better than others adsorbing four time more water vapor.

The main conclusion is that it takes at least 25 hours for the RH level in the desiccants to restabilize, all following the same rate. However, silica gel has a significantly higher adsorption capacity than molecular sieves or zeolites. These results are congruent with the values reported by the literature in the range of 40-10% RH in isothermal curves [3].

Breathers for Natural Ventilation

Since CPV modules must be equalized with the environment, there will always be moisture inside that will potentially end up condensing. That is why ventilation is a key element in controlling the formation of condensation, especially to force it to disappear when it does form. The element that allows ventilation is known as a breather and is fundamentally defined by the exchange area it presents and by the impedance it presents to the passage of air.

There are two types of breathers available on the market: 1- labyrinth type where the equalization between the module and the environment is directly allowed by blocking the passage of water through an inner labyrinth structure and 2- with PTFE membrane (Gore) that allows the passage of air and water vapor but not of the molecules in liquid form.

Both models have been tested on the monitored experimental platform presented in [2]. The labyrinth type breathers used have an area of 4 cm^2 while the Gore type have an area of 8 cm^2. However, the Gore membrane is expected to exert a much higher impedance to the passage of air than the labyrinth type. Figure 2 shows the test mockup modules together with the two types of breathers already installed.

FIGURE 2. Photograph of the experimental setup consisting of two monitored mockup modules. One module uses labyrinth type breathers while the other uses Gore membrane type breathers.

Figure 3 shows the evolution after forcing the humidity level to condensation in both modules (a). After 3 sunny days, it can be clearly seen how the module with ventilators has been able to remove more humidity than the one using Gores (b).

(a) (b)

FIGURE 3. Camera view of the monitored mockup modules. Upper module contains labyrinth type breathers, lower module uses Gore membrane type breathers. (a) Condensation in both modules after adding water (b) Same modules after 3 sunny days that help de-condensation

Controlled Condensation

The moisture control processes presented above are based on well-known methods. Considering the specific context of a CPV module and in particular the planar micro tracking architecture, it is proposed to make use of radiative cooling that causes condensation [4,5] in a controlled situation.

Considering that a body exposed to outer space sees an effective temperature as low as 3 K, a remarkable radiative emission is produced for the glass at ambient temperature, so a thermal gap appears between the glass and the ambient due to radiative cooling as exposed in Eq. 1

$$\Delta T_{glass-amb} \propto \sigma \cdot \left({T_{glass}}^{4} - {T_{sky}}^{4} \right) \quad (1)$$

However, the atmosphere notably blocks this process except for the so-called "atmospheric window" which is between 8 and 13 µm [6,7]. This spectral range is precisely where most of the emission from a body at ambient temperature of typically 250-300 K is found, so if it presents high emissivity there will be radiative cooling. It should be noted that in practical terms, basically due to the content of water molecules in atmosphere, the effective temperature of the sky is around 20-25 K below ambient (see Fig. 4).

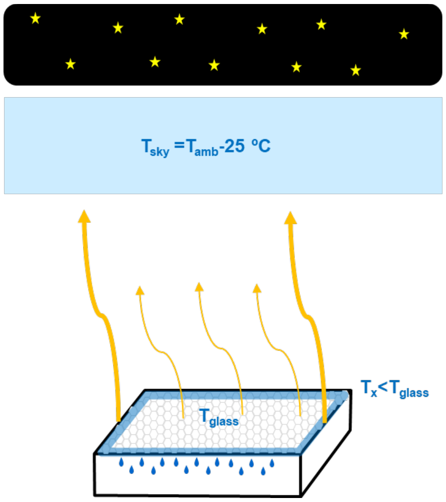

FIGURE 4. Schema of the glass of a CPV module radiating to the sky. Blue stripe represents a high-emissive material that achieves a lower temperature than glass when cooling by radiation, forcing condensation before than in the glass area.

Over a period of several weeks, the temperature of the outer glass of the modules in the experiment was monitored at night with respect to the effective sky temperature. This temperature has been estimated by measuring the longwave radiation using a pyrgeometer. In addition, the wind speed was also monitored to estimate the effect of convection on the glass temperature. As can be seen in Fig. 5, there is a certain correlation between the low effective sky temperature and the thermal jump between the environment and the module glass. In addition, wind convection reduces the effect of radiative cooling because the ambient is at a higher temperature than the glass.

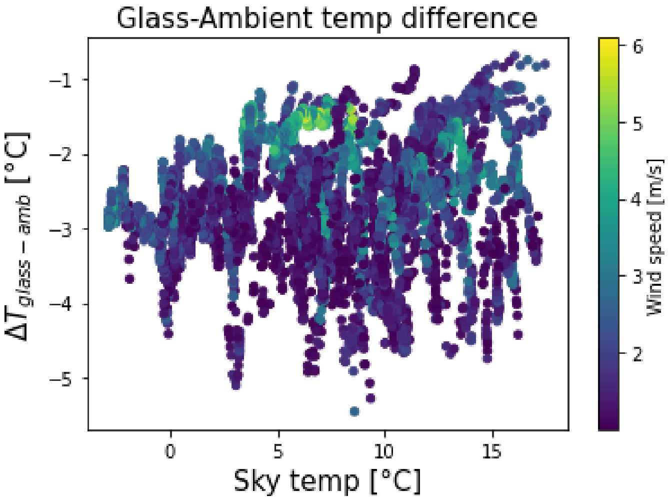

FIGURE 5. Glass-ambient temperature difference due to radiative cooling of the CPV module glass with respect to the sky effective temperature measured by pyrgeometer. Convective effect of the wind is shown to reduce the radiative cooling since ambient is hotter than the glass.

In this context, it is proposed to force radiative cooling of the module in areas exposed to the sky, but which are not critical (see perimetral stripe in Fig. 4) so that when it occurs first in the perimetral area it protects the lenses, like the methodology of using a sacrificial anode in metallic structures to prevent corrosion.

For this method to work, the sacrificial material must have a higher emissivity in the spectral range of the atmospheric window than the glass of the module. For this purpose, various materials have been tested that the literature indicates are suitable for radiative cooling, such as low-density polyethylene (LDPE) [8,9], PVC tape [10], or white paint based on TiO2 [11]. These materials have been placed in a test module by monitoring the temperature of the glass together with the measurement of an uncovered area as a reference (Fig. 6).

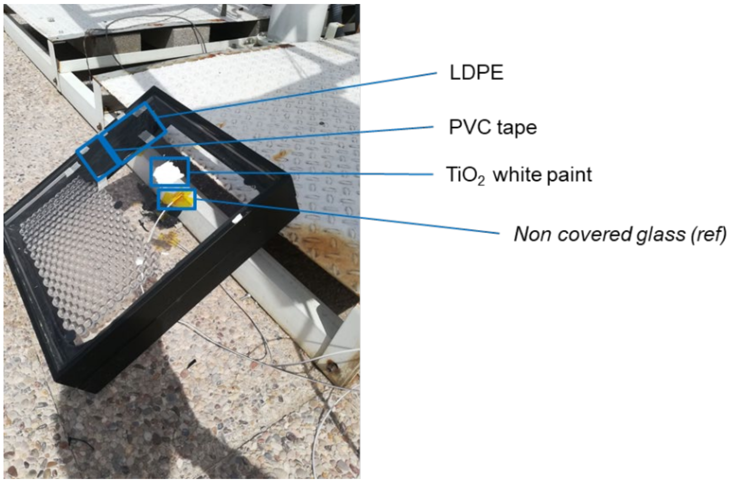

FIGURE 6. Experimental setup to measure the effect of different materials due to radiative cooling on glass temperatures of a mockup module.

The results show that up to a thermal jump of up to -0.5 ºC and -0.7 ºC is achieved for LDPE and PVC tape respectively while the used white paint is not showing any improvement. Although the difference is not very perceptible due to the high emissivity value of the solar glass [12], it may be sufficient to protect the module from condensation in the lens area.

After this initial validation, the next step is to configure the mockup modules in the experimental monitored area with camera to differentially investigate the effect of controlled condensation. Additionally, a breather drain can even be installed to expel liquid water so that condensation is not only controlled, but also removed from the indoor air.

CONCLUSION

Desiccants can function as moisture "buffers" to move away from the dew point. Indoor experiments have validated that silica gel is a better buffer than molecular sieves or zeolites.

Ventilation is the key to eliminating condensation while breathing area and pressure drop affect performance, then we have proved that labyrinth breathers show a better air exchange rate than Gore.

A passive solution has been proposed to reduce moisture content by radiative cooling. However, a material with high emissivity is needed in the atmospheric window. A comparative assembly with LDPE and PVC tape is being prepared to monitor the potential humidity control.

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REFERENCES

1. M. Aghaei, A. Fairbrother, A. Gok, S. Ahmad, S. Kazim, K. Lobato, G. Oreski, A. Reinders, J. Schmitz, M. Theelen, P. Yilmaz, and J. Kettle, Renewable and Sustainable Energy Reviews **159**, 112160 (2022).
2. R. Núñez, S. Askins, A. Soofi, L. Anglade, I. Antón, and C. Domínguez, CPV-17 (2021)
3. R.S. Barlow, NASA STI/Recon Technical Report N **83**, 29828 (1982).

4. J. Trosseille, A. Mongruel, L. Royon, and D. Beysens, International Journal of Heat and Mass Transfer **172**, 121160 (2021).
5. T.M.J. Nilsson, W.E. Vargas, G.A. Niklasson, and C.G. Granqvist, Renewable Energy **5**, 310 (1994).
6. S. Jeon and J. Shin, Scientific Reports **10**, 13038 (2020).
7. D. Zhao, A. Aili, Y. Zhai, S. Xu, G. Tan, X. Yin, and R. Yang, Applied Physics Reviews **6**, 021306 (2019).
8. J.F. Maestre-Valero, V. Martínez-Alvarez, A. Baille, B. Martín-Górriz, and B. Gallego-Elvira, Journal of Hydrology **410**, 84 (2011).
9. T.M.J. Nilsson and G.A. Niklasson, Solar Energy Materials and Solar Cells **37**, 93 (1995).
10. R. Family, Procedia Environmental Sciences 8 (2017).
11. A.W. Harrison and M.R. Walto, Solar Energy **20**, 185 (1978).
12. I. Subedi, T.J. Silverman, M.G. Deceglie, and N.J. Podraza, Solar Energy Materials and Solar Cells **190**, 98 (2019).