

## COMPARISON OF MOISTURE INGRESS IN PV MODULES WITH DIFFERENT BACKSHEETS USING HUMIDITY SENSORS

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**ABSTRACT:** Moisture ingress into a photovoltaic module accelerates the degradation phenomena in different ways [1-3]. Polymeric components of photovoltaic modules are sensitive to moisture, due to hydrolysis reactions which can cause changes in their chemical structure and therefore in their properties. Hydrolysis of EVA leads to the formation of acetic acid, which accelerates the corrosion reactions of metallic parts of the circuit. PET hydrolysis is also an undesirable process caused by the presence of water inside the module. In addition, moisture ingress will reduce the adhesion between glass and EVA.

This work is focused on investigating the behaviour in terms of moisture ingress of some new backsheets that have recently appeared in the PV market due to the shortage of Tedlar®. After a market survey, suitable humidity sensors have been selected and used to quantify the humidity content inside the module while it is being exposed to damp heat conditions. Gravimetric measurements have also been carried out to evaluate the water vapour ingress rates at different exposure times to various conditions of temperature and relative humidity.

Keywords: moisture ingress, backsheet, permeability

### 1 INTRODUCTION

Backsheets are used to provide electrical isolation and to act as a barrier layer against chemical agents, ultraviolet radiation and water vapour. During the last years, films manufacturers are dedicating their efforts to develop a material that could be an alternative to the widely used Tedlar®, but up to now no material has been identified as a clear substitute. The new developed layers are based on composites of different polymers, as PET with modified properties, PVDF, ECTFE, ETFE, PMMA, PTFE, etc.

Three new materials were selected for this work, and a standard Tedlar® (PVF/PET/PVF) layer was also introduced in the experiments as reference. Table I shows the composition and water vapour transmission rates (measured at 38°C and 90%R.H.) of the selected films.

**Table I.** Thickness and WVTR data supplied by manufacturers.

backsheet	thickness	WVTR (g/m <sup>2</sup> day)
PET/PET	295	2,47
PVDF/PET	350	0,5
ETFE	50	5
PVF/PET/PVF	180	1,3

Breathable backsheets allow moisture ingress easily, but they do not trap molecules inside the module, so that water and other chemical substances can leave of the system at high temperatures. However, if a more impermeable layer is used, the water vapour ingress is minimized, but it is more difficult for water and other molecules to leave the module once they are inside, which can accelerate corrosion rates. Therefore, it is not clear which is the better choice for back covers.

This work explores water ingress and water desorption in different conditions with four back covers of different permeabilities, by using commercial humidity sensors as well as gravimetric methods.

### 2 SENSOR TECHNOLOGY AND CALIBRATION

#### 2.1 Sensor technology

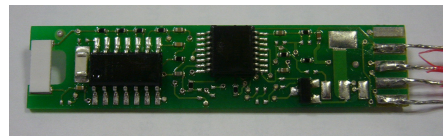
After a market survey, a capacitive humidity sensor was chosen to carry out the tests. The sensor must be able to withstand lamination conditions and the aggressive environment of damp-heat (85°C/85% R.H.) inside the climatic chamber.

The capacitive technology is based on a hygroscopic polymer layer that acts as dielectric, deposited between two conductive electrodes. When water molecules go into the polymer layer, the dielectric constant changes and causes an increase in the capacitive signal, which is directly proportional to the relative humidity.

Resistive sensors are another option. They measure the change in electrical impedance of a hygroscopic medium such as a conductive polymer, salt, or a treated substrate.

Between resistive or capacitive technologies, the capacitive sensor was preferred because the dielectric polymer is capable to resist higher temperatures, it presents a rapid response, it has a low temperature coefficient and it is able to detect low humidities. The disadvantage is that it could be sensitive to dewing, so it could saturate in environments with humidities above 85%.

To avoid the difficulty of monitoring capacitance, the sensor has an integrated circuit that translates the capacitive signal into a voltage output, easy to monitor with a datalogger.

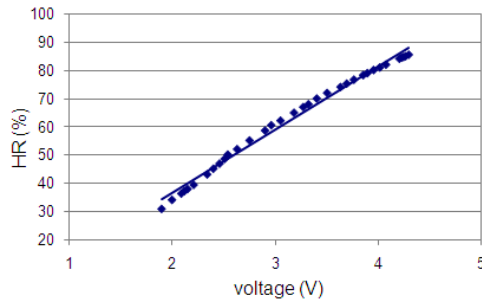


**Figure 1.** Capacitive humidity sensor used to monitor moisture ingress in modules.

#### 2.2 Sensor calibration

The first step was to calibrate the sensor at 85°C. For this purpose, a bare sensor was introduced in the climatic chamber at 85°C and different humidities ranging from

20% to 85%. The response of the sensor was demonstrated to be almost perfectly linear (Fig. 2).



**Figure 2.** Calibration of the sensor at 85°C and different humidities.

With this correlation it is possible to obtain relative humidity values with a simple equation:

$$R.H. = 22.528 V - 8.6857 \quad [1]$$

### 2.3 Samples construction

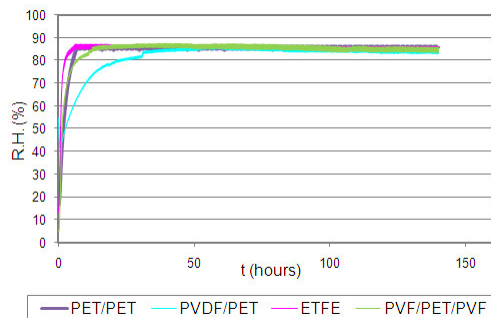
Four samples of 365x330 mm were fabricated with the structure glass/sensor/EVA/backsheet. To avoid curing of EVA on top of the sensor, which can affect its signal, a small square of EVA was previously cured and then placed on top of the sensor. In this way there is a small air gap in which the sensor can detect moisture changes. The thickness of the cured EVA layer was 230 μm.

## 3 EXPERIMENTAL RESULTS

### 3.1 Moisture ingress at 85°C/85% R.H.

The samples laminated with the sensors were introduced in the climatic chamber in damp-heat conditions. The voltage output of each sensor was monitored using a datalogger and converted into a relative humidity value.

A bare sensor was also introduced in the chamber to check that the environmental humidity remains stable at 85%, and also to evaluate the stability of the sensor in these hard conditions. The humidity was correct during the whole test and the sensor continued functioning, so it could be dried and reutilized again. The results of the test are shown in Fig.3.



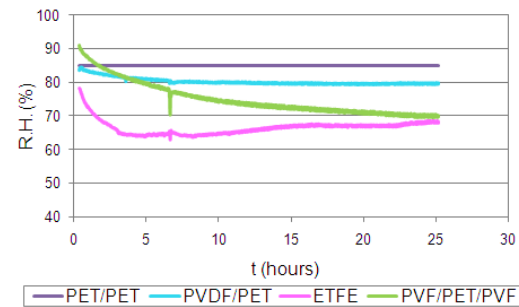
**Figure 3.** Relative humidity inside the samples at 85°C/85% R.H.

As can be seen in the graph, the sample with lower WVTR (PVDF/PET), is the last one to reach equilibrium, at approximately 40 hours. It is a material of low permeability. The behaviour of PET/PET and PVF/PET/PVF is similar, being in equilibrium in approximately 10 hours.

ETFE reaches 85% R.H. in 4 hours after the beginning of the test. This is in agreement with the differences in WVTR, since its permeability is much higher than those of the rest.

### 3.2 Water desorption at 25°C

Once the samples were out of the chamber, the relative humidities were monitored during the drying of the sensors at room temperature.



**Figure 4.** Water desorption at 25°C.

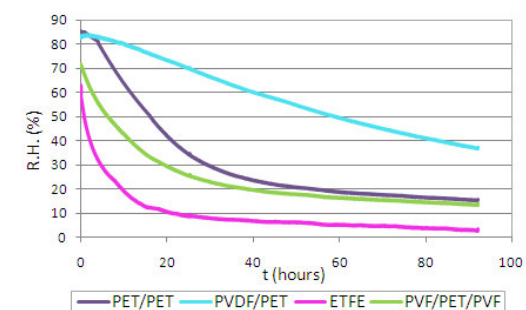
The environmental humidity was measured with the bare sensor and it remains stable at approximately 40%.

After 24 hours, the decrease in relative humidity is almost negligible, except in the case of ETFE, which begins to dry immediately when it is taken out of the chamber, due to its high permeability.

This means that in these common conditions of temperature and humidity it is very difficult that a module could eliminate the water absorbed in other conditions, if it is not a high permeable material.

### 3.3 Desorption at 50°C

The same experiment was repeated at 50°C, to evaluate the desorption rates at higher temperatures. Samples were introduced in an oven at 50°C. The results are shown in Fig. 5.



**Figure 5.** Water desorption at 50°C.

The bare sensor was also introduced to measure the environmental humidity, which was 20% during the whole test.

As it was expected, ETFE rapidly begins to dry. It is followed by TPT. PET/PET remains saturated for 5

hours, but then starts to dry fairly quick. On the other hand, PVDF/PET shows great difficulty in eliminating moisture.

#### 4 GRAVIMETRIC MEASUREMENTS

##### 4.1 Weight gain in damp-heat conditions

Samples of 300x200 mm with the structure backsheet/EVA/backsheet were laminated and introduced in the climatic chamber. The initial weight after lamination was measured, and then the samples were weighed at regular intervals during the damp-heat test. In this way it is possible to quantify the moisture ingress through the backsheet, which depends on its water vapour transmission rate. The results are presented in Table II.

**Table II.** Weight gain in damp-heat conditions.

t (hours)	50	150	300
PET/PET	0,19%	0,26%	0,34%
PVDF/PET	0,45%	0,41%	0,43%
ETFE	0,28%	0,28%	0,32%
TPT	0,39%	0,35%	0,39%

Three of the four materials show a similar behaviour. Their weight increases at the beginning of the test, during the first 50 hours; then it remains stable. This means that after 50 hours of damp-heat conditions the system backsheet/EVA/backsheet is saturated and cannot absorb more water. However, the PET/PET film shows a different behaviour and continues increasing its weight with time. A possible explanation is that the polymer is degrading and this is the reason why it has not reached equilibrium.

##### 4.2 Water absorption

All polymeric materials absorb moisture. Water molecules enter in the polymer structure and cause different processes such as swelling, dissolution, plasticizing or hydrolysis. This can lead to discoloration, embrittlement, loss of mechanical and electrical properties and lower resistance to weathering.

To evaluate the ability of the materials to absorb water at 25°C, films samples of 200x100 mm were initially weighed and then immersed in distilled water at room temperature. After 24 hours, the samples are taken out of the water, their surface is dried and then they are weighed again.

**Table III.** Water absorption in the films at 25°C.

Material	Weight gain
PET/PET	1,19%
PVDF/PET	0,49%
ETFE	11,98%
TPT	1,08%

The results obtained agree with the WVTR data supplied by film manufacturers. The weight increase in the most permeable material (ETFE) is dramatically higher than in the rest. PET/PET and TPT present similar results, whereas PVDF/PET suffers a slight gain, since it is the least permeable.

It is important to consider the possibility of water

absorption in polymers, because it could lead to the loss of their electrical and mechanical properties. Considering the results, this parameter has to be seriously taken into account if a more permeable layer is chosen. In this case it is necessary to assure the long-term stability of these materials.

#### 5 CONCLUSIONS

Moisture ingress in mini-modules during damp-heat conditions has been monitored using capacitive humidity sensors, as well as desorption rates in different conditions. The results obtained correlate well with the WVTR data supplied by films manufacturers. This typical value is measured in determined conditions, at 38°C and 90% R.H. However, water diffusion is well-known to be highly dependent with temperature.

In damp-heat conditions, it has been observed that no film can avoid water ingress into the module, even by using a very low permeability material.

Once the water is inside, modules with low permeability films can hardly be dried in typical one day period, so the water molecules and other chemical degradation products remain trapped inside the system, and this can accelerate corrosion rates.

In climates where the possibility of module drying exists, ie zones with large temperature and humidity oscillations between day and night, a more permeable film could be a good option. On the other hand, if wet and hot climates are considered, module drying is not possible due to the constantly high environmental humidity, and it would be better to minimize the water vapour ingress with a high moisture barrier layer.

In addition, water absorption has been measured in different conditions. The ability of polymers to absorb water inside their molecular chains is related to the loss of their electrical and mechanical properties. The most permeable films have also shown higher water absorption, so the long-term stability of these materials in terms of mechanical and electrical properties should be further investigated.

#### 6 ACKNOWLEDGEMENTS

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