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CONTROL SYSTEM FOR OBTAINING WATER FROM AIR DEHUMIDIFICATION BY PELTIER CELLS

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ABSTRACT

In this article the implementation of a dehumidification system based on Peltier cells that allows water particles condensation from the air is presented. A PI (Proportional Integral) control design leads the temperature from the cold cell face toward the dew point to improve the system performance. The system performance is evaluated comparing the system operation without control with the controlled system, in order to set the improvements that allows increase water production and reduce the electric power consumption. These tests indicate that when applying control, the water production increases, while power consumption is reduced, evidencing a remarkable improvement in system efficiency.

Keywords: dehumidifier, cells Peltier, PI control, drew point, condensation.

1. INTRODUCTION

Water is the main natural resource for the survival of most living beings, vital for the human being and the development of activities, like energy production. Its high consumption demands a large amount, but the availability of this resource suitable for human consumption is limited. Likewise, factors such as pollution make the valued liquid acquisition harder every time. Nowadays, many engineering projects have taken path towards the searching, designing and implementation of new systems or methods that allow water acquisition by using environmentally friendly resources (Sacristán, 2011). Some companies have developed systems that allow to perform this process and have developed equipment with the capability to produce 12000 daily gallons (Aquasciences, 2015). Other alternatives seek that in addition to produce water condensation it can also be possible to generate the necessary energy for its operation by using an aerogenerator (Eolewater, 2012).

This theme has obtained a great importance worldwide and has become in the main topic for researching works and development of new water generation alternatives. It is how is made a system that do the cooling process by air dehumidification using a photovoltaic panel (Méndez, et al., 2011). The system includes calculation parameters and the determination of refrigerating elements as evaporator, condenser and compressor. In a new project an atmospheric water generator base on wet drying is been built (Niewenhuis, *et al.,* 2012). It is concluded that is not a practical method of water generator, because the efficiency achieved is lower than the obtained at other systems.

In this project is developed a dehumidification system based on the Peltier cell, it allows water acquisition by water particles condensation from the air. It is also designed a PI controller applied on the system to improve its efficiency. The content is organized as follows: Initially, the system hardware is implemented, and the variables used for modeling are obtained. Then the model identification is done by using the System Identification Toolbox from Matlab to obtain the transfer function that describes it. A PI controller is used, it is applied to the system and performance tests are made. Finally, the obtained results are shown at the time to compare the system without control performance with the controlled system, and the conclusions are presented.

2. MATERIALS AND METHODS

2.1 Process description

The dehumidification system is made mainly by two walls of 4 Peltier cells located face to face, they bring in their cold faces the condensation surface as shown in Figure 1. A heatsink is attached to each wall and a fan to the heat side to keep the temperature and avoid cells damages. A temperature sensor S1 is attached between the two cold walls and other is in the exterior that measures the ambient temperature S2. It is also a sensor to measure the relative humidity S3.

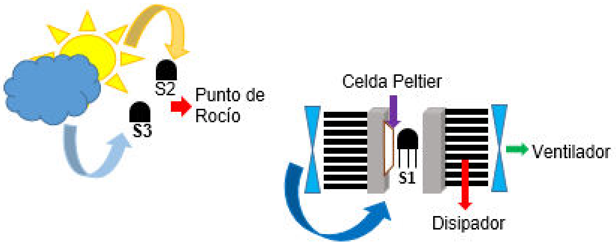

Figure-1. Dehumidification system.

It is intended to control the temperature of the cells' cold face to carry it to the drew point where water is condensed. The input variables considered in the process are ambient temperature and relative humidity, needed to calculate the temperature at the drew point to be in the cold side to generate condensation. The cold side temperature sensor output voltage is the system variable output.

2.2 Prototype implementation

After several prototypes, a final device was implemented. This system consists of two blocks of two cells on each side with its respective heatsink and fan located face to face and separated about 1cm as shown in Figure-2. Due to the tests performed, it is concluded that the larger the space between the cold sides, the greater the thermal loss, so there will be less production, an enough distance is left for the formation and the waterdrops.

Figure-2. Final prototype.

2.3 Data acquisition

For the acquisition of the data that describes the behavior of the system, a NI MyDAQ is connected to the computer by using an USB cable. This board receives the sensor LM35DZ signal, in charge of monitoring the temperature of the cold side of the cell (output) and the supply voltage signal (input). This set of signals are entered to the LabVIEW platform, where the signal conditioning program is implemented, as shown in Figure-3.

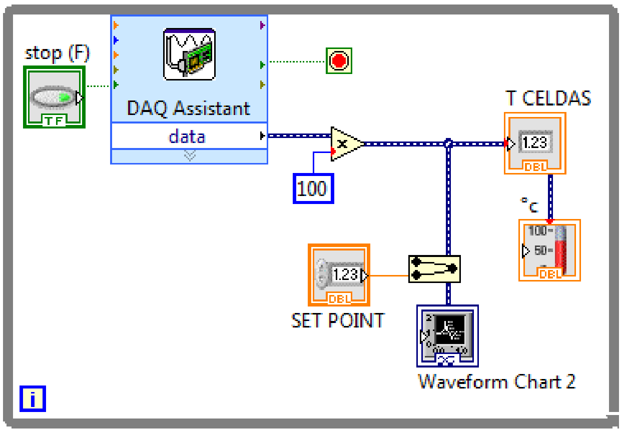

Figure-3. LabVIEW conditioning program.

A train of pulses of 180 seconds (red line) is applied to the system to observe its answer. The output signal (black line) obtained is shown in Figure-4.

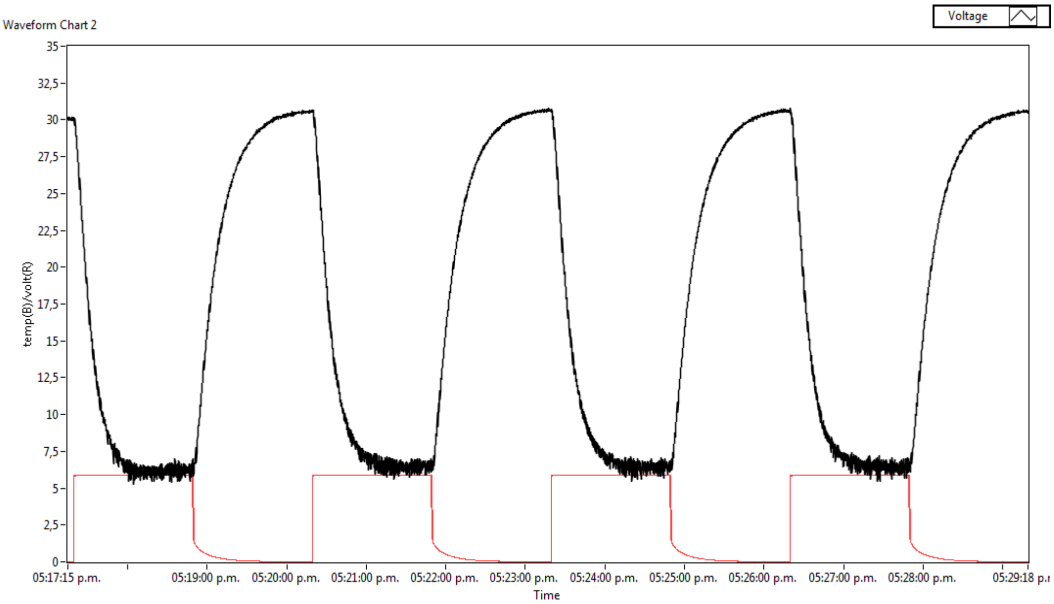

Figure-4. System response to a pulse train.

The cold side temperature sensor obtained data describes the system behavior to be used to obtain its model, then its transfer function is also obtained. The controller is designed using the transfer function.

2.4 System identification

The graphic mode identification is proposed using the obtained data from the system response. Based on the standard second order system transfer function, its proposed to find the parameters K, T1 and T2 to be replaced in equation 1.

$$G(s) = \frac{K}{(sT_1 + 1)(sT_2 + 1)} \tag{1}$$

To obtain these values, the system is considered as a pure retarded one, together with a first order system. The Ziegler Nichols model for overdamped systems is described in equation 2 (Ruiz, 2011).

$$G(s) \approx e^{-sT_d} \frac{K}{1 + sT} \tag{2}$$

The Padé approach for the exponential function is used as shown in equation 3.

$$e^{-sT_d} \cong \frac{1 - s\frac{T_d}{2}}{1 + s\frac{T_d}{2}} \tag{3}$$

So, the system transfer function is represented as shown in equation 4:

$$G(s) \approx e^{-sT_d} \frac{K}{1 + sT} = \frac{1 - s\frac{T_d}{2}}{1 + s\frac{T_d}{2}} \frac{K}{1 + sT} \tag{4}$$

Td is the system delay time and T is the time the system response is over Td and reaches the 95% of the final value.

This data is obtained from the experimental response, then $T_d = 4seg$ and $T_{95\%} = 44seg$. T is calculated by using equation 5.

$$3T = T_{95\%} - T_d \tag{5}$$
$$T = \frac{40}{3} = 13.33seg$$

The second order transfer function is shown in equation 6, and the step response is shown in Figure-5.

$$G(s) = \frac{-0.0975}{(s + 0.25)(s + 0.073)} \tag{6}$$

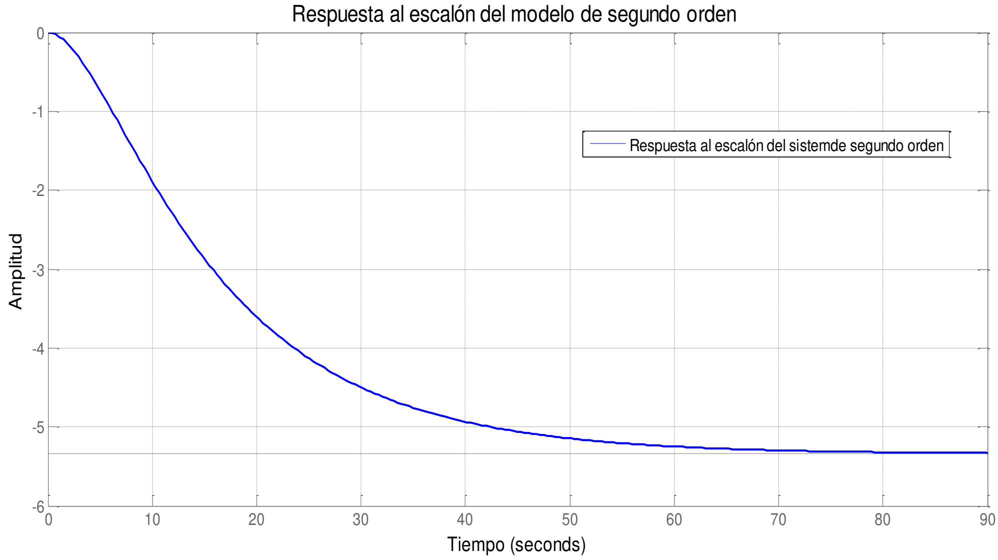

Figure-5. Second order system step response.

A gain adjustment is done to bring it closer to the real response as shown in equation 7.

$$G(s) = \frac{-0.0725}{s^2 + 0.323s + 0.01825} \tag{7}$$

The model response is compared with the real system response as shown in Figure-6.

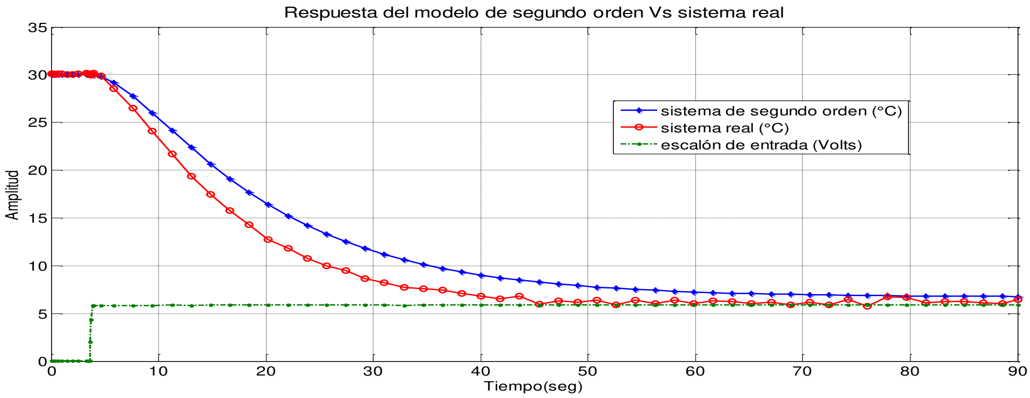

Figure-6. Second order system step response vs real system response.

A similar real system response is obtained by the identified model, nevertheless, a new model using the MatLab identification tool Ident is proposed. Due to some unknown parameters for the mathematic model, the input and output data are used to estimate the approximated computational model. The obtained model is adjusted in 96.23% to the real system response as shown in Figure-7.

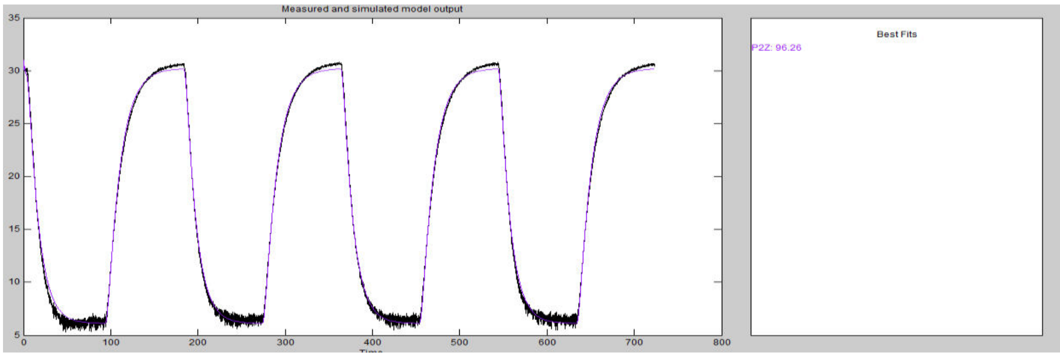

Figure-7. Model obtained in Ident from MatLab.

The model estimation with Matlab is based in a second order model parameters, as described in equation 8.

$$G(s) = \frac{K}{(1 + Tp1 * s)(1 + Tp2 * s)} \quad (8)$$

The model response identified in Ident from Matlab is compared with the real system response as shown in Figure 8. It is concluded that this model has more accuracy due to the transient response is near to the real system response.

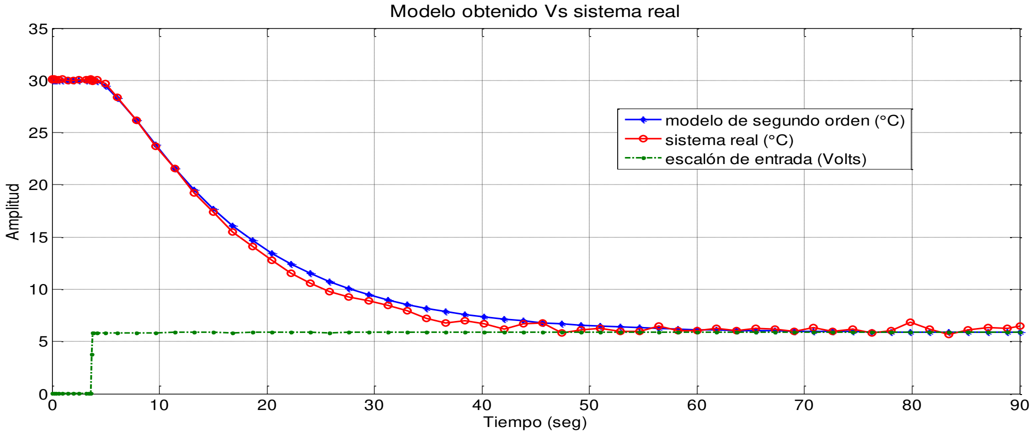

Figure-8. Model response obtained with Ident vs real system response.

2.5 PI controller design

The cold side of the cell is the controlling variable. This variable must follow a reference signal set as the drew temperature and had to keep it near as possible to the referencing point to get a constant water condensation. According to the system data obtained, a PI controller is designed using the Ziegler Nichols method (Ogata, 2010). This controller is tuned with Simulink from MatLab and the result is shown in equation 9.

$$C_{PI} = \frac{-260.11s - 18.07}{2.33s} \tag{9}$$

The simulated response of the controlled system to a unit step input is shown in Figure-9.

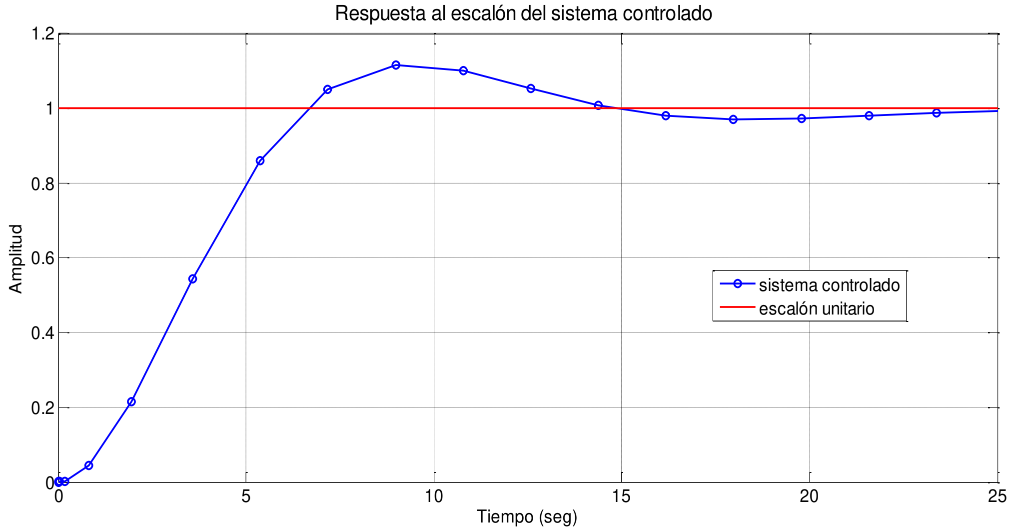

Figure-9. Simulated response of the tuned controlled system.

The voltage signals from the sensors are entered to the microcontroller where are adjusted to temperature values and relative humidity respectively; then, the microcontroller calculates the drew point. The temperature values at the cold side of the cells are used as comparing signals. With the setpoint and the comparation signal, the microcontroller runs the PI control and the controlling signal is entering to the system.

3. RESULTS AND DISCUSSIONS

Several probes of the controller performance in real time are tuned with different setpoints. As a result, the real controlled system response with a setpoint at 12°C is shown in Figure-10.

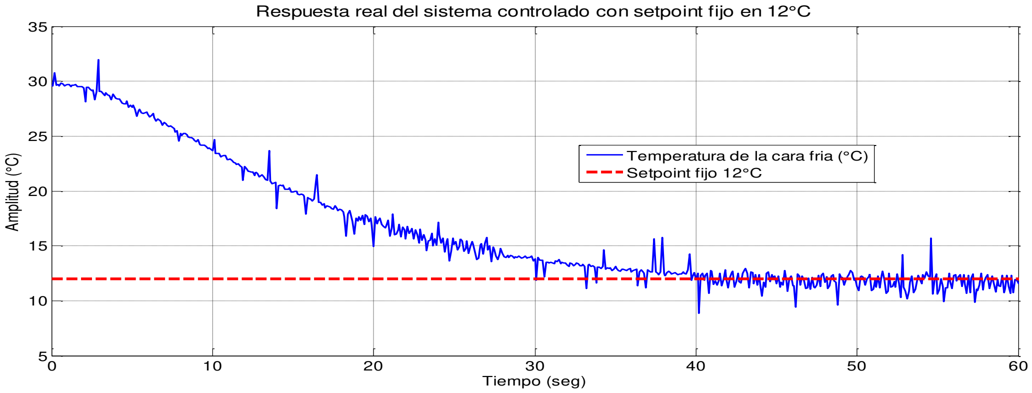

Figure-10. Actual response of the controlled system with fixed setpoint at 12°C.

The obtained responses comparison between the simulated system and the real system is performed in order to validate the design, as shown in Figure-11.

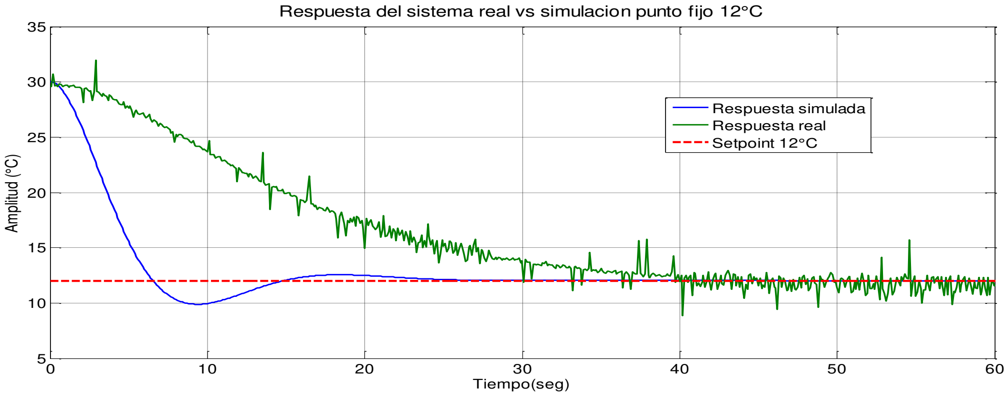

Figure-11. Comparison of real responses and simulated system with 12°C setpoint.

In Figure-11 are shown some differences in the transient between the simulated and the real responses. The simulation shows a characteristic overshoot of the second order model obtained, while an overdamped behavior is shown in the real system. Therefore, the stable state behavior in both cases is similar, with about 50 seconds. A good control performance is shown when it is established in the desired drew point.

For the system implemented and the control action designed validation is done, there were made performance probes of the controlled system vs the uncontrolled system in a short time window, as shown in Table-1. The intention is to see the produced water in that time, and the electric consumption necessary to obtain that quantity of water. The probe was performed in the city of Neiva for 8 hours, from 6:11 a.m. to 12:11 m.

Table-1. Controlled water production data vs uncontrolled water production, in the city of Neiva.

SYSTEM TYPE	RELATIVE HUMIDITY (%)	AMBIENT TEMPERATURE (°C)	DREW POINT (°C)	TIME
Uncontrolled System	37,14	30,09	13,89	06:11
	37,94	32,19	16,11	07:11
	39,37	31,98	16,50	08:11
	40	29,79	14,77	09:11
	42,07	28,79	14,64	10:11
	45,42	27,9	15,02	12:11
	QUANTITY OF WATER OBTAINED=30 (ml)			
	AVERAGE CURRENT=0,4326 (mA)			
Controlled System	38,57	29,09	13,58	06:11
	42,07	27,8	13,74	07:11
	45,89	27,4	14,72	08:11
	47,64	27,8	15,67	09:11
	51,46	28,69	17,71	10:11
	53,06	26,5	16,15	12:11
	QUANTITY OF WATER OBTAINED=32 (ml)			
	AVERAGE CURRENT =0,39 (mA)			

From this data, energetic consumption in Watts and the water production cost is obtained as shown in Table-2.

Table-2. Water production costs in the city of Neiva.

Parameters	Uncontrolled System	Controlled system
$kWh	422,21	422,21
Average consumption in amperes (1h)	0,43	0,39
Volts consumption	120,00	120,00
Watts consumption	51,91	47,16
Consumption in $ W/hour	21,92	19,91
Water quantity in an hour (ml)	3,33	3,55
Hours/1 liter of water	300,03	281,69
Cost of 1 liter of water $	6575,99	5608,85

The obtained data shows a better efficiency from the controlled system due to the quantity of condensed water increases, and the electric power needed to get it is much lower. In addition, the controlled system has a better performance while calculating how many hours are needed to produce 1 liter of water. In this case, the saving is about $1000 per liter produced.

Although the counted system shows a better efficiency and electric power consumption saves, there is a disadvantage related to the time required to condense large quantities of water, due to the small condensation surface and the prototype as an experimental model.

4. CONCLUSIONS

The design and implementation of the air dehumidification system allowed to obtain water from air condensation using Peltier cells as main element. As a result, the cold side temperature to produce the drew effect was controlled.

During the probes with Peltier cells it was determined that the dissipation elements and sensors must be fully integrated to them, if not, the correct temperature dissipation is precluded and may cause wrong data. It is also convenient to isolate the sensor placed in the cold side to obtain correct reads and avoid the ambient temperature to cause issues and measurement variations.

It was designed a black box model because some of the mathematics modeling parameters are unknown, getting an approximated dynamic of the system. The system behavior is inverse due to its output shows a temperature decrease, so the temperature is inverse and must be shown in its own model.

The PI control implemented allows to maintain the cold side nearly to the drew point, improving the system performance. As a result, it is evident a water production increase and a significant reduction of power consumption.

The dehumidification system allows to obtain a significant quantity of water for experimental purposes; therefore, it is a low level in production terms due to the condensation surface is made by two cold sides and the Peltier cell is small. To solve it, is proposed to increase the quantity of cells used in the system.

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