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Solar Dryer with Electronic PID Controller for Dry Potato Production

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ABSTRACT

The objective of the research was to determine the amount of moist extractable matter from the precooked potato dough with the cut in the shape of sticks and the acceleration of the subtraction of moisture from the matter to be dried inside the solar dryer, controlling the flow of dry air entering the collector through six fans. The temperature and relative humidity in the dryer vary with the flow of air that enters the interior of the dryer and by the heat of the brass generated by the exposure of the extraction chamber to radiation from the Sun from 9:00 am. to 5:00 pm. The temperature and relative humidity values detected by the DHT 22 sensor were processed by the Arduino based microcontroller that has embedded the PID control program, whose outputs acted on the fans and heaters, fed with conventional energy, with respect to the setpoints of temperature 36.5 °C and relative humidity 33%. 26 temperature and relative humidity samples were taken during the day, inside the solar dryer chamber with electronic PID controller. As a result, an average controlled temperature of 36.36 °C and relative humidity of 33.115% were obtained in the dryer chamber, allowing the extraction of 73.16% of the weight of the wet matter from the precooked potato. Achieving, dry potato weighing 26.84% of the initial mass, in a drying time of 8 hours.

Keywords: dry potato, solar dryer, dehydrator, PID control, dry matter.

INTRODUCTION

In industrialized countries, the consumption of natural and healthy products is increasing [García-Oliveira et al., 2020]; In times of high production of food such as grains, aromatic herbs, fruits, meats and others, the consumption surplus since ancient times has been conserved through natural drying with the Sun, prolonging its conservation for months and years; the quality of the food of the producers is ensured, the use of clean energies at no cost, and the generation of work in the production área [Nukulwar & Tungikar, 2021; Sharif et al., 2017].

The potato production in Peru registered in 2019 was 5.3 million tons, being the first producing country in Latin America and the 14th largest producer worldwide after countries such as: China, Russia, India, Poland, United States. The United States, Ukraine, Germany, the Netherlands, Belarus, France, Iran, Turkey and Canada; In its production it has given 110 thousand permanent jobs, in addition to the impulse of the local economy of each production area, benefiting 711.3 families, mostly in the highlands of Peru [Acosta Cuintaco, 2019].

The production of the various varieties of potato in the Huancavelica region, occurs in the months of September to June of each year has the highest production [Becerra, 2017]. This too much production is not consumed in its entirety, the surplus of the potato production, it is necessary to conserve it, but it is difficult to preserve it for more than two months, so the peasant resorts to the traditional methods of the ancestors for its conservation, among them: the Chuno and the dried potato, in addition these derivatives are more profitable and easily transported to the places of sale [Camayo Lapa et al., 2020].

The dehydration of food or the drying of food is an ancient method for preserving it, the drying process removes the water present from the food, which is a means for the presence of bacteria and fungi, causing the food to become deteriorate [Kannel et al., 2007], the elimination of water in food is very important for its conservation, the use of dryers by means of the Sun is the most used method, adding the technology of control of air flow and humidity inside the dryer the product eliminates the liquid mass in less time; Investigate the elimination of the water present in the pre-cooked potato using a solar dryer with electronic control of the dry air flow, the temperature and humidity inside the dryer, a dry product is obtained in less time than the dryers without control [Das et al., 2021; Goel et al., 2019; Gupta et al., 2017].

The dry potato is obtained from the process of cooking and drying or dehydrating it, obtaining yellow or black dried potato, for the drying process different technologies are used, which in its vast majority is the artisanal process and the rest uses intermediate technology. use third and fourth quality potatoes [Raghavi et al., 2018]; the yellow dried potato is of the Yungay variety, and the other known as black dried potato made from the other varieties and is considered to be of lower quality [Lati et al., 2017]

To obtain quality dry potatoes, several intermediate processes are required, one of them is selection; where potatoes are picked by variety. The peeling can be carried out by three methods: manual abrasive and chemical, in the first one the human hand intervenes, the process being slow, in the second case it is carried out by means of rotating or vibrating machines such as washing machines whose walls are covered by filings of abrasive, turning and sucking the water leaves the potato clean and the chemical based on NaOH [Damayanti et al., 2021]. The grinding is carried out with sharp blades and is intended to eliminate the deep eyes that the potato may have. Cooking takes place for approximately one hour.

The boiled potatoes go through the process of cutting by machines or manual mills, it can have different shapes like the sticks used in this work [Pedreschi et al., 2018]. Drying is carried out in semi-industrial dryers or outdoors with exposure to sunlight [Singh et al., 2017]. By means of the first form, the approximate drying of the potato is two days, by means of the second option, drying is achieved in three days in full sun, in addition to requiring a protection mechanism against contaminants from the elements [Camayo Lapa et al., 2020; Eltawil et al., 2018]. So it was necessary to implement a solar dryer with electronic PID controller[Bista, 2016], to improve dry potato production in the Huancavelica-Peru region.

MATERIALS AND METHODS

The renewable energy of the Sun in the form of heat, allows to dry all organic matter that is exposed to the solar rays, where the energy of the photons is established by the equation $E = hf$, known as the Planck-Einstein relation, with $h = 6.626\times10^{-34}$ J·s and f that represents the wave frequency associated with sunlight. The use of artificial dryers that use fuel has been used for several decades, due to its low cost of fuel, due to the increase in its cost, dryers that use solar energy have been developed, with the use of new techniques and drying methods outdoor [Batubara et al., 2017]. The energy from the Sun that reaches the earth's surface in the form of heat or electromagnetic particles (photon) is used to heat the air flow inside the solar dryer due to the greenhouse effect.

The elements of the solar collector are: a concentrator of the heat energy of the solar rays, which consists of a metallic surface, this absorbs the solar rays that impact on its surface, the heat generated by this concentrator heats the air by conduction, the metal it must be black in color, and of a suitable thickness to concentrate the heat, its orientation, being located in the department of Huancavelica-Peru, is to the north with an increase of 10°. To maintain the greenhouse effect, the cover was made of glass, which made it possible to avoid the loss of heat energy.

To improve the performance of the dryer, additionally conventional electrical energy was used as an auxiliary energy source, for cloudy days that have less solar radiation, this dryer allowed the flow of warm and dry air and the temperature of the environment, which are the main elements for drying the product. There was a chamber that contains trays made of mesh where the product to be dried rested, allowing the flow of hot air to extract water from the product until it was dry.

Inside the solar dryer, a better drying environment was achieved for the pre-cooked potato, where the temperature doubles with respect to the outside environment of the town of Huancavelica, in the same way the setpoint of the relative humidity was established inside. of the solar dryer at 33%, and evaporate 70% of the water. The dryer was of the tetrahedron type with a rectangular base measuring 0.8×0.6 m and a height of 0.4 m, enclosing a volume of 0.192 m^3, with 0.4 mm thick glass walls that improved heat absorption and transmission.

The solar dryer plant is first order with delay, as presented in equation 1,

$$G_{(s)} = \frac{T_{(S)}}{q_{in(S)}} = \frac{K}{\tau S + 1} e^{-t_d S} \quad (1)$$

where: K – own or static gain of the process,
t_d – delay time,
τ – time constant.

Initially, the dehydration system was simulated in Matlab without the electronic controller, giving as a response the curve shown in Figure 1.

According to the Ziegler and Nichols oscillation method, the parameters of the proportional-integral-derivative (PID) controller were determined; In the simulation circuit in Matlab, Kp was varied until the oscillation was found, obtaining Kc = 553750 and Pc = 0.01 s. The output signal oscillates in a period of 0.01 s. With this period the values of Kp, Ti, and Td were determined; where Kp = 0.6, with Kc = 332250 recalculated, Ti = 0.005 and Td = 0.00125. The PID controller has equation 2:

$$PID_{(s)} = K_p(1 + \frac{1}{0.005\ S} + 0.00125\ S) \quad (2)$$

In Figure 2 the simulation of the response to the unit step of the PID controller of equation 2 is presented, where for the value of the different constants the output stabilizes at 0.05 s.

The use of the Sun's energy through radiation inside the automatic drying system; allowed the temperature to reach the desired control point, in the same way with the control of the ventilation of the interior the relative humidity required to dry the pre-cooked potato was reached, these control points were maintained with the use of the PID controller implemented in the Arduino microcontroller.

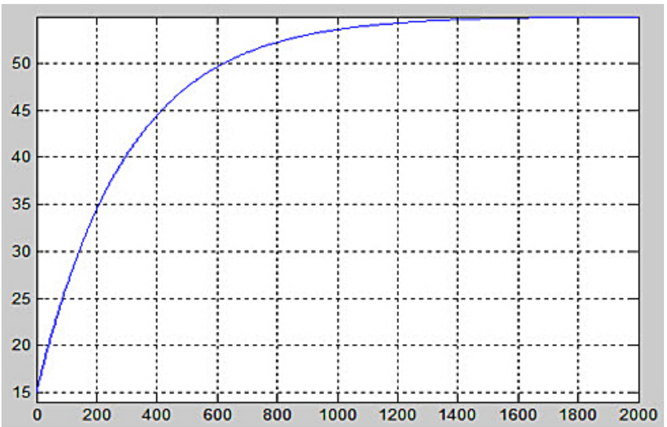

Figure 1. Uncontrolled dehydrator system simulation

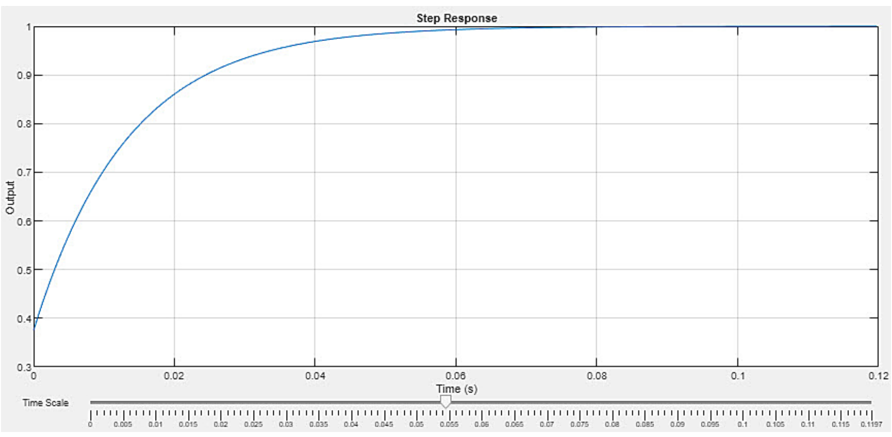

Figure 2. Matlab simulation of the response to a unit step of the PID controller

RESULTS AND DISCUSSIONS

The samples taken inside the hermetic solar dryer consist of temperature and relative humidity, these being a total of 26; Likewise, for the performance of the system, weight data were taken at the beginning (pre-cooked potato) and at the end of the drying period (dry potato). The value of measurements of the samples with a traditional dryer is presented in Table 1, where the average temperature is 23.36 °C and average relative humidity is 45.92%

The drying percentage of the total mass is dehydrated in 71.0%, with a standard deviation of 2% and variance of 0.05%. The average dry mass of potato obtained after drying in the traditional way is 29%, this in at least three days and in full sun from 9:00 am to 5:00 pm.

To improve the drying process of the pre-cooked potato by means of the implemented system, the temperature and relative humidity sensors were installed in suitable places inside the solar dryer, the data recorded by the sensors are compared with the ideal data (points of setpoint) of drying of the pre-cooked potato, if there is a difference, the error occurs, the system corrects the error until it is reset to zero, inside the hermetic solar dryer there will be a constant drying temperature, even though the outside changes temperature and humidity, achieving a drying of the pre-cooked potato and a dry potato product in less time. The PID control system was built to control the variables temperature and humidity, the control is carried out based on data provided by the DTH 22 sensor. It is corrected by suction of air by the fans until the error is null. To avoid the temperature drop when the sky is cloudy, the PID controller activates the heater to continue the potato drying process without interruption.

With the solar dryer with PID controller implemented, temperature and relative humidity measurements were carried out by means of the DHT 22 sensor inside the dryer plant. The data obtained are presented in Table 3.

From the statistical analysis of Table 3, a mean temperature of 36.423 °C was obtained, with a standard deviation of 1.238. For a setpoint of 36.50 °C, the temperature inside the dryer plant was subjected to a comparison test of means of both tails, obtaining a p-value of 0.754 for $\alpha = 0.05$, with these data it was determined, with 95% certainty, that the temperature inside the plant is statistically 36.50 °C

In the same way, the relative humidity was analyzed, obtaining an average of 33.115% with a standard deviation of 1.532. For a setpoint of 33%, the relative humidity inside the dryer plant

Table 1. Measures of ttemperature and relative humidity inside the traditional drying system

No.	T, °C	RH%	No.	T, °C	RH%
1	17.9	41.3	14	26.1	49.4
2	25.9	41.9	15	24.2	48.7
3	17.0	31.6	16	29.0	46.0
4	15.8	41.5	17	24.7	54.2
5	17.0	51.2	18	23.3	34.1
6	24.7	51.1	19	22.4	51.1
7	26.1	50.0	20	25.9	49.1
8	24.5	49.7	21	19.0	54.0
9	30.2	49.7	22	19.2	31.2
10	26.0	50.7	23	22.5	52.0
11	29.8	39.6	24	16.0	47.0
12	26.0	47.7	25	23.4	49.1
13	25.2	40.1	26	25.8	42.0

Table 2. Weight samples at the beginning and end of traditional potato drying

Observation	Start weight (g)	Final weight (g)	Dehydration (%)	Dry material (%)
W1	500	150	0.70	0.30
W2	600	190	0.68	0.32
W3	1200	360	0.70	0.30
W4	1100	290	0.74	0.26
W5	1000	330	0.67	0.33
W6	1200	340	0.72	0.28
W7	800	240	0.70	0.30

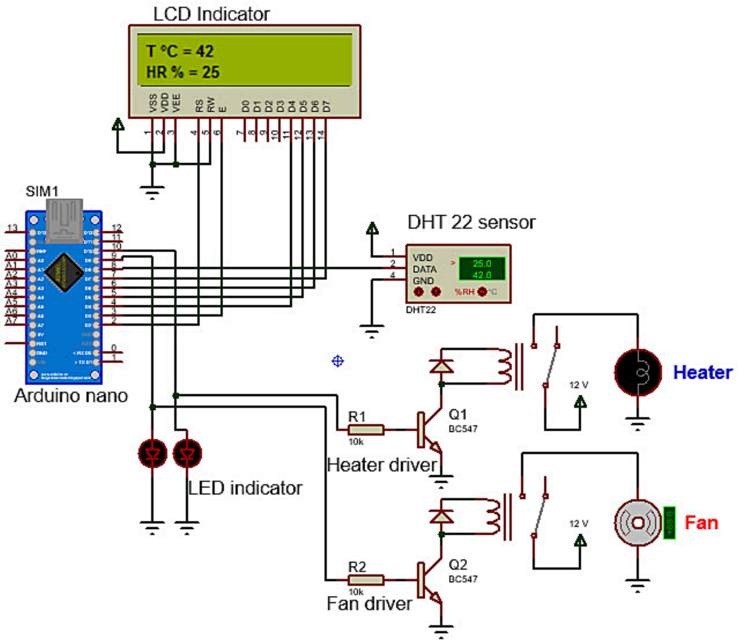

Figure 3. Electronic control circuit temperature and relative humidity

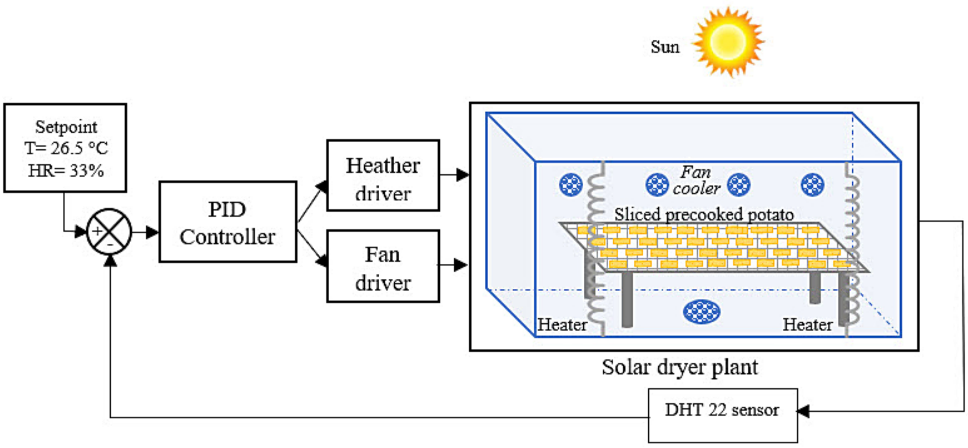

Figure 4. Hermetic solar dryer with PID controller diagram

Table 3. Temperature and relative humidity measured inside the solar dryer with controller plant PID

Observation	T (°C)	RH (%)	Observation	T (°C)	RH (%)
1	37	34	14	37	34
2	38	32	15	38	36
3	38	33	16	36	32
4	36	35	17	36	32
5	36	33	18	37	36
6	38	31	19	36	34
7	38	31	20	37	33
8	35	32	21	34	33
9	35	32	22	35	32
10	36	34	23	36	32
11	37	34	24	35	35
12	38	31	25	35	35
13	38	31	26	35	34

was subjected to a comparison test of means of both tails, obtaining a p-value of 0.704 for $\alpha = 0.05$, with these data it was determined that the Relative humidity inside the plant with a certainty of 95%, it is stated that it does not vary significantly from the set point (33%).

Figure 5a shows the distribution of the precooked potato for drying inside the solar dryer with PID controller of temperature and relative humidity, exposed to solar radiation for approximately 8 hours, and Figure 5b shows the balance of weighing the dry precooked potato.

Table 4 shows the percentage of reduction of the mass of the precooked potato dried with the solar dryer with PID control of temperature and relative humidity. It was determined that the precooked potato inside the solar dryer with PID control of temperature and relative humidity reduced its weight to 26.84% in an approximate period of time of 8 hours, which indicates that 73.16% of the moisture content was extracted. of the potato.

From the results, with respect to the temperature, inside the solar dryer it doubles the temperature outside the solar dryer, this occurs due to the brass and its color, which is an accumulating element of heat energy.[Patil et al., 2018], irradiating in a homogeneous way towards the air concentrated inside the solar dryer plant where the precooked potato is located[Camayo Lapa et al., 2020]; This made it possible to control the temperature by means of the PID controller, keeping the temperature at 36.5 °C.

Table 4. Percentage reduction of the mass of the precooked potato with the solar dryer with PID control temperature and relative humidity

Observation	Weight reduction (%)
1	27.27
2	27.78
3	26.39
4	26.36
5	26.73
6	27.00
7	26.34

The relative humidity outside the solar dryer was 46.08%, for the proper drying of the precooked potato cut into sticks it decreased to 33%, this humidity percentage allowed to reduce the drying time of the precooked potato mass to 8 hours, compared to traditional drying time which is more than 24 hours [Norton, 2017].

The weight of dry mass of the precooked potato obtained in the traditional way is 29.91% of the initial weight in 24 hours distributed in three sunny days [Camayo Lapa et al., 2020]. Using the dryer with the PID temperature and relative humidity control system, it was possible to obtain a dry mass of precooked potato of 26.84% of the initial weight in 8 hours.

(a) (b)

Figure 5. (a) distribution of the precooked potato inside the solar dryer with PID control, (b) weighing the dry potato

CONCLUSIONS

The solar dryer, implemented with a PID control system for temperature and relative humidity, maintains the temperature inside the dryer at 36.5 °C. Likewise, the relative humidity is controlled, keeping it at 33%. Consequently, the solar dryer installed in the city of Huancavelica-Peru, allowed to dehydrate the precooked potato with cut in the form of sticks obtaining 26.84% of the initial mass, in a period of time of approximately 8 hours that lasted the drying process of the precooked potato. We can take advantage of solar energy, especially its calorific power for drying other agricultural products of the Huancavelica region (beans, wheat, barley, airampo etc.) and types of meat (chicken, hen, truca, beef, sheep and camelids), with solar drying systems controlling the temperature and relative humidity inside.

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