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Design of a solar and gas dryer to use coffee pulp in food processes in Peru

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ABSTRACT

In the central jungle region of Peru, within the wet processing of coffee, the coffee pulp is discarded. This objective is to design a dual solar and gas dryer with continuous operation, for the dehydration of waste from wet processing of coffee for human use. The proposed objective is part of a broader project to apply the circular economy in the use of waste from wet coffee processing financed by Pro Ciencia. The following procedure was followed. At first, a 100 kg/Bach capacity gas and solar system dryer was designed applying the proposed technology development methodology in mechanical engineering and secondly arriving at the construction of the prototype. The results are to have a design methodology and the built prototype of the dual dryer (solar and gas) of continuous and semi-automated operation that has a control panel to allow programming and monitoring the drying process in real time. At the end of the project, the proposal will allow a continuous dehydration of the coffee pulp with quality, low cost and the industrialization of its by-products such as coffee pulp flour, filters and functional drinks.

Keywords: Solar dryer, Coffee pulp, Solar collector, Photovoltaic, Gas.
Article type: Research Article.

INTRODUCTION

Faced with the problems of climate change, the UN promotes the Sustainable Development Goals by 2030, including one of them substantially increasing the percentage of renewable energy in the set of energy sources (ONU 2021). Drying techniques reduce food spoilage after harvest. However, conventional drying consumes between 20% and 25% of the energy used in food processing industries (Ananno *et al.* 2020), these post-harvest losses of agricultural products is 30 to 40 % of total production due to inappropriate practices (Iriarte *et al.* s. f.; Conde 2017) even more so in developing countries (Hegde *et al.* 2015). Conde (2017) states that the traditional drying system, although it is natural but is contaminated. In the case of coffee, it should be stored or covered at night to prevent it from re-absorbing environmental humidity and the impossibility of drying a high volume of coffee, which corroborates Guevara-Sánchez *et al.* (2019) and that conventional mechanical drying is better for coffee but this process is expensive. For this reason, coffee-drying is common in greenhouse-type dryers. Quintanar-Olguin & Roa-Durán (2017) evaluated these types of dryers and managed to dry parchment coffee until reaching 11 % humidity in 5 sunny days, reaching a thermal efficiency of the solar dryer of 12%. Sun-drying processes, such as those of artisanal systems (canopies) conditioned by weather conditions and subjected to solar energy, cause fatty acids and sucrose in coffee beans to decrease more significantly (Avila *et al.* 2020). Agricultural exporters need for higher volumes and continuous operation. One of the studies on the drying coffee pulp is by Torres-Valenzuela *et al.* (2019) who reported that drying in an oven is a good conservation alternative, since coffee pulp has the presence of high-quality biocomponents, interest caffeine and chlorogenic acid that are not lost due to the effect of the drying process and the changes in color are slightly perceived by the human eye, the only thing that is expensive for electrical energy. The object of present study was to define the dual indirect dehydrator, where the solar collector and the drying chamber go together and the product to be dried goes in this

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chamber (Guevara & Sabas 2017). Its drying function is to extend the useful life of the product under controlled conditions. To understand the object of study, which is the indirect solar dryer, we built a black box (Fig. 1).

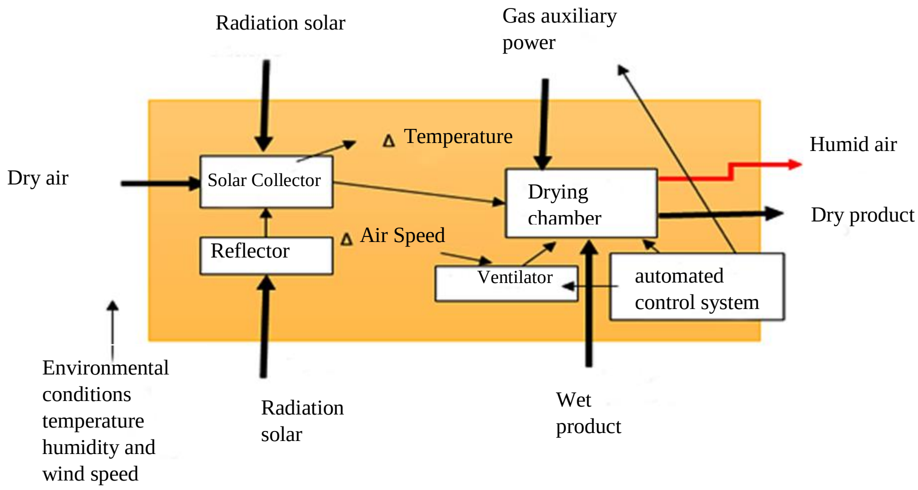

Fig. 1. White box of an indirect solar dryer.

In Fig. 1, in the indirect solar dryer, the product is not directly exposed to sunlight. We also identify the main elements that are the solar collector allows converting solar radiation into heat in the drying cabin where the product to be dried, enters. In addition, the secondary elements such as the flat solar reflector increases the heat by reflecting the solar rays to the solar collector. Moreover, the air heating system through conventional energy, in this case gas, helps its continuous operation. An automated control system for temperature, humidity and weight within the drying cabin activates a photovoltaic system for the sensors and fans for the entire drying system. We identify inputs that are solar radiation, ambient air, humid product and an auxiliary air heating system through gas, as well as a photovoltaic system to activate the fans and controls through sensors. The outlets are the hot humid air expelled from the drying system and the dried product. The entire system is within a context of environmental conditions that need to be measured, such as temperature, humidity, and wind speed as well as direction from the external environment through a station. Due to the previous problems, it is necessary to experiment with the optimization of hybrid indirect solar dryers with conventional energy in this case for their continuous operation, considering the flat reflectors, as a photovoltaic system to activate the fans and temperature, humidity and weight controls of the product in order to meet the requirements and technical standards for export. The purpose of the proposal is to generate a circular economy model through the use of residues from the coffee wet processing process through the use of a solar system and gas dryer (100 kg/Bach). In this way, we maximize using coffee fruit and, above all, benefit families with additional income, as well as the fulfillment of the objectives of the Oxapampa Asháninka Yanesha Biosphere Reserve. It also has an evident impact on the final quality of the product and opening up new entrepreneurial options, reduction of losses and export with a green seal (Espinoza 2016).

MATERIALS AND METHODS

Application of scientific methodology for the development of technologies in a dryer of 100 kg coffee pulp

The activities that will be applied to the design of a dryer to dehydrate coffee pulp produced in the city of Villa Rica in the Province of Oxapampa, Paco Region are the following:

Activity 1: Selection of the technological alternative

Due to the continuous drying conditions, the most appropriate is the solar and gas dryer with collector and indirect cabin that you have according to the scheme of Fig. 2.

Activity 2: Design of the autonomous solar and gas drying system

- **Drying chamber design**

The morphology and drying conditions of the coffee pulp (coffee waste) will be taken into account. To calculate the dimensions of the drying chamber, the following parameters are taken: Quantity of product to be dried, cross-sectional area of the hot air flow and manual discharge of the products to be dried.

- **Design of flat solar collectors**

The meteorological variables are taken into account: wind speed, solar irradiation, latitude, humidity and air temperature (information obtained from the test site), in addition to the analysis of thermal circuit in a flat plate collector. Energy balance should be taking into account the heat absorbed, the useful heat, and the losses at the top and bottom of the flat plate solar collector. The theoretical calculation of the efficiency of the flat plate solar collector is carried out, determining the optimal catchment area and the passage area (air flow) considering the reflectors and photovoltaic system for forced flow, with which the dimensions can be optimized for the collector (length, width and height).

- **Design of forced air systems**

Taking into consideration the control of temperatures inside the drying chamber and the humidity of the pulp and shell of the coffee.

- **Design of control systems**

Stabilization and monitoring temperatures, humidity and speed in solar drying

RESULTS AND DISCUSSION

Coffee pulp study

The proximal chemical characteristics of the pulp and shell of pulped coffee (Torres-valenzuela *et al.* 2019). The pulp has a high moisture content (greater than 80%) and most report an average of 85%

Calculation and design of the solar drying system

Conceptual design of solar dryer

This result allowed us to determine the technology and define the geometric shape of the solar dryer and it has the following characteristics:

1-**Characteristics of the coffee pulp**: Manually manageable size, as it is like an amorphous mass. Similarity geometry, by layers of 0.5 - 1 mm. It is a delicate fruit, sensitive to the direct incidence of solar radiation. High initial moisture content is 80-85%

2-**Conditions and drying requirement**: Drying with hot air at 60 ºC is recommended. Preferably uninterrupted drying and in batches of 100 kg. Final humidity is 12%.

3-**Selected technology**: We choose an indirect solar drying with forced air, that is, we can achieve the drying conditions at 60 ºC with a solar collector as well as regulating by forced air ventilation and by photovoltaic energy.

4-**Characteristics of the place**: In the city there is electricity available, but not in the countryside, so we will use solar energy and photovoltaic gas. Villa Rica is a town located in the province of Oxapampa in the department of Pasco. It is located at an altitude of 1467 masl, with average temperatures of 15 ºC minimum and 27 ºC maximum average, with average annual radiation of 3.6 kW/m ^{2} /day (Limaymanta 2019).

Drying room

Deposit that will contain the coffee pulp to be dried, whose shape: Since it is a manipulable and fragile product, it is proposed to accommodate it in trays, which was obtained experimentally at 12 kg m^{-2}. Therefore, the chamber is proposed as parallelepiped , whose volume is considering the following: flow form: parallel; simple frame tray with millimeter mesh; Chamber bottom dimension 1.00 m; collector width 2.00 m; chamber height: given 20 trays and 2 trays per row makes 10 trays per floor and with spaces of 0.10 m, it is 1.20 m. Therefore, the dimensions of the drying chamber are as observed in Table 1.

Flat solar collector

Device that allows us to transform radiant solar energy into thermal energy in the form of hot air (Espinoza 1991). The size of the collector: In this part it can be approximated by a drying factor that is 1.0 kg water/m^2 (Espinoza 1991). According to the humidity conditions of the coffee pulp, it is necessary to evaporate approximately 73 kg of water. Estimated area per day is 73 m^2. The result obtained would mean that 73 m^2 of flat collector is needed to dry in one day, therefore 24.3 m^2 in three days . So later we will make more precise calculations. For the moment, for the conceptual design we will stay with the alternative for the collector of 24 m^2 and drying in three days, also assumed that the width is 2.5 m, and the length 9.6 m.

Table 1. Dimensions of the drying chamber.

Characteristics	Inside	Abroad	
Internal width	0.75	0.85	The difference provides for isolation
Internal length	1.2	1.30	
Internal Height	0.75	0.85	
Trays	Length 0.72 × width 0.46 m		
Volume Of Work	0.63 m ^{2}		
Space Between Trays	57mm		
Ability	20 trays		
Capacity Per Tray	3 – 5 kg		

Designing calculations for drying 100 kg of coffee pulp

Within the design process, it is necessary to carry out some referential or verification calculations (Espinoza 1991). If we wish to dry 100 kg of a product such as coffee pulp from 85% initial humidity to 12% final humidity, we have: 73 kg of water to evaporate, taking into account that the latent heat of evaporation of water at temperature solar drying = 2440 KJ kg^{-1} water. So the necessary energy = 73 kg water × 2 440 KJ kg^{-1} water = 178 120 KJ. The annual average radiation in Villa Rica is 3.6 kw.h m^{-2} of solar radiation (Limaymanta 2019) the equivalent energy is 12,960 KJ m^{-2} day^{-1}. Assuming 24 m^{2} of collector and assuming a total efficiency of 40%, we have available energy: 124,416 KJ day^{-1}, which means 1.43 days of drying. Therefore, we would need 1.43 days of sunshine. Therefore, having collectors 2.5 m wide × 2.5 m long, we would need 3.35 collectors and if we place reflectors such as flat mirrors, we would only need 2 solar collectors to dry in a single day. By the proposed collector in quantity of only one, it would dry in two days if there is continuous sun, which is the most recommended. To check the length of the solar collector we will use the following equation 2 (Espinoza 1991).

$$\Delta T = (0{,}131H)(1 - e^{-0{,}12L/v})\Delta T = (0{,}131H)(1 - e^{-0{,}12L/v})$$ Equation. 1

where: $\Delta\Delta$T= Air heating through the collector (°C)

HH= Solar radiation in W m^{-2}

LL= collector length (m)

vv= air velocity through the collector

Giving radiation data from 600 W m^{-2} to 900 W m^{-2} , a length of 2.50 m, velocity of .6 m s^{-1}, the collector can increase by 28 °C to 43.0 °C (Table 2).

Table 2. Temperature increase at different radiations and with a 2.5 m collector and an air velocity of 0.6 m s^{-1}.

AT (°C)	H (w/m2	and	L(m)	*v* (m/s)
11.35	200	3.1516	2.5	0.6
17.03	300	3.1516	2.5	0.6
22.71	400	3.1516	2.5	0.6
28.39	500	3.1516	2.5	0.6
34.06	600	3.1516	2.5	0.6
39.74	700	3.1516	2.5	0.6
45.42	800	3.1516	2.5	0.6
51.09	900	3.1516	2.5	0.6

Note: Application of empirical equation 1.

Table 2 depicts that by 100 W m^{-2} and 900 W m^{-2}, an average increases of 5 °C and 51 °C can be achieved respectively. These data allow us to make decisions for the length of the collector. The data obtained in Table 2 allows us the feasibility of drying in two days in full sun since the temperature in the collector would reach a maximum of 68 °C when there is a minimum ambient temperature of 17 °C, while up to 78 °C if it is maximum temperature of 27 °C.

Design of forced air systems

Calculation of the air flow necessary to dry 100 kg wet product, from 85% to 12% final humidity such as coffee pulp: Given the average drying rate of 7.87×10^{-6} kg water/kg dry-s and the 100 kg wet product is made up of 85 kg water and 12 kg dry matter, the average evaporation rate would be:

7.87×10^{-6} kg water/kg dry-s × 12 kg dry = 9.4×10^{-5} kg water/s

This amount of water will have to be evaporated in an air current of a certain flow rate and drying capacity, which we obtain from the psychrometric chart for air at pressure and temperature conditions of the place where the drying will take place. A total of 20 kg of drying air has the capacity to evaporate 13 g water and, the condition to evaporate: 9.4×10^{-5} kg water/s, so the necessary air flow is 7.23 g air/s.

Calculation of the flow (Q) and velocity (v) of the air:

The flow is calculated from:

$$Q = \frac{\dot{m}}{\rho} Q = \frac{\dot{m}}{\rho}$$

where:

$$\rho = densidad\ del\ aire\ \left(1.2\,\frac{kg}{m^3}\right) \rho = densidad\ del\ aire\ \left(1.2\,\frac{kg}{m^3}\right)$$

and

$$Q = \frac{\dot{m}}{\rho} = \frac{0.0072\ \text{kg}\frac{\text{aire}}{\text{s}}}{\frac{1.2kg}{m^3}} = 0.6\, {m^3}/{s} Q = \frac{\dot{m}}{\rho} = \frac{0.0072\ \text{kg}\frac{\text{aire}}{\text{s}}}{\frac{1.2kg}{m^3}} = 0.6\, {m^3}/{s}$$

The flow we need is 0.36 $m^3\ s^{-1}$ and the recommended velocity is 1 m s^{-1} to 2 m s^{-1} (Espinoza 1991).

Result of the final dimensions of the solar dryer drying chamber

The interior dimensions are 0.75 m; internal width, 1.128; internal length; 0.75 m; and internal height 0.05 m is provided for insulation (Table 3).

Solar collector

The dimensions of a collector of 2.4 m wide, 2.4 m long and o.20 m height were taken into account, which will need 2 flat mirror reflectors for the collector. It is estimated that it can dry in two sunny days as solar powered only.

Solar panel sizing

404.8 Wh of energy per day is required, a 120 Wp panel is sufficient for a continuous operation of 3.6 h. Below is the complete dual dryer (solar and gas) built (Fig. 2). Fig. 2 shows the complete system of the dual dryer (solar and gas), in the front part the solar collector with forced ventilation system and in the back part the drying cabin. The photovoltaic system is located on the roof and to the left of the solar collector. The gas cylinder and the burners are located in the lower part of the drying chamber. Also, we present the control cabin with all its components, which can be observed in Fig. 3. Fig. 3 shows the control cabin and its components that will be detailed in Figs. 4, 5 and 6.

Dual Solar Dryer Control Board

The control board contains a main master control board, which is a main electronic circuit of the semiautomatic system in charge of controlling the dryer's static and editable variables, sensor data acquisition (temperature, humidity, current and voltage) and information processing. For the activation of actuators (fans and motors). From time to time it needs the supervision of trained personnel.

Fig. 2. Dual sun and gas dryer.

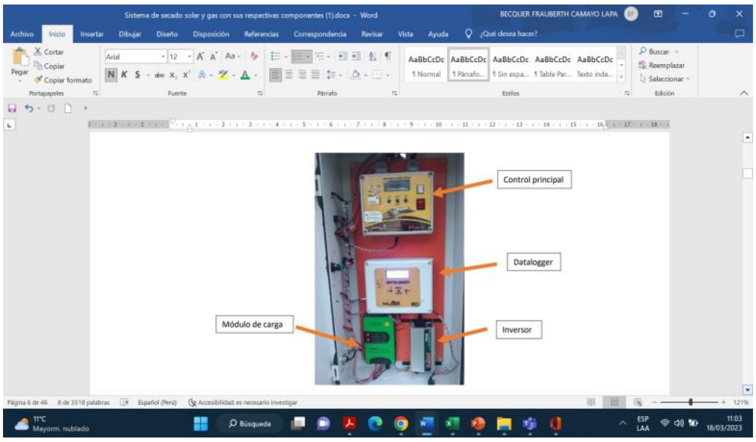

Fig. 3. Control cabin of the solar and gas dryer.

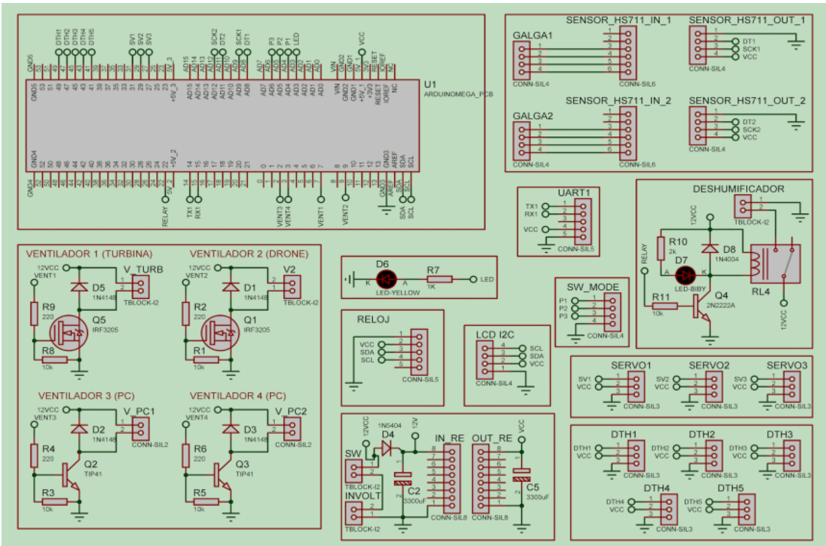

Fig. 4. Main Master Control Board.

Fig. 4 depicts the master control board that does not work alone, but has constant interaction with the slave secondary electronic board (Fig. 5), and the datalogger control board (Fig. 5). These use the UART communication protocol.

The slave electronic board

It is a secondary electronic circuit of the semi-automatic system in charge of controlling the variable weight of the dryer. It acquires the data in voltage and processes it to be able to convert it to weight expressed in kg (Fig. 5).

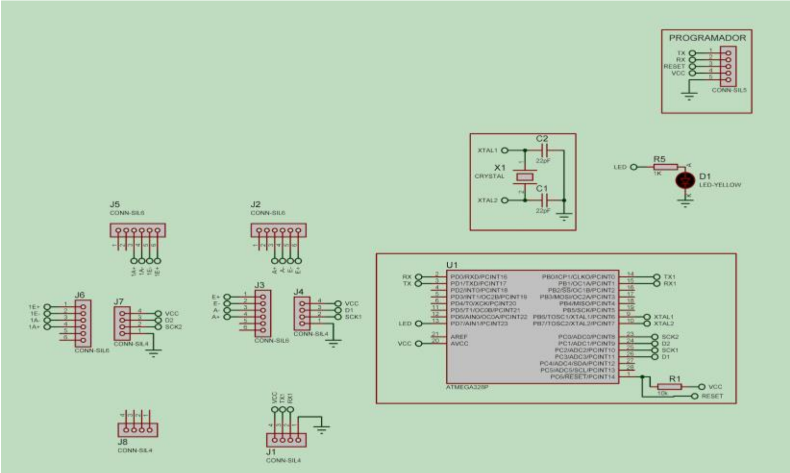

Fig. 5. Secondary slave electronic board.

Fig. 5 shows the configuration of the slave secondary electronic board, which sends the weight information to the **main master control board**, so that it can process the data and make decisions, which use the UART communication protocol

Control Datalogger

The Datalogger electronic circuit of the semiautomatic system in charge of receiving the processed information from the main master control board, registered study variables of the sensors and encrypted response of the actuators. The aforementioned board is in charge of decrypting the data and converting it into an acceptable format, recording it in the microsd memory (See Fig. 6).

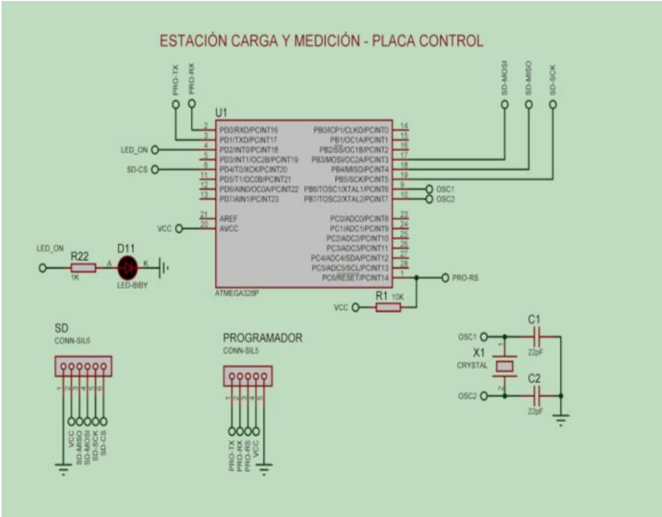

Fig. 6. Datalogger Control.

Fig. 6 illustrates the Datalogger control board that receives the encrypted information from the **main master control board** using the UART communication protocol.

CONCLUSION

There is a procedure for the designing and providing prototype of a solar dryer for the waste from the wet processing of coffee (pulp). It is autonomous and automated operation and as an auxiliary programmable gas energy source, it has an indirect drying cabin with a capacity of 100 kg per Bach, which is fed by increasing the temperature of a solar collector with flat reflectors. A photovoltaic system that energizes the control through a panel with an automated control viewer for the dryer. It also has a Datalogger to store the recorded data from sensor data (temperature, humidity, current and voltage) and an information process for the activation of actuators (fans and motors) contained in the indirect drying cabinet. Due to its continuous and programmable operation, the dual drying system (solar and gas) can be used to dehydrate any agricultural product for export due to the safety of the process and low cost.

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