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Design and construction of a forced convection solar fruit dryer in the municipality of Durango

Diseño y construcción de un secador solar de fruta por convección forzada en el municipio de Durango

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Abstract

The main aim is the design and build of a Convection Forced Solar Dryer used to dry Spicy Pineapple. The prototype was designed using Inkscape 1.1.2 software with 60cm*44cm*44cm dimensions, having a Drying chamber of 5 trays, two air-circulation serpentine heaters on top and back of the drying chamber and two solar modules of 6v each to power some fans to force convection. The main material used was MDF laser cutted for assembly, then black paint was applied due to the absorption capability and finally water sealer for humidity protection. Finally tests were carried on in State of Durango with Mean Solar Radiation of 5.7 kWh/m^2*day been 6.5 the Peak Sun Hour on may, concluding on three days' time needed for drying 3 kilograms of Spicy Pineapple, average initial temperature of 28°C and 55°C max, humidity reduced from 55% to 24% inside the system.

Solar dryer, Relative humidity, Solar radiation

Resumen

En la presente investigación se tuvo como objetivo el diseño y construcción de un secador solar de convección forzada para conservar piña enchilada. Se diseñó en el software Inkscape 1.1.2 con las dimensiones de 60cm*44cm*44cm, consta de una cámara de secado con cinco charolas, dos cámaras de circulación de aire anexas una en la parte superior y otra en la anterior cuyo sistema es similar a un serpentín de condensación y dos paneles solares de 6v lo cuales alimentan a los ventiladores en el proceso. El principal material utilizado para la construcción fue MDF utilizando una cortadora laser para su posterior ensamblado, se utilizó pintura color negro por su capacidad de absorción y sellador para protegerlo de la humedad. Al terminó del ensamblado se evaluó su funcionamiento en el Estado de Durango teniendo una radiación Promedio de 5.7 kWh/m^2*día y siendo el mes de mayo la radiación solar promedio de 6.5 HPS terminando con un tiempo de secado para la piña en 3 días para 3 kilogramos, con una temperatura promedio inicial de 28°C y una temperatura máxima promedio de 55°C, así mismo los valores de humedad relativa dentro del sistema variaron desde 55% a 24%.

Secador solar, Humedad Relativa, Radiación Solar

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Introduction

Food preservation is necessary for the daily life of human beings, as well as for the development of the population, with the increase in the cost of electricity, it is therefore necessary to take up alternative sources of energy for food preservation, one of the most widely used techniques is the drying of food using solar energy (Maupoey, 2001), either directly or indirectly (Lingayat, Chandramohan, Raju, & Meda, 2020); indirect exposure drying is preferred for the controllability of food quality, as it is possible to control the process by measuring the Water Activity (Aw) ensuring the quality of the final product (Badui Dergal, 2006).

Another advantage of the use of solar dryers is the prevention of the generation of Greenhouse Gases (GHG) in food preservation, and by reducing the mass and volume of the food by eliminating the water content, it is possible to reduce the cost of storage. The State of Durango is located at a latitude of 24.0277, longitude of -104.653 24° and 1′ 40″ North, 104° 39′ 11″ West presents an average radiation potential of 5.7 kWh/m²/day, thus providing optimal conditions for development and implementation of photovoltaic and photothermal solar energy systems. based on this it was decided to develop a solar dehydrator for residential use, using low cost and high availability materials such as MDF for mass marketing. The climatic conditions of the average temperature and relative humidity in the study area according to (CONAGUA, 2022) were identified as 24.7 and 25.8 respectively, whose values were considered for the sizing of the solar dryer.

Inkscape 1.1.2 design software was used to create and edit lines, graphics and design images. The system was then laser cut, assembled, painted and sealed. The drying time was approximately 3 days, during which time temperature and humidity measurements were taken inside the system in order to evaluate its performance. It is recommended to carry out thermodynamic analyses of the system, as well as tests to determine the quality of the product in accordance with NOM-044-FITO-1995 (DOF - Diario Oficial de la Federación, 1999).

Development

Characterisation of the study area

This project was carried out for residential use in the municipality of Durango, so the following climatic conditions were considered for the month of May 20202, according to CONAGUA 2022.

Climatological variable	Value
Precipitation	0
Relative humidity	27.3%
Solar radiation	670 w/m^2
Wind speed	4.08 k/h
Temperature	14-24°C

Table 1 Climatic conditions
Source: (CONAGUA, 2022)

Forced convection solar dryer design

Inkscape 1.1.2 software was used for the design of the system, its dimensions were 60cm*44cm*44cm. The stages of the design and construction of the solar dryer are shown below:

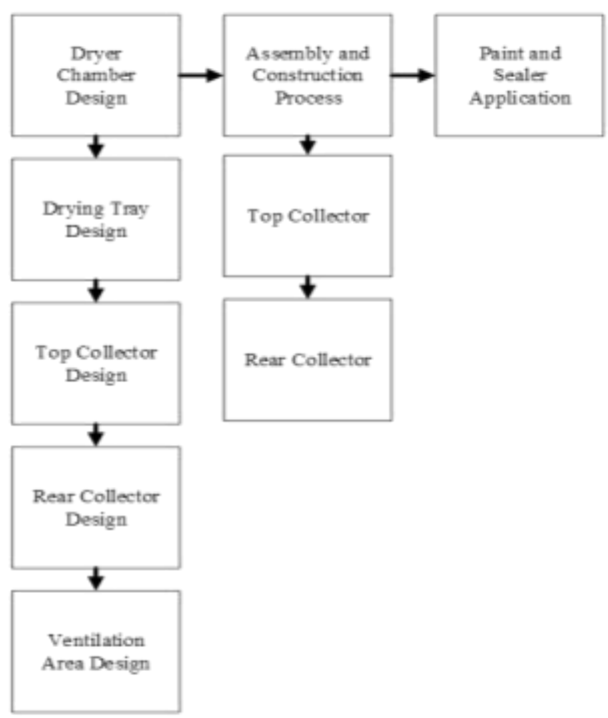

Figure 1 Flow diagram of the design and construction of the solar dryer
Source: Own elaboration

We started with the drying chamber in which we considered 5 previously sealed trays for fruit drying, with a capacity of 600 g of fruit each.

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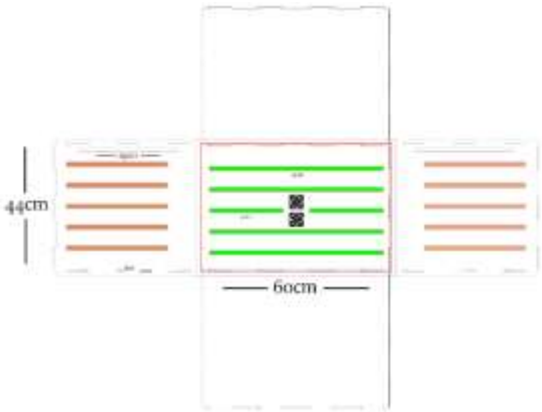

Figure 2 Design of drying Chamber in Inkscape
Source: Own elaboration

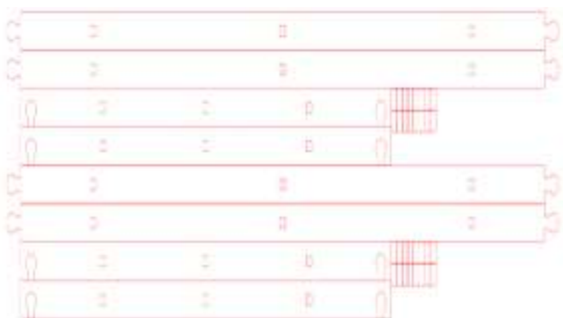

Figure 3 Design of drying trays Pieces in Inkscape
Source: Own elaboration

For the Upper Collector a condensing coil system was considered inside which the air was heated by the sun rays and therefore its air velocity increased and went directly into the drying chamber.

In Figure 4 the black arrow indicates the cut for assembly of the parts having a serpentine type assembly, the green arrow indicates the air circulation inlet, the blue arrow indicates a reduction in the circulation area for an increase in the air flow velocity.

Figure 4 Design of Upper Collector parts in Inkscape
Source: Own elaboration

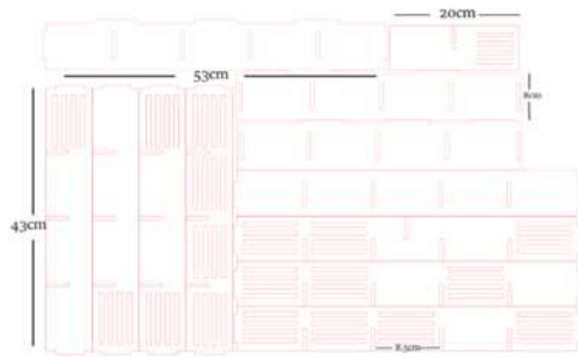

Figure 5 Inkscape rear manifold part design
Source: Own elaboration

The rear collector measures 53cm*43cm*8cm with circulation spaces of 5cm, these dimensions allow to support the glass which is the final layer of this chamber. For the forced convection, there are two 40mm x 40mm fans for the circulation of hot air, and thus have an adequate flow for drying, these will be powered by a 6v solar panel, with a capacity of 330mA, sufficient to achieve the operation of both fans.

Assembly, painting and sealing of the system

The parts were manufactured on the CO2 laser CNC using parameters of 10mm/s speed and 30% laser power. The parts were assembled, having first the sides, and the placement of the trays, as well as the top and bottom of the drying chamber, as shown in the following images:

Figure 6 Drying chamber assembly
Source: Own elaboration

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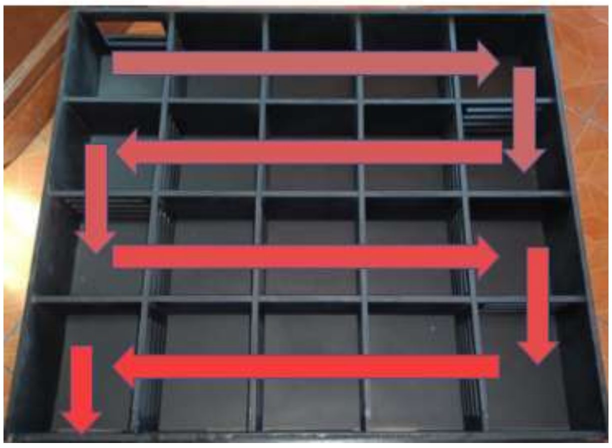


Figure 7 Airflow in the upper collector
Source: Own elaboration

Figure 8 Air Flow in the rear collector
Source: Own elaboration

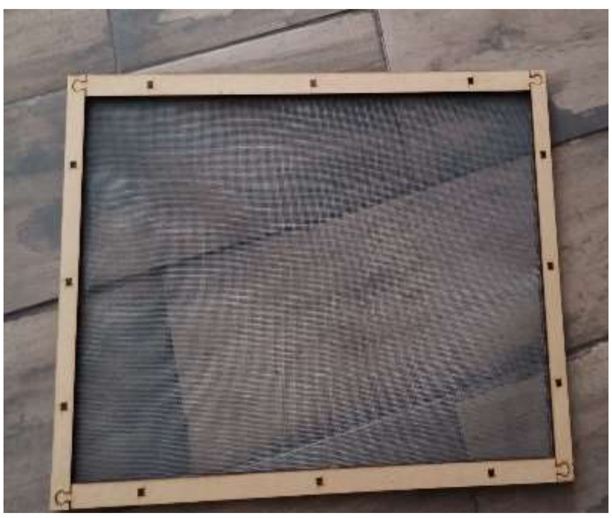
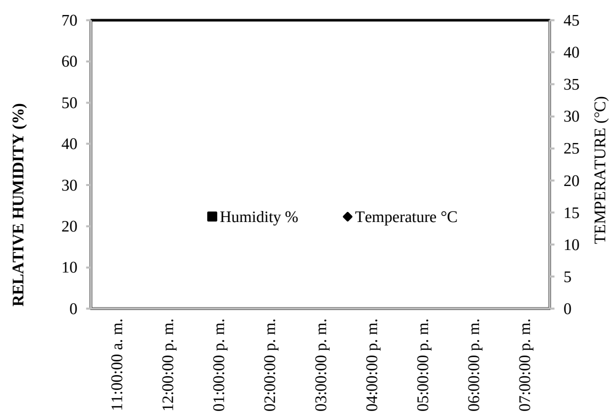


Figure 9 Drying tray assembly
Source: Own elaboration

Figure 10 Final finish of the solar dryer
Source: Own elaboration

Drying of honey pineapple under ambient conditions

Approximately 3kg of piñamiel were placed to dry at ambient conditions corresponding to the month of May. The temperature and humidity inside the system were measured and the following values were obtained:



Graphic 1 Dehydration test - day one
Source: Own elaboration

Measurements were taken from 11:000 am to 18:00 h, as shown in graph x, the highest temperature in the system was recorded at 16:00 h with a temperature of 43°C and a relative humidity of approximately 38%.

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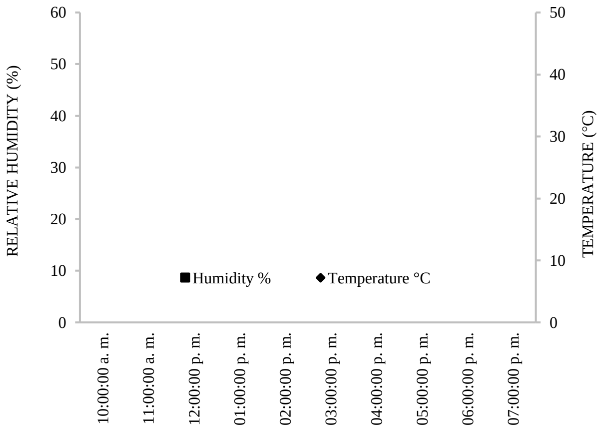
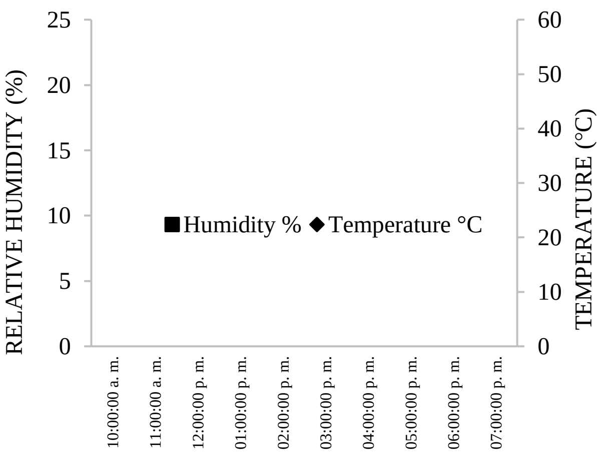


Graphic 2 Dehydration test - day two
Source: Own elaboration

As can be seen, the initial temperature was 28°C, and relative humidity was 54%. One hour later, after the fans had been turned on by the solar cells, and the humidity in the drying chamber had levelled off, the temperature increased to 39°C and the humidity dropped to 39%, For the next hour at midday the temperature increased to 44°C and the humidity decreased to 36%, in comparison to the previous day a decrease in humidity can be observed, serving as a reference that the pineapple is following the dehydration process, the highest temperature on this day was at 5: 00 p. m., also coinciding with the lowest humidity, achieving a temperature of 45°C with a humidity of 19%, ending at 7:00 p.m. with a humidity of 25%, having a humidity 50% lower compared to the previous day and its temperature was 31.5°C.



Graphic 3 Dehydration test - day three
Source: Own elaboration

As can be seen in this graph, the humidity started with 23%, and a temperature of 30°C, this at 10:00 am. After two hours it can be seen that the humidity dropped sharply, having 15% humidity and 52°C temperature, equalling at that time the humidity of the environment, the following two hours, this humidity rose due to a decrease in the temperature of the dehydrated, this thanks to the fact that the day was not completely sunny, the temperature was 49°C and a humidity of 17%, to finish the dehydration process at 5:00 p.m. with a constant humidity: 00 p.m. with a constant humidity of 15% and a temperature of 52°C, it is observed that in the temperature decrease there was no increase in humidity, which indicates the completion of the process.

Cost estimation of the system

The following table shows the costs for the production and assembly of the solar dryer.

Description	Unit cost (MXN)	Quantity	Total cost (MXN)
Sealer	130.00	1	130.00
Paint Can	50.00	3	150.00
MDF 5.5mm	320.00	1	320.00
Laser	20.00	7	140.00
Solar panel 6v	110.00	1	110.00
Fan 40mm	80.00	1	80.00
Glass plate 3mm	110.00	2	220.00
Mesh	5.00	5	25.00
Power	150.00	1	150.00
Labour	250.00	1	250.00
		Total:	1575.00

Table 2 Unit and total costs
Source: Own elaboration

Conclusions

The efficacy of the design was proven, as well as presenting lower manufacturing costs than those found on the market, resulting in a technically and economically viable solution, as solar dryers with similar capacities were found available to the public for more than 3 times the cost of the prototype presented in this document.

The objective of the next stage of the project is to obtain the drying curve characteristic of the process, in addition to the thermodynamic analysis of the system. As for the product, a quality analysis is planned.

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