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***Full Length Article***

# Solar Drying System for the Agro-products Dehydration

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## ABSTRACT

The proposed solar thermodynamic drying system reduces the traditional dehydration process of Roselle used in the western region of Mexico, from approximately four days to four hours. In addition to the 95% reduction in process time, this system also maintains the Roselle's nutritional content, especially that of ascorbic acid (Vitamin C). The proposed drying system is based on current operating conditions in Colima, Mexico as well as on three quantifiable control variables of Roselle: product weight, product humidity and product drying temperature. The product control variables were quantified and defined during the project as: Initial weight (1.0 kg of fresh product), final weight (0.152 kg of dry solid), initial humidity (84.8%), final humidity (14.3%) and dry temperature (48ºC to 68ºC). Based on these control variables, the proposed system operates a continuously moving band at a constant speed. As the Roselle moves along the band through the system's drying chamber, it is dehydrated by heated air. Initially, the system uses solar energy to heat fluid (i.e., water or thermal oil). The heat generated is transferred from fluid to surrounding air via a forced convection process. By greatly diminishing drying time and controlling humidity, the system affords considerable control over optimal end-product quality (i.e., protection from pollutants & destructive microbial activity). The proposed system's settings can be easily adjusted to accommodate other products as well, making it even more commercially viable for agro-industrial producers. The drying process eliminates the water or moisture content of the calyxes yet maintains the nutritional properties specifically, the ascorbic acid content. A low cost and durability of the system is considered in the design.

**Key Words:** Low cost solar; Dehydration system; Roselle; Thermodynamics system; Agro-products dehydration

## INTRODUCTION

Roselle (*Hibiscus sabdariffa* L.) is a tropical shrub found around the world with an approximate height of three meters (Fig. 1). Barrios (2000) stated that it is commercially harvested in several states in Mexico, most notably in Colima, Jalisco, Guerrero, Oaxaca and Veracruz. As part of the plant's flower system, the calyx consists of the group of sepals, which surround and protect the flower petals. This is what is usually harvested and processed, not the flower petals themselves (*calyx,* which at times is simply referred to as *Roselle*). The dark red calyx is used in the production of teas and juices and also in the treatment of various physical ailments, such as those related to the kidney or stomach. Tsami (2000) stated that the Roselle is also believed to help lower harmful levels of cholesterol and fatty acids found within the blood and thus is used in the prevention of cardiovascular-related diseases. Irudayaraj (1999) stated that the High levels of humidity make the Roselle calyx more susceptible to decomposition and high levels of dryness reduce color and flavor.

Traditionally, Roselle calyxes are spread over open-area floors and dried naturally by the incidence of solar radiation. At sundown, the calyxes are gathered up and stored and the process is repeated the next day. This procedure takes an average of three to four days, depending on such conditions as ambient temperature and relative humidity. End-product quality is often adversely affected by open-air exposure to pollution and the like; lower quality output can in turn lead to lower economic profits for producers. The drying process eliminates the water or humidity content of the calyxes yet maintains the nutritional properties specifically, the ascorbic acid content . The dehydrated content of Roselle specific to the Colima region is; fat 0.1 g/100 g, carbohydrates 12.3 g/100 g, principally. Irudayaraj (1999) and Khattab (2002) stated that in dehydrated foods, due to minimal water activity, microorganisms cannot proliferate and most of the chemical reactions, which alter plant's chemistry are stopped. Thus, dehydration is a method used to preserve foods for long periods of time. In this way, agricultural products such as Roselle can be sold year-round, in and out of season. Krause

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(2002) reported that the optimizing solar thermal systems consist in the control of critical variables. In this paper present the design and assembly of a drying system, it consists on a solar drier and a solar hotter system developed to obtain dried Roselle calyx.

**The dehydration process.** In the region of Colima, Mexico, the average of relative humidity is about 80%, then the amount of water that can be absorbed by the surrounding air is small and the traditional dehydration process of Roselle can be rather slow. Such high levels of relative humidity can be artificially lowered by warming the surrounding air. In this case the proposed system utilizes controlled drying conditions under atmospheric pressure to achieve product dehydration.

**Batch versus continuous process drying.** The proposed solar drying system uses continuous process drying, which offers certain advantages over batch process drying. One of these advantages is that continuous process drying is not constrained to individual process runs potentially, all but one process cycle is needed to process any desired level of product. Another advantage to consider is that the method of heat transference used by continuous process drying offers better product dehydration results and end-product quality. With continuous process drying, the nature of the product and how efficient surrounding air is mixed with this product influences the level of drying. With respect to a product's nature, low to moderate temperatures used during the continuous dry process could favor the proliferation of fungi and bacteria, because of the presence of product humidity. The presence of microbial activity can quickly lead to product decomposition. Thus, Fu and Rich (2002) stated that a level of drying, which is not too low must be determined that avoids product decomposition. On the other hand, utilizing temperatures that are too high may destroy a product's nutritional content (i.e., certain vitamins important to color & flavor may be lost). Therefore, an adequate level of drying, which is not too high must be determined that prevents nutritional depletion.

## MATERIALS AND METHODS

In this section the Design, Analysis, and Proposal of Solar Drying System is presented, where four stages were defined in the design and analysis of the proposed solar drying system.

1. Determine the basic properties of Jamaica in order to establish various control variables.
2. Design and construct a solar dryer prototype based on the established control variables.
3. Analyze the test results obtained using the first prototype.
4. Design and propose a solar thermodynamic drying system based on the prototype analysis.

**Stage one–establish control variables.** The first stage included determining several control variables based on the basic properties of Jamaica. These control variables were categorized as either qualitative or quantitative:

1. Qualitative Variables: color, flavor, texture, purity, homogeneity and aroma.
2. Quantitative Variables: product weight, product humidity, product drying temperature and ascorbic acid content.

Initially, the variables for Jamaica were defined before any testing began. Next, ten grams of calyx was processed over thirty test runs in a thermo balance machine to simulate the traditional drying process. Finally, the product variables were measured after testing. The initial and final results were as follows:

Qualitative Variables (determined through sensory observation):

- Color = Initial: *dark red* Final: *deeper, darker red.*
- Flavor = Initial: *acidic* Final: *un-changed.*
- Texture = Initial: *moist and resilient* Final: *less moist and fragile.*
- Purity = Initial: *some surface dust* Final: *some impurities from drying process*.
- Homogeneity = *Homogeneous size after drying.*
- Aroma = Sweet smelling.

Quantitative Variables (the three variables determined using thermo balance):

- Weight (Initial) = 1.0 kg of fresh product.
- Weight (Final) = 0.152 kg of dry solid.
- Humidity (Initial) = 0.848 kg of water per 1.0 kg of fresh product.
- Humidity (Final) = 0.143 kg of water per 0.152 kg of dry solid.
- Drying Temperature = 48ºC to 68ºC.

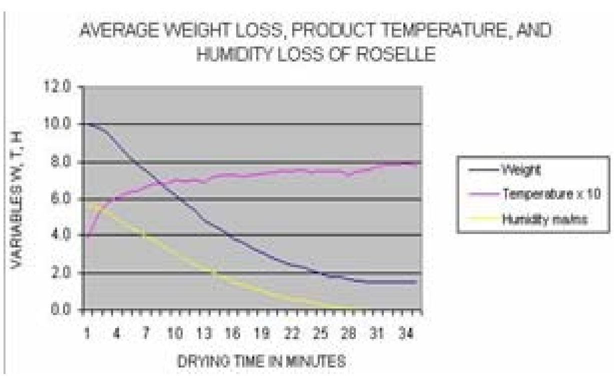
**Stage two–design and construct prototype.** After establishing weight, humidity and drying temperature variables of Roselle, the second stage was designing and constructing a solar dryer prototype. Because drying temperature and air humidity are important to the drying process, the prototype was designed to incorporate tight control over these factors. Maintaining drying temperature affords better control in the preservation of Roselle's basic properties during the dehydration process; managing air humidity enables better control over the speed of drying. The prototype was first constructed with a solar concentration to obtain Roselle's temperature and drying time profiles (Fig. 2). Later, the prototype was modified with a pyramid-shaped glass cover (Fig. 3) to improve the temperature performance of the prototype. The temperature profiles for the modified version were obtained in the same way as the flat glass model.

**Stage three–analyze prototype results.** The third stage included analyzing test results obtained using the original and modified prototypes. The environmental conditions related to humidity (*H*) and dry bulb temperature ($T_{db}$). As the dry bulb temperature (or ambient air temperature) increases during the course of the day, air humidity diminishes and solar drying conditions are at their most

**Fig. 1. Roselle harvested in Colima, Mexico**

**Fig. 2. Solar concentrations for hot oil of the interchange**

**Fig. 3. Illustrates Roselle's average weight loss over time (blue curve), average humidity loss (yellow curve), and average product temperature (pink curve)**




favorable. This is to say, as air humidity decreases, there is less outside humidity available for product absorption and product humidification does not increase. On the contrary, the surrounding, un-saturated air actually absorbs the product humidity, furthering the dehydration of Roselle.

Fig. 4a and b demonstrate the drying kinetic process characteristics of Jamaica using ten grams of calyx over ten

**Fig. 4a. kinetic process characteristics of Roselle to vacuum pressure of 60 mmHg**

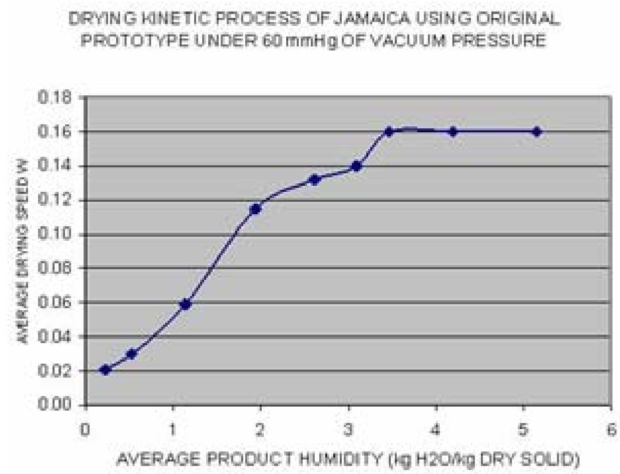
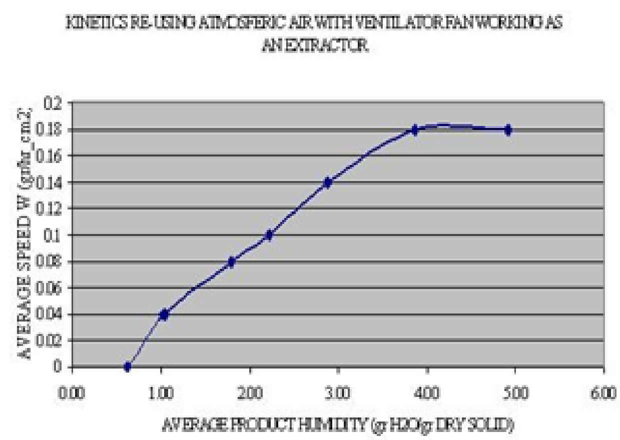



**Fig. 4b. Drying kinetic process characteristics of Roselle to atmospheric pressure using an air ventilator as an extractor**




sample runs. Two different tests were conducted utilizing the original prototype: the first under a vacuum pressure of 60 mm Hg (Fig. 4a) and the second under atmospheric pressure using an air ventilator as an extractor Fig. 4b. The vacuum pressure test exhibited a drying kinetic period at constant speed followed by a period of decreasing speed. The atmospheric pressure test only displayed a drying period at decreasing speed.

The kinetic drying speed of Jamaica was calculated using the following formula:

$$W = S/A\,(-dx/dt) \qquad (1)$$

**Stage four–design and propose solar drying system.** The fourth and final stage is proposing the design of an autonomous, low-cost and robust solar thermodynamic drying system for the dehydration of Jamaica and other agro-industrial products. This system was used to investigate the dehydration processes of Roselle and other products. The proposed design works under the subsequent

requirements:
1. The mechanism needs solar energy to function.
2. Solar energy through forced convection warms the air used in the drying process.
3. The mechanism has to be intelligent enough to respond to the temperature and band-speed requirements during the drying process.
4. The drying system will serve as the basis for the creation of other viable systems working with solar energy.
5. The mechanism must keep the product free of contaminants, un-like traditional drying methods.
6. The dehydration system must be economically feasible, allowing for the fast recovery of a purchaser's investment in the acquisition of the system.

**Description of proposed solar drying system.** The proposed solar dryer consists of seventeen elements as seen in Fig. 5. Surrounding air is introduced to a drying pre-chamber (17) via a ventilator (11). After being heated, the air rises cross-currently in the drying chamber (14) and dehydrates the product (13) as it moves along on transporting bands. The band speed is controlled by a frequency variator (9), which controls the speed of the engine motor (8). The motor is connected to the transmission by a speed reducer (7), which decreases the speed by a 30:1 relationship. The system has a cylindrical parabolic solar energy collector (2), where Castañeda (2000) stated that this system is alignment use of solar light follower to fall into radiation collector by differential optical sensor with useful implemented computer algorithm, which warms fluid (i.e., water or thermal oil) fed to it by a pump (4) from a thermally isolated container (3). The heated fluid then passes through a tube (16) to a radiator (5), where the heat is transferred via forced convection to surrounding air introduced by a ventilator (11). The heated air, along with product humidity, is expelled from the drying chamber (14) to the environment by another ventilator (6).

**Installation and calibration of the measuring system.** The measuring and monitoring system for the proposed dryer consists of electronic and mechanical components, allowing the manipulation of the process through a personal computer. A data acquisition system through a MCU card connected via wireless communication with in a personal computer, the dehydrations product will be monitored through this array, feedback system through a software and hardware embedded in a microcontroller. Computer software controlled the end parameters of dehydration and thermodynamics process by an algorithm developed for finding all parameters of solar drying. The temperature sensors acquired the heat in situ and are installed between the separations of each transporting band. For monitoring air humidity it has a relative humidity analyzer. For both the humidity and environmental temperature analysis it has a wave psycho meter for data verification of the digital analyzer. It has as well an anemometer to measure the air speed that the ventilator provides to the drying chamber. In Fig. 5, the product is fed to the drying system via a stainless

**Fig. 5.Proposed solar thermodynamic drying system for Roselle and other products**

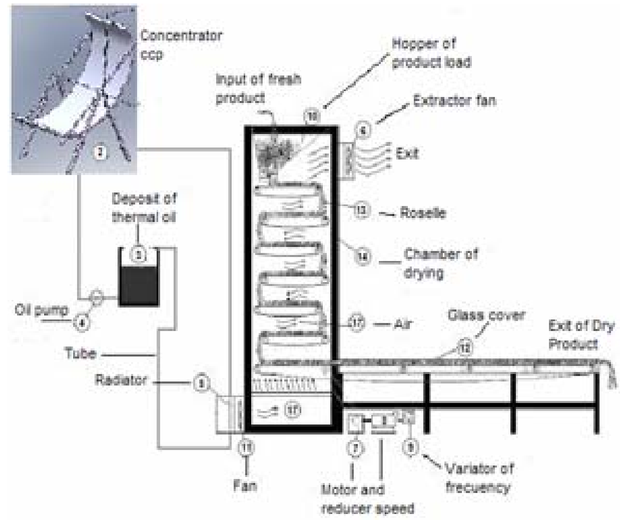
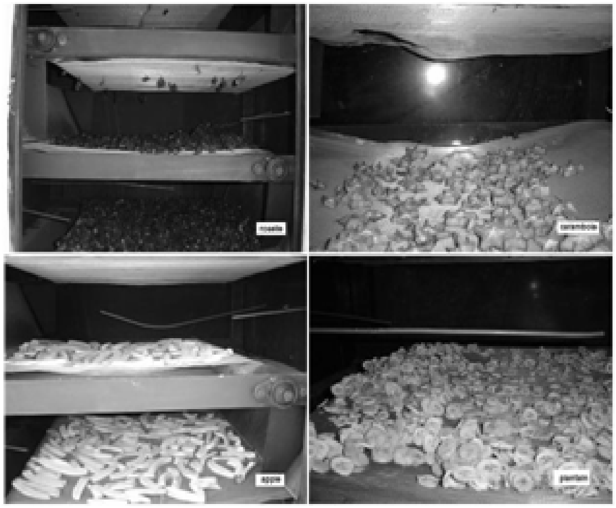



**Fig. 6. Picture that show the real solar drying system for Roselle and other products**

steel hopper (10) or funnel located at the top of the mechanism. After passing through the drying system and along the final band (12), the product is then collected in a glass-protected chamber (1), where its final humidity is measured for quality assurance purposes by a humidity sensor. The product is then ready for packaging and shipment. The preparation of the drying system involves the drying chamber cleaning activities, supervision and cleaning of transporting bands, supervision and proofs with the fan, cleaning of the parabolic cylindrical concentrator, pipe cleaning with water steam to avoid obstructions by fouling formation, glass cleaning of the drying camera, revision of the heat transport fluid into the system, revision and repair

**Fig. 7. Different products that are drying by the solar thermal system**



of the thermal insulator of both the pipe and the drying camera to avoid possible heat losses. In what concerns to the product, this it does not require of a pre-cure. Roselle is introduced in the dryer once it has been harvested. However, before it is fed into the system, it is extended to supervise that it has no solid impureness. They can be attached to the product, while transporting it from the country to the drying system facilities. Revision is carried out extending it in a clean surface free of polluting agents from where it will be taken to make the feeding through the system's hopper, the solar drying system is shown in the Fig. 6. By different products that are drying by the solar thermal system is necessary changed the parameters to dehydrate, in the control program are modified by obtain dried fruit; the agro products dehydration is show in the Fig. 7.

**Dryers efficiency.** Efficiency in a drying system is normally reported as: dryer efficiency, heat collection efficiency, collector efficiency. Efficiency in a drying system is specified by the change of the ratio at the specific humidity extraction. For a solar dryer, it is measured by the following ratio:

$$\eta_{nc} = \frac{Q_a}{Q_c} \qquad (2)$$

Tokar (1997) stated that by for dryers that use plane collectors and air flow by natural convection, the generated heat is in a range efficiency of 40 to 60%. The efficiency of removing the product using air in the dryer is determined by the following equation:

$$\eta_p = \frac{(h_o - h_i)}{(H_{as} - h_i)} = \frac{W}{PV_t} \bullet (H_{as} - H_i) \qquad (3)$$

We can observe in this expression that efficiency (pick-up) normally decreases as products humidity declines. Mastekbayeva *et al.* (1998) stated that the efficiency in the drying system let us know every thing about thermal working, including the collector efficiency and the drying chamber efficiency as well, which is measured with the energy entrance (Solar Radiation) into the drying system. When evaluating natural convection drying the following equation is used:

$$\eta_s = \frac{WL}{(K_A + P_f)} \qquad (4)$$

For hybrid dryers, which use energy as a second resource, efficiency is measured by:

$$\eta_s = \frac{WL}{(IA + P_f)} + (mbXLCV) \qquad (5)$$

Where the add term (mb X LCV) indicates any additional energy that the system would require. Jannot (1998) stated that the measure dryers working using working rates such as: evaporation capacity. It is a measure of the effect of environment's air temperature and humidity as well over the solar dryer's performance. Another common rate is SMER (Specific Moisture Extraction Rate). This one describes dryer's effectiveness. It is also a reversal effect to the specific energy consumption (SEC) and it is expressed by the quotient of removed moisture and total energy entering into the system.

$$SMER = \frac{\text{Removed moisture rate from the product during the drying process}}{\text{Total energy entering into the system}} \qquad (6)$$

**Experimentation results.** The procedure described below was carried out to accomplish experimentation, the determination of the system physical characteristics. Maximum temperature that the energy concentrator delivers to the entrance of the radiator, where the air to dry the product is warmed up was determined. Both physical data for the dryer and for the collector were registered. The solar radiation was determined for both the concentrator and for the final part of the dryer, both charge and discharge time was determined. The air flow that is introduced into the drying chamber was determined. Determine both temperature and relative humidity at the entrance of the drying chamber as well as at the exit of it. Determine temperature by sectors in each of the drying stages. Register both humidity and temperature every 20 min and determine the fresh product fed weight into the drying system. Get a product sample every 20 min to analyze humidity loss using the thermo-balance. Is possible determine the system efficiency using equations 4 and 3. Qualitative properties of the dried product are verified. Afterwards, they must be compared with traditional-dried product.

## CONCLUSION

Based on these control variables, the proposed system operates a continuously moving band at a constant speed. This process flexibility makes it possible for the system to be used with other agro-industrial products and affords better control over end-product quality by maintaining material content. Because the system uses solar energy (designed for this system), it is not dependent on electricity or other costly forms of energy, providing further adaptability in the workplace. The manufacturing cost of the proposed system would be lower compared to most non-solar dehydration systems found on the market. The solar thermodynamic system provides several benefits over traditional and alternative drying methods. This system provides environmentally advantages to agro-producers from Colima, Mexico and around the world.

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