Low-Enthalpy Geothermal Food Dehydrator

Héctor M. Aviña Jiménez[1], Patricia Severiano Pérez[2], Olga Velázquez Madrazo[2], Eduardo Pérez González [1], and Andrea Jasso Rivera[1]

[1]iiDEA, Instituto de Ingeniería, Universidad Nacional Autónoma de México
[2]Depto. de Alimentos y Biotecnología, Facultad de Química, Universidad Nacional Autónoma de México
havinaj@iingen.unam.mx • eperezg@iingen.unam.mx

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ABSTRACT

iiDEA group, an applied research group part of the National Autonomous University of Mexico is focusing on low-enthalpy direct uses of geothermal resources in Mexico. A food dehydrator capable to preserve highly perishable food using geothermal energy was designed. During its construction important parameters such as heating permissible temperature were determined (55 °C) in order to fulfill food safety and sanitation regulations. Different processes such as food and vegetables lay-out and food poisoning avoidance was standardized. Furthermore, a microbiology test and a sensory profile of fresh and dehydrated tomato (*Lycopersicum esculentum)* was evaluated. Even under a critical scenario the low-enthalpy geothermal food dehydrator is still profitable and has a wide range of variations that could improve its marketability and profitability. Hence, it is concluded that market studies would benefit the implementation of the project and ensure the required demand, reducing the investment risk. Finally, several standards during the dehydrated fruits microbiology tests were achieved by evaluating coliforms, salmonella, molds, yeast, and aerobic mesophilic samples.

Introduction

Regarding worldwide installed capacity of geothermal power, Mexico holds the fifth place [1]. While several countries have been exploiting low-enthalpy geothermal energy for direct uses, Mexico has used this potential primarily for recreational purposes. In the 1990s, the Federal Electricity Commission (FEC) started the development of some pilot projects in Cerro Prieto, Los Azufres and Los Humeros geothermal fields. These projects included district

Figure 1. Hot-water spots in the Gulf of California.

heating, greenhouses, germinated bulbs, accelerated production of flowers, nursery edible fungi, fruits and vegetables dehydration and wood drying [2], unfortunately these projects were abandoned because the main objective of CFE was to generate electricity and were not given any follow-up.

Over 37% of the food produced in Mexico for domestic consumption is wasted [3], including oranges and tomatos [4]. Therefore, iiDEA group developed a Geothermal Food Dehydrator (GFD) capable of taking advantage of the low-enthalpy geothermal potential for use in preserving food through dehydration. The project is focused on high-demand national diet products like tomato, garlic, avocado, banana, chili pepper, orange and papaya, among others.

Figure 2. Location of Mexicali and Sinaloa.

Table 1. Approximate ranges of effective moisture and temperature in some organic products [5,6].

Product		Fresh Moisture (%)	Dry Moisture (%)	Maximum temperature (°C)
Grains	***Rice***	22-24	11 - 14	50
	Corn	35	14	60
	Wheat	20	13	50
	Peanut	40	9	
	Coffee	50	11	
Tubers	***Potato***	75	11	55
Vegetables	Pea	80	5	60
	Cauliflower	80	6	50
	Carrot	70	5	60
	Onion	80	4	55
	Garlic	80	8 - 10	50
	Leafy vegetables	80	10	50
	Chili paper	86	5	60
	Tomato	95	8	65
Fruit	***Peach***	85	18	
	Apple	84	14	50
	Banana	78	15	55
	Guava	80	7	
	Grape	80	15 - 20	55
	Mango	85	12 - 15	65
	Papaya	85	2 - 15	65
Fish	***Without salt***	80	15	40
	Salty	80	35 - 45	40

Design

Mexicali, Baja California (Figure 2) was selected as an area of interest due to its agriculture and the abundance of energy resources. Baja California is the second national producer of tomato, behind Sinaloa [5]. Based on an early exploration of geothermal energy sources in Mexico, the Baja California Peninsula (Figure 1) has been identified as one of the highest geothermal potential sites, holding the second largest geothermal power plant worldwide. Based on some recent evaluations, the calculated potential exceeds 400 MWe, including six geothermal spots with an estimated temperature above 200 °C [6].

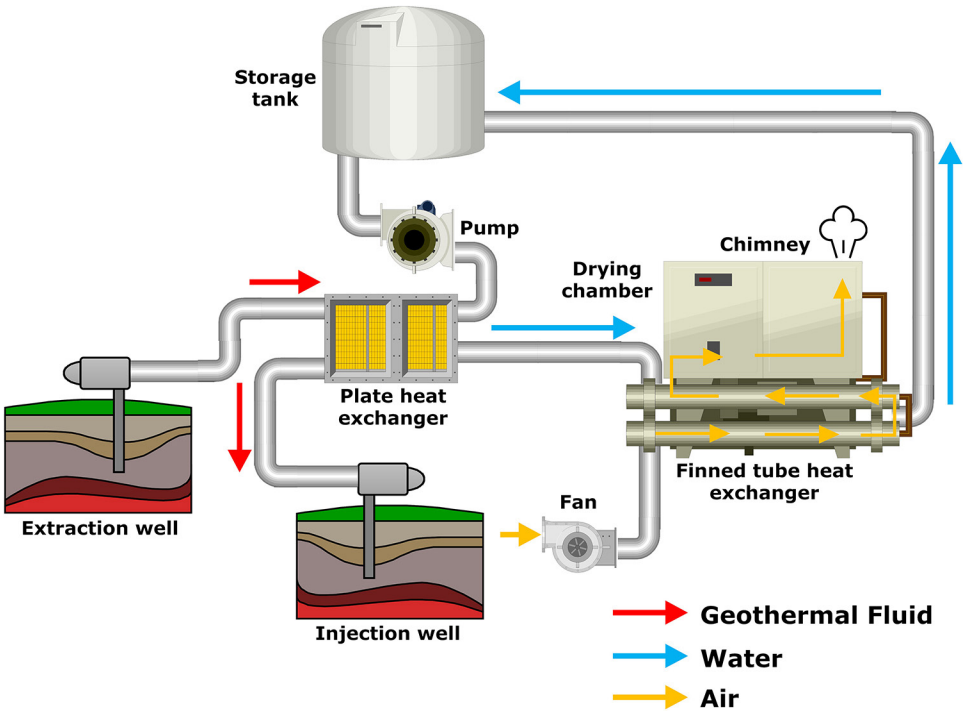

Figure 3. Schematic Diagram of Geothermal Food Dehydrator (GFD).

With the intention of having a robust design under critical conditions, tomato was considered a set point, because of its high moisture content, around 95% [5, 6]. Table 1 shows moisture content of different products, along with their maximum permissible temperature.

In order to ensure the safety and quality of the product, the operating temperature of the dehydrator was defined above 45 °C and below 65 °C, since the ideal temperature range for bacterial growth is between 25 °C and 45 °C and the product may be perished if the temperature exceeds 65 °C [7]; for instance, ascorbic acid (vitamin C) is sensitive to high temperatures and very humid environments [8].

Based on the operational conditions previously defined, a schematic diagram of the system is shown in Figure 3. Low-enthalpy geothermal fluid (~80 °C) is extracted from the well, then led through a plate heat exchanger, ceding thermal energy to water, then reinjected into the well. The heated water (~65 °C) passes through a finned tube heat exchanger, placed inside a heating chamber, where it transfers heat to air.

A fan drags air into the drying chamber, passing it through the heating chamber, raising the temperature of the air up to 55 °C. The gradual removal of moisture in food is a slow process, taking over 15 hours, depending on the humidity of each fruit and the air temperature. The drying process is completed when the final moisture is about 12 %. Finally, moist air exits the drying chamber through a chimney.

Besides tomatoes, the GFD has been able to dehydrate guava, orange, papaya, tomato, kiwi, apple, pineapple, pear, mango, prickly pear, strawberry, star fruit, watermelon, banana and melon. At the same time, four sensors were distributed throughout the dryer, monitoring the process and recording temperature and humidity.

The dehydration process begins by placing the trays loaded with fresh product inside the dehydrator, previously heated to 50 °C. Slices must be cut homogeneously (7 to 11 mm thick) ensuring the quality of the product and the richness in ascorbic acid [9] and other vitamins like β-carotene.

Air enters the heating chamber with high relative humidity (70%) and an average temperature of 21 °C; once it passes through the finned tube heat exchanger, its average temperature rises to 48 °C and its relative humidity decreases up to 19%. Once the air passes through the drying chamber outlet, its relative humidity is 29%, with a temperature of 41 °C. The process is finished when the humidity of the air entering the drying chamber is the same as the humidity of the air at the outlet.

With the purpose of ensuring a certain shelf life of the product, allowing its commercialization, quality and safety of dehydrated tomatoes (Lycopersicon esculentum) was assessed through microbiological tests and sensory profiles in collaboration with the Department of Food and Biotechnology of the University.

Food Dehydration: Current World Situation

Internationally, the most popular dehydrated food products are the following [10]:

- Fruits: Mango, pineapple, banana, avocado, papaya, plums and cashews
- Vegetables: Carrots, tomatoes, onions, garlic and hot peppers
- Herbs: Aromatic (coriander, parsley, celery, mint, etc.)
- Infusions: Roselle flower, chamomile, orange blossom, lemon tea and orange blossoms
- Spices: bay leafs, thyme, rosemary, oregano, etc.

Table 2. Major importing countries of dried fruit [10].

Countries	Percent
Russia	12%
Germany	11%
United Kingdom	11%
U.S	10%
China	7%
Spain	5%
France	5%
Canada	4%
Holland	3%
Others	32%

Based on data of Prol CHILE and the Global Trade Atlas [10], imports of dried fruits rose 9.55% in 2010 compared with the previous year, which means a sum of 1,504.87 million USD, showing the hype that these products are gaining in the food sector.

Turkey topped the list of exporting countries with shipments estimated in 294.67 million USD, followed by the US with 264 million USD and Chile with a total of 163.81 million USD. In addition to this, Mexico, is located in 14th place regarding countries importing dehydrated food, and has the highest annual increase in the list with 38.97%, followed by China (38.34%) and Russia (24.03%) [10].

This data shows that the GFD may be an attractive and profitable product, mainly because of the quality of the product obtained and the type of energy resource it uses.

Analysis of Current Demand and Supply of Dehydrated Food in Mexico

1,300 geothermal spots were analyzed by the Federal Electricity Commission; 601 correspond to surface emanations of low enthalpy with temperatures below 100 °C, distributed over several states of the Mexican Republic. While these points are ideal for supplying thermal energy to the GFD, the vast majority maintains an average temperature of 38 °C, so the drilling of wells would be required, increasing costs and compromising the viability of the project. As a consequence, only 18 regions cover the requirement of average superficial temperatures for dehydration at 85 °C.

The states of Baja California, Guanajuato, Jalisco and Michoacán hold the highest number of industries engaged in the production of dehydrated food with gas or solar energy, with a total of 111 companies in the sector producing 60% of the total dehydrated food consumed in Mexico.

Profitability Analysis

To define the value of the project we used the "take of effective flood method." This method is also used to determine if the project is viable and shows the conduct in a set time horizon. The main points of this method are:

- Definition of the premises of analysis
- Financial Income
- Horizon Analysis
- Financial analysis
- Cost-benefit Analysis

Since the project was evaluated considering the value of money based on time, the criteria used to determine the profitability of it was the Net Present Value (NPV), however the estimated Internal Rate of Return (IRR) was performed as studio factor and the Time of Return on Investment (Tr) was calculated as a parameter for the sensitivity analysis, if you want to see the entire study it can be seen in Torres, Fernando's written work 2016 [10].

The parameters used for profitability analysis are the following: Internal Rate of Return (IRR), Net Present Value (NPV) and Rate of Return (ROR), shown in Table 4.

Based on the parameters shown in Table 4, the project turns out to be profitable as a consequence of the IRR and NPV being positive; in addition to this, the ROR is 4.6 years, as shown in Figure. 4.

Table 3. Dehydrated fruit and vegetables consumed in Mexico.

Product	Average cost USD/100 g
Tomato	2.45
Mango	2.29
Apple	3.81
Strawberry	1.53
Apricot	1.91
Pineapple	2.07
Grape	0.98
Banana	2.34

Table 4. Parameters used in profitability analysis of GFD [10].

Parameter	Value
IRR	31 %
NPV (USD)	$37,644
ROR (Months)	55.17

Physiochemical Results

Physiochemical attributes of dry tomatoes using the GFD were compared with those of commercially dried tomatoes. It was found that the water activity (Aw) in the dehydrated products using the GFD was slightly higher, and it is related to the sensory attributes determined [11]; therefore, commercial samples are crispy, while the ones processed in the GFD remain flexible. Table 5 summarizes the results.

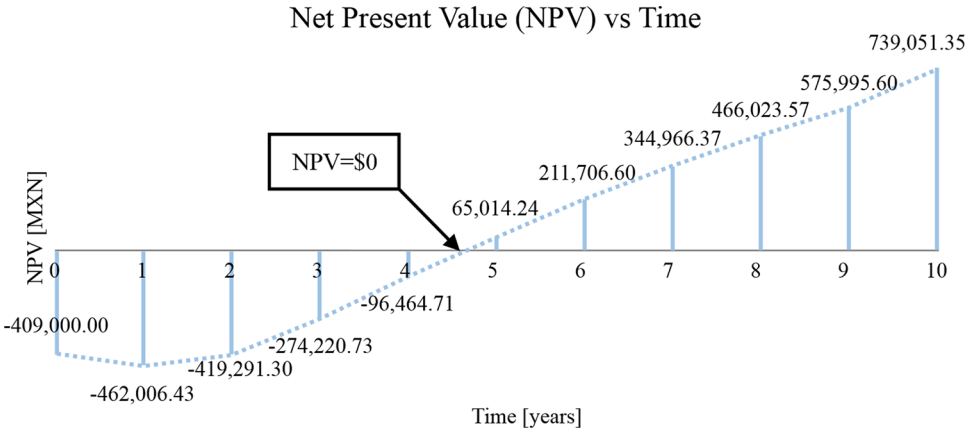

Figure 4. Behavior of NPV over time [10].

Sensory evaluation was made by "Flash Profile" with a panel of untrained judges; the attributes of appearance, texture, smell and taste were characterized. Flash Profile is a quick methodology derived from a profile of free choice, along with a management scale, based on the simultaneous presentation of products to evaluate. Flash Profile has the advantage of not requiring a panel of acquainted judges with the attributes to evaluate, so no training is required, costs are reduced by not using standards or references and evaluations are performed in a short time [12]. There are no Mexican norms establishing sensory attributes for dehydrated tomatoes, but there are for onion and garlic dehydrated, so they were taken as a comparison parameter from an already established references[13] and [14].

Table 5. Comparison of dehydrated samples using the GDF and commercial samples.

Sample	Aw	pH	Temperature (°C)
iiDEA (11/05/2015)	0.3617	4.4	25.04
Commercial product (11/05/2015)	0.3395	4.3	25.04

In consequence the commercial dried tomato was perceived sour and salty; tomatoes dehydrated using the GFD were perceived as fresh and sweet.

In the analysis of commercial dried tomatoes, the following results were obtained:

If these results are compared with the specifications of standards available for dehydrated onion and garlic, it can be considered that both are good microbiological quality products. There are no Mexican norms for microbial quality for tomatoes.

Table 6. Microbiological results of commercial dried tomatoes (see Table 7 for microbiological results of GFD-dried tomatoes).

Brand	Aerobic mesophilic bacteria ufc/g	Total coliforms NMP/g	Fecal coliforms NMP/g	Molds and yeasts ufc/g	*Salmonella* in 25 g	*S. aureus toxigenic ufc/g*
La Merced	$35x10^2$	< 0.3	< 0.3	200	Absent	Absent
Superama	320	< 0.3	< 0.3	60 e.v.	Absent	Absent

According to the analysis of fresh tomato, the results are acceptable, considering that they must be washed and dried beforehand. The sanitization was made following the indications in the Standardized Operating Procedures (SOP). It is a guide which was designed by Department of Food and Biotechnology, UNAM.

Hand washing was made following the procedure established in the Official Mexican Standard norm NOM-251-SSA1-2009, Hygienic practices for food processing, beverages or dietary supplements, in Chapter 5, numeral: 5.12.4 & 5.12.5 [15]

As part of SOP ware washing was evaluated, especially the washing of tomato, the following washing diagram that is shown below was designed especially for this product.

Microbiological results should be "interpreted" based on a standard norm; however, these don´t exist for tomatoes in Mexico or codex Alimentarius and there are few specifications of other referents countries dehydrated fruits. We have compared the results with the parameters of existing products on the market and with specifications for the other dehydrated products whose commencement is to preserve, coincides with this project.

Salmonella and Staphylococcus aureus enterotoxigenic results are satisfactory; dehydrated and Staph is not present in the samples.

For the preparation and dilution of samples, determination of *aerobic mesophilic* bacteria based on the Mexican Official Standard Norm 092-SSA1-1994 was performed; total and fecal coliforms were determined usingnorm 112-SSA1-1994; finally, fungi and yeasts were determined according to NOM-111-SSA1-1994.

Moreover *Salmonella spp* and *Staphylococcus aureus* were determined using rapid tests enterotoxigenic CompacDry®.

Table 7. Results of microbiological testing for fresh tomatoes and dried.

Sample	Aerobic mesophilic bacteria ufc/g	Total coliforms NMP/g	Fecal coliforms NMP/g	*Salmonella spp* in 25 g	*Staphylococcus aureus* UFC/g	Molds and yeasts ufc/g	pH
C. Abastos 6 Oct 2015*	<25.e.v	<3.e.v	<3.e.v	Absent	<10.e.v	<15.e.v	4.6
Bel Ara®	500	<3.e.v	<3.e.v	Absent	<10.e.v	200	4.4
Hefzi ba®	300	<3.e.v	<3.e.v	Absent	<10.e.v	210	4.3
Labizet®	410	<3.e.v		Absent	20	94x10^2	4.2
Lauvid®	120	<3.e.v	<3.e.v	Absent	<10.e.v	10	4.2
Tostifrutas®	59x10^2	0.7		Absent	<10.e.v	220	4.4
iiDEA 3*®	5.e.v	<3.e.v	<3.e.v	Absent	<10.e.v	50	4.3

* Results performed after the washing method proposed.
e.v estimated value, sensitivity of the method

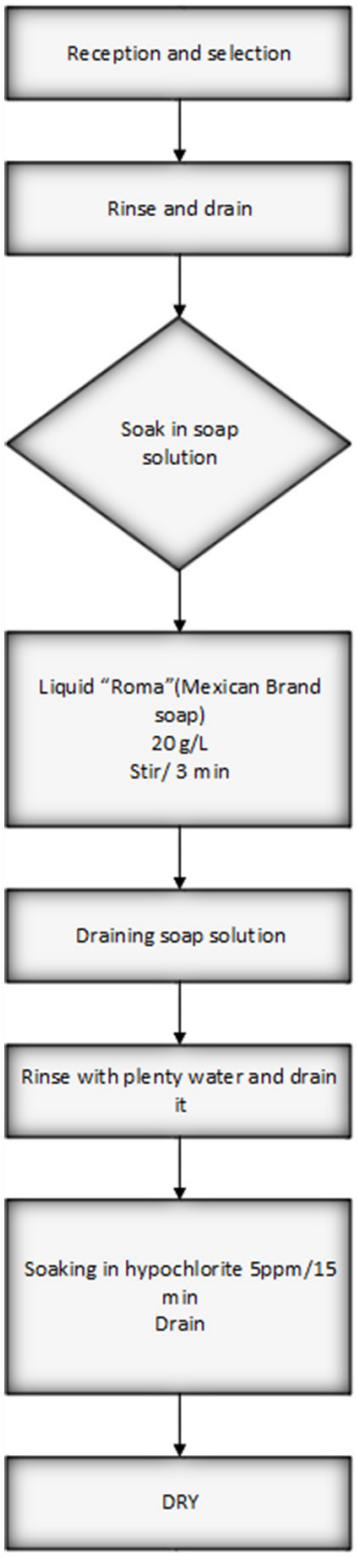

Figure 5. Flow diagram involving the washing process of tomatoes.

Conclusions

The main operating characteristics of the geothermal dehydrator were established considering its performance in critical conditions, taking tomato as a set point providing settings for its use with other products needing less thermal energy, expanding the range of suitable equipment installation in geothermal areas.

Results from the microbiology tests show that dehydrated fruits meet the Mexican onion and garlic dehydrated standards (López, 2016). Furthermore, low microbial load was obtained as a result of the implementation of SOP (Velázquez, Yazmin Carmona, Salinas, & Pérez, 2015).

From the previous information it can be ensured that, according to the data of the financial model and calculations, the project turns out to be profitable in the analysis horizon as the consequence of positive results on TIR and NPV. Additionally, the return time (4-6 years) is less than 10 years. A discount rate of 10.08% was used corresponding to the rate of processed food sector in Mexico, obtained by the capital asset pricing model (Capital Asset Pricing Model (CAPM))

Mexico has an abundance of geothermal resource, and agriculture is a major economic activity in the country. The exploitation of a GFD benefits both sectors, enhancing a new market and encouraging national development. There are many spas that may take advantage of this resource for its operation adding the commercialization of dehydrated food a cascaded use. Direct use of geothermal energy in Mexico is limited to recreational activities as a consequence of the absence of appropriate technologies and education; this represents an area of opportunity for technological development and investors, as Mexico has many regions with low-enthalpy geothermal energy distributed along the majority of its territory.

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