Drying of Banana Through Geothermal Steam, Berlin Geothermal Field, El Salvador

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ABSTRACT

Geothermal energy can be used both for electricity generation and direct use with many applications such as the drying of fish or fruit, as well as the heating of spaces and greenhouses.

El Salvador has explored geothermal resources since the 1970s. To make good use of these resources, a study will be conducted to analyze some drying techniques for different types of fruits from different countries; those available to dry and the most used. By studying similar cases, it will be determined which is the best technique to apply for the drying of bananas in El Salvador.

The study took place in the geothermal field of Berlin in El Salvador because it has abundant banana fruits and geothermal resources with temperatures between 138 and 184°C. The thermal energy can be used in a binary cycle and can also be used to dry bananas.

1. INTRODUCTION

El Salvador has two geothermal power plants: one located in Ahuachapán and the other in Berlin. San Vicente and Chinameca are the two geothermal fields currently under exploration. Their administrative offices are in Santa Tecla.

El Salvador is one of the 82 countries that have geothermal resources (Boyd and Lund, 2015); this energy is considered a renewable source like hydropower, biomass, wind and solar energy.

In terms of categories of direct uses throughout the world between 1995-2015, we have geothermal heat pumps, space heating, greenhouse heating, aquaculture pond heating, agricultural drying, industrial uses, bathing and swimming cooling / melted snow and others (Boyd and Lund, 2015).

This report includes information on the different direct uses for which geothermal energy can be applied. The report shows examples of direct uses in different countries around the world. In this case, the use of banana drying in El Salvador is analyzed.

2. GENERAL INFORMATION

2.1 Geothermal energy

Geothermal energy is obtained from the heat coming from the interior of the earth. It is renewable and is considered one of the least harmful to the environment since it releases fewer greenhouses gases into the atmosphere compared to other sources that use non-renewable energy.

El Salvador has harnessed the geothermal resource since the 1970s and currently has a total installed capacity of 204 MW, which represents 23% of the electric power produced in El Salvador

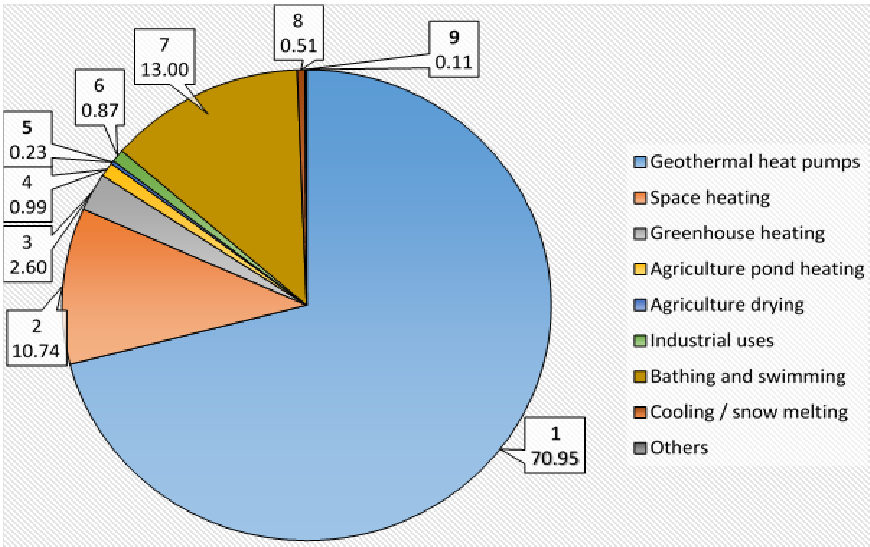


Figure 1. World-wide capacity (with heat pumps) in MWt (Boyd and Lund, 2015)

2.1 Utilization Category

In different countries, the use of geothermal energy is not limited to the generation of electricity but also applies to direct uses. In Figure 1, the direct use of geothermal worldwide in 2015 is distributed by percentage of the total installed capacity (MWt) (Boyd and Lund, 2015).

In the year 2015, there were 15 countries that made use of geothermal energy for agricultural crop drying. Among these examples are: seaweed (Iceland), onions (USA), wheat and other cereals (Serbia), fruits (El Salvador, Guatemala and Mexico), Lucerne of alfalfa (New Zealand), coconut meat (Philippines) and timber (Mexico, New Zealand and Romania). Table 1 shows the different direct uses of geothermal (Boyd and Lund, 2015).

Table 1. Different uses for geothermal energy

Direct uses	Number of countries
Bathing and swimming	70 countries
Geothermal heat pumps	45 countries
Greenhouse heating	31 countries
Space heating	28 countries
Aquaculture	21 countries
Agricultural crop drying	15 countries
Industrial process heating	15 countries
Other Uses	13 countries
Snow melting & space cooling	6 countries

3. ANALOG CASES

3.1 Iceland

This is one of the countries where large-scale industry employs the use of geothermal energy in the drying of algae, fish and heads of cod. These are the most common products that are dried in this way. It is a source of employment; around 20 companies dry their fish using geothermal energy, hot water, and steam (Nguyen et al., 2015).

3.2 Greece

A local plant in Nea Kessani, Xanthi, operating since 2001, performs small-scale tomato drying activities (Nguyen et al., 2015).

3.3 Kenya

The eburru geothermal drying unit was built by an English settler around 1939. It has different uses such as drying of maize and pyrethrum flowers (Land O'Lakes Inc. and Winrock Inc., 2013).

4. REFERENCE FRAMEWORK

4.1 Drying

The drying consists of eliminating the moisture contained in the food with the aim of improving its efficiency, storage and conservation time. In the drying process, the simultaneous mechanisms of heat and mass transfer is used. In this process, parameters that directly affect the quality of the dehydrated product are temperature, speed and relative humidity of the drying air.

Many studies found that in the drying process of fruits, grains and vegetables, the most important factor in the kinetics of drying is the air temperature (Dimitrios et al., 2014).

4.2 Drying techniques

Over the years, several drying techniques have been developed such as oven drying, paddle dryers, spray dryers, freeze dryers, vacuum dryers, and drum dryers. (Arason, 2018a).

The type of process to consider for banana drying analysis is geothermal energy.

5. DRYING OF BANANA WITH GEOTHERMAL ENERGY

In general, all industrial drying process is carried out using electrical energy. This provides the heating source to get the right temperature and start the process of evaporation of certain moisture content from the product (grain, fruit, vegetables, meat). The drying is through hot air at a relatively low temperature between 35 to 80°C. Therefore, the low temperature of the geothermal fluids could be used for the drying of agricultural products (Popovska, 2014).

El Salvador has the resource of geothermal energy; therefore, an alternative to electric generation is proposed such as the application of direct use methods. This report analyzes the geothermal field in Berlin for the location of a banana drying cabinet using low heat through a heat exchanger to reach the temperature required for the drying of the banana.

The project involves the use of water with a temperature below 100 ° C. The steam is introduced into the dehydrator through a heat exchanger in a pipeline with geothermal fluid (180°C).

An available area is determined in the reinjection well TR-12. The rack drying cabinet can be located in this well and is close to several communities that would receive benefits such as a source of work and income for their homes. The well is located about 5 km from the main street which is a beneficial for obtaining raw material and for distribution of the product.

6. MASS BALANCE

The equilibrium of matter is a mathematical method used especially in chemical engineering. The basis of the law of conservation of matter is that the mass of a closed system remains constant (Wikipedia, 2018b).

The mass or the material balance*: Mass in = mass out + mass stored + losses*

The energy balance: *Energy in = Energy out + Energy stored + Losses*

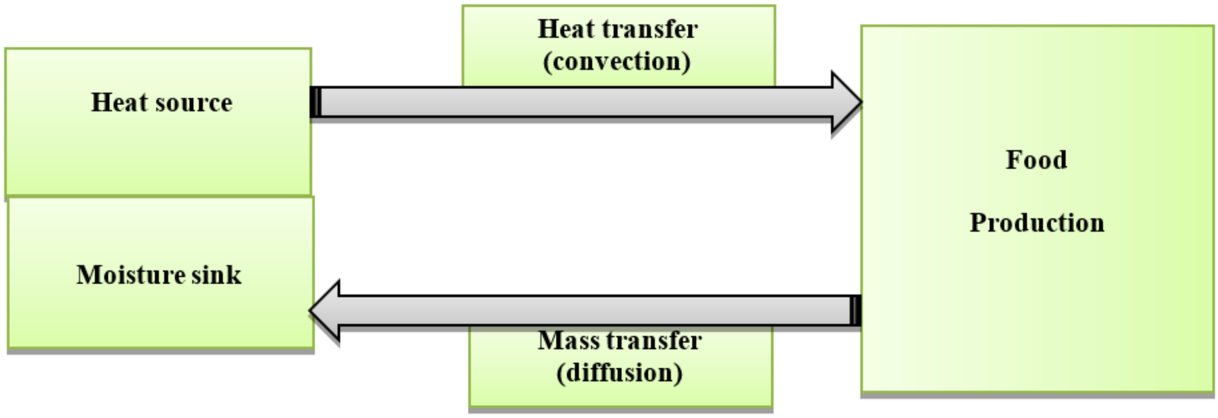


Figure 2. Drying process with geothermal energy (Arason, 2018)

In figure 2, you can see the drying process. When geothermal energy is used for the dehydration process, a cycle is started until the desired result is obtained. The graph shows the application of a heat source by means of convection since the heat transfer is carried out by heating. Because of the high temperature that geothermal water brings, steam can be applied in the first cycle to the product by means of the diffusion of the mass transfer to be able to obtain a first drying to the product.

For the calculation of the mass flow of drying bananas, we started with the analysis of the primary drying that can be observed in figure 3 and the analysis of the secondary drying is observed in figure 4 (Arason, 2018).

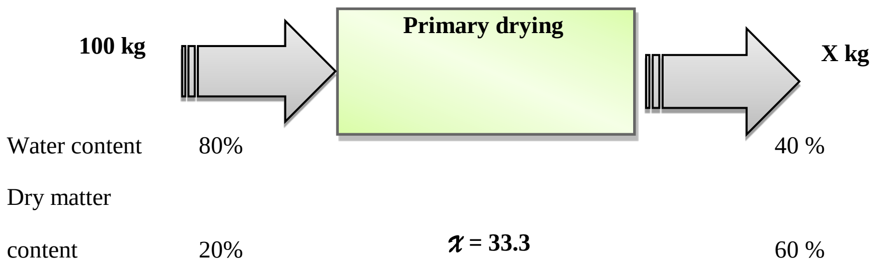


Figure 3. Primary drying / income 100 kg of quality and you get "X" amount of dry material with a percentage of humidity, x = percentage of the amount of water extracted from the material (Arason, 2018)

In order to determine the amount of product that will be obtained by dehydrating 100 kg of material, the process in figure 3 begins with primary drying where the amount of water contained in the product at the inlet is 80%, while the amount of water at the outlet is 40%. Likewise, it is determined that the dry matter at entry is 20%, and at the end of the first drying 60% dehydration is obtained in the product.

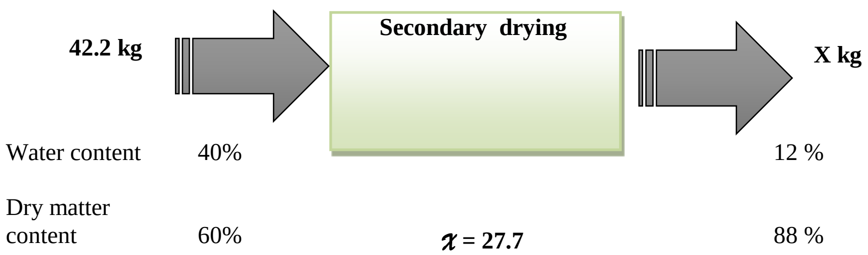


Figure 4. Secondary drying / entry 42.2 kg of quality and you get "X" amount of dry material with a percentage of humidity, x = percentage of the amount of water extracted from the material (Arason, 2018)

Continuing with the process in figure 4, we obtained the secondary drying where we determined that the quality X after dehydrating the product is 27.7. So, to obtain 1 kg of product we need 4.40 kg of raw material.

Raw material = 4.40
Product = 1

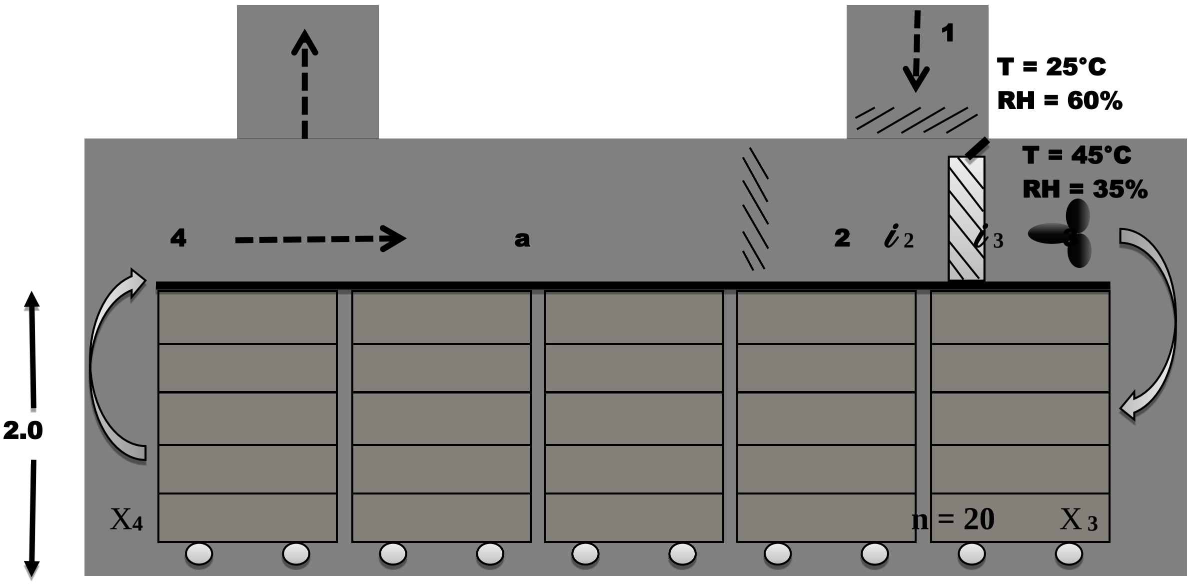
Table 2. The condition of air drying and the information from figure 6 of T and RH to be considered in the drying cabinet

nr	T (°C)	RH (Relative humidity) (%)	X (Humidity ratio: moisture grains per kilogram of dry air) (g water / kg air)	i(enthalpy) (kj / kg air)
1	25	60	12.00	55
2	37	52	20.50	90
3	45	35	20.50	98
4	40	50	23.00	98

$\Delta i = i_{3-} i_2$
Enthalpy air: in = 90 kJ/kg; out = 98 kj/kg
Humidity air: in = 20.50 g/kg, out = 23 g/kg
Air humidity in the outside air = 12 g/kg
Air circulated (%) = 77.50 % (a)

The data shown in table 2 is related to the temperature, humidity and enthalpy located in the different spaces within the drying tunnel of Figure 5. The inlet temperature and relative humidity can be observed. Likewise, it can be analyzed how the enthalpy of entry through a heat exchanger can cause the temperature to increase from 25°C to 45°C and the relative humidity to decrease from 60% to 35%. Within the process of the drying tunnel, the objective is to make the air flow and extract the moisture from the product until it reaches an equilibrium point where the temperature, humidity and time needed to dehydrate it are determined. In this case study, it is banana.
Based on the results, the product is expected to maintain its nutrients, taste and appearance necessary for it to be marketed. All this will be achieved if the temperature, time and relative humidity that were determined in the psychometric chart are applied.

Nr. of the condition of air



1. Air inlet
2. Geothermal heat exchanger
3. Fan
4. Air out

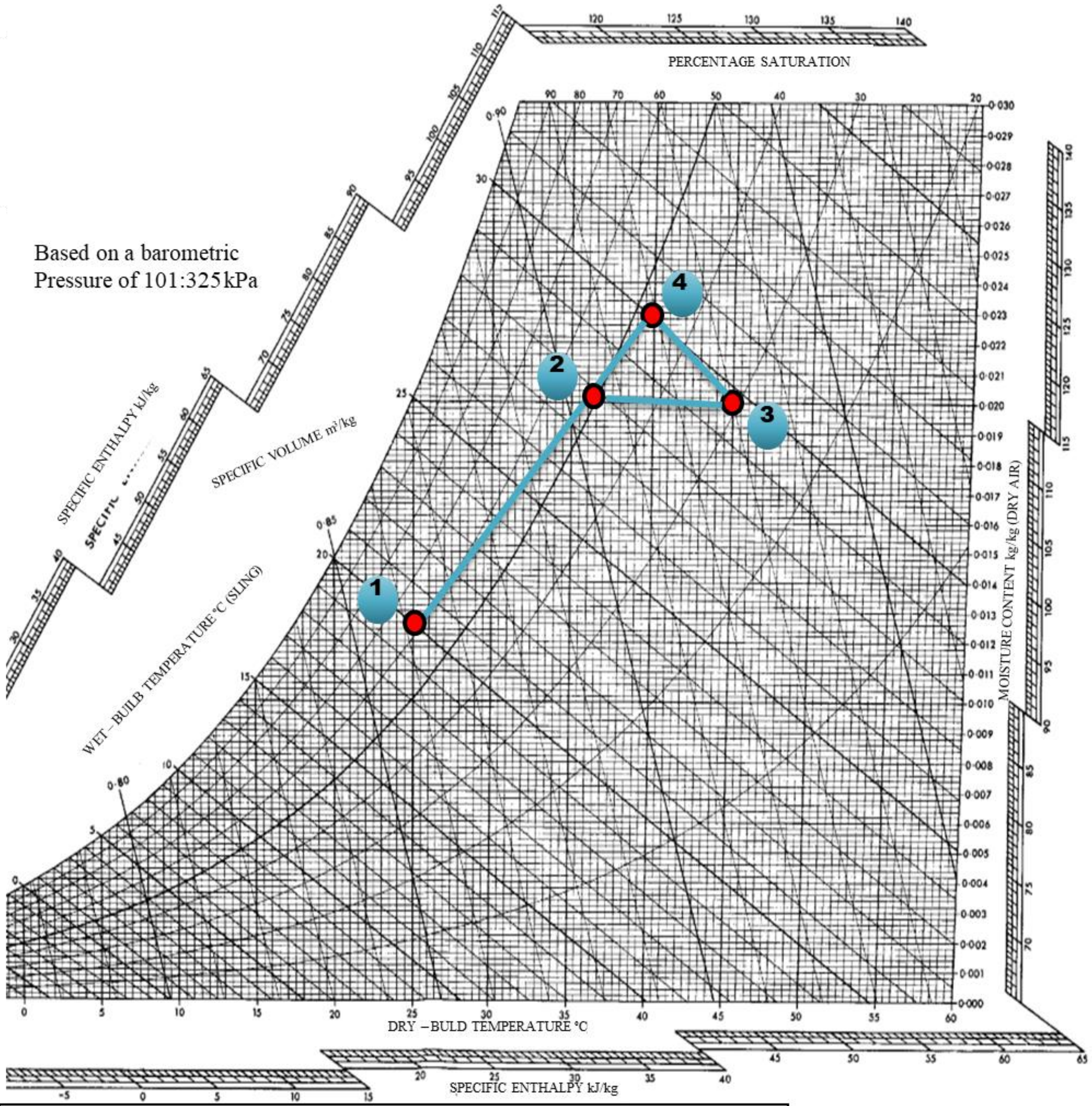
T = temperature
RH = Relative humidity

a. Air circulated
n. Number of pallets
i**2.** Entrance enthalpy
i**3.** Output enthalpy

X_3. Humidity ratio: moisture grains per kilogram of dry air (inlet)
X_4. Humidity ratio: moisture grains per kilogram of dry air (outlet)

Figure 5. Drying in one tunnel, the number describe condition of the air (Arason, 2003)

In the psychometric chart, the enthalpy is determined and used for the determination of the mass balance (see Figure 6).



Enthalpy air: in = 90 kj/kg (2); out = 98 kj/kg (3)
Humidity air: in = 20.50 g/kg (3), out = 23 g/kg (4)

Point 1: Air at room temperature under thermodynamic conditions of 25°C and moisture content of 55 g/kg of dry air enters the drying chamber.
Point **2**: When entering the chamber, the air mixes with the chamber, increasing its temperature from 25 to 37° C and a humidity of 90 g/kg of dry air, also increases the enthalpy from 58 to 90 kJ/kg on the point.
During process **1** and **2**, there is an increase in the specific volume of air, as well as the amount of humidity of the ambient air that entered at the same time as temperature increase.
From point **2** to **3**, there is a heating when it passes through the heat exchanger, the process is heating without variation of the moisture content. The enthalpy of the air changes from 90 to 98 kJ/kg, the temperature of 45°C.
Point **4:** The moisture content of the air outlet is 23 g / kg and the outlet temperature is 40°C.

Figure 6. CIBSE – PSYCHROMETRIC CHART (Jones, 2001)

7. PROCESS IN BANANA DEHYDRATION

The shape of the banana before being dehydrated is usually elongated, oval and somewhat curved. Depending on the variety of banana, the length has a range of 5 – 15 cm and the weight fluctuates between 100 – 200 grams (Banana market profile, 2009). When the banana is dehydrated, its presentation for marketing is oval and its thickness is a thin layer. Usually, its color is yellow or light brown and the sweet smell and taste characteristic of the product can vary depending on additives used for marketing such as honey or specific oils.

When drying the banana and increasing its shelf life, there are different aspects of the quality that have to be considered. Among these are the freshness, color, texture and nutritional content.

Values to consider when drying banana (Cook with the sun, 2018):
Moisture fresh food (HF) = 80
Water content (%) = 15
Maximum temperature for drying (°C) = 70

7.1 Process description

Maturation: To obtain a better result in the quality of the banana, get the green banana and make it mature. This can be done by dipping the green bananas in water with an ethyl's solution with 0.25% (liquid to mature) for up to 3 minutes. After submerging, they are placed in a container at room temperature for a period of 5-7 days. In that period the banana acquires a different color to the eye and is ready when it reaches a yellow tone and the touch is firm (Carangui et al., 2014).

Selection: The bananas are placed in a tank at the same time, but not all of them ripen adequately. So, the yellow ones are used and green fruit and overripe ones are discarded (Carangui et al., 2014).

Washing: The banana that have been selected for use are washed in a chlorinated water bath. The proportion of chlorine to water is 2ppm (Carangui et al., 2014).

Peeling and cutting: Banana peeling is done manually, as is the cutting, which is regulated and specified (Carangui et al.,, 2014).

Bathing with sulphites: The peeled banana is immersed in a solution of potassium sorbate and sodium bisulfite for 5 days. This is done to prevent the colour change of the banana in a shade darkened by the oxidation reaction and to prevent the growth of micro-organisms in the final product (Carangui et al., 2014).

Distillation: After five days of submerging the bananas in a solution, they are removed and placed on a structure that allows them to distil excess water (Carangui et al., 2014).

Drying: The bananas are accommodated in square trays of 1.0 x 1.0 m with a height of 0.10 m. Each pallet contains 20 tanks. Drying is done for 30 hours with a temperature of 45 °C. At the end of drying, the water content must be less than or equal to 15%.

Packing: Once the drying process is finished, bananas are packed and a proper seal is applied to avoid contact with oxygen (Carangui et al., 2014).

7.2 Quality control

Raw material: At the time of the acquisition of the green bananas, it should be verified that there are no parts where the fruit is almost ripe or overripe as this causes more waste. The ripening process should be controlled as well as the ripening time and the handling of the fruit (Carangui et al., 2014).

The purpose of the adequate preparation of the raw material is to guarantee the efficiency in the following stages so as to guarantee the quality of the final product.

Processing: In this stage, the control over time, relative humidity and temperature are important aspects to ensure that the final product meets the necessary quality (Carangui et al., 2014).

Packing: The packages have to be checked one by one to ensure that the seal is adequate and the product is not damaged by contact with oxygen (Carangui et al., 2014).Vacuum package seal will be used. This is of better quality because it prevents the proliferation of micro-organisms and delays enzymatic degradation. On the other hand, the packaging will allow it to close again when it has already opened.

Final product: The last stage of quality before storing and delivering the product is to determine the weight, moisture, sulphites and the content of microorganisms. In order to determine and guarantee that everything is in an adequate manner, it must be periodically analyzed in a laboratory as a guarantee. On the other hand, the product that is stored has a shelf life at room temperature in a dry space, clean and protected from light (Carangui et al., 2014).

8. PROPOSAL

With the analysis performed where it can be demonstrated that this drying tunnel prototype can be used to dehydrate banana, it is intended to be implemented in the geothermal field of Berlin, where the resource will be used and at the same time the immediate communities will benefit since a source of work will be provided.

The prototype needs an infrastructure for its operation, so the drying cabinet will be located near the geothermal plant in Berlin on the platform called "TR-12". Figure 7 shows the zoning of the different architectural spaces necessary for the construction of a physical space where it can function, these are:

1 - Main access

2- Secondary access for internal distribution

3- Parking

4- Administrative area (office, toilet, reception)

5- Machinery area (preparation for drying, selection, washing, peeling, cutting, sulfite bath application, machinery area (drying cabinet)

6- Storage area (packaging, warehouse)

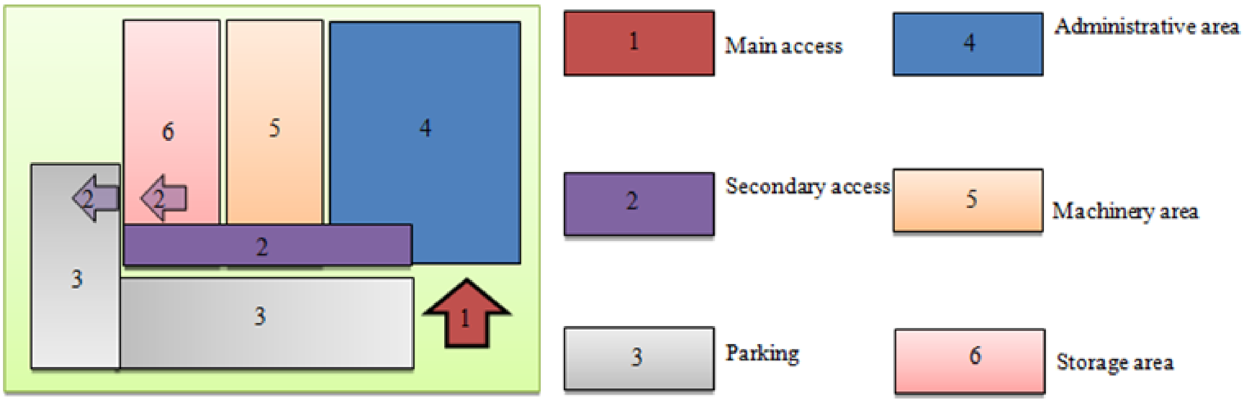


Figure 7: Infrastructure zoning

The values to consider for banana drying are temperature (°C) = 45, relative humidity (RH) = 60 and water content (%) 15.

For the operation of the drying cabinet, the connection can be made from the pipe coming from the binary cycle to the reinjection well TR-12. The arrival temperature to the well is 180°C which means a heat exchanger is needed before connecting the drying tunnel in order to lower the temperature to 45°C.

The data of temperature and time for the operation of drying of banana can also be used for the drying of tomato. That can be alternative or complement for the use of the drying cabinet in Berlin. The design of the drying cabinet is similar to that used for drying fish in Iceland, so in the future it can also be used considering the corresponding mass balance for drying fish.

The quality that was considered in this product is high and can be exported to Central America, the United States and Europe. This depends on the investment and the initial scope. However, the expansion may be long-term.

9. CONCLUSION

In this paper, when analyzing one of the categories of direct use of geothermal energy, it is determined that El Salvador, which is one of the 82 countries that possess this resource, can also add to the generation of energy the drying of the banana as a category of direct use of geothermal energy.

The geothermal capacity of the geothermal fluids that comes from the binary cycle and the reinjection into the platform of the TR-12 can be used for the drying of banana by means of the tunnel of the dried interior.

Banana is a fruit that has a high demand in different countries and the market for its acquisition is high. This creates an opportunity for potential clients in El Salvador. Considerations can be made to export to Central America, United States of America and Europe.

In the document when carrying out the mass balance, it was determined that the temperature to produce the drying is 45 °C, a time duration of 30 hours is needed and a relative humidity less than 15%. This temperature, time and humidity guarantee that the color of the banana is the right one to be attractive when sold. The texture will be the right one for the palate and the conservation of the vitamins in the fruit is also guaranteed.

The direct use of geothermal energy can be a source of income for the immediate communities of the TR-12 like Bob Graham, Buena Vista and Berlin. This project, developed by Fundageo, guarantees the financing and support of an institution.

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