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DRYING OF BANANAS THROUGH GEOTHERMAL STEAM, BERLIN GEOTHERMAL FIELD, EL SALVADOR

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ABSTRACT

Geothermal energy can be used both for the generation of electricity and for its direct use in many applications, such as the drying of food e.g. fish and fruit, as well as space heating and greenhouses. El Salvador has explored geothermal resources since the 1970s. In order to make good use of these resources, a study was conducted to analyse some techniques for drying different fruits in different countries, techniques available for drying and the most used. With the study of similar cases, it will be determined which is the best technique to apply in the drying of bananas in El Salvador. The study will be applied to the geothermal field of Berlin in El Salvador, which has abundant banana fruits and a geothermal resource with temperatures between 138 and 184°C that is used in a binary cycle and can also be used for drying bananas.

1. INTRODUCTION

1.1 Background

El Salvador has two geothermal power plants, one located in Ahuachapán and the other in Berlin. It has two fields under exploration, San Vicente and Chinameca. LaGeo S.A. de C.V. is responsible for the production from the geothermal fields. Its administrative offices are located in Santa Tecla, a part of the capital San Salvador.

El Salvador is one of 82 countries that is using geothermal resources according to Lund and Boyd (2015). This energy is a renewable source as are hydroelectricity, biomass, wind and solar energy. Included in categories of direct use of geothermal energy throughout the world are geothermal heat pumps, space heating, greenhouse heating, aquaculture, agricultural drying, industrial uses, bathing and swimming, snow melting and cooling and others (Lund and Boyd, 2015).

This report is prepared as a part of project work during geothermal training at the UNU Geothermal Training Programme in Iceland. It includes information on how geothermal energy can be used directly, showing examples direct of uses in different countries around the world. Then the report focuses on drying of tropical fruits with emphasis on banana drying in El Salvador.

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 less greenhouse gases into the atmosphere compared to most sources of non-renewable energy. El Salvador has harnessed geothermal resources since the 1970s and currently has a total installed electric capacity of 204 MWe, which represents 23% of the total installed capacity of electricity in El Salvador. The installed capacity comes from the plants of Ahuachapán and Berlin. The fields of Chinameca and San Vicente are under exploration ad are believed to have a potential of 50 and 30 MWe, respectively.

The first generating plant was inaugurated in the Ahuachapán geothermal field in 1975 with a capacity of 30 MWe from a single-flash turbine. In 1976, the second single-flash unit was inaugurated also with a capacity of 30 MWe. In 1980 a double-flash unit was added with a capacity of 35 MWe. The total installed capacity in the geothermal field of Ahuachapán is therefore 95 MWe.

In 1976, work began in the Berlin geothermal field in, and in 1982 a feasibility study for 55 MWe production was completed. However, it was not until after 1992 that operation started, from a 10 MWe wellhead plant (2 × 5 MWe). In 1999, a 56 MWe condensation plant was installed with two 28 MWe units. In 2007 an expansion of 44 MWe was added, and in 2008 a 9.4 MWe binary unit was added, while the old wellhead generators were sold. With that production in Berlín reach 209 MWe.

2.2 Utilization categories

In many countries, the use of geothermal energy is not limited to the generation of electricity, but direct uses are sometimes as important. Figure 1 shows direct use of geothermal worldwide in 2015, as distributed by percentage of the total installed capacity (MWt) (Lund and Boyd, 2015).

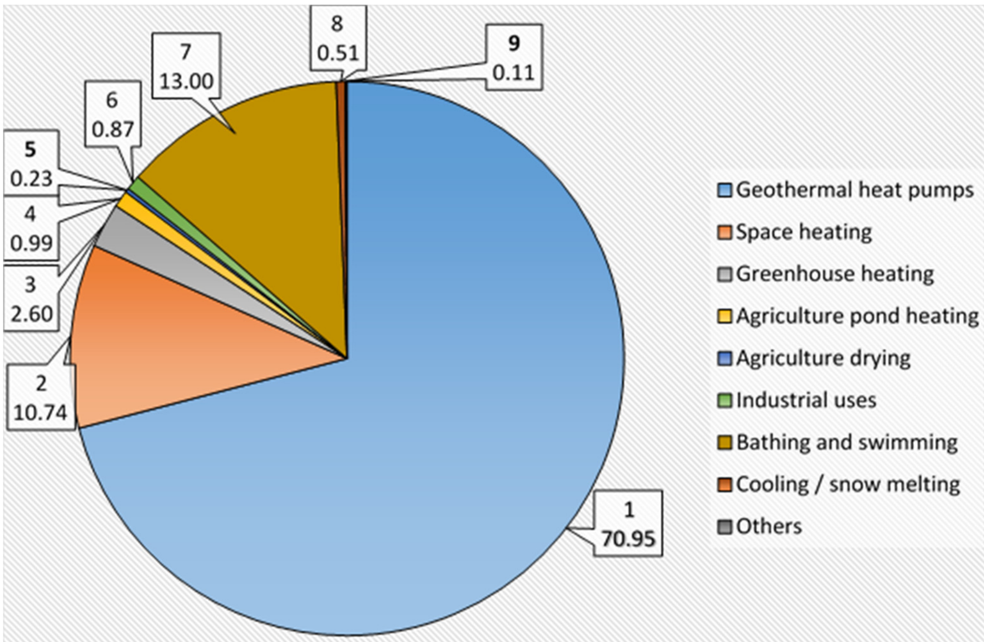


FIGURE 1: World-wide capacity of geothermal utilization including with heat pumps in MWt (Lund and Boyd, 2015)

TABLE 1: Geothermal direct use summary (Lund and Boyd, 2015)

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

Examples of direct use of geothermal were seen in many countries as manifested by Lund and Boyd (2015). With regards to drying, the following are probably most important: drying of seaweed and fish-heads (Iceland), drying onions (USA), drying wheat and other cereals (Serbia), drying fruits (El Salvador, Guatemala and Mexico), drying Lucerne or alfalfa (New Zealand), drying coconut meat (Philippines) and timber drying (Mexico, New Zealand and Romania). Table 1 summarizes different direct uses of geothermal with regards to countries (Lund and Boyd, 2015). As can be seen, drying of agricultural products with geothermal energy is manifested in 15 countries.

3. ANALOGOUS CASES

3.1 Iceland

Iceland is one of the countries where large-scale industry uses geothermal energy in the drying of seaweed and fish. Small fish, fish heads, backbone, fillets and whole fish are the most common products that are dried in this way. It is a source of employment; around 20 companies dry fish using geothermal energy, hot water, and steam (Nguyen et al., 2015). Drying of cod heads is carried out in two stages, primary drying and secondary drying. The cod head is treated in three different ways before drying.

FIGURE 2: Placing fish heads on a frame

Primary drying
This drying is done in a rack cabinet or a conveyor belt cabinet. The most commonly used is the rack cabinet, as can be seen in Figure 2, where employees place heads on a frame (the area of each frame is 1 m^2) with an approximate weight of 25 kg / m^2. The requirements of the drying air temperature range from 18 to 25°C, relative humidity is 20-50%, and airspeed around 3 m/s. The approximate drying time is 24-40 hours (Arason, 2003a).

Secondary drying
With semi-dry cod heads, secondary drying is carried out in a container with a volume of 1-2 m^3 and hot air blown in. The semi-dry cod heads obtained can be seen in Figure 3. For secondary drying, the conditions are temperature between 22 and 26°C, humidity of 20-50% and an air speed of 0.5-1 m/s. When the secondary drying is finished, the water content in the fish must be less than 15% (water activity should be below 0.6). The drying process takes around three days (Arason, 2003a).

Air-drying equipment - Batch dryer – rack type.

In Iceland, the most commonly used equipment for drying fish is a rack cabinet (Figure 4). The design of the cabinet is two tunnels with a pyramid in the middle. The air valves are in the inlet and outlet recycling. The coordination of the valves is controlled by the humidity of the air. At the inlet there is a valve for hot water connected to a thermometer. In the same place there is a humidity sensor which controls the temperature of the drying cabinet (Arason, 2003b).

FIGURE 3: Fish head after drying

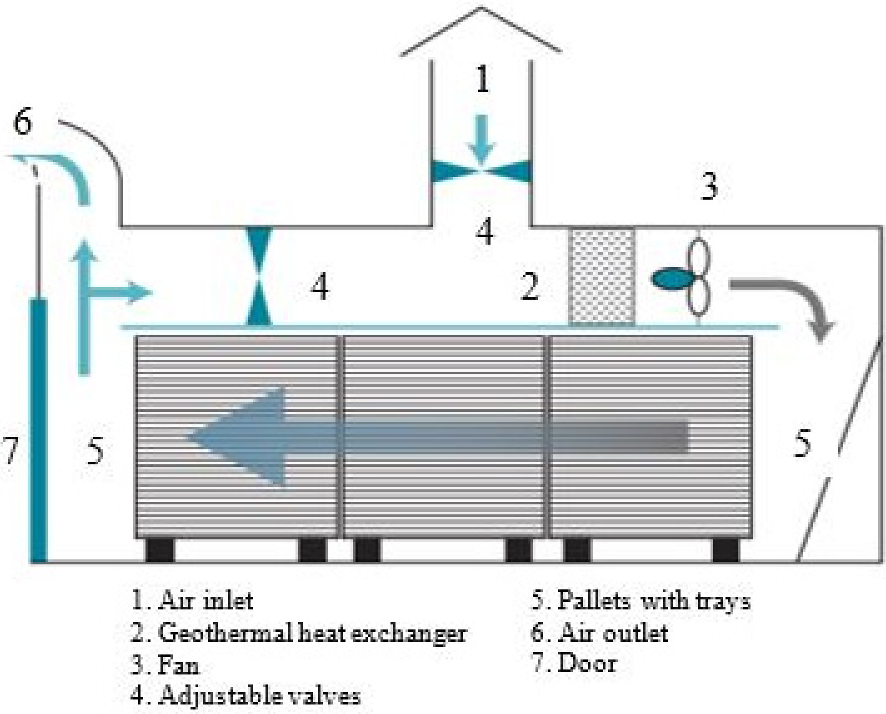


FIGURE 4: Rack tunnel dryer using geothermal energy for fish drying (Arason, 2003a)

3.2 Greece

A local plant located in Nea Kessani, Xanthi, since 2001, carries out small-scale tomato drying. To develop the activity, it uses geothermal water at a temperature of 59°C in a tunnel that's 14 m long, 1 m wide and 2 m high. The process for tomato drying consists of washing, cutting in half and placing the tomatoes in a stainless-steel band. The tomatoes are placed on a 100 × 50 cm^2 tray. The lots are composed of 25 trays (Figure 5). The drying time is 45 minutes, with approximately 7 kg of product in each tray. The dried tomatoes are then put in a container that contains olive oil after which they are ready for transport and sale (Nguyen et al., 2015).

3.3 Kenya

Eburru geothermal drying

The Eburru geothermal drying unit was built by an English settler around 1939. It has different uses, such as drying of maize (white corn) and pyrethrum flowers. The supply of energy for drying is from geothermal water at 95°C. However, the pipe not insulated, so the heat supplied in the construction is only 43°C. The geothermal drying (Figure 6) is used by 110 members of a local cooperative (Land O'Lakes Inc. and Winrock Inc., 2013). The community also uses the Eburru geothermal drying unit for drying tobacco (Nguyen et al., 2015).

FIGURE 5: Tomatoes loaded on drying racks (Nguyen et al., 2015)

4. REFERENCE FRAMEWORK

4.1 Drying

Drying consists of eliminating the moisture contained in the food, with the aim of efficiently improving storage and conservation for a longer time. In the drying process, the simultaneous mechanism of heat and mass transfer is used. In the process, the parameters that directly affect the quality of the dehydrated product are temperature, speed and relative humidity of the drying air. The results of many studies on the parameters used in the drying process of fruits, grains, and vegetables determine that the most important factor is the air temperature (Dimitrios et al., 2014).

FIGURE 6: Pyrethrum dryer (Land O'Lakes Inc. and Winrock Inc., 2013)

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). Three types of processes are analysed with one to be selected in the drying of bananas.

4.2.1 Outdoor drying - sun drying

Drying is one of the oldest forms of food preservation. For thousands of years man has dried perishable foods to preserve their nutritional properties. Sun-drying is one of the simplest methods that exist. It is based on the use of natural environmental conditions to dehydrate food. The humidity of the food can be removed slowly with natural heat and wind. This is an artisanal way of drying food, and has been used for a long time.

The process for outdoor drying requires several consecutive days where the number of days will depend on the product to be dehydrated. In this process a minimum temperature of 30°C and ambient humidity values of less than 60% are required. Then, it is essential to assess the local climatic conditions (Cook with the Sun, 2018a). Dehydration of food will depend on the type of product, the resources available and the technique that best adapts to it. Example of a solar dehydrator is shown in Figure 7.

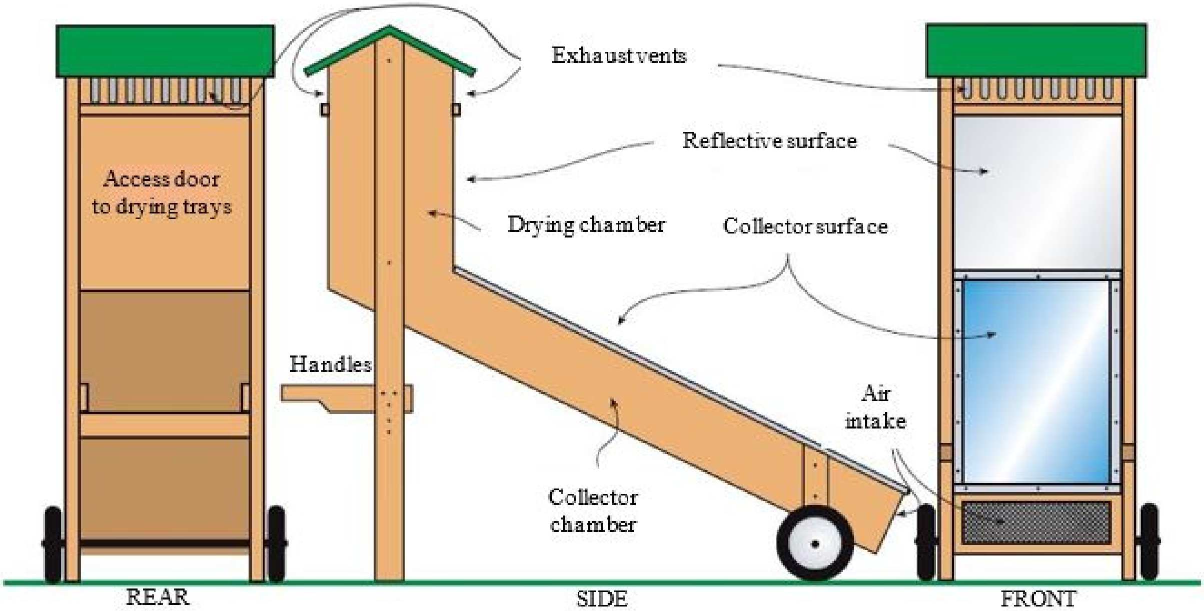


FIGURE 7: Solar dehydrator (Scanlin et al., 1999)

4.2.2 Indoor drying – air tunnel

Main advantages obtained with this drying are: shorter time, as it is possible at any time of the year, increasing quality of the product, there is no contamination of the product by insects and it uses local energy sources. Iceland has for more than four decades used geothermal energy for the drying of salted fish, stock fish, seaweed, small fish and other products (Arason, 2018b). Figure 8 shows the price in different types of energy for heating one kilogram of dried cod head (Arason, 2018b).

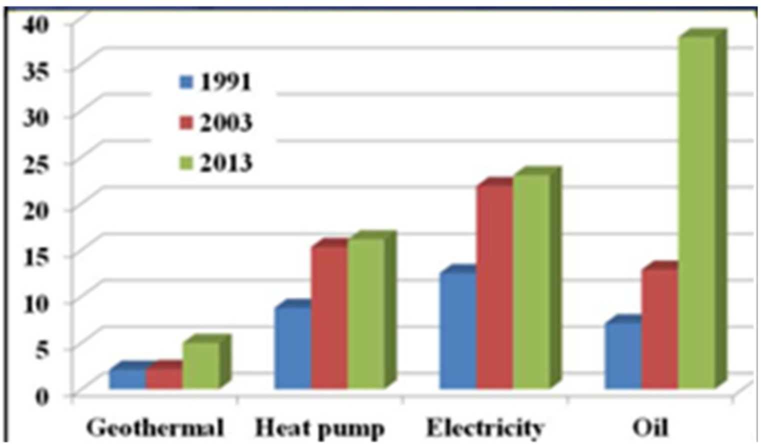


FIGURE 8: Prices (ISK per kWh) for different types of energy for heat drying a kilogram of dried cod head

4.2.3 Freeze drying

Freeze-drying is used for the drying of chemical products, pharmaceuticals, biological and food products. The process consists of the elimination of water through a sublimation process. Freeze-dried products are in great demand due to the advantages they offer in their storage, long lifetime and high quality. Since no refrigeration is required during storage, and because they are light, the cost of transportation is low.

The food products to which this type of drying can be applied are several as shown in Table 2 and include fruits, vegetables, meats, seafood, and ready meals such as dinners, military rations, camping foods, baby food; and drinks such as coffee and tea (Dimitrios et al., 2014). The classification of the products for freeze-drying is determined in three categories as shown in Table 2.

TABLE 2: Product classification freeze-drying (Dimitrios et al., 2014).

Liquid products	**Individual quick-freezing products (IQF)**	**Product combinations**
Coffee	Segments of whole fruits	Rice dishes
Tea	Berry segments	Soup
Juices	Seafood	Baby foods
Milk products	Meat	Camping foods
Other extracts	Vegetables	

4.3 Numerical models for drying bananas

Numerical models are mathematical models carried out with the purpose of establishing a simple and idealized summary of a process or problem, elaborated with mathematical operations and symbols (Wikipedia, 2018a; 2018b). However, mathematical modelling is a resource; the success of which depends on the accuracy of the numerical representation.

In tropical countries, variety of fruits are produced, banana being one of these. However, 40% of the produce is lost due to over-production. It is possible to take advantage of the abundant production by drying the bananas. This study proposes several models to simulate the drying of bananas in a thin layer at different temperatures of 40, 50, 60 and 70°C. The time used varies from 1,200 (at 70°C) to 3,265 (at 40°C) minutes. The maximum drying speed occurs at the beginning of the process in the range of 1.95×10^{-3} (40° C) and 3.60×10^{-3} (70°C) min^{-1} (Pereira da Silva et al., 2014).

Bananas production increases every year. It is considered a fruit of high demand by consumers in most parts of the world. It is a food that is rich in minerals, carbohydrates, vitamin A, potassium and sugar (Gouveia et al., 2004). The drying of bananas is a method for preservation and at the same time serves to modify the flavour of the product and its texture, in order to satisfy a larger consumer demand and to increase the value in the market (Janjai et al., 2009).

Two main groups of mathematical models can be used to describe the drying of a thin layer of an agricultural product. The first group is empirical models (Turhan et al., 2002; Diamante et al., 2010; Kaleta and Górnicki, 2010; Mundada et al., 2011; da Silva et al., 2012a) and the second group is diffusion models (Karim and Hawlader, 2005; Nguyen and Price, 2007; da Silva et al., 2012b; Darvishi et al., 2013).

Empirical models describe the elimination of water in a thin layer, as well as the penetration of heat when the water is removed with hot air. In this case, the heating is governed by the diffusion equation that implies the drying speed of the energy in equilibrium (Karim and Hawlader, 2005; Mariani, 2008). The empirical model is also used in deep bed drying.

The empirical model, applied in our case, explains the kinetics of thin-layer drying of banana. Different temperature and velocity data were considered, with the aim of obtaining mathematical expressions that produce results to consider in the process.

Diffusion analytical model includes (Pereira da Silva et al., 2015):

- Constant convective mass transfer coefficient (h);
- Effective diffusivity of water (D);
- Homogeneous and isotropic material;
- Uniform initial humidity distribution;
- The only water transport mechanism is diffusion;
- Insignificant variation.

Both the empirical model and the diffusion model can be used in a continuous or intermittent process of drying bananas. Each of the drying types was analysed to know which one obtains the greatest amount of benefits. This is determined by evaluating the empirical equations. In the Peleg model it is observed that eight hours of continuous drying were equivalent to four hours of discontinuous drying with 1 hour of intermittence. This is the best model to describe the intermittent drying of the bananas. It is concluded that not only the intermittency ratio but also the intermittent time are important for the description of the drying kinetics. Another benefit is that time saved equals the energy saved (Pereira da Silva et al., 2015).

5. DRYING OF BANANAS WITH GEOTHERMAL ENERGY

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

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

5.1 Air as drying fluid

The primary use of air, as a drying fluid in the process, is the evaporation of moisture through heat. The temperature of the hot air depends on the product to be dried, and the time of the drying duration depends on the maximum amount of temperature allowed. Using a higher temperature than the approved one can cause physical and chemical damage to the product (Popovska, 2014).

When a higher temperature is used in a drying process of grains such as corn or rice; it can cause physical and chemical damage to the products. This damage can be observed in the cracking of the product. On the other hand, when the product to be dried is a fruit or a vegetable, and the temperature used is higher than the allowable one, the product is affected in its structure, with damage occurring to the aroma, the nutrients, the colour, and other quality losses. To avoid this, it is necessary to incorporate the following:

- Use of lower temperatures;
- The drying of the grains must be slow;
- Remove only limited part of the moisture that is subject to the specific product;
- The air being used must contain a percentage of moisture as a drying fluid at an elevated temperature (Popovska, 2014).

5.2 Heat exchangers and geothermal energy for drying

Considering that the temperature for drying grains, vegetables or fruits is relatively low, low-enthalpy geothermal fluids can be used as a heat source. However, the lowest temperature available in the geothermal field of Berlin is 138°C, so it is necessary to use heat exchangers and lower the temperature, to the range of 40-80°C, which is the temperature used for drying bananas.

5.3 Location of a drying cabinet in the Berlin geothermal field

When a geothermal source that can be used to dry fruits has been identified, it is necessary to consider different elements, such as the temperature of the geothermal fluid, distance from the resource to the location site of the cabinet, flow of the geothermal fluid, chemical composition, and cost in the modification of the temperature used. This information will be used to identify if it is feasible or not to use the geothermal source for the drying process (Popovska, 2014).

Since 2003, work has been done in El Salvador on the dehydration of fruits in the facilities of the geothermal power plants. In Ahuachapán a dehydrator was built using heat from a hot water pipe, in which a fan is rotated to achieve the drying of fruit. In Berlin, the first dehydration tests were carried out in 2004 with tropical fruits using fluids from the TR4 well. The practice was carried out with the support of women from the local community. Since 2006, FundaGeo has been in charge of supporting the neighbouring communities of geothermal energy plants. They conducted a pilot test to resume the dehydration within its community care programme as shown in Figures 9 and 10; this time with the support of Technological Institute Central America (ITCA) for the manufacture of a new dryer.

FIGURE 9: Preparation of fruit, by communities in the neighbourhood of the geothermal plant (LaGeo, 2005)

FIGURE 10: Dehydrated fruit (LaGeo, 2005)

The dehydrator worked without problems. The dehydration times vary according to the fruit or the material to be dehydrated, at an average temperature of 65°C for a time of 8 to 11 hours as shown in Figures 11 and 12. The project used water at 50°C. The steam is introduced into the dehydrator and the water is pumped at room temperature and passed through a heat exchanger in a pipeline with geothermal fluid (180ºC), making the water temperature increase from 24 to 55°C.

Currently, El Salvador is working towards direct use applications, in addition to electricity generation of geothermal energy. In 2017, a study was carried out for the design of a coffee dryer using the energy

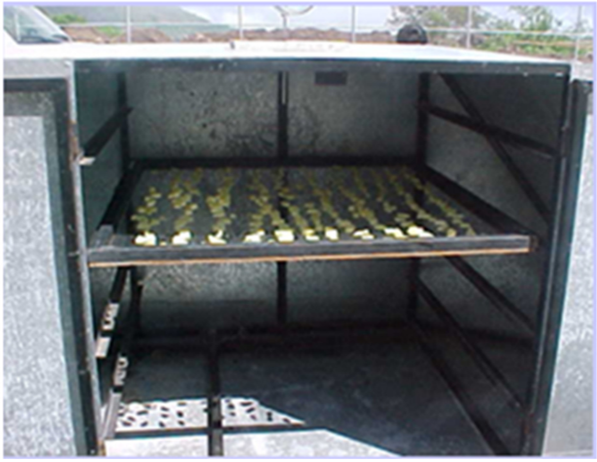


FIGURE 11: Interior of dehydrator (LaGeo, 2005)

FIGURE 12: Prototype dehydrator (LaGeo, 2005)

contained in the geothermal fluids in the Berlin geothermal field. Currently, coffee drying is done by drying in patios. Using this drying process, there are obstacles to overcome, such as the weather and drying times, which are quite long. On the other hand, LaGeo made use of the low-enthalpy resource in order to support the neighbouring communities and carried out a study and proposal of a coffee dryer, through graduate work at the University of El Salvador. The coffee dryer will be located near the reinjection well TR-12 (Martínez et al., 2018) as shown in Figure 13.

FIGURE 13: Location of rack drying cabinet at reinjection well TR-12 (LaGeo, 2005)

The results of the coffee dryer prototype are a total drying time of 29 hours and air temperature in the range of 39.3-50.5 °C. The humidity of the coffee inlet cannot be determined with the measuring equipment that was available (Martínez et al., 2018).

In this report, the drying of fruits and grains in El Salvador is analysed through the application of direct use of geothermal energy, based on prototypes that have been in use since 2003. Now continuing with the implementation of direct use in the drying of bananas, the different processes for drying have been studied, as well as the application of geothermal drying of fruit, the mass balance and the location for the rack drying cabinet. An available area has been selected, within the reinjection well TR-12, located close to several communities that would receive benefits, as shown in Figure 13 (LaGeo, 2005). This could be a source of work and income for their homes. At the same time the well is located about 5 km from the main street which is beneficial for obtaining raw material and for distribution of the product.

5.4 Mass balance and the drying process

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 is:

$$Mass\ in = Mass\ out + Mass\ stored + losses$$

While the energy balance is:

$$Energy\ in\ = Energy\ out + Energy\ stored + losses$$

Figure 14 (Arason, 2018), shows the geothermal drying process.

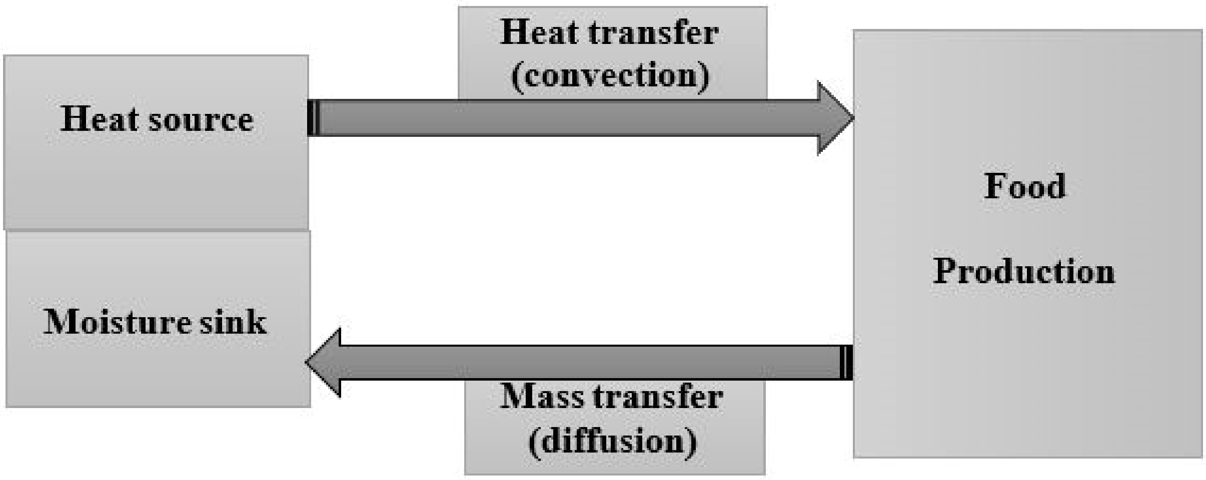


FIGURE 14: Drying process (Arason, 2018)

Mass flow for drying bananas:
Calculation of the mass flow start with analysis of the primary drying as can be observed in Figure 15 and then it is continued with the analysis of the secondary drying observed in Figure 16 (Arason, 2018).

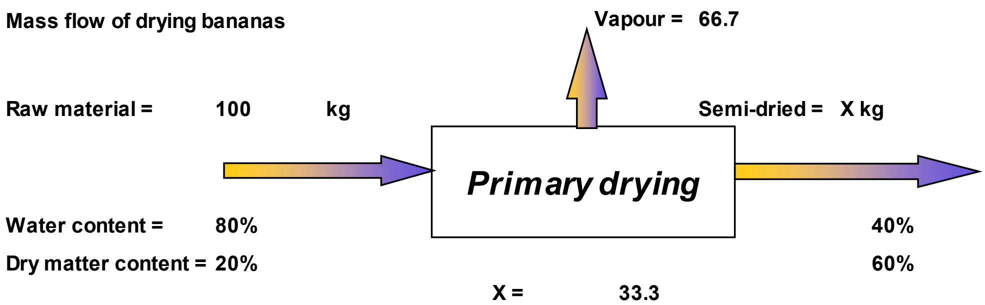


FIGURE 15: Primary drying – input is 100 kg of quality material giving "X" amount of Semi-dry material (33.3 kg) with a certain percentage of humidity, (Arason, 2018)

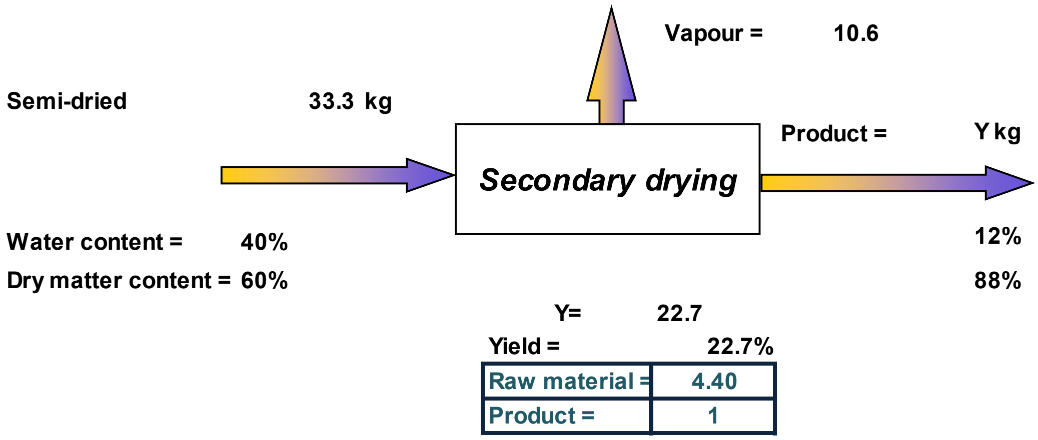


FIGURE 16: Secondary drying - input of 33.3 kg of quality material giving "Y" amount of dry material with a percentage of humidity, the product (Arason, 2018)

Table 3 shows the conditions of air drying and the information available in Figure 17 on temperature (T) and relative humidity (RH) to consider in the drying cabinet.

TABLE 3: Data for an air-drying condition

No.	T (°C)	RH (%)	Humidity ratio – x* g_{water} / kg_{air}	Enthalpy - i (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

*moisture grains / kg dry air

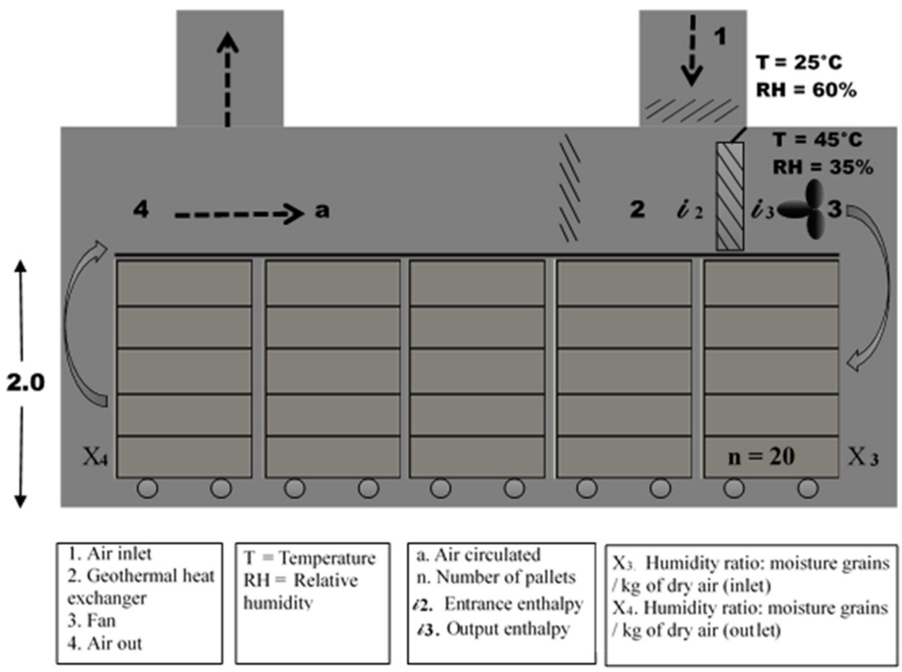


FIGURE 17: One-tunnel drying - the numbers describes the condition of the air (Arason, 2003)

Conditions for the air are the following:

Enthalpy of air:	in = 90 kJ/kg; out = 98 kJ/kg
Humidity of air:	in = 20.50 g/kg, out = 23 g/kg
Air humidity of outside air	= 12 g/kg
Air circulated	= 77.5%

Tables 4 and 5 show the data for calculation of quantities used in the drying tunnel.

TABLE 4: Determination of quantity in tunnel

	No. pallets/width	No. pallets/length	Width (m)	Length (m)	Height (m)	No. frames in one tunnel	Quantity in tunnel
Frame			1.02	1.02	0.10		
Tunnel	5	5	5.30	6.80	2.10	500	3,000

TABLE 5: Quantity of drying in one tunnel

Quantity one frame (kg)	No. frames one pallet	Quantity one pallet (kg)	No. pallets one tunnel	Quantity one tunnel (kg)
6	20	120	25	3,000

With the quantity data to be used in the tunnel obtained (Table 5), the calculation of the mass balance for drying can be carried out as shown in Table 6.

TABLE 6: Mass balance for the first drying

Parameter	Results		Comments
	%	Value	
Mass - Raw material weight (kg)		3,000	
Weight of dry matter at beginning (kg)		600	
Dry matter content in raw material (%)	20%		
Semi-dry product (% dry matter)	60%	1,000	
Water evaporation for filling (kg)		2,000	
Water evaporation per hour (kg)		67	Drying time 30 hours
Airflow – relative - g_{water}/kg_{air} (kg/h)	2.5	26,667	
Airflow (m^3/h)	1.2	22,222	Specific gravity of air 1.2 kg/m^3
Airflow (m^3/h) - actually		24,444	

Airspace between frames = 0.4; Air velocity = 1.4 m/s

With the data obtained in the first drying, the energy necessary for the operation of the drying cabinet can be determined - Table 7.

TABLE 7: Energy needed for air heating

Power (kJ/h)	Energy (kWh)	Water flow (l/s)	ΔT (°C)
213.333	59	0.5	30

The drying of banana is done in two stages, primary drying and secondary drying. The time and temperature variants are considered in both stages of drying so that the quality of the humidity is adequate and the fruit maintains its nutrients and the adequate texture. The data of the mass balance in the second drying can be seen in Table 8.

TABLE 8: Mass balance for secondary drying

Parameter	Results		Comments
Semi-dry product (% dry matter)	60%	1,000 kg	
Dry matter in the product	88%	682 kg	
Water evaporation f. filling		318 kg	
Water evaporation per hour		11 kg	Drying time 30 h
Relative airflow - g_{water}/kg_{air} (kg/h)	0.3	1,178	
Airflow (m^3/h)	1.2	982	Specific gravity of air 1.2 kg/m^3
Airflow (m^3/h) - actually		2,946	

With the data of the second drying, when acquiring the semi-dry product percentage and multiplying it by the amount in a container, the maximum amount of material to use in the containers for drying can be determined as shown in Table 9.

TABLE 9: Maximum quality, number of dry containers for indoor drying

Quantity one container (kg)	Maximum no.
75.0	13.3

With the calculation of the mass balance, the raw material required to get the amount of product necessary is determined according to the design proposed for the drying cabinet. On the other hand, when determining the evaporation of water per hour, it can be obtained by a simple method in Table 10, which shows the amount of water needed in l/s according to the design of the drying cabinet.

TABLE 10: Simple method

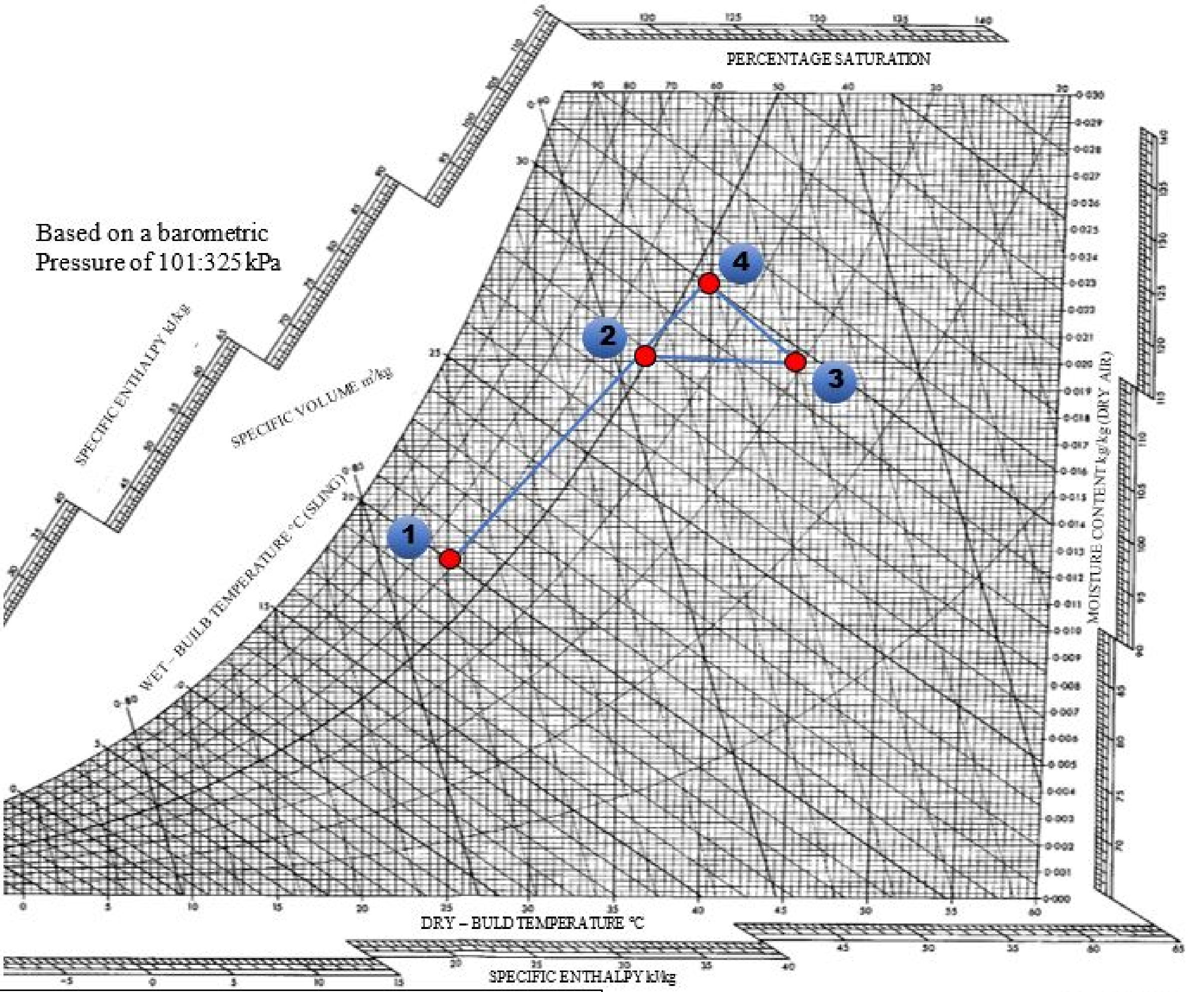
Evaporated water (cal/kg)	Energy (kcal)	Water flow (l/s)
1,100	73,333	0.68

Table 11 presents the data for the operation of a drying cabinet through the connection of the TR-12 pipeline throughout a year.

TABLE 12: Production per year

Active months	Yield (%)	Product from one filling (kg)	Fillings per week	Product in month (tonnes)	Raw material/year (Tonnes)	Product per year
11.5	22.7	682	3	8.6	435	98.8
Drying time/week	**Weeks/ month**	**Water flow (l/s)**	**Time s/h**	**Number of tunnels**	**Hot water/month/ tunnel (Tonnes)**	**Hot water/ month (Tonnes)**
90	4.2	0,5	3600	1	656	656

In the psychrometric chart, the enthalpy is determined and used for the determination of the mass balance, see Figure 18.



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, in point **4** the moisture content of the air outlet is 23 g / kg and the outlet temperature is 40°C.

FIGURE 18: Cibse - Psychrometric Chart (Jones, 2001)

6. PROCESS IN BANANA DEHYDRATION

6.1 Product description

Banana are a common product from the countries of the Central American area where production is high, and excess production can be dehydrated and used for export (Carangui et al., 2014). Bananas belong to the Musaceae family, raw edible banana (musa cavendishhi). (Banana Market Profile, 2009).

There is a great variety of bananas in the world. 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 is 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 colour is yellow or light brown, with a sweet smell and the taste characteristics of the product can vary, depending on additives used for marketing, such as honey, or a specific oil. When drying a banana and increasing its shelf life, there are different aspects of the quality of the product that must be considered. Among these are the freshness, colour, texture and nutritional content.

A dehydrated banana retains most of the properties of the fruit in its natural state. The vitamins it has are A, C, B6, phosphorus, calcium, proteins, iron, folic acid, and potassium (Cook with the Sun, 2018b).

Values to consider when drying banana (Cook with the Sun, 2018)a:
Moisture of fresh banana (%) = 80;
Water content of dried banana (%) = < 15;
Maximum temperature for drying (°C) = 70.

6.2 Raw material and ingredients

For preparation of dried banana the following is needed:

- Green bananas;
- Sodium bisulfite; and
- Potassium sorbate.

The raw material includes the treatment of the chemical material when dehydrated, in order to minimize the damage of the food during dehydration and maintain or improve the quality of the product. In the dehydrated banana, better results are obtained with a sulphite bath rather than it being acidified, as browning is prevented, as well as the loss of vitamin C and A (Full health, 2014).

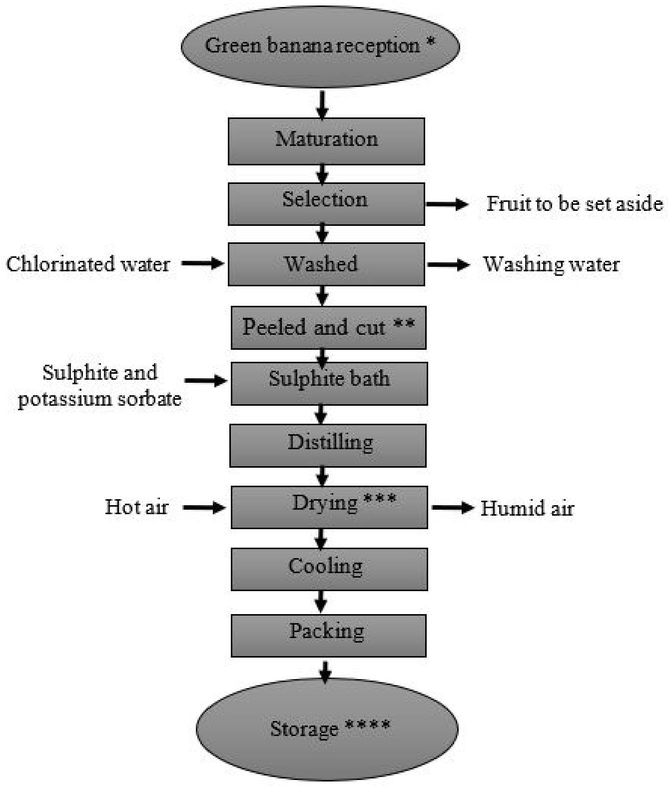
6.3 Installation and equipment

Installation
The drying cabinet for the banana will be located at the TR-12 well, in the Berlin geothermal field. The area is suitable for the space required for its operation such as the reception, administration, sanitary services, selection of raw material, preparation, drying area, packaging, storage, distribution and parking. The building will be of block walls (height 1.2 m), a finished, painted and corrugated sheet metal structure, zinc roof, air extractors in the roof, metal structure, uneven floor, and concrete finish to facilitate the cleaning and prolong the lifetime. Windows will be projected with ribbed sheet with a structure of metallic square, folding door, and a wooden door. Also present are an electrical connection to an immediate source, connection to drinking water and existing black water.

Necessary equipment
Equipment needed for the drying cabinet is: reception shelves, selection table, knives, weighing machine, preparation table, drying cabinet, storage shelves, furniture for washing, sealing and packaging table.

6.4 Flowchart for the preparation of dehydrated bananas

Beginning with the selection of green bananas until placement in the storage room, all the necessary processes are specified in the flow chart in Figure 19.



* Material mass balance, for 100 kg.
** Peeled banana product is 22.7kg.
*** Drying divided into two stages. In drying I, with a raw material of 33.3 kg and drying II with a raw material of 16.7 kg.

FIGURE 19: Flowchart (Carangui et al., 2014)

6.5 Process description (Carangui et al., 2014)

Maturation: To obtain a better result in the quality of the bananas, the green banana should be made mature. The green bananas are submerged in water with a 0.25% ethyl solution (liquid to mature) for 3 min. 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 colour and is ready when it reaches a yellow tone and the touch is firm

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 fruits and overripe ones are discarded.

Washing: The bananas which have been selected for use are washed in a chlorinated water bath. The proportion of chlorine to water is 2 ppm.

Peeling and cutting: Banana peeling is done manually, as is the cutting, which is regulated and specified.

Sulphite bath: The peeled banana is immersed in a solution of potassium sorbate and sodium bisulphite for five days. This is done to prevent the colour change of the banana by a oxidation reaction and to prevent the growth of micro-organisms in the final product.

Distillation: After five days in the sulphite bath, it is removed and placed on a structure that allows it to distil excess water.

Drying: The banana is accommodated in square trays of 1.0 × 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 the drying, the water content must be less than or equal to 15%.

Packing: Once the drying process is finished, the product is packed, and the proper seal applied to avoid contact with oxygen.

6.6 Quality control

Raw material: At the time of the acquisition of the green banana, 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 has the required 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). A vacuum package seal will be used which 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 been opened.

Final product: The last stage of quality control 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 analysed 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).

7. PROPOSAL

The drying cabinet expected to be located close to well TR-12, needs an infrastructure for its operation. Figure 20 shows the zoning of the different spaces; administrative area, including office, sanitary service and reception; machinery area intended for preparation for drying, selection, washing, peeling, cutting, sulphite bath application; machinery area for the drying cabinet; and a storage area for packaging and cellar storage.

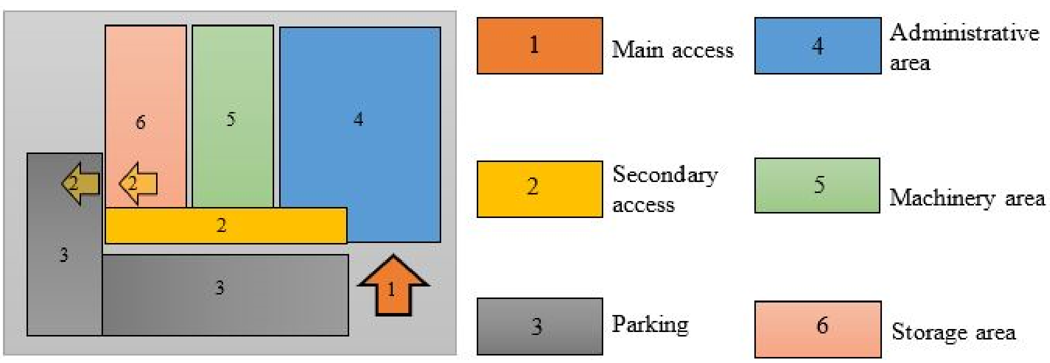


FIGURE 20: Infrastructure zoning

TABLE 13: Parameters important for banana drying

Relative humidity (RH)	60
Water content (%)	15
Temperature (°C)	45

The parameters to consider for banana drying are temperature, humidity and the drying time, see Table 13. The processes within the machinery area and storage area can be observed in Figure 21.

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

The parameters of temperature and time for the operation of drying of banana can also be used for the drying of tomatoes which is another alternative 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 for that, considering the corresponding mass balance for drying fish.

The product is high quality 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.

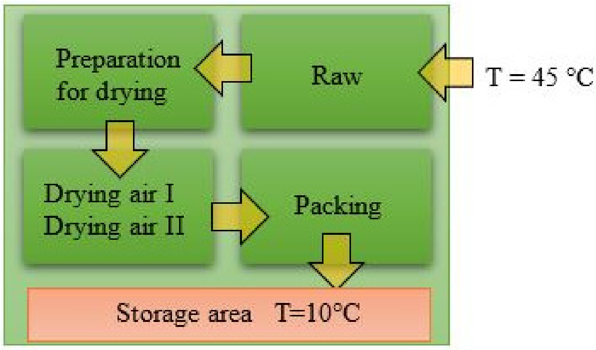


FIGURE 21: Processes in the machinery and storage areas

8. CONCLUSION

When analysing possible categories of direct use of geothermal energy, here it is determined that El Salvador, one of the 82 countries that possess this resource, in addition to the generation of electricity energy through the use of geothermal energy, can also make a case for direct use through the process of drying banana.

Energy capacity is available in the geothermal fluids that come from the binary cycle power plant in Berlín to be reinjected through the reinjection well TR-12. This energy can be used for the drying of banana.

The banana is a fruit that has a high demand in different countries and the market for the fruit's acquisition is high. This creates an opportunity for potential clients in El Salvador. Possibilities are also in export to Central America, USA and Europe.

When calculating the mass balance for the drying process, it was determined that the suitable temperature for the drying is 45°C, with a time duration of 30 hours needed and a water content of the dried products less than 15%. This temperature, time and relative air humidity guarantees that the colour of the banana is the right one to be attractive when the product is 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 well, including Bob Graham, Buena Vista and Berlin. If developed through FundaGeo, the project should receive adequate guarantees in financing and institutional support.

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