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Food Conservation with Geothermal Energy in Mexico and the World

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ABSTRACT

This work deals with one of the main direct uses that are possible with the geothermal energy of low enthalpy developed in the world; it is the dehydration of food through which the product is given a benefit, and its shelf life is extended up to one year. At the beginning of the work, a compilation of the different countries that have adopted this activity is presented as one of the solutions to food preservation, and the reduction of greenhouse gases with geothermal dehydration. Finally, the dehydration project in which the Instituto de Ingeniería of UNAM (IIUNAM) has ventured is detailed, through the financing granted to the Mexican Center for Innovation in Geothermal Energy (CeMIE-Geo), where IIUNAM participated with the project number eleven: "P11: Technological development for the use of low enthalpy geothermal energy", the project was developed from 2014 to 2018.

1. INTRODUCTION

The dehydration of foods is considered as a natural method of conservation, by removing the water contained in them, the growth of molds, fungi, yeasts and microbes is inhibited, the main agents that cause the decomposition of food (Aviña et al., 2016).

Dehydration of food are not new, probably before the first historical records, the man used the dehydrated, dried, smoked, salted and pickled as means of preservation, often in combination (Pérez-González et al., 2016).

Currently, the dehydration of products of fruit and vegetable origin, such as fruits, vegetables, herbs and cereals, are products that have a greater participation in the market every day (Torres et al., 2016). The most used method is hot air, either direct or batch direct dehydrators.

2. DIRECT USES OF ENERGY IN THE WORLD

The geothermal resources of intermediate to low temperatures (<200 °C) are susceptible to be exploited in a great variety of industrial, agricultural and service activities; grouped under the generic name of Direct Uses (DU). Within the iiDEA group, a DU classification has been developed, see Figure 1.

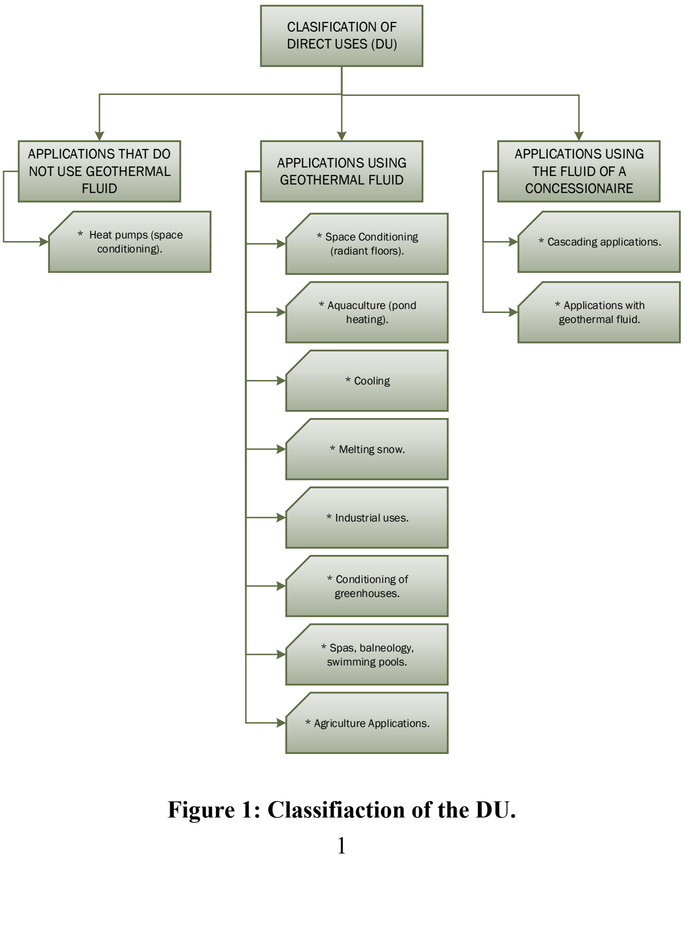

Figure 1: Classifiaction of the DU.

The main DU applications registered in the world are: balneology, space conditioning, greenhouses, heat pumps and aquaculture, among others.

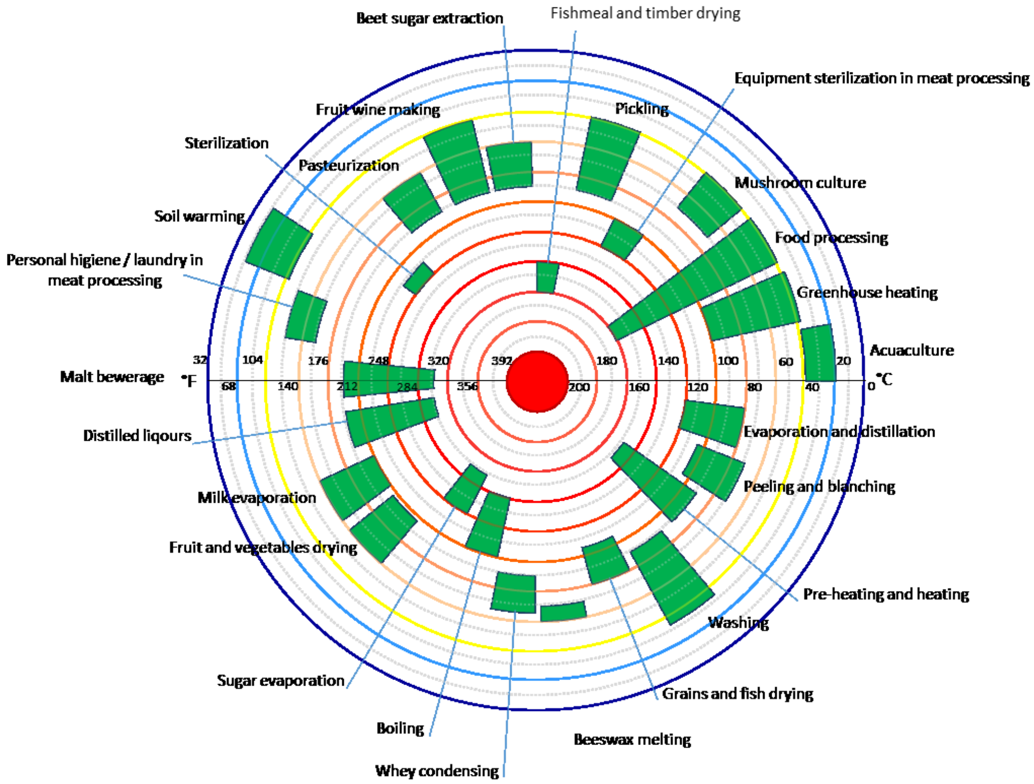

Figure 2: Diagram of Lindal, DU.

The importance of the DU and the growing investment in projects of this nature, lies in the energy savings they represent. In the year 1995, only 28 countries took advantage of geothermal energy; in 2000, 58; 2005, 72; 2010, 78, and finally in 2015 the figure reported was 82 countries. With this growth in the use of geothermal energy, energy savings amounted to 350 million barrels of oil annually, this translates into stop emitting 46 million tons of carbon and 148 million tons of CO_2 (Lund et al., 2015).

Table 1: Summary of the various categories of DU worldwide for the period 1995-2015 (Lund et al., 2015).

Application	1995	2000	2005	2010	2015
Geothermal Heat Pumps	14,617	23,275	87,503	200,149	325,028
Space Heating	38,230	42,926	55,256	63,025	88,222
Greenhouses Heating	15,742	17,864	20,661	23,264	26,662
Aquaculture Pond Heating	13,493	11,733	10,976	11,521	11,958
Agricultural Drying	1,124	1,083	2,013	1,635	2,030
Industrial Uses	10,120	10,220	10,868	11,745	10,453
Bathing and Swimming	15,742	79,546	83,018	109,410	119,381
Cooling/Snow Melting	1,124	1,063	2,032	2,126	2,600
Others	2,249	3,034	1,045	955	1,452
Total	**112,441**	**190,699**	**273,372**	**423,830**	**587,786**

3. CLASIFICATIÓN OF DEHYDRATORS

The removal of moisture from food can be possible by different methods. However, this work focuses on hot air dehydration. Figure 3 is a classification based on the type of heat transfer.

It is worth mentioning that the word dehydrator and dryer is commonly used interchangeably, however, there is a difference between the two concepts, this lies in the percentage of relative humidity in which the food is left at the end of the process. It is said that a food is dry if at the end of the process it has a humidity between 15 to 20%, but a food will be considered dehydrated if said humidity oscillates between 3 to 5%; Although both words are not synonymous, they will be used indifferently only for practicality (Pérez-González et al., 2014).

Despite the wide variety of dehydrators there are, about 85% of the dehydrators used in the industry are direct dehydrators, and their ranges of gas heating with which the humidity of the products is removed ranges between 50 and 400 °C, which depends on the nature of the product to be dehydrated (Mujumdar et al., 2010).

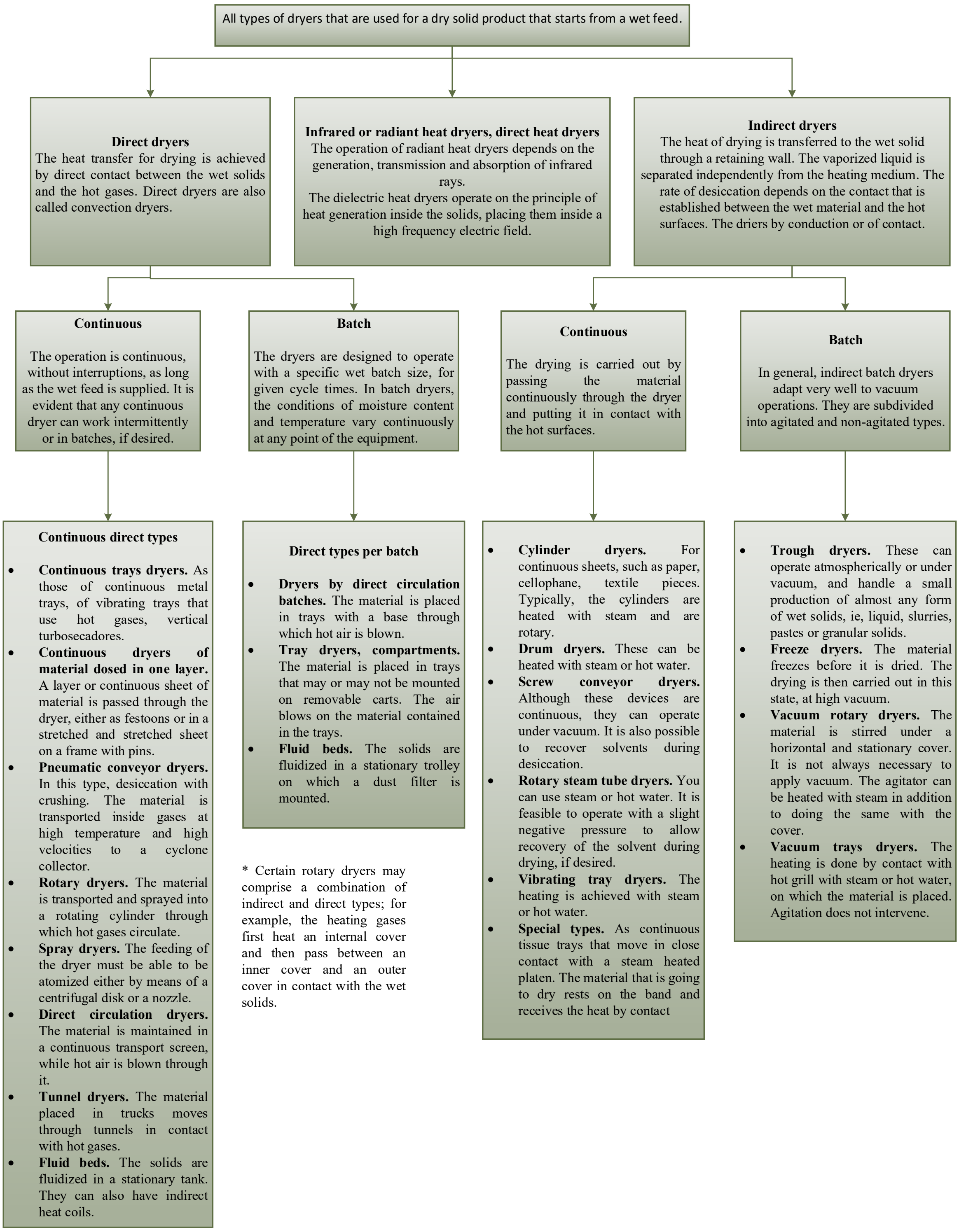

Figure 3: Classification of dryers, based on method of heat transfer (Perry et al., 2001).

4. GEOHTERMIC DEHYDRATORS IN THE WORLD

The dehydration of food or the drying of products such as: wood, paper, concrete block or even leather, using geothermal energy, are productive processes developed throughout the world, with the objective of taking advantage of geothermal energy, and generate diverse products, at the same time as new markets are opened due to their added value. Geothermal energy is classified as high (T> 200 °C), medium (150 ≤T≤ 200 °C) and low (80 ≤T<150 °C) enthalpy (Ordaz et al., 2011; New Energy Low of Mexico, 2014). Food dehydration ranks number seven in the various activities highlighted in the UD worldwide. The countries that dehydrate geothermally are:

Table 2: Summary of dehydration worldwide, 2020, adapted from (Lund et al., 2015); NM: Not Mentioned.

Country	MWt	TJ/yr
China	95.00	1,198.0
Iceland	70.00	910.0
Hungary	25.00	297.1
United States	22.41	292.0
Romania	6.32	102.7
Russia	4.00	69.0
El Salvador	1.70	21.1
Turkey	1.50	50.0
Kenya	1.00	10.0
Serbia	0.97	26.9
Mexico	0.53	13.2
Guatemala	0.50	12.1
Vietnam	0.50	11.8
Greece	0.28	1.8
Thailand	0.04	0.3
Indonesia	NM	NM
New Zealand	NM	NM

The following is a summary of the aforementioned countries and their experience in food dehydration, most of them have continued this activity and have even increased their installed capacity, as well as their experience in various products.

4.1 China

China is the leader in the dehydration of foods with geothermal energy in the world. The main products that dehydrate are grains, fruits and vegetables. The installed capacity reported at the end of 2009 was 82 MWt, 984 kg/sec. of average geothermal resource used and 1,037.5 TJ/yr (Zheng et al., 2010; Lund et al., 2011). For its annual closure in 2014, 95 MWt were reported, with 1,135 kg/sec. of mass flow and 1,198 TJ/yr, which indicates an annual average growth of 3.2% (Zheng et al., 2010; Lund et al., 2015).

The provinces with dehydration of food are Fujian, Yunnan, Xiaoyanghou and Hebei; it is worth mentioning that low enthalpy geothermal developments are cascade applications, where industrial applications, heating, air conditioning, aquaculture and balneology intervene. Figure 4 shows the cascade use, which is the model scheme of the project in Xiaoyanghou Province, Nanjing (Zhonghe, 2017).

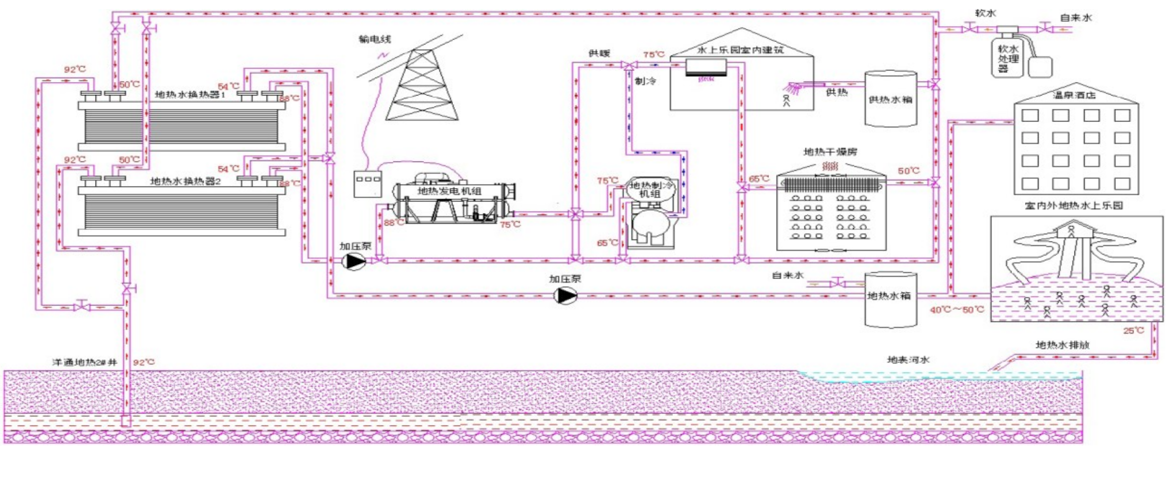

Figure 4:Process Flow Diagram (Zhonghe, 2017).

Another similar development is known as the Dengwu project, located in Fengshun in Guangdong province. The residual energy of a geothermal binary cycle is used for cooling by adsorption, a food dehydrator and a heating system for balneology. These systems have an efficiency of 70 to 80% compared to individual applications, which range between 25 and 30%.

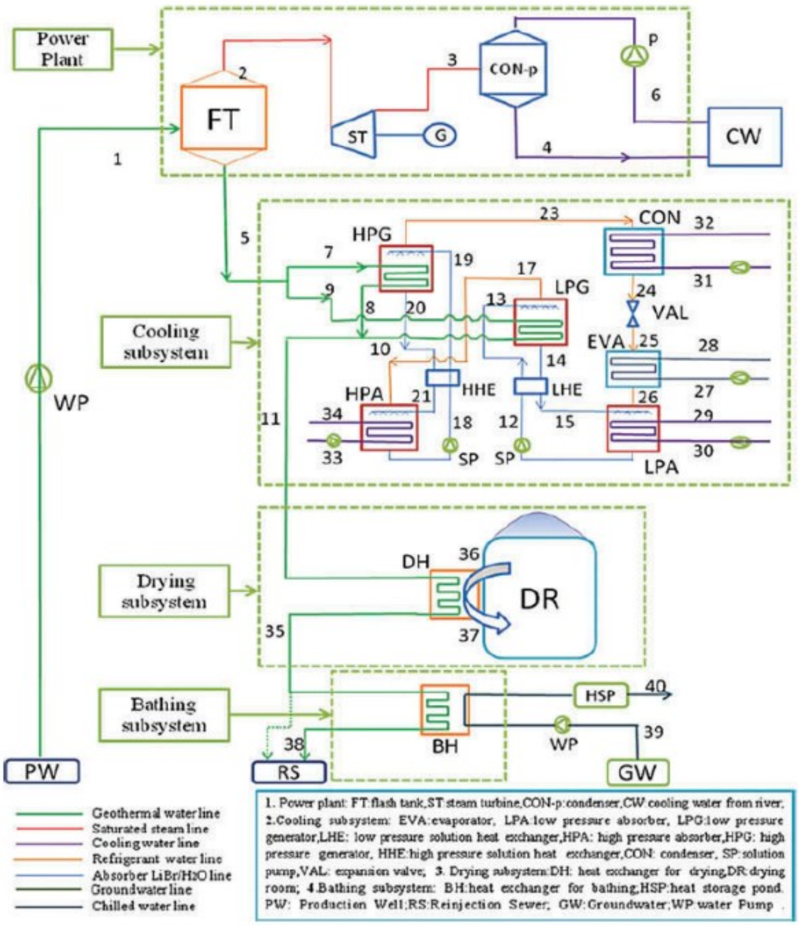

Figure 5: Process Flow Diagram (Xianglong et al., 2015).

The cascade system in question works with hot water at 91 °C and a flow rate of 60 kg/sec. The power generation plant contributes 300 kWe and has an annual operation of 8,000 hours. Dehydration systems work with hot air. They use water-air heat exchangers to raise the air temperature to 48 °C and thus remove the water from the food gradually.

4.2 Iceland

The main source of energy in Iceland comes from geothermal energy, which represents 68%. It has been reported a large share of this energy in various industrial activities such as drying horticultural products, salt extraction by evaporation and crystallization, space heating, livestock breeding, greenhouses, floor heating, swimming pools, and biodegradation processes by fermentation , hot water supply, snow melting and aquaculture. Among the diverse applications, those that interest this investigation are the dehydration of marine algae and fish (Thorhallsson et al., 2017); At the Thorverk dehydration plant, located in western Iceland (Gissurarson et al., 2018; Lund et al., 2015), it started operations in 1975, and produced 2 thousand to 4 thousand tons of dried seaweed. Uses 34 lt/sec. of geothermal water at 117 °C; with this resource the air, which is used for drying, is heated to 85 °C (National Energy Authority and Ministries of Industry and Commerce, 2006); 2015 data report an installed capacity of 8 MWt and an energy used of 200 TJ/yr (Ragnarsson, 2015).

Another product that has been successfully dehydrated for 38 years has been salted fish, cod head, small fish, among other products. Iceland and Norway are the largest producers of dried cod. 15,000 tons of fish heads are exported annually, mainly to Nigeria. In 2006, 20 companies dehydrated this product, of which 16 did so with geothermal water and only one, Haustak, uses geothermal steam (National Energy Authority and Ministries of Industry and Commerce, 2006). Haustak uses 1.3 kg/sec. of steam that comes from the geothermal power plant near Reykjanes; only its annual production is 2.5 thousand tons of dry product, for which 12 thousand tons of fresh product must enter (Ragnarsson, 2016).

Finally, other applications reported with great success is the drying of products for the preparation of pet food. An annual production of 500 tons is estimated. The curing of cement block and baking of bread are other applications of direct uses with geothermal in the country (National Energy Authority and Ministries of Industry and Commerce, 2006).

4.3 Hungary

Since 1987, peas, corn and rice have been dehydrated (Lund, 1989). The main provinces that dehydrate are Csongrád, Felgyő, Hódmezővásárhely, Kistelek Makó, Miskolc, Szarvas, Szeged, Szegvár and Szentes. For the year 2010, a use of 10 TJ/yr of geothermal energy was reported for the dehydration of agricultural products (Toth, 2010). Currently, the installed capacity for dehydration corresponds to 25 MWt, with an annual energy used of 297.13 TJ/yr and a load factor of 0.38 (Toth, 2010; Lund et al., 2015).

It is a geothermal dehydrator that dries the product entering it at the top, the food goes down, at the same time that a current of air is induced to counter flow, reducing 20% moisture of the product. It is a direct dehydrator and batch, since it must be expected to collect all the grain in the lower part to later enter another load through the upper part of the equipment.

4.4 United State

This dehydrator is located northwest of Nevada, near Empire and Brady's Hot Springs. The dehydrator was the initiative of a German company that markets various types of food. The geothermal resource comes from a binary cycle plant, at a temperature of 130 °C and with a flow rate of 56.67 kg/sec. at the end of the process the temperature drops to 71 °C. It is reported a production of 6.3 tons/yr, of which, 3.78 tons are onion and 2.52 tons of garlic.

The dehydrator is a unit composed of a mechanical band, its path is 64 m and it is 3.6 m wide. The process is divided into eight stages: a) harvest, b) shipment of the product to the plant, c) cured, d) washed, e) sliced, f) dehydrated, g) ground or pulverized and h) packaged.

Table 3: Dehydration temperatures for each section and the humidity of the food at the end of each section.

Section	°C	%HR
A	96	85
B	85	30 a 10
C	74	4 a 6

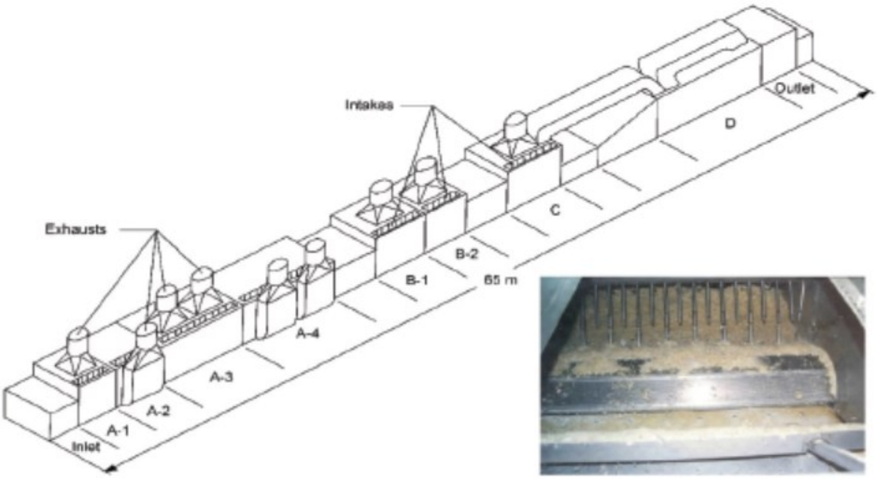

Figure 6: Onion and garlic conveyor belt dehydrator (Lund et al., 1994).

4.5 Romania

The drying of ceramics and wood were carried out with geothermal energy of low enthalpy, however, in 2013 these activities were stopped (Bendea et al., 2015). No more reports mentioned about it and no more information about the type of dehydrators. In the last report of Lund in 2015 is mentioned the installed capacity and the amount of energy used per year in the dehydration of fruit and vegetables products, 6.32 MWt and 12.70 TJ/yr, with a load factor of 0.06 units (Lund et al., 2015).

4.6 Russia

In 2004, among other DU applications, the dehydration of grains, leaves for tea, algae and even drying and curing of concrete blocks and wood drying was reported. The installed capacity for agricultural products in 2004 was 4 MWt, an annual energy use of 69 TJ/yr and a capacity factor of 0.55 (Kononov et al., 2005). However, nothing else is mentioned about the type of dehydrators with which it is produced. In the articles by Povarov K.O. and Svalova V.B., 2010 and 2015 (Povarov et al., 2010; Svalova et al., 2015) is not detailed on dehydration, it is only limited to indicate that there are such activities. However, in the report on the DU of Lund, JW, 2015 (Lund et al., 2015), it is mentioned that, based on the personal communication established by Dr. Lund and Dr. Svalova, the energy conditions for the dehydration of food, reporting the same values that had been indicated since 2004.

4.7 El Salvador

The geothermal electric field in Berlin is located in the eastern part of El Salvador, approximately 100 km from the capital, San Salvador. The dehydrated fruits are pineapple, apples, bananas, coconuts, among others; The project is called "Proceso de Deshidratado Natural Geotérmico ". It is estimated that the installed capacity for food dehydration is 1.7 MWt and 21 TJ/yr of energy used (Lund et al., 2015). While the prototype coffee drier attends the production of the FundaGeo farms in Berlin, Usulután. The objective of this prototype is to characterize the technology for a future scaling to a commercial dryer, with a capacity of little more than a ton of coffee beans per day.

4.8 Turkey

The first geothermal food dehydrator in Turkey, settled in the community of Karakurt, in the city of Kirsehir.

The foods that have been dehydrated are: banana, palm, quince, orange, pineapple, pear, apple, kiwi, peach, watermelon, melon, tomato, pepper, cucumber, eggplant, onion, green beans, white cabbage, lettuce, spinach, garlic, leeks and carrots.

Due to its great food diversity, Turkey ranks fourth worldwide as a food producer, producing 28 Mtons of vegetables annually (Hakan et al., 2014).

Reports from 2014 estimate an exploitation of 1.26 MWt for the dehydration of food in Turkey. Process temperatures vary depending on the products to be dehydrated and range from 50 to 95 °C for air that removes moisture from food.

4.9 Kenya

The geothermal complex of Ebrurru is located 40 km north of the geothermal power plant in Olkaria, Kenya. In the area there are fumaroles, hot muds and superficial steam vapors of hot water, with which dehydrate leaves for tea, macadamia nuts, herbs, coffee, fruits and the *Anacyclus pyrethrum*[1]. The temperatures used during the dehydration process are less than 100 °C. This new way of dehydrating has represented a great advantage because of the energy saving and the reduction in CO_2 emissions; Typically, dehydration is done in the sun, burning wood or gas and/or with electrical resistances.

The Eburru geothermal dehydrator was built by English settlers in the year 1939, originally used for the drying of the *pyrethrum flower* and corn. The geothermal water used has a temperature of 95 °C, despite this, it is reported that, due to thermal leaks due to lack of insulation, the water temperature reached 43 °C (USAID-Washington and the Kenya Geothermal Development Company, 2013).

It is a natural convection dehydrator, it uses radiant tubes that transport the geothermal fluid; the cabinet and the trays are made of wood. The temperatures used for the UD in the region are between 30 and 150 °C (Martha, 2012; Lund et al., 2015).

It is estimated that the geothermal resource used is 2 kg/sec. with an initial temperature of 130 °C and at the end of the process its temperature is reduced to 93 °C (Lund et al., 2015; Kinyanjui, 2013).

4.10 Serbian

Dehydration of wheat has been reported, mainly, as well as other cereals, the location where this activity is carried out is in B. Petrovac. To carry out this process, 11 kg/sec. of geothermal fluid with a temperature of 45 °C are used and at the end of the process its temperature is 24 °C. For the year 2010, an installed capacity of 0.97 MWt and an energy used of 19.39 TJ/yr were reported, with a capacity factor of 0.63 (Martinovic et al., 2010). However, the last report of 2015 indicates that the load factor increased to 0.88, thus increasing the energy used by 26.87 TJ/yr (Oudech et al., 2015; Lund et al., 2015).

4.11 Guatemala

In 1999, the Agroindustrias La Laguna dehydration plant was built, which operates with a geothermal resource from the Amatitlan field. The company dehydrates pineapple, mango, banana, apple, pear and chili peppers. It is estimated that the energy used in dehydration is 0.5 MWt and 12 TJ/yr. Table 4 shows the production capacities for each food, as well as the hours the process lasts (Merida, 1999; Lund et al., 2015). No information is reported that allows to deduce the type of dehydrator or data relevant to its operation.

Table 4: Dehydrated products and production capacities (Merida, 1999).

Product	Capacity kg	Time h
Banana	816	22
Mango	726	16
Pineapple	816	18
Pear	680	12
Apple	680	12

4.12 Vietnam

Dehydration tests of plantain, coconut meat, cassava, and medicinal herbs have been reported since 1983. The tests were aimed at demonstrating the potential and benefits of dehydrating food with geothermal energy; for example, reducing the humidity of tea leaves up to 13% required 1.5 hours; for the drying of the cassava it required 26 hours, to reduce the humidity from 60 to 25% (Linh et al., 2010). However, the type of dehydrator and operating conditions are not reported. For the year 2015, an installed capacity of 0.5 MWt and an energy used of 11.83 TJ/yr was reported (Lund et al., 2015).

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[1] It is a plant species of the Asteraceae family, with creeping stems and a gray-brown root with a spicy flavor. In North Africa chewing is used to relieve toothache, its tincture is used as antirheumatic, however, it is widely used as an insecticide to kill lice, fleas and other parasites.

4.13 Greece

In Neo Erasmio, Greece, a tomato dehydrator was installed, which dehydrates the agricultural production of the Aegean islands. The tomato is cut in half and then dehydrated. The stages through which the tomato has to pass are three: pre-dehydration, dehydration and post-dehydration. In the first step, the tomato is selected according to its degree of maturation, then halved and placed in trays of 100 x 50 cm^2, with a capacity of 7 kg per tray. The next step of dehydration is carried out in a dehydrated tunnel per batch.

In the first year of operation of the dehydrator, 4 tons of tomatoes were produced, for which one TJ/yr of energy was necessary, which in 2001 represented 0.5% of the total geothermal energy used in Greece. In the nine years after its installation, an average annual production of dehydrated tomato of 9.22 tons (Andritsos et al., 2010) is reported, however, in 2008 the plant was modified so that it could produce twice its capacity (Andritsos et al., 2011).

Another product that is grown and dehydrated with geothermal energy is spirulina, photosybtesizing cyanophyte (green-blue algae), which grows in hot environments, 35 and 37 °C and high alkaline concentration. The cultivation of spirulina began in 1990 in Nigrita, Serres, and later another plant was installed in the geothermal field of Sidirokastro (Andritsos et al., 2015). After its harvest it is dehydrated; In 2007, 4 tons of spirulina powder was produced in a presentation of capsules, and in 2008 production increased by half a ton more. In the last report of 2015, a production of 7 tons/yr is estimated, the installation capacity is equal to 0.9 MWt reached with three plants installed so far.

Other products such as fig have been produced, and in May 2002 dehydrated about one ton, as well as peppers, onions, mushrooms, olives, asparagus, apples and cherries (Andritsos et al., 2010; Andritsos et al., 2015).

4.14 Thailand

In 2014, 97 geothermal nodes were reported, of which 12 correspond to high enthalpy, 16 to medium enthalpy and the rest to low enthalpy. Regarding its applications, generation of 3,909 kWe with binary cycles is estimated, 304 kWt for air conditioning, 2,408 kWt for the dehydration of 200 tons/day of food (Ramingwong et al., 2000).

The processes of dehydration of food in Thailand are two; one of them is a dehydrated chamber, which consists of 8 rooms, while the second is a dehydrator that uses a Geothermal Heat Pump (GHP). The dehydrating chamber uses the geothermal fluid directly in its air heating process, while the Vapor Compression Heat Pump (VCHP) uses the R-290 refrigerant as working fluid, thus exploiting the geothermal energy with temperatures between 40-50 °C to heat water up to 70 °C, which will be used in the dehydration process.

In Figure 7 a diagram of the dewatering chamber is shown. The geothermal water 60-80 °C flows through a heat exchanger, point 1, and exits through point 2. A fan at point 3 moves a mass of air that wraps around the heat exchanger, heating the air ready for process, point 4; the air at high temperature passes through the trays with the food in them and once done the removal of the humidity, the humid air is released to the environment through a window, point 6, that leads it to an upper conduit, point 7. The dehydrator measures 3.30 m x 4.80 m x 3.20 m and has a production capacity of 3 tons, however, the author does not specify the period of time in which said quantity is produced (Chaiyat et al., 2014).

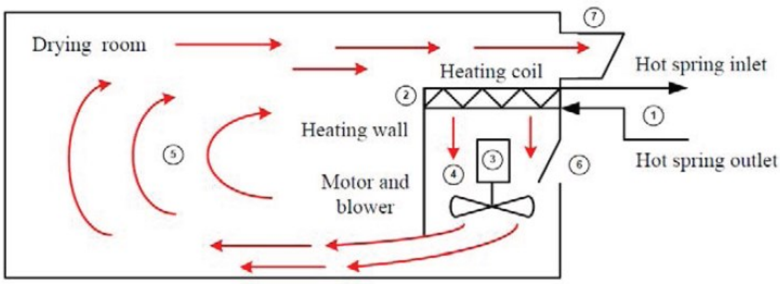

Figure 7: Schematic diagram of the dehydration chamber (Chaiyat et al., 2014).

The dehydrated with the GHP is composed of a VCHP. The heating system is composed of: a compressor, condenser, evaporator and expansion valve, see Figure 8. In state 1, the vapor phase fluid is compressed at a high temperature and pressure, state 2, it is subsequently condensed to be liquid saturated, in state 3, the liquid is strangulated to the isenthalpic process at a low pressure, state 4, in this way it will be able to evaporate with the low temperatures of the geothermal resource with which this dehydration system works, finally the cycle is restarted; It is worth mentioning that it has the same production capacity as the dehydration chamber indicated above (Chaiyat et al., 2014).

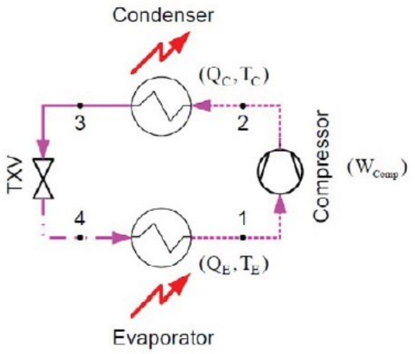

Figure 8: Schematic diagram of the VCHP (Chaiyat et al., 2014).

Unfortunately, in 2015 reports it is indicated that the pilot plants for space conditioning and dehydration were closed due to high maintenance costs. Reports indicate that tobacco, plantain, chili, garlic, corn, and peanut were dehydrated until then (Ramingwong et al., 2000).

However, a dehydration chamber was maintained that uses residual energy from a binary cycle, with an average temperature of 70 °C. It is estimated that its installation capacity is 0.04 MWt and 0.3 TJ/yr of energy used (Lund et al., 2015).

4.15 Indonesia

In 2007, in the geothermal field of Kamojang, west of Java, in Indonesia, hot water is used from a geothermal well with an average temperature of 160 °C, the system used is a coffee bean dryer. The dryer exchanges heat from the geothermal fluid to a mass of air that is taken from the environment, this is done by forcing the air with a fan to a tube coil, which transports the geothermal water (Sumotarto, 2007). The main characteristic of this prototype is that the heating is done directly from the geothermal water to the air that dries the grains, which indicates that the capacity of corrosion and incrustation of the geothermal fluid has no relevance, otherwise, it would have to implement a intermediate heating system.

In the geothermal field of Way Ratai, located in Lampung, there are some natural wells of hot water, 80-98 °C. The heat from the well is transferred to a tubular coil submerged at 2 m depth, heating the water to room temperature to 50 °C. It is estimated that the production capacity is 200 kg/day. In the future it is planned to take advantage of the energy remnant of a geothermal power plant of 110 MWe, with temperatures between 175-180 °C to dry leaves for tea, since the project will be installed in the vicinity of a tea plantation. It is expected to displace the burning of ome million liters of diesel annually, which would not only represent a great economic saving, but would also reduce CO_2 emissions (Surana et al., 2010; Darma et al., 2010).

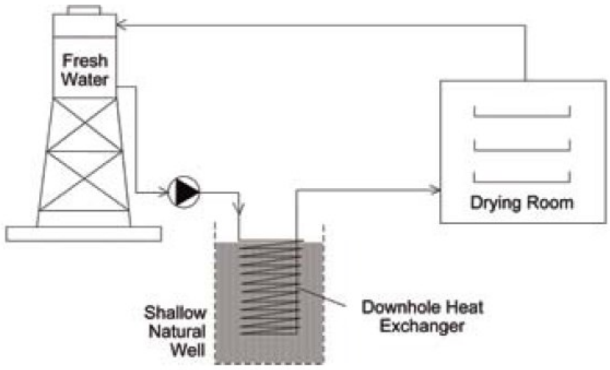

Figure 9: Scheme of the cocoa dehydrator, left side; Photograph of the well from which the geothermal heat is taken (Surana et al., 2010).

4.16 New Zealand

The DUs in New Zealand have a great history, being the first settlers, The Maori, beneficiaries of this energy resource, its main use is intended for the heating, cultivation, curing, drying and/or dehydration of products in general, for example, the production of milk powder.

In 1972, New Zealand dehydrated agricultural products, particularly alfalfa. The geothermal field of Taupo Lucerne supplied hot water to an alfalfa dehydrating plant located 30 km northeast of the geothermal field. The dehydrator used 7 tons of saturated steam at 11 Bara of pressure; with this energy, air was heated up to 124 °C. This pilot plant was developed by the company The Broadlands Lucerne, who had in mind to do the technological validation of said pilot plant, and later to scale it to a production of 2.25 tons of alfalfa. For this, the feasibility of using the geothermal fluid remaining from a geothermoelectric plant was analyzed. However, there is no more record on these projects for the reports in the subsequent years. A report of the year 2009, indicates that there is no dehydration of agricultural products in the country, the only DU reported are: Heating and conditioning of spaces, supply of hot water, greenhouses, aquaculture, industrial processes and balneology, in total 9.55 TJ/yr of energy used (White, 2009). However, for 2015, a decrease of 931 TJ/yr of energy used for DU was reported, probably because in 2010 two paper production plants closed due to the decrease in newspaper printing in the country (Lund et al., 2015).

4. 17 Mexico

However, due to the great geothermal potential of Mexico, the development of activities such as geothermal energy DU has not been as relevant as in other countries. Currently, Mexico is the 31st place in the world in direct utilization of geothermal energy with total amount reaching 4,184 TJ/yr. The 99.89% is used to balneology; the rest is for heat offices and dormitories in Los Azufres geothermal field, in the state of Michoacán, and recently, a dehydrator food.

The DUs in Mexico go back to a series of pilot projects developed by the Federal Electricity Commission (CFE), which demonstrated the technical feasibility of direct applications of geothermal heat in Mexico, applications that were implemented in geothermal fields: Cerro Prieto, Los Azufres and Los Humeros. These projects were office heating, greenhouses (Ortega, 1997), fruit and vegetable dehydrator (Casimiro, 1997; Lund et al., 1995), bulb germination, accelerated flower production, edible fungal nursery (Salazar, 1997) and wood drying (Pastrana, 1997).

The dehydrator of food in Los Azufres was installed in April 1995, which had the capacity to dehydrate 400 kg of fruit and produce 40 kg of average dry fruit. For its operation, 0.03 kg/sec. of geothermal fluid was needed, which was equivalent to an energy consumption of 10 kJ/sec. The temperature inside the dehydrator was 60 °C (Casimiro, 1997).

However, the project could not continue because of energy policies; the norms around geothermal energy were strictly referring to the generation of electrical energy, which was exclusively entrusted to CFE and for that, the government company, at that time, should be subject to the existing provisions on the exploitation of the waters of the subsoil. Currently, after the Energy Reform in 2013, a Geothermal Energy Law was published on August 11, 2014. Through which it is possible to take advantage of the geothermal resource not only for power generation, but also for DU as productive activities for the country (Martínez, 2016), this has been an incentive for the development of more productive processes, such as the dehydration of food.

The Geothermal Food Dehydrator (DGA) is a project that the IIUNAM took back from the financing granted by the CeMIE-Geo to the P11 project "Technological development for the use of low enthalpy geothermal energy", which was developed as of 2014, and ended in October 2018.

The first prototype with which we worked was in the DGA10 model; It is classified as a direct batch dehydrator. The dehydrated is by means of hot air that runs through the dehydrated chamber, horizontal section (3 m long) with capacity to process 10 kg in 15 hours; the hot and dry air when in contact with the food removes the humidity, due to the vapor pressure differential between the environment and the food. The moisture inside the food moves by diffusion between the capillary pathways of the organic tissue that is to say by capillary flow hydrodynamics.

This system is designed to operate with geothermal water of low enthalpy, at 80 °C, which is entered into a plate heat exchanger, where it transfers part of its energy to another working fluid that corresponds to fresh water. Once this heat transfer process has been carried out, the geothermal fluid is reinjected into the aquifer from where it was extracted or, failing that, it is sent to another process, such as cascade systems. The clean water that was heated by the geothermal fluid, at approximately 75 °C, is flowed through a finned tube heat exchanger. This radiator will increase the air temperature to 60 °C (the air temperature can be modulated depending on the speed of the air and mass flow of the geothermal resource), which will enter at one end of the heating chamber, and once heated will enter the drying chamber for the gradual extraction of moisture from the food, until leaving them with an adequate percentage of humidity (8-12%, depending on the food).

Parallel to the validation work of the DGA10 field technology, the design and analysis of the DGA200 model began. It is currently installed in the place where the DGA10 was located in the Domo de San Pedro geothermal field, which is managed by Dragón Group. The geothermal field is located on the side of the "Cerro Grande" elevation with coordinates 21°11'05.46"N 104°43'17.46"W. The physiographic province of the neo-volcanic axis covers most of the municipal surface. A very small percentage belongs to the Sierra Madre del Sur. The eastern part, north and south of the municipality, is formed by slopes of the plateau with stony ground; The semi-flat and flat areas are represented by alluvial deposits where agriculture is practiced. Most of the soil of the municipality is formed by rocky terrains of the igneous extrusive type of the Cenozoic era, highlighting the rocks of the acid tufa type and the basalts.

The climates that predominate in the municipality are the warm subhumid and semi warm-humid. The average annual rainfall is 683.4 mm; concentrating 90.44% during the months of June to October. The average annual temperature is 20.4 °C.

The dehydrating plant that houses the DGA200 is composed of a set of maritime containers, three standard containers of 20 x 8 x 8.6 ft, with a weight of 2.3 tons and a capacity of up to 28 tons. Each one is formed by a base, composed of two lower lateral rails and 13 support type C profiles, which are welded together as a single component.

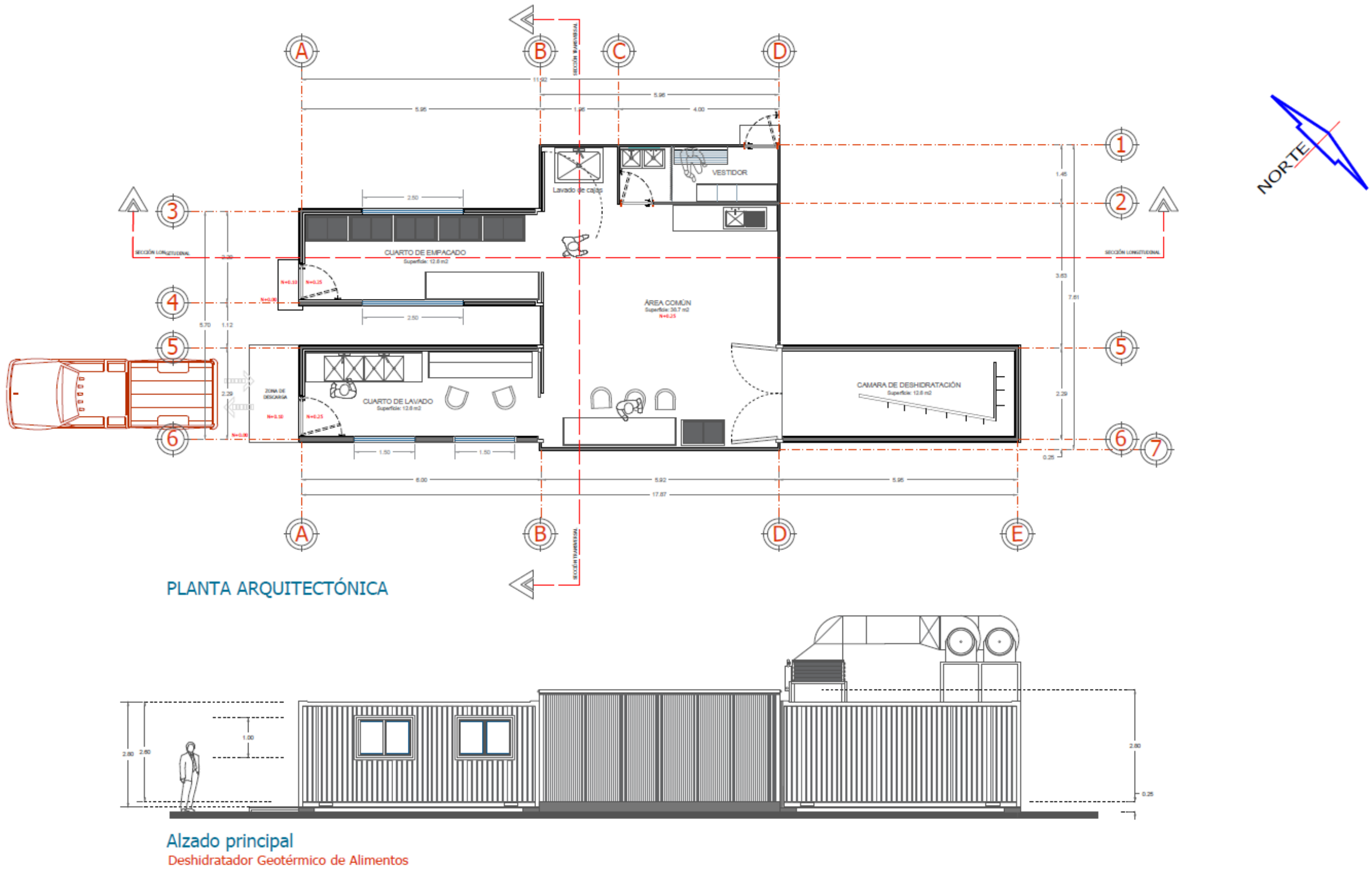

Figure 10: Plant view and front view of the DGA200

5. Conclusion

The DGA200 dehydrator system is aligned with the objectives proposed at the beginning of this applied research work. The first one is the promotion of the development of new technologies, especially national, for the use of geothermal energy of medium and low enthalpy. The second objective is the energy security that the project has, not depending on fluctuations in the price of gas or coal, fuels with which it traditionally continues to dehydrate. In third place is the environmental factor, the use of other energy sources, such as geothermal, can displace the use of fuels that, when burned, are a source of CO_2 emissions. Finally yet importantly, the social factor, which is very important from the labor point of view, since the development of this type of productive processes generates a value chain, in which the communities are involved; in such a way that it allows to break paradigms that are usually taken on geothermal energy.

The development, in particular, of the basic and detail engineering of DGA200, is based on the use of the energy remnant of the geothermal power plant in Nayarit. 1.67 kg/sec. of geothermal water is used at 180 °C, and it is taken from one of the lines leading to one of the silencers in the plant. In order to achieve the above, a derivation of the line was made, and through a pipeline, this flow is transferred to the area where the DGA200 is located.

A day can process up to one ton of pulp and produce between 150 and 200 kg of dry product. Pineapple, mango, cucumber and jackfruit have been the main dehydrated products. The system started operation in November 2018, and is the only one operating in Mexico.

Table 5: Utilization of geothermal energy for dehydration in Mexico as of 31 December 2019.

Project	Type	Maximum Utilization				Annual Utilization		
		Flow rate	Temperature °C		Capacity	Ave. Flow	Energy	Capacity
		kg/sec.	Inlet	Outlet	MWt	kg/sec.	TJ/yr	Factor
* Los Azufres, Mich.	A	0.100	77.0	60.0	0.007	0.030	0.067	0.300
iiDEA-DGA200, Nay.	A	1.6667	180.0	105.7	0.531	1.350	13.235	0.750

** Out of operation since 2000*

The dehydrator installed in the Los Azufres geothermal field was operational for five years, from 1995 to 2000, and was subsequently closed. Until 2012, the project was resumed by IIUNAM and it was completed in 2018. Work is currently underway to scale up the technology, with the PRODETES 2019[2] prize won by the company PI. INGENERA S.A. de C.V. and IIUNAM, it is intended to triple production by the end of the year with a DGA600 dehydrating plant.

The use of geothermal energy for the dehydration of food is a small step that contributes to the reduction of greenhouse gas emissions. On the other hand, it is an alternative to food preservation processes in a safe and natural way. With the installed capacity of DGA 200, equivalent to 3,676.36 GWh/yr, 338.55 t CO_2/GWh are no longer issued, or equal to 1.25 Mt CO_2/yr.

As presented in this work, various countries around the world have worked and presented different alternatives for the dehydration of foods; Most of their equipment is direct dehydrators, some work by batch and others do it continuously. The difference in the heating dynamics of the air also depends on the nature of the geothermal fluid, that is, the chemical composition it has, and therefore, the degree of corrosion and scale damage it will have on the water-air heat exchangers. For a little harmful or corrosive fluid it allows to heat air directly, on the contrary, it will be necessary to make an intermediate heating with a third working fluid, which can be water too, but without too many salts and minerals like the geothermal fluid, to avoid corrosion and incrustations within the main equipment.

Regarding dehydrated products, the results were favorable, the dehydration times range from 10 to 17 hours with average temperatures of 55 to 60 °C, depending on the type of food. Quality assessed qualitatively is very good compared to commercially dehydrated products (Carmona, 2016). A very simple way to do this evaluation is through the color of the product. If we have darkening in the food, or Maillard reaction, it is a reflection of nutritional degradation due to excessive temperatures and prolonged times of exposure to these temperatures (Pérez-González, 2017).

Regarding the social part, 15 direct jobs have been opened, 13 in production, one operator and one supervisor. On the other hand, the solution provided to the producers, in this case of the pineapple, to whom they are bought, just over two tons of pineapple per day, represents an alternative with a greater impact on the economy of the producers, since that with the DGA10 prototype only 10 kg/day of pineapple were purchased for processing.

In conclusion, the objectives proposed at the beginning of the project have been met, and in the future it is expected to have a DGA600 plant that further strengthens the four pillars, social, technological, environmental and energy that have been working. To ensure that the plant has the highest standards of quality has been training staff in Good Manufacturing Practices, in parallel with proper planning in Hygienic Design in accordance with the documents generated by the European Hygienic Engineering & Design Group (EHEDG).

[2] The Government of Mexico through the Ministry of Finance and Public Credit (SHCP), Nacional Financiera (NAFIN) and the Secretariat of Energy (SENER). It signed a grant agreement with the World Bank and the Global Environment Facility for the implementation of the Sustainable Energy Technologies Development Project (PRODETES)

Table 6 Summary of dehydration with geothermal energy in the world 2020; NM: Not Mentioned.

Country	Year	Product	Flow rater	Maximum utilization		Capacity	Annual Utilization		
				Temperature °C			Ave. Flow	Energy	Capacity
			kg/sec.	Inlet	Outlet	MWt	kg/sec.	TJ/yr	Factor
CHINA	2009	Grains, fruits and vegetables	984.00	NM	20.00	82.00	193.40	1,037.50	0.40
	2014		1,135.00	NM	20.00	95.00	454.00	1,198.00	0.40
ICELAND	2015	Seaweed	56.00	112.00	70.00	8.00	36.00	200.00	0.79
	2016	Fish	1.3*	220.00	NM	70.00	NM	910.00	0.41
HUNGARY	2010	Pea, corn and rice	NM	NM	NM	NM	NM	10.00	0.38
	2015		NM	NM	NM	25.00	NM	297.13	0.38
UNITED STATES	2015	Garlic and onion	NM	130.00	71.00	22.41	56.67	292.00	0.41
ROMANIA	2015	Grain, fruit and vegetables	NM	NM	NM	6.32	NM	12.70	0.06
RUSSIA	2015	Grain, tea leaves, seaweed and wool	NM	NM	NM	4.00	NM	69.00	0.55
EL SALVADOR	2018	Pineapple, apple, coconut and banana	NM	NM	NM	1.70	NM	21.10	0.39
TURKEY	2015	Fruit and vegetables	NM	NM	NM	1.50	NM	50.00	NM
KENYA	2013	Flowers, grains and fruits	2.00	130.00	93.00	0.31	2.00	NM	NM
SERBIA	2010	Wheat and other cereals	11.00	45.00	24.00	0.97	7.00	19.39	0.63
	2015		11.00	45.00	24.00	0.97	9.70	26.87	0.88
GUATEMALA	2015	Banana, mango, pineapple, pear and apple	NM	NM	NM	0.21	NM	3.96	0.60
MEXICO	2018	Mango, pineapple, cucumber, among others	1.667	180	105.7	0.531	1.350	13.235	0.750
VIETNAM	2015	Banana, coconut, cassava and medicinal herbs	*NM*	92-210	NM	0.50	NM	11.83	0.75
GREECE	2015	Peppers, onions, mushrooms, olives, asparagus, figs, apples, cherries and tomatoes	6.94	58-60	51.00	0.28	9.70	1.79	0.20
	2015	Spirulina	15.00	36.50	23.00	0.90	2.40	9.81	0.35
THAILAND	2000	Tabacco	NM	60-80	NM	0.50	NM	11.80	0.75
	2015	Banana, corn, peanut	0.724*	49.60	48.61	0.00	0.75	0.72	NM
			0.232*	44.80	37.60	0.01	0.22	0.23	NM
INDONESIA	2010	Tea and chocolate	NM	80-95	NM	NM	NM	NM	NM
NEW ZEALAND	1980	Alfalfa	1.94	184.00	180.00	0.03	1.94	NM	NM

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