

DRYING OF AGRICULTURAL PRODUCTS WITH GEOTHERMAL ENERGY

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Introduction

The basic idea of drying agricultural product is to provide: longtime storage without degradation, early harvesting which reduces field losses, higher prices of agricultural products and better quality.

The industrial drying processes are performed with consumption of heat and electricity for driving the auxiliary equipment. Basic energy requirements are connected to heating the product to suitable temperature in order to initiate the process of evaporation (of the moisture) and energy necessary to evaporate certain percentage of the moisture. Mostly, the process goes by direct contact of the prepared product (grain, vegetables, fruits, etc.) submitted to drying with warm air at relatively low temperature (35 to 80°C). Therefore, low temperature geothermal fluids can be utilized as energy source to heat the air for drying of agricultural products.

1. BASICS

Basic requirements in designing drying equipment are reaching maximal intensity of the drying process under optimal conditions for preserving the quality of the material.

1.1. Air as drying fluid

Air as drying fluid in drying process has several responsibilities, such as: carrying the heat needed for evaporation of the moisture, transport of the evaporated water out of the plant, and, after the drying process is finished, to cool down the dried product.

Temperature of the warm air has limited values depending on the products in question. For example, maximal recommended temperature for drying grains is usually 43°C. Most of the grains would be damaged if they were submitted to temperature of 52°C. When milled grains are in question, temperatures above 60°C are not allowed.

Consequently, the duration of drying process will depend on the maximal allowed temperature, i.e. the higher is the temperature of the drying air the shorter will be the time necessary to dry the product.

Higher temperature than the allowed one in a drying process may cause physical and chemical damaging of the products. When grains (rice, corn, soybeans) are considered, this means cracking and checking. Higher temperatures than the allowed for fruit and vegetables in question would cause damage of the nutrients, structure, aroma deterioration, lost of the typical color and other quality losses. To avoid such negative consequences it is necessary:

- To use lower temperatures for drying,
- To cool the dried grains slowly,
- To remove only a limited part of moisture content (different for each type of product),
- To use air with certain humidity as drying fluid at elevated temperature.

1.2. Heat exchangers and geothermal energy

It was already mentioned that maximal allowed temperatures for drying bio products are relatively low (especially for drying grains, i.e. 40 to 65°C). This temperature range is suitable for application of low-enthalpy geothermal fluids as heating source.

Principal reason to use heat exchangers in geothermal systems is to confine the geothermal waters with their inherent impurities where corrosion or scaling can either be controlled by material selection or where cleaning will be relatively easy and economical. However, application of heat exchanger involves additional decrease of the available temperature difference between the primary and secondary fluid; for example 3 to 5°C when plate heat exchanger is used.

Principally, air is used as heating media for drying purposes. So, either the air will be heated with secondary fluid (through secondary heat exchanger) if more complex system is in question (integrated geothermal project where geothermal energy is used for many different purposes); or it can circulate as secondary fluid in the heat exchanger, extracting the required heat energy from the geothermal water.

Preparation and preservation of food is a very sensitive problematic since high level sanitary conditions must be maintained. This, again, involves inevitable application of heat exchangers whenever geothermal energy is used.

1.3. Geothermal source

When a geothermal source is on disposal to be applied for drying purposes, following influencing factors should be determined and taken into account:

- Distance from the planned site,
- Temperature of the geothermal fluid,
- Geothermal water flow,
- Chemical composition,
- Possible integration with other applications,
- Cost of used temperature difference.

When having this figures and comparing them with the desired application, the decision has to be made whether it is feasible or not to utilize the geothermal source for drying processes.

1.4. Pre-drying/post-drying processes

The technology of pre-drying and post-drying processes is different depending on the type of the dried product (grains, vegetables, fruits) and the desired result (moisture, shape, further processing). Fig.1 presents typical technology lines for grains and fruits & vegetables.

1.5. Designing driers

Thermal calculation in great degree depends on how the heat is introduced to the material that is dried. For convective heating, the drying regime (actually the parameters that determine the time necessary for drying) is defined with the temperature, streaming velocity, and with the relative humidity of the drying media; although for other ways of heat introduction in the drying process (contact, thermal-radiation, current with high frequency etc.) the intensity of the heat flux is set so that the temperature of the material does not cross given limiting value.

Drying agricultural products usually involves convective drying.

Thermal calculation of drying furnaces and calculation of the construction depend not only on how the heat is introduced, but also from the type and construction of the furnace.

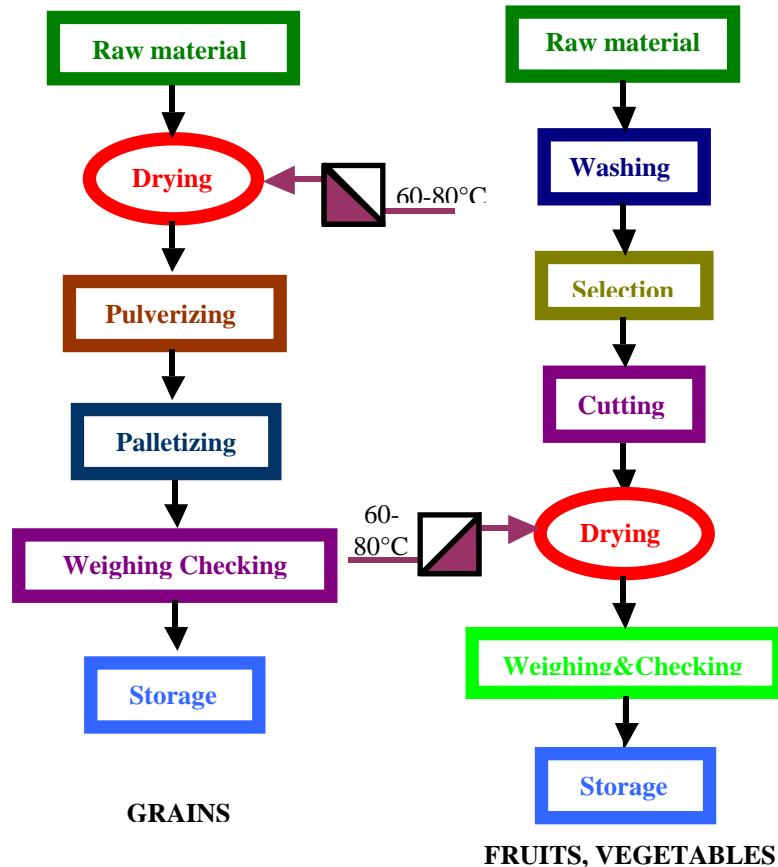


Figure 1. Technology line for drying grains and fruit & vegetables

1.5.1. Convective driers

Terms of reference for design the drier should consist: drier type, material to be dried with its initial and final moisture, drying regime or the initial parameters of the drying air.

When designing convective driers it is essential to do the following:

- Composing the principal scheme of the drier, consisting design parameters, given and those that should be determined
- Composing the material balance and calculate the humidity flow in the dryer
- Drawing the process in h-x diagram and determining the necessary mass flow of dry flow. In advance, thermal flux necessary to heat the material must be determined, then thermal flux which is exhausted to the surrounding through the walls, and thermal flux necessary for evaporation of the moisture and internal balance of the drier
- According to the calculated values of: internal drier balance, total heat losses and given values of the initial parameters of the drying air and final parameters (temperature or relative humidity) to draw the h-x diagram of the drying process and to find out the parameters of the drying air at the exit of the drying chamber
- According to the mass of evaporated moisture in the drier, calculating the mass of the drying air which is necessary for evaporation of 1 kg moisture, and also the heat flux and total quantity of heat needed for drying the material
- Determining the values of the specific volumes of humid air at the entrance and at the

exit in relation to 1 kg of dry air

g) According to the flow and mass of the drying air in the drier and the pressure necessary to overcome the aerodynamic resistance in the drier, to chose suitable fan, and to chose heat exchanger according to the drying air flow.

Concluding phase of drier design is determination of the basic techno-economic indicators, i.e.:

- a) Total and specific investment expenses.
- b) Specific energy expenses.
- c) Necessary number of people to be employed for drier exploitation.
- d) Price of drying 1 kg evaporated moisture.

1.5.1.1. Types of convective dryers

There are three basic ways of convective drying:

- Drying with reheating of the air (multi-zone driers, for drying of thermo-sensitive materials, that do not allow use of air with high initial temperatures,
- Drying with re-circulation of the used air (the air that leaves the drier is partially exhausted to the atmosphere, and partially mixed with fresh air, where the mass of the fresh air is equal to the one of the exhausted air), and
- Combination (this drying process is mostly used in multi-zone driers, with counter current flow).

Chamber dryers

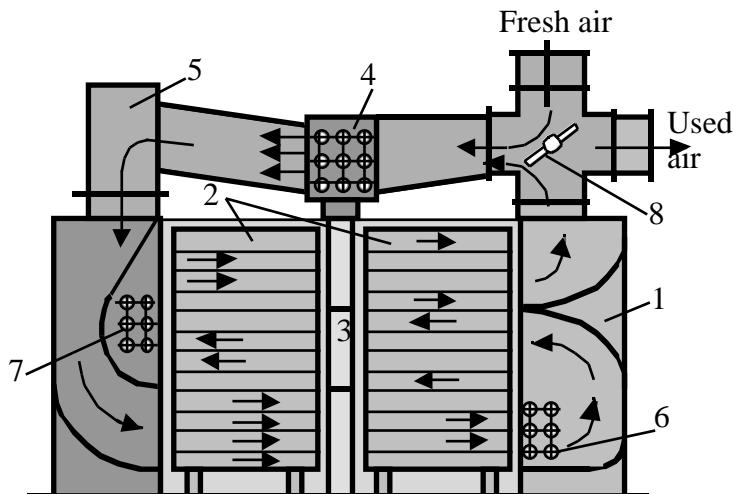
These types of driers work periodically and at atmospheric pressure. Basic part of the chamber dryer (fig.2) is the chamber with rectangular cross section, where the material is placed. The material is in fixed position during all the drying cycle. Loading and unloading of the material is made only from one side of the drier. They can be with: trays, compartments, hooks and with wagons. Normally, the use is for timber drying, insulating plates, ceramic and silicate objects, different disperse and fibrous materials. Application is convenient for small quantities of material and in cases when precise regulation of the drying regime is required.

These dryers are characterized by low productivity and longer drying period. The drying is not even due to the uneven disposition of temperatures in the chamber, resulting from the partial flow of the air in upper layers through shorter ways (through clearances).

Bad side of this type of dryers is the high need for manual work.

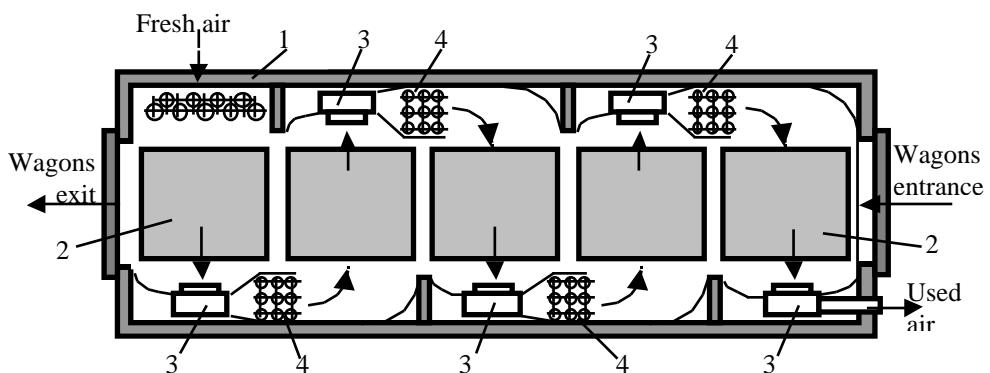
Tunnel (corridor) dryers

These types of dryers have continual principle of work. Basic part of the dryer (fig.3) is the elongated drying chamber. The inter-connected wagons are slowly moving on rails along the chamber. At the entrance and the exit the tunnel is equipped with hermetical doors. They are opened simultaneously and periodically in order to enable loading and unloading the drier with material. Drying air is moving in the same or opposite direction relative to the movement of the dried material. The circulation of the air can be natural or forced but better effect is achieved with countercurrent forced movement. Tunnel driers can work with single use of the heated air, with re-circulation or with air reheating.



1-drying chamber; 2-wagons; 3-partitions; 4,6,7-heat exchangers;
5-fan; 8-flow regulating valve

Figure 2 Chamber dryer



1-Drying chamber; 2-Wagons; 3-Fan; 4-Heat exchanger

Figure 3 Tunnel dryer

Conveyor dryers

Conveyor dryers are used for drying of cotton, wool and other fibrous materials (peaces with 5 to 7 mm thickness and 20 to 30 mm width - fruits, vegetables, tea, hemp straw, peat, etc.). These driers have continuous principle of work (fig.4), by the use of a chamber, where the drying material is placed and moves on the loading strip. The drying is performed with temperature of the air (or gas) between 70 to 170°C.

Circulation of the drying air is enabled by the use of axial fans. Dried material is collected from the strips in a basket or some other transporting device. These driers are constructed with the line width of 2 to 2.2 m and lengths of 40 m. Negative side is the uneven drying through the height of the layer, which is greatly reduced thanks to mixing when passing from one to another strip. Other negative aspect is the dirtiness coming from the particles passing through the protection screen that falls down on the heat exchanger. Specific heat consumption is $q = 5000$ to 7500 kJ/kg.

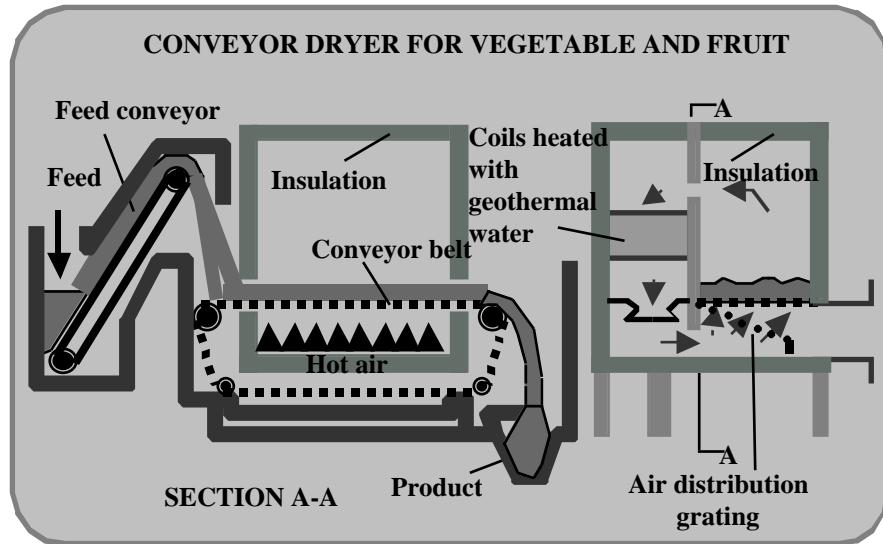


Figure 4 Conveyor dryer for vegetables and fruits

Drum dryers

These types of dryers are suitable for drying of beer and sugar refuse, grains, diary food plants and other materials. Basic part is the horizontal or leaned cylindrical drum (fig.5), with 0.5 to 0.8 turns per minute, enabling moving and mixing the disperse material. The angle of the drum relative to a horizontal line (for gradual moving of the material from one to the other end) is usually 0.5 to 3 degrees. Inside the drum and depending on the material, different kind of compartments are placed that contribute for better drying of the material.

Specific heat consumption $q = 3350-5000 \text{ kJ/kg}$ and electricity for turning and ventilation 5 to 7 kWh/1000 kg.

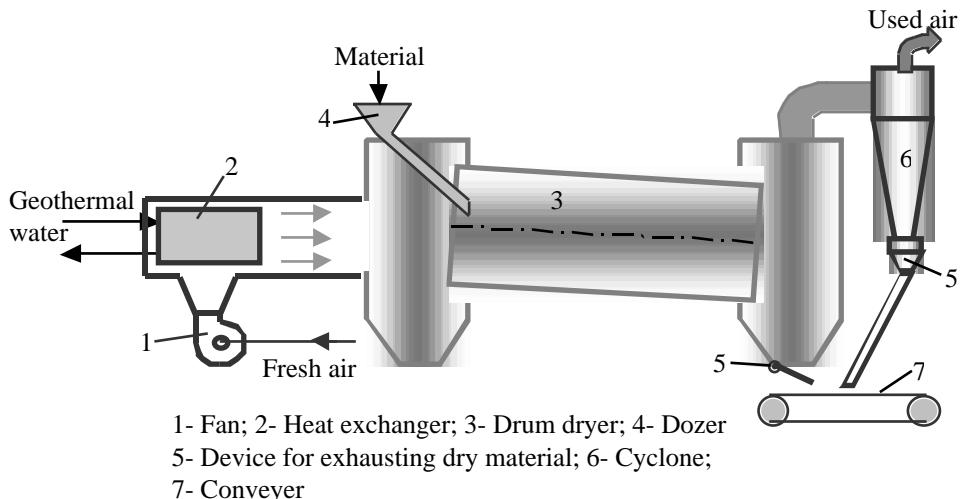


Figure 5 Drum dryer

Pneumatic dryers

Basic part of these dryers is the chamber or tube (fig.6) in which the disperse material is dried during pneumatic transport. Velocity of the air must be higher than the velocity of particles levitation (10 to 20% than levitation velocity of the largest particles) in order to

transport of the particles. It is maintained in the frame of 10 to 40 m/s depending on the particles dimensions. That requires additional electricity consumption.

Principally, the work of pneumatic dryers is continual. They are used for drying grains, chopped dairy food, vegetable leafs, etc. Passing of particles through the tube does not exceed 1 to 2 seconds, and that's why it is possible to evaporate only the superficial moisture which results with moisture content decrease of only for 6 to 10 %. $q = 3800$ to 6700 kJ/kg.

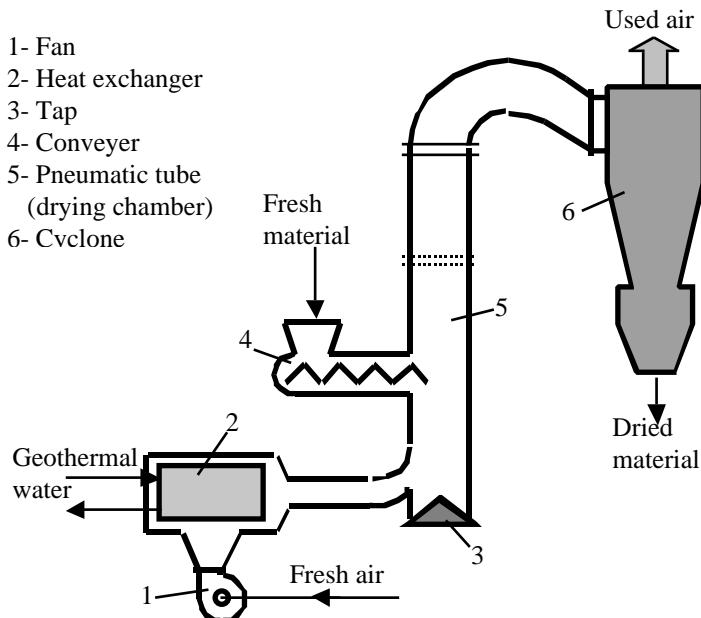


Figure 6 Tube-pneumatic dryer

2. EXAMPLES OF GEOTHERMAL DRYERS

2.1. Geothermal rice-drying unit

The example of the rice-drying unit in Kotchany-Macedonia is one of the few examples in the world of geothermal energy application for drying agricultural products.

Geothermal water comes from Podlog springs and the drying unit belongs to the agricultural combine "Kotchansko pole" in Kotchany.

Main characteristics of the source are:

- Temperature of 75°C ,
- Low content of minerals, and
- Low rate of scaling and absence of corrosion problems.

Characteristics of the rice-drying unit are as follows:

- Production capacity:	10 t/h, rough or milled rice,
- Heating capacity:	1360 kW
- Moisture content of the rice:	inlet 20%, outlet 14%,
- Temperature of the heating air:	35°C
- Out-door conditions:	temp. 35°C , relative humidity 60%
- System of dryer:	cross-flow dryers.

Separate sections of the dryer are:

- Grain feeding been at the top,
- The upper cells of the drying zone are streamed with warm air (warm air duct, heat

- exchanger and fan),
- The lower cells of the drying zone are streamed with cool fresh air (fan blowing outside air through the grains)
- Device for discharging the dried rice, at the bottom.

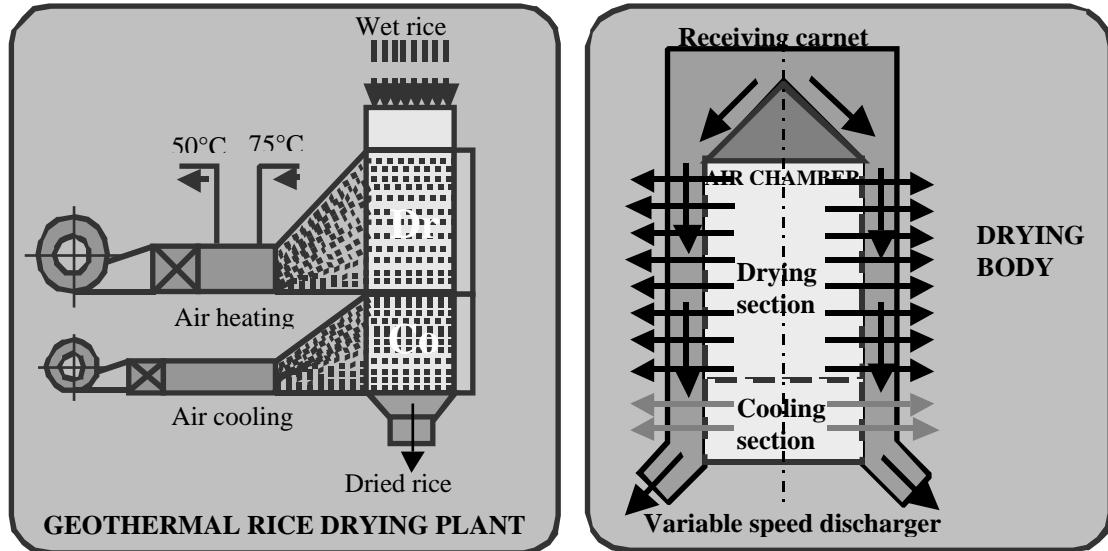


Figure 7

Rice-drying unit in Kotchany

Rice moves downward with an equal velocity at all points of the cross-section. There is gravitational mixing of the grain as the column of the grain moves downward.

Flows of the heating and cooling air are perpendicular to the direction of the grains movement.

Outside air is with forced through the heat exchanger where geothermal water 75/50°C is used as heating fluid.

In order to prevent the cracking of the rice, the temperature of the warm air is automatically controlled to be below 40°C.

Cooling of the grains is necessary after the process of drying has been finished since exposing warm grains at ambient air would cause rapid absorption of moisture.

One of the great advantages of this unit is that requires heat energy in a period of year (summer) when the greenhouses are not heated.

2.2. Tobacco Drying Unit - Using Geothermal Energy (not realized)

The first step in the process of tobacco preparation for industrial production is the primary drying. The traditional way of doing that is to expose the wet fresh tobacco to the natural conditions, actually to solar radiation. Nowadays, modern drying plants with different capacities are used, enabling control of the drying conditions, even quality of the dried tobacco, all independently of the changeable outside conditions.

Maximal allowed temperature of drying air is between 45 to 50°C, so geothermal water with relatively low temperature can be applied.

The mixture of fresh and re-circulated air (after filtration) is heated in a geothermal heat exchanger. The channel fan is discharging the warm air through the chamber end. Part of the used air is discharged through an over pressure dumper, and the remained one is re-circulated.

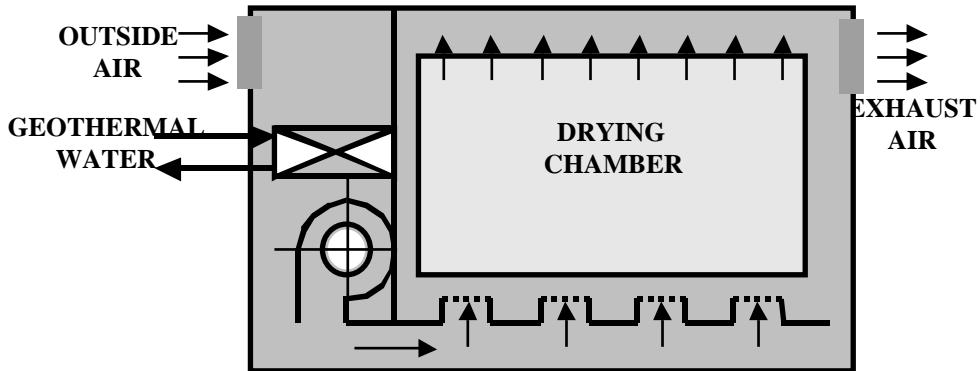


Figure 8 Scheme of small tobacco dryer using geothermal water as heating fluid.

Regulation valve, regulator and temperature sensors maintain temperature of the drying air. The set point of the temperature is adjusted manually during the drying. Relative humidity is maintained by means of humidity sensor and a fresh air damper.

2.3. Geothermal Tomato Drying Unit

Dried tomatoes are a typical food of Mediterranean countries. Traditionally, they are dried in regions with high solar income and intensive winds. Usually, dried tomatoes are prepared in glass jars with olive oil and different spices.

Drying of tomatoes by the solar energy use has a lot of negative consequences, as are the following ones: change of the color, disposition to insects and dust, long duration of the process, etc. These problems can be solved if the drying is performed under controlled conditions, i.e. in driers.

In general, dried tomatoes undergo the following process steps: pre-drying treatments (size selection, washing and placing), drying or dehydration, and post-dehydration treatments (inspection, screening and packaging). Optimal temperatures for drying tomatoes are between 45 and 55°C. Exposing the tomatoes to higher temperatures would cause quality losses regarding color and aroma, and may lead to case hardening-formation of hard outer shell which impends the drying of the interior part of the product.

The example comes from Greece-N. Erasmio, 25 km south of Xanthi. The unit began with operation during the summer of 2001. It uses low cost geothermal water to heat atmospheric air to 55°C in finned tube air heat coils. 4 tones of high quality dried tomatoes have been produced during the first year of operation.

Process of drying begins after the tomatoes passed the pre-treatment and are cut into two halves and placed on the stainless steel trays and charged into the drying chamber. The drying itself is then performed in the tunnel dryer. This drying system consists of the following main components:

- Finned-coil air-water heat exchanger for heating the drying air. Outside air of about 20-35°C enters the heat exchanger and leaves the exchanger at an almost constant temperature of 55°C. The inlet water temperature is 59°C and the outlet 51-53°C. The mean water flow rate used during the first drying period has been about $23 \text{ m}^3/\text{h}$.

- Fan units. Two centrifugal fan units are installed in the system, enabling the warm air to stream around the trays loaded with tomatoes.

- Drying tunnel of 14 m length (width of 1 m and height of 2m), with rectangular shape, constructed of polyurethane aluminum panels. The heated air flows counter-current relative to the trays movement in the tunnel. The tomato-loaded trays are placed at the entry of the tunnel and they are conveyed towards the end (where the hot air enters the tunnel) in a semi-continuous manner: approximately every 45 min a series of 25 trays with dried product are

removed and 25 trays loaded with raw tomatoes are inserted at the entry and push upstream toward the end. About 7 kg of raw tomatoes are placed on each tray.

- Measuring instruments for continuous monitoring of the inlet and outlet temperatures of both air stream and geothermal water.

The final weight of the dried tomatoes is about 10 to 12 times less than in the raw condition. The residence time of the product in the drier has been estimated to be 30 h to achieve the best results.

Dried tomatoes (in the conditions described) appear to retain the color and the aroma.

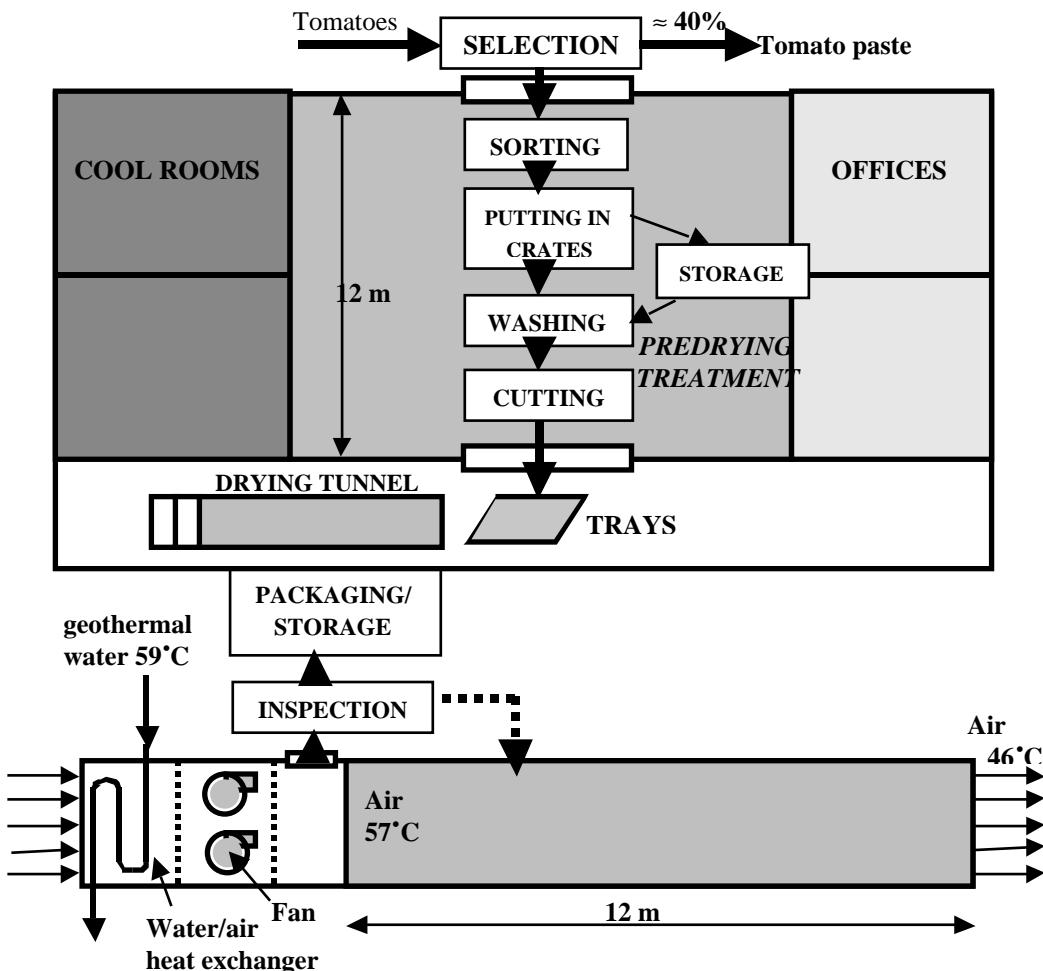


Figure 9 Geothermal tomato-drying unit

2.4. Other reported applications of agricultural drying with geothermal energy

A drying wool plant is installed in China, Gaoyang County. The temperature of the geothermal water in the well is 114°C, with artesian flow of 2160 m³/day. For the drying application geothermal water of 100°C is used to heat the drying air at the desired temperature of 95°C. The installed equipment in the plant consists of a net conveyor belt drier, with capacity of 280 kg/h of dry wool. The reduction of the moisture is from 40% to 15%, relative to wet wool basis. Residual water from the drying plant is used for: greenhouse and district heating (50°C), raw wool washing (50°C), fishponds and geothermal bathing (35°C).

In Guatemala, an agricultural drying plant for drying grains, fruits and vegetables is completed. The installed capacity is 0.500 MWt, with 12.094 TJ/yr annual energy use and 0.787 capacity factor.

CONCLUSIONS

Drying of agricultural products is very convenient for application of low-enthalpy geothermal fluids, as it was shown with the examples and also with the summary of general characteristics of the drying processes. Convenience comes from the fact that it can have positive influence to the heat-loading factor of the geothermal source, which is one of the most important factors of feasible exploitation of the geothermal sources.

In addition to the above said, the use of geothermal energy gives contribution to the environment protection (protection of the reservoir and ambient air), by re-injection and absence of exhausting pollutants to the atmosphere.

Using geothermal resources makes the country more independent from expensive and pollutant fossil fuels, and the investments in this sector gives possibility to develop own energy resources, industry and to open new employments.

Despite the great advantages that geothermal energy offers, such applications are still very limited in the world.

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