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SIZING CONVECTIVE DRYING CHAMBERS DESIGNED TO FRUITS AND VEGETABLES DEHYDRATION

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Abstract: In the recent years, a rapid increase has been noticed from farmers and business men in fruit and vegetables dehydration, requiring dehydrating installations of up to 2-3 tons/charge, rarely being registered demands fot larger machines. Among these requests over two thirds have been asking for machines for up to 400 kg of fresh fruit per charge. Taking into account these requirements, it is recommended to use the convective dryers with trays. The paper presents a method of choosing and calculating the equipment and operating parameters according to productivity, product type, fuel, construction and cost optimization.
Keywords: vegetables, fruits, conditioning, dehydration, capitalization, consumption

1. INTRODUCTION

Fruits and vegetables assure fibers, minerals and vitamins required by the human body. Consumption of fruits and vegetables play an imporatant role in preventing chronic deseases, cardiovascular problems, diabetes type II, dementia and certain types of cancer. These observations have led to recommendations made by World Health Organization according by which, the daily quantity of vegetable products must be of minimum 400g. Besides the vitamins and minerals, fruits and vegetables represent a source of fibers and essential nutrients with benefic effects on health, such as antioxidant and anti-inflammatory substances, which determine fats decrease and have a good influence on blood pressure and endocrine system [9].

Although fruits and vegetables assure a higher level on nutrients, their preservation is required in order to ensure these elements the whole year long. Products preservation by using high temperatures or exposure to oxygen lead to loss in a great part of nutrients, especially vitamins, some of them being destroyed at temperatures beyond 40 degrees Celsius [5]. Preserving these products in fresh state is possible only during a limited period of time[19].

Dehydration is one of the oldest methods of fruits and vegetables preservation. Using dehydration, the product's water content is reduced in order to preserve it, but also for reducing its mass and volume, its package, store and transport cost [4]. In order to dehydrate them, the products shall be selected, cleaned, cut and can be previously treated, for example, by blanching sterilization. By blanching the products, the enzyme reactions are stopped, harmful microorganisms are destroyed and dehydration time is reduced [6]. Sometimes, the products are treated with a sulphur dioxide solution to maintain the colour and reduce the loss of carotene and sorbic acid. In order to preserve nutrients and vitamins, certain cold dehydration technologies have been developed, this equipment being much more expensive and complex than classical convective systems, and as a general rule, this procedure is used in high priced products and phamaceutical industry. After dehydration, the products are packed and stored at temperatures between 10 and 25 Degrees Celsius, depending on their final humidity content and destination.

2. METHODS AND INSTALLATIONS DESIGNED TO DEHYDRATE FRUITS AND VEGETABLES

Dehydration is the process by which the natural water content of a body, is reduced. Dehydration can have multiple aims: food preservation, mass and volume decrease, changing of certain physico-chemical features of products, stopping the development of microorganisms preventing products damages etc. Water is the most abundant element within a fruit or vegetable [14]. Following the dehydration, products have to keep their initial characteristics, such as: taste, colour, nutritive value, vitamins etc. When the products are dehydrated for rehydrating them subsequently, it must taken into account that the moisture content should be small enough for a long-time preservation, but also long enough for a correct rehydration.

Dehydration is an energy intensive process, a great part of energy used in industry being used by this process, varying from country to country, between 15 and 20% out of the total industry's energy consumption [1,2], that is why, choosing the appropriate equipment is an important factor in improving technological processes, reducing pollution and increasing economic throughput.Dehydration can be performed using many types of equipment, each type being optimized for certain products. In the case of small and medium time productions or long-time processes, dryers with discontinous operation are generally used, air pressure convection or vacuum dryers. In case of large factories which require a continous flow of dry matter, it is recommended to use continous operating dryers, where the material is carried within the dryer from inlet to outlet.

In this paper, we shall focus on convective dryers. We have chosen these installations for several reasons, the most important being: small cost of manufacturing, maintenance and servicing, flexiblity in terms of shape, sizes and type of material to be dehydrated; also, they do not require an advanced knowledge for operation and can be supplied with varied sources of energy (gas, wood, solar energy, etc.).

Convective dryers are used to dehydrate fruits, vegetables and plants, honey dessication, meat and fish drying, lumber drying, construction materials drying etc.The most wide-spread dehydration method for fruits and vegetables is the convective one (fig. 1), in which a heat source and an agent for removing water vapors from the body surface, are used.

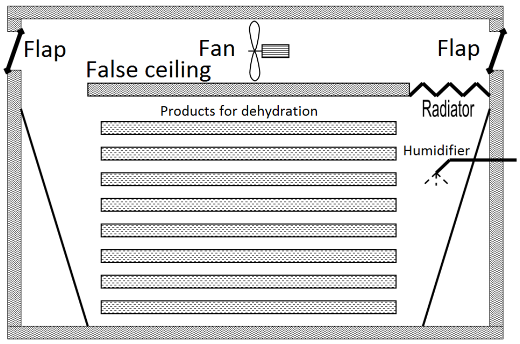

Figure 1 - Convection drying chamber – schematic

3. CHOOSING THE DRYING CHAMBER

The lenght of a process and type of product

The length of process is influenced by many factors, the most important being the type and shape of the product subject to drying and the temperature. When comparing the technical performances of two dehydrating equipments, the time within which the process is performed must be precised for the same product and presentation form of this product, otherwise the comparison is not eloquent. In order to support those mentioned above, we may consider the example of the same product as a whole and sliced, subjected to the drying process. The time span of dehydration of a whole product is longer than the time required for the same sliced product, in both cases being used the same installation and the same drying temperature. In the following tables is presented data regardings for some fruits and vegetables[6, 8, 12, 13] after the dehydrating process.

Table 1. *Parameters of fruits dehydration process*

Den. No.	Name	Duration [h]	Temperature	Final humidity	Density kg/mp
1	Apricots	18…24	45…50 / 55…65	15	4…5 (halves)
2	Cherries and sour cherries	6…10	45…55 / 65…72	6…12	6…8 respectively 8…10
3	Peaches	6…12	55…60	16	5…6
4	Plums	24…30	50…55 / 70…75	22…24	10
5	Grapes	12…20	50…55 / max. 70	13…20	8…10
6	Sliced apples	6…10	50…60 / 70…72	5-12	6
7	Sliced pears	5…9	45…50 / 65…70	10…12	13
8	Sliced quinces	6…8	65…70	22	10
9	Sliced bananas	6…8	70	5-15	4…6
10	Strawberries	5…8	50…60	9-12	7…8

Table 2. *Parameters of vegetables dehydration process*

Den. No.	Name	Duration	Temperature	Final humidity	Density kg/mp
1	Peas	8…10	50…57	5...6 / 15…20	4…5
2	Green beans	8…12	5…65	6…8	(3…5) 6…7
3	Spinach	4…5	55…60	5…6	1…2
4	Spices plants	1…2	55…60	2…5	1.5…2
5	Tomatoes	10…12	60…62	5…8	2…3 (slices of 6mm)
6	Eggplants	6…8	55…62	5…6	5…6
7	Peppers	3…5	62…70	Max. 8	6
8	Onion	3…6	(50) 62	4…6	6…7 (8)
9	Leek	4	55…60	5…8	6…7
10	White and red cabbage, cauliflower	5…6	60-62	6…7	5…6
11	Carrots	3…4	70	6…10	8
12	Celery and parsley	1…3	52…60	3…10	6…7
13	Parsnip	1…2	60…65	4…12	6…7
14	Potatoes	5…8	72…80	6…7 (10…14)	8…9
15	Mushrooms	4-18	50-60…65	<6	1…3
16	Garlic	6…8	55	5	2…4

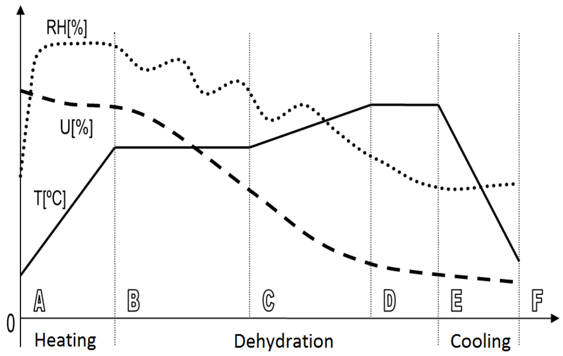

Figure 2 - Dehydrating process stages used in our experiments

A product drying process comprises several stages, each of them containing more steps. The main phases of dehydration are: products heating (A-B), dehydration (B-E) and cooling (E-F). In the dehydrating stage several steps of parameters set can be found.

Drying Calendar

In order to achieve an efficient production, the equipment has to work all year long. But, not always this is possible and, most of the time the equipment must able to dry different types fruits and vegetables depending on ripening period or, at the same time, similar products, but of different varieties, which ripening periods could allow their harvesting and drying. When ripening periods for two fruits are ovelapping, the fruits which cannot be stored without deteriorating, then, shall be dehydrated first.

Energy sources and energy consumption

Energy consumption will represent the main operation cost of a dehydrating equipment. The energy consumption is represented by thermal energy consumption required to heat and vaporize water and the electric energy required to circulate the air and powering the control system.

The equipment which operates convectively, without heat recovering systems, has an efficiency of maximum 50% due to the heat evacuated along with air that contains the humidity taken from the products. By using a heat economizer, the thermal efficiency of a convective dehydrating installation can be increased by up to 30%, but this device can be used only in certain situations, because it involves a periodical cleaning and because its internal structure can be rather complicated.

In the case of a convective dehydrating installation working within the range of 40 – 90 °C, the thermal energy used is about 1.4 kWh/kg of evaporated water [3], taking into account the maximum theoretical efficiency of about 50% of this type of equipment. At the same time, for circulating the air, fans with 1 to 3 kWh power requirements, are used. In order to ensure an optimum transfer of humidity, the air speed must have a velocity situated between 2 and 4 m/s. As an average, for each 100 kg of products is required electrical energy of about 1.5 kWh for air circulation and control system operation.

In the case of a heat pump dehydrating system, the efficiency is similar to that obtained when using a heat recovering system, but it must taken into account that heat pumps mostly operate based on electrical energy, which can be three times more expensive than thermal energy produced by fuels or waste combustion. That is why, a higher drying efficiency does not mean necessarly financial savings. In the case of this equipment, its acquisition, maintenance and servicing are much more expensive than those of a classic equipment. This type of equipment may be used for expensive products or products which are heat sensitive, such as sea buckthorn, that dehydrates at 40 °C, at most, because when surpassing this temperature threshold, the product's characteristics are changed. At the same time, this equipment may be successfully used mostly during the hot period instead of the cold one. This is explained by the fact that during the summer, if the products require a 40 degrees for dehydration and the atmosphere air has 30-35 degrees and a relative humidity of 70-80%, this type of equipment can diminish the air moisture content so that this process appropriately develops, which does not happen in the case of classic dryers. Though, in mountain and hill areas in Romania, most of the time the classic dehydrating installations can be successfully used.For an installation operating with a thermal consumption of 1.4kwh/kg evaporated water, energy requirements for different fuels related to 100 kg of evaporated water, are shown in the following table 3. For the heating station sizing, it has been taken into consideration the shortest drying time among products to be dehydrated and the following equation can used for calculating the minimum amount of power required:

Table 3. Consumption of fuel comparing to 100 kg evaporated water

Den. No.	Fuel type	Energy required for 100 kg of evaporated water
1	Electric	140 kWh
2	Gas (38 MJ/mcN ~ 10 kWh/mcN)	14 mcN
3	Fire wood (1800 kWh/mc ~ 4.2 kWh/kg)	0.08 mc sau 34 kg
4	Pellets (5.3 kWh/kg)	27 kg
5	Chopped wood (4 kWh/kg)	35 kg
6	GPL (25.8 kWh/mc)	5.5 mc
7	Gas oil (11.8 kWh/kg)	12 kg
8	Coal (15…25 MJ/kg ~ 4.1…7 kWh/kg)	34…20 kg
9	Solar (1…1.4 kWh/mp)	14…10 mp panels *

* - it has been calculated for a 10 hour process.

$$P_{min} = \frac{m_{fruits}[kg]\cdot(m_{water\_i}[\%]-m_{water\_f}[\%])}{100}\cdot\frac{1.4[\frac{kwh}{kg}]}{t_{min\_process}[h]}, \qquad (1)$$

where: P_{min} -is the minimum power of the heating station [kw]; m_{fruits} -mass of fruits subject to dehydration [kg]; m_{water_i} -initial water content of the products [%]; m_{water_f} -final water content of the products [%]; $t_{min\_process}$ -minimum time of dehydration required [h].

Productivity

The tray surface on witch the product are placed for drying is dependent of the quantity of fresh or dehydrated products. In the previous tables, the quantities recommended for loading the trays according to product type, are shown. When the same equipment is used for dehydrating several types of products, in different processes (such as-sliced apples and whole plums for example), the less advantageous value will be chosen, namely the apples, because their mass on the same surface is smaller than the plum's, ocupying a larger surface; in this way, the required quantity of apples and also of plums is easily adapted, although for plums the equipment being oversized.

Figure 3 - Loading the drying surfaces (halves of plums and slices of apples)

The hot air in most equipment will circulate along the drying surface and this way the fruits's surface will allow the humidity transfer to air. In case of equipment which circulate the air perpendicularly to the drying surface, the space between products will have to be larger to allow an appropriate circulation and to ensure a sufficient air velocity for all the equipment's drawers.After choosing the products quantity according to surface, the required number of trays can be calculated. As a general rule, in food industry, standardized trays will be used, so that they can be easily handled by operators. Therefore, the most common dimension used in food industry is 600 x 400mm. This tray has a surface of 0.24 m^2.

Construction of drying systems

Thickness and quality of the insulation are the most important characteristics of a dehydrating system. The energy efficiency of the installation depends on these specific elements. An insulation inappropriately built or too thin can determine high losses of heat, which will decrease the installation's efficency. The thicker the installation is and the weaker the thermal bridges between the chamber's internal and external surfaces are, the greater the efficiency becomes. An important care must be taken in case of joints and mobile elements, such as the doors. They have to be endowed with fittings which impede the air to leak out. A good insulation for this type of installation should be made out of mineral wool of 100 mm thickness between twoo sheets. Another solution is represented by "sandwitch" panels, but because their utilization in a moistenvironment, it will be necessary that, at least, the side exposed towards the interior to be manufactured out of an inoxidable material (such as plastic, aluminium or sainless steel).

Figure 4 -Insulation with mineral wool (left) or thermo-insulating panel type (right)

Air ventilation is one of the factors which influences the dehydrating speed. An air velocity of 4m/s on the product's surface it is considered to be enough, for ensuring an optimum dehydration. It should be ideal that, depending on the product type, this speed could be decreased. The use of frequency converters for driving the fans motors can accomplish this task. The fans can be of two types: axial and centrifugal.

Axial fans have the advantage of allowing the reversing of rotation direction, and implicitely, the air's direction. Shifting the air's direction determines a homogenization of producrts humidity and prevents the unequal drying along the installation.Centrifugal fans have the advantage of having the motors placed outside the flow circulated, so that their cooling is not an issue, compared to the axial ones. The disadvantage is the fact that shifting the rotation direction does not change, implicitely the air circulating sense, but leads to a reduced output flow.

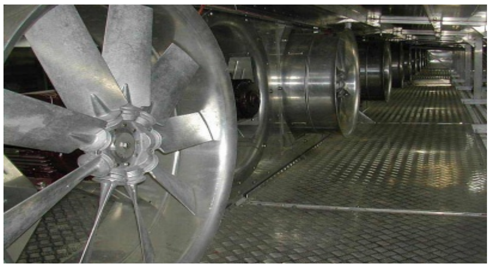

Figure 5 -Axial fans for dryers (Photograph courtesy of Eco High Tech)

The heating system of drying system generally depends on the type of energy used. In case of electrical energy, it can be made out of tubes with electric resistances or radiators with hot water, when electric energy is first converted to thermal energy by heating the water as intermediate medium. When the installation is fitted with heating radiators for hot water, the type of energy can be different, the only requirement being that the existence of a heating station that should heat the water at an appropriate temperature. Generally, the optimum temperature is by 10-15 Celsius degrees greater than the maximum temperature required by process. As a general rule the heating stations, no matter what the fuel is, must be able to produce hot water at 95 Celsius degrees.

The heating system must be fitted with a device for controlling the flow of the fluid flow. In the case of water, it can be an electric valve with 2 or 3 ways. Generally, the valves with 3 ways are used, because it is appropriate to recirculate the non used fluid back to station for reducing the installation's starting time.

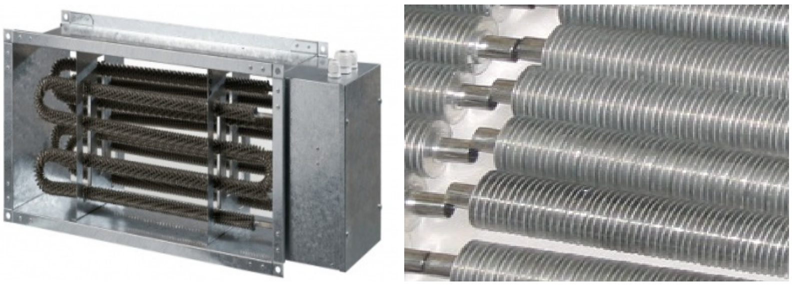

Figure 6 -Set of electric resistances and tubes with extruded blades for water-air heating exchanger (Photograph courtesy of Eco High Tech)

Evacuating the used air must be done so that its energy can be used the most efficiently. Depending on the installation's operation mode, the air is either totally recirculated, or partially recirculated, or it is not at all recirculated.

In the case of total recirculation, monitoring of air's humidity is required for being evacuated and replaced with fresh air when any exchange of vapors between the product's surface and the air stops. In the case of total recirculation, when the air is replaced the temperature inside will diminish.

In the case of partial recirculation, during the whole process, the air is maintained at certain parameters established by the recirculation percent. Within the system, the fresh air is permanently introduced and also the used air is evacuated. Due to the fact that fresh air is permanently introduced, we shall need an energy source able to maintain a steady temperature of the drying fluid.

When the air is not recirculated, there is the risk that in case that the installation is unsuitably sized and built, differences of humidity between fruits exist and the efficency may be very low. This type of dryers can be built based on solar system with direct heating of air, being an "environmental-friendly" alternative, possible to be adopted by anybody which has the required space and does not aim to obtain a large production [10].

The construction of air exhaust system depends on the placement of the system's recirculating fans. There are two methods which are most used: with flaps placed in front and behind the fan, which is often used at dehydrating systems with false ceiling or, by extracting and introducing the air pushed by additional fans. Both methods are valid and are chosen depending on the necessities and possibilities.

Figure 7 -Flaps for air exhaust and motor operator for driving it (Photograph courtesy of Belimo)

Air moistening is sometimes required in case of products sensible to sudden humidity decreas. This system consists in a nozzle which sprays the water into the air for raising its humidity. Water flow is generally controlled by means of an electric valve.

Nowadays, the automation system represents a requirement for raising the efficency and decreasing costs within a more and more competitive market. The automation system consists in 3 main elements: input data, data processing for process control and execution elements.

The input data are values of physical measurements taken by different sensors and converted into information compatible with a computer system. In general, in the case of dehydration systems useful physical quantities are in order of their importance: the air temperature, air relative humidity, product temperature, mass products and airspeed. Using these parameter values, an automation system will make decisions on the process development.

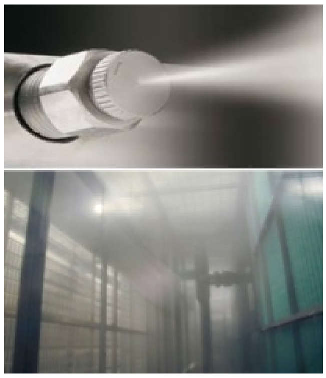

Figure 8 -Nozzle for water spraying (Photograph courtesy of Blue Spark Systems)

Data processing is made by a specialized program that can run on different devices, such as PLC, computers, tablets or microcontrolers. Whatever is the platform used, the program should meet several important functions: temperature and humidity control, time counting and stopping the process under certain conditions.

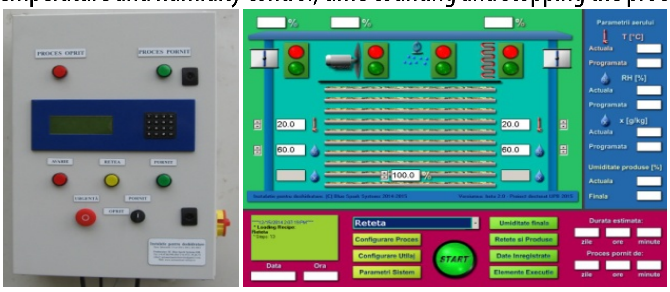

Figure 9 -Automation pannel and graphical interface of PC software (Photograph courtesy of Blue Spark Systems)

Figure 10 - Dehydrating chamber for fruits and vegetables (Photograph courtesy of Blue Spark Systems)

Elements of execution are those presented previously: fans, heating, flaps and humidification. The program which conducts the automation system of a dryer according to input data and logic of dehydrating process will also control these elements.

Materials of which the trays are manufactured must be approved for being used in food industry because they are in direct contact with product.

Materials used in building the chambers must survive in the hot and humide environment where they will operate. The dehydrating chambers's exterior can be made even out of steel sheet protected by paint, instead the internal part, where the surface must be manufactured out of aluminim, inox or alimentary plastic.

4. CONCLUSIONS

Acquisition of a dehydaring equipment must be achieved after a rigurous analysis, as its characteristics influence both the technological flow and the initial costs of this type of business. When establishing the equipment size, we must take into account the quantity of dried or fresh product to be dehydrated. When we take into account the quantity of dry product, the mass of fresh product to be dehydrated should be calculated, in order to be able to calculate the drying surface, the heating station and the rest of elements. After establishing the dehydrating surface, the trays dimensions and their arranging mode will be chosen. The heating station will be chosen depending on the availability of an energy source and required power.

Regardless on the preservation procedure chosen, it is important that the technological process should not stop at this point, but should continue by processing the raw material, packaging it and obtaining high end products which will ensure a high value return and high quality products.

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