SOME EXPERIMENTAL ASPECTS OF PEARS DRYING IN MEDIUM OF INERT GASES USING SHF ENERGY

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Abstract: Fruits like grapes, figs, plums, apricots and peaches have been dried over centuries, and represent an important portion of the worldwide food trade. However, more recently some other fruits have also been dried, like apples, mango, pawpaw, pineapple banana or pears, but not so many people have tried to minimize the oxidation process while drying process. The proposed laboratory installation allows research of the pears drying process in medium of inert gases, which influences the drying period, final products' quality, color and properties. It is possible to use different gases such as: helium (He), argon (Ar), carbon dioxide (CO_2) etc. It is also possible to extract the pears' flavor and use it in different branches of food industry.

Key words: installation, drying, SHF energy, inert gas, pears.

1. INTRODUCTION

The operation of drying has been widely used to preserve food products and fruits in particular, since the reduction of their water content to certain levels inhibits microbial growth and enzymatic modifications. Additionally, food drying presents other advantages like avoiding the need of using expensive cooling systems for preservation, or facilitating transport and storage due to the reduction in size. On the other hand, it allows the diversification of available food products, with different flavors and textures [Hayashi, H., 1989]. The implementation of drying conditions is becoming more sophisticated to reduce drying time and improve product quality. Drying no longer needs to be carried out in a continuous constant process due to the availability of advanced controllers that are capable of tuning the drying parameters, such as air velocity and temperature, to a preset schedule. The use of time-varying drying schemes is in line with real-time optimization of product quality and reduction of total energy consumption via shorter drying time.

The dryer can be considered a reactor since it causes a number of reactions within the food material as water is removed. The reaction rates of quality parameters, such as non-enzymatic browning and vitamin C, are highly temperature dependent. It is, therefore, logical to minimize the degradation of these quality parameters of heat-sensitive food products using lower drying gas temperatures. However, operating with lower gas temperature often lengthens the drying time to reach the desired moisture content. The duration of product exposure to the drying environment is consequently longer. A longer drying may further degrade the product quality. One way to alleviate this bottleneck in quality and drying time is to dry with high gas temperature and lower it once the drying regime enters the falling rate period which is controlled entirely by internal transfer rates [Devahastin, S. et al., 1999]. In thermal dehydration process, the loss of nutrients is inevitable. To reduce these losses, it is necessary to search for different optimal thermal dehydration conditions that produce high product quality. One possibility is through tempering-intermittent drying. From [Pan, Y. K., et al., 1999] we can conclude that the tempering-intermittent drying of carrot has shown promising results in terms of product quality and drying rate. In their study, they found that during the tempering process, the moisture from the center of the material is redistributed to the surface. After tempering, it can be dried further to the desired moisture content. Thus, the high temperature of the material is avoided and the energy consumption is reduced.

2. GENERAL INFORMATION

The main goal of drying is the effective removal of water from the wet solid but during the drying process also quality, economic and environmental aspects must be taken into consideration.

To obtain high quality products various criteria must be fulfilled that is e.g. vitamin, protein, aromatic contents, minerals, colour, biological activity, texture, etc. characteristic of the wet material should be preserved during the drying. In addition to this, quality requirements depending on the employment (such as e.g. the particle size distribution, the rehydration capacity, final moisture content, storing possibilities, etc.) are also very important.

The most commonly used methods of agro-food processing in inert gases, meanly thermal treatment, is anoxianabioza - the use of inert gases (carbon dioxide or nitrogen) as bio inhibit agents, which consists in special conditions' creation (low temperature, partial dehydration, osmotic pressure increase, etc..), which reduces so vital body processes and the factors of deterioration (pests, microorganisms, parasites, etc.).

Typically, inert gases are used in various sizes and configurations products' storage. Drying in medium of inert gas is less studied and used, that is why it causes a particular interest.

Pears, like other plants, have numerous beneficial elements for human body. Besides water, fiber, lipids and chlorophyll, these fruits contain important components for human's health: mineral salts, calcium, phosphorus, potassium, iron and vitamins A, B and C. This series of substances is complemented by the presence of sucrose, which make them easier to be digested by people with digestive system diseases and for diabetes. Therefore, a more qualitative pears' drying is very important, the ultimate goal being to obtain a high quality, preserving both color and flavor, and chemical composition.

The preservation of foods by means of drying has some advantages over other preserving methods, namely by reducing storage and transportation costs, by preventing the spoiling due to microbes and by enhancing the development of appreciated textures, flavours and colours.

One of effective methods to increase the duration of plant products' storage is their dehydration. These products are characterized by high moisture content (± 80%) and soft tissue structure. In order to reduce the moisture content they are subjected to thermal treatment processes, using different techniques, the most common being solar convective drying, convective drying, microwave drying (MW) and the use of infrared rays (IR).

Drying of fruits allows its preservation by reduction of its water content, inhibiting microbial growth and enzymatic modifications. Some important advantages of drying of some food products are namely the reduction of their size and weight, which facilitates transportation and reduces storage space, and more importantly, avoids the need of using expensive cooling systems for preservation. Finally, it increases food diversity allowing alternatives to the consumption of the food products in fresh and improving quality of life in rural areas [Martins, M. A. G., 1988].

The solar drying has been used for centuries, but it is restricted to countries with tropical or semi-tropical climates, with a high solar incidence on the areas around the Mediterranean Sea. In ideal conditions, and in spite of slow drying process and the need of much handwork, this is undoubtedly the cheapest of drying methods. However, it has some important disadvantages, like the dependence on natural factors that cannot be controlled as well as the need of great exposure areas [Sousa, I., et al, 1992].

In our view, the most advantageous method of drying is electromagnetic field (microwave) which has a number of advantages over others, namely:

-Processing speed is enhanced;

-Uniform heating throughout the product;

-Dawn turned to outside temperature gradient favoring productive mass transfer in product temperature gradient is caused by loss of heat from a hot product to the less hot or even cold environment;

-High precision control of the drying process by providing the necessary heat quantity at desired temperature;

-Low inertia of thermal treatment process.

Microwave drying is an efficient alternative to the conventional drying processes because the internal generation of heat does not depend on the thermal conductivity of the material. The advantages offered by the microwave include fast operation, energy safety and accurate control of the process. Water contributes to the increase in the volume of dielectric components of most foods, especially fruits with high water content. These products are receptive to microwave applications and absorb microwave energy quickly and efficiently. The application of microwave offers, therefore, a different advantage: the absorption of energy proportional to the residual water content. For the same material with the same moisture content, microwave drying time is shorter than the drying time in forced convection. With the increase of microwave power, the drying time is reduced. The shorter microwave drying time is easily explained by the additional energy supplied to the system by the fast heat penetration and the forced expulsion of the gases. Many studies have been made combining the microwave with conventional processes in the drying of different products. Several authors affirm that this technique reduces the drying time significantly and improves the product quality compared to the conventional processes. A recent innovation is the combination of techniques, convective and microwave, where the heating is induced simultaneously by both actions. The microwaves penetrate the material to promote internal heating, while convection is responsible for surface heating. This represents an obvious advantage with respect to the conventional convective process, where the necessity for a driving force from the outer to the inner parts of the sample generates an energy flux, which usually leads to extremely high temperatures at the surface of the sample, and in turn leads to the deterioration of the quality of the product.

3. MATHERIALS AND METHODS

In order to investigate the influence of inert gas on pears microwave drying process, it was proposed the development of a microwave drying laboratory installation with inert gas and recirculation.

The installation was elaborated in laboratory conditions, with admissible errors.

Below there is presented the laboratory installations work principle scheme (fig.1, 2):

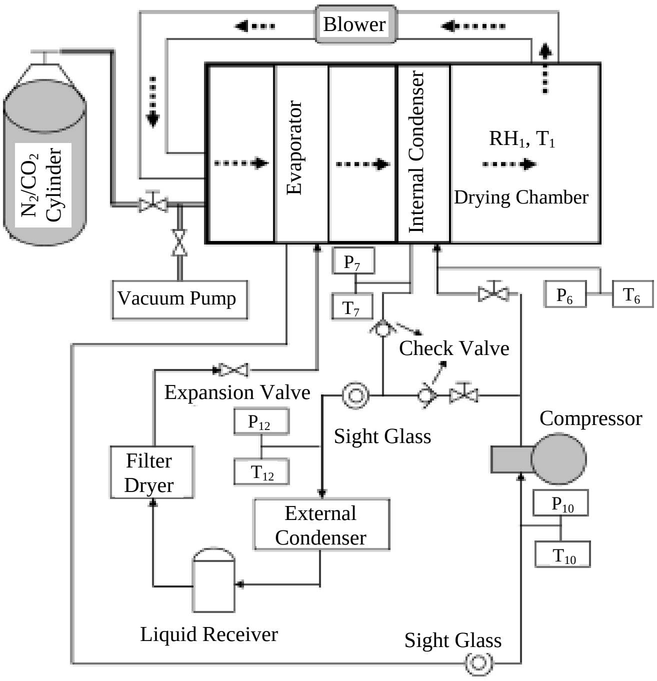

Fig. 1. Principle scheme of the installation of inert gas drying with recirculation

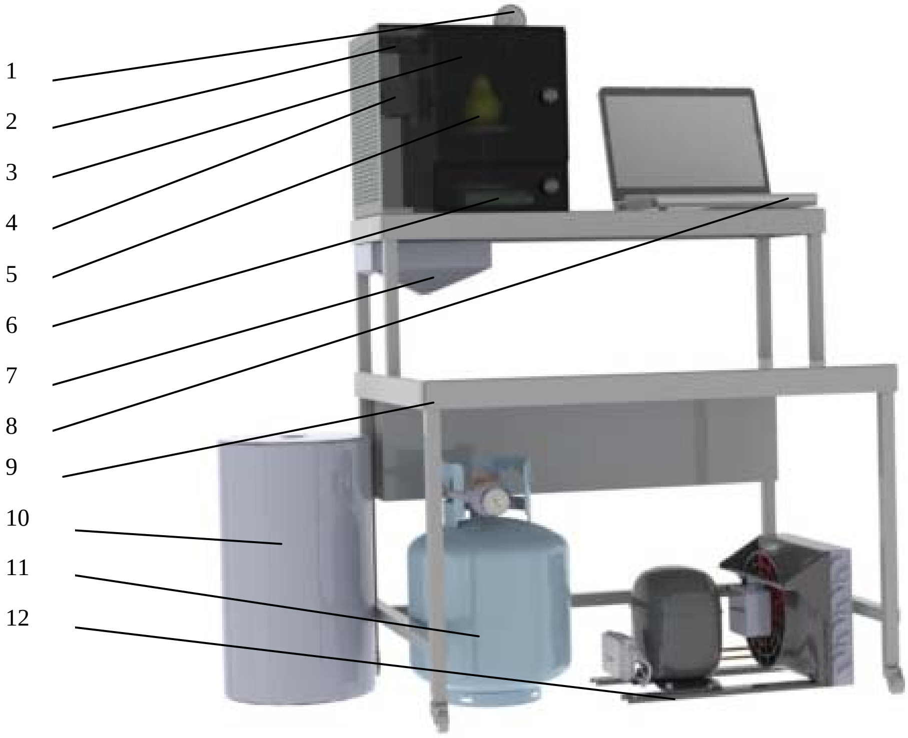

Fig. 2. Laboratory installation for studying pears' microwave drying process in medium of inert gas
1 – manometer, 2 – fan, 3 – drying chamber, 4 – magnetron, 5 – pear,
6 –electronic scales, 7 – condenser, 8 – computer, 9 – work table, 10 – tank,
11 – inert gas reservoir, 12 - compressor

On the desk 9, it was mounted the drying chamber 3, electronic scales with product support 6, product 5, the magnetron 4 and its cooling fan 2. Test data is processed and viewed by computer 8. Inert gas enters the chamber from tank 11.

In order to minimize the loss of gas, it was decided to perform a recirculation system consisting of compressor 12 and condenser 7. Hot air with inert gas, is discharged from the drying chamber 3, gets into the condenser 7, where occurs the process of flavor and juice condensation, stored in tank 10. Through compressor 12, the gas is sent back to the drying chamber 3, being heated preventive. Manometer 1 serves to regulate the pressure in the drying chamber. Since the leak of the chamber is too hard to be achieved in laboratory conditions, it was decided to create an excess of pressure, so preventing the passage of air, leading to the oxidation of dried product.

During experiments there were obtained the following results:

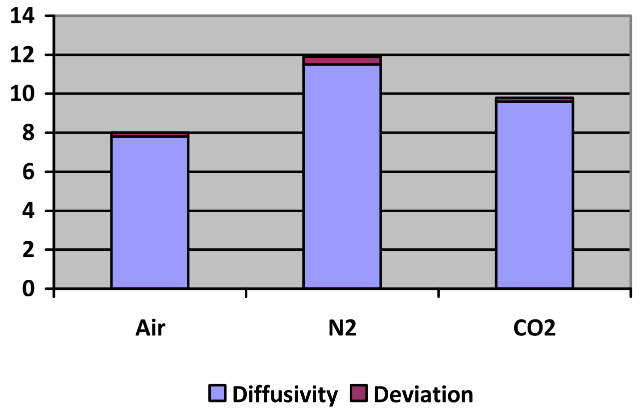

Fig. 3. Comparison of different gases diffusivity

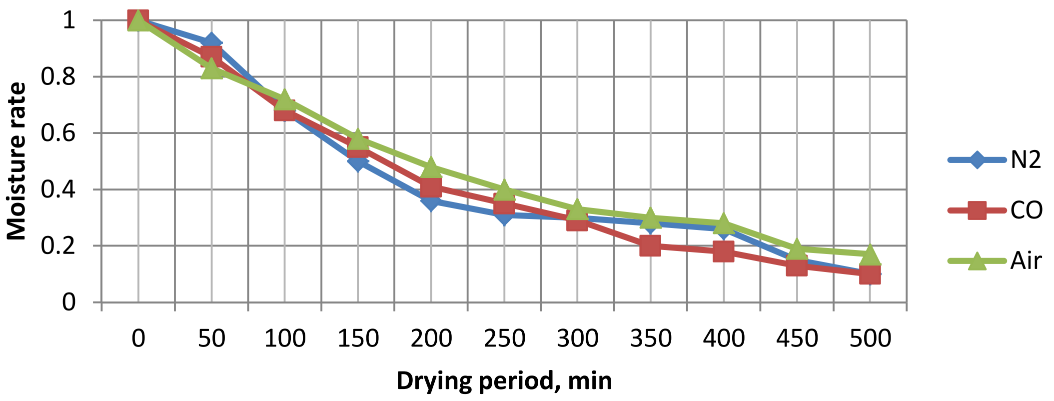

Fig. 4. Effect of inert gas on pears’ drying

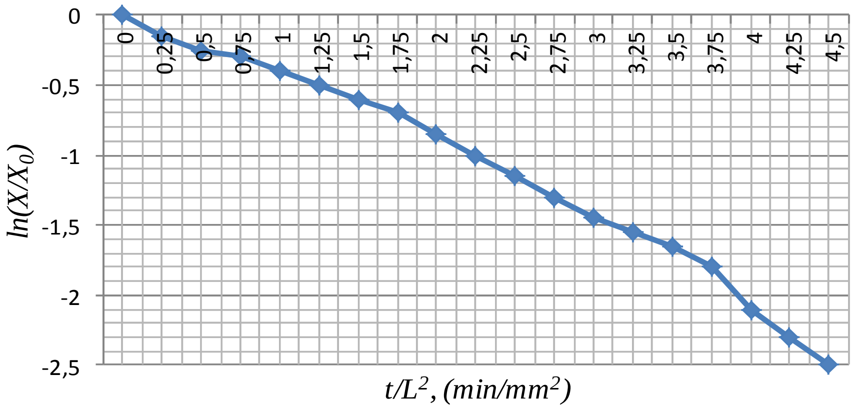

Fig. 5. Variation of *ln(MR)* over t/L^2

In many cases, the chemical reactions that occur in fruits while drying them, are stimulated by various inorganic catalysts (Fe, Cu, Zn), even in smaller quantities than the permissible dose. High temperature causes increased oxidation chemical reactions, corrosion, acid hydrolysis, condensation. The processes of acid hydrolysis of sugars, lipids and proteins takes place under the action of acids and are favored by increasing temperature. Under the action of light rays and oxygen from the air, there take place photochemical reactions that lead to the destruction of valuable products items (destruction of vitamins), affecting its appearance (by changing color) and total degradation. The undesirable phenomena are also characteristic for microwave heat treatment, even if it occurs in a reduced period of time. In order to eliminate these short comings it is proposed to carry out the drying process using microwave power in medium of inert gas, which would exclude product's contact with oxygen during the stage of drying, while achieving the most advanced temperatures.

In thermal treatment processes nitrogen is used most often, which is quite expensive, requiring construction of various closed recirculating systems, leading to the need to create sophisticated and relatively expensive equipment. When using CO2, it can be used a semi-closed system, some gas and moisture extracted from the product being repressed in the atmosphere [Kudra, T., et al., 2006].

CO2 drying advantages compared with N2 drying are the following:

- CO2 is much cheaper compared with N2 (about 10 times), is widely used in alcoholic and soft beverages and does not require the mandatory use of sealed systems;
- CO2 has higher density, providing a less volumetric flow rate at the same heat capacity;
- CO2 requires additional expenses' reduction.

In the literature [Mujumdar, A. S., et al., 1995], generalized drying curves have a constant region and the region in the fall. If we consider only radial diffusion, neglecting the effect of temperature and total pressure, the moisture transfer during the drying process can be described using Fick's second law.

4. MATHEMATICAL METHOD

The main objective of any drying process is to produce a dried product of desired quality at minimum cost and maximum throughput, and to optimize these factors consistently. Often good quality of a biological product implies that the dried product undergoes to several, physical, chemical or biological changes to yield a product of desired specifications. Drying is a notoriously energy intensive operation that easily accounts for up to 15% of all industrial energy usage, often with relatively low thermal efficiency in the range of 25% to 50%. Thus, in order to reduce energy consumption per unit of product moisture, it is necessary to examine different methodologies to improve the energy efficiency of the drying equipment. One possible method is to apply time-dependent drying schemes to reduce the drying time to obtain desired product moisture content.

We admit that we have a product of thickness L, which is dried on both sides and the initial conditions are:

$$t = 0; 0 \le x \le L; M(t) = M_0$$
$$t > 0; x = 0; M_t = M_{eq}$$

where t is the drying time (s, min);
L – product layer's thickness (mm);
M – moisture, %.

In the absence of external resistances, we obtain the following solution [Rao, M. A., et al.]:

$$MR = \left(\frac{M(t) - M_{eq}}{M_0 - M_{eq}} \right) = = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left[-(2n-1)^2 \pi^2 \frac{D_t}{L^2} \right] \tag{1}$$

$$\ln(MR) = \ln\left(\frac{M(t) - M_{eq}}{M_0 M_{eq}} \right) = \ln\left(\frac{8}{\pi^2} \right) - \left(D \frac{\pi^3 t}{L^2} \right) \tag{2}$$

Another widely used equation is Page's equation:

$$MR = \frac{X(t) - X_{eq}}{X_0 - X_{eq}} = \exp(-Kt^B) \tag{3}$$

where:
K is the drying constant;
B – Page's parameter;
K – Lewis' parameter;
t – drying processes duration (s);
D – effective diffusion and MR – moisture ratio.

$$\ln[-\ln(MR)] = \ln K + B \ln(t) \tag{4}$$

5. PEAR GEOMETRY

Drying of fruits allows its preservation by reduction of its water content, inhibiting microbial growth and enzymatic modifications. Some important advantages of drying of some food products are namely the reduction of their size and weight, which facilitates transportation and reduces storage space, and more importantly, avoids the need of using expensive cooling systems for preservation. Finally, it increases food diversity allowing alternatives to the consumption of the food products in fresh and improving quality of life in rural areas. [Guine, R.P.F., et al., 2003]. When studying the physical properties of food products, particularly fruits, it is crucial to have good estimations for variables such as shape, size, and volume. Methods to determine these properties, based on the longitudinal and cross sections of the fruits, have been developed, and the results compiled in the form of charts for apples, peaches, and potatoes. In some cases, however, the shape of the products can be approximated to known geometric forms, facilitating the calculation of their surface area and volume. [Raquel, P. F., et al., 2006]:

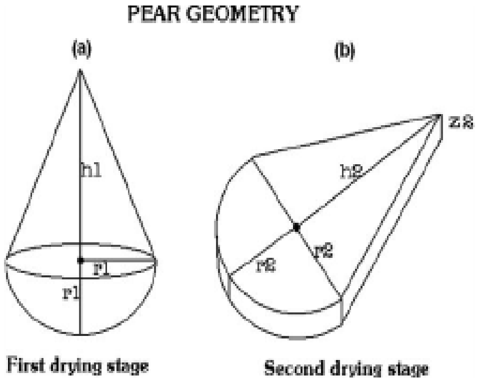

Fig. 6. Approximation of the form of the pears to know geometric shapes

-First stage:

$$\text{Volume}=\frac{1}{2}\text{Volume}_{\text{sphere}}+\text{Volume}_{\text{cone}} \qquad (5)$$

$$V_1=\frac{1}{2}\left(\frac{4}{3}\pi r_1^3\right)+\frac{1}{3}\pi r_1^2 h_1=\frac{\pi}{3}r_1^2(2r_1+h_1) \qquad (6)$$

and

$$\text{Surface area}=\frac{1}{2}area_{sphere}+ \\ +area_{cone}-area_{\text{base of cone}} \qquad (7)$$

$$A_1=\frac{1}{2}\pi r_1^2+\pi r_1\left(\sqrt{r_1^2+h_1^2}+r_1\right)-\pi r_1^2 \qquad (8)$$

-Second stage:

$$\text{Volume}-\left(\frac{1}{2}\text{Area}_{\text{circumerince}}+\text{Area}_{\text{triangle}}\right)\cdot \\ \cdot\text{Thickness}_{\text{perimeter}} \qquad (9)$$

$$V_2=\left(\frac{\pi r_2^2}{2}+\frac{2r_2h_2}{2}\right)z_2=\left(\frac{\pi r_2^2}{2}+r_2h_2\right)z_2 \qquad (10)$$

and

$$\text{Surface area}=2\text{Area}_{\text{base}}+\text{Perimeter}\cdot\text{Thickness} \quad (11)$$

$$A_2=2\left(\frac{\pi r_2^2}{2}+r_2h_2\right)+z_2\left(\frac{1}{2}2\pi r_2+2\sqrt{r_2^2+h_2^2}\right) \quad (12)$$

6. CONCLUSIONS

Based on the analysis of the results presented it was possible to reach the following conclusions:

- The equipment adaptation showed efficient and satisfactory operation;
- The drying rate increased with the microwave power level;
- Pears' drying using microwave power input in medium of inert gases reduces drying duration, energy consumption and chemical effects of products' oxidation;
- It can be also used another system of recirculation, but the used one is good and can be implemented on an industrial scale.

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