Microwave versus Radiofrequency in drying dielectric materials

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Abstract ***– The method of drying by microwaves and the method using the radiofrequency can be compared from the point of view of their quality and efficiency, in view of facilitating the choice of drying method used.***

Keywords: ***Microwave, radiofrequency, drying***

I. INTRODUCTION

The two characteristics of the two frequency areas for the dielectric heating that make it particularly attractive , as a drying means belong to the volumetric nature of heating and the selectivity of water heating in the presence of some materials that represent the base / bearer. The first allows an increased rate of heat transfer, compared to the conventional methods of heating through radiation, direction and convection, which can only heat the product's surface.

The main reason for which the dielectric heating was not accepted in a broader area within the drying industry is an economical one [1]. Both capital and bearing operational costs can normally be justified for products with a relatively high value with modest raw materials. However, there also are the technical reasons, especially the nature of solid structure that could determine the fact that the increased rate on which the heating can be introduced would not fit the structure's ability to allow the steams to pass through it without causing any damage.

The University of Oradea, has developed, both microwave and radiofrequency applications[4].

II. DRYING OPERATIONS

Drying by Microwaves

Once the mechanical water discharge is fulfilled, the drying can take place at any temperature and it relays on the existence of a steam pressure difference between the wet body and the surrounding gas, obviously the air. In many industrial drying operations, the driving force is achieved by raising the temperature of the body that needs to evaporate the liquid water also by blowing hot air over the exterior surface.

The facility of water moving in the liquid phase depends on the material's structure. In time, in the capillary porous materials there is a natural redistribution within the body as the surface water evaporates. However, many materials have structures in which the size of pores is much too high or discontinued to allow this operation; in other materials, the water is stored in a matrix that does no allow the movement of the liquid.

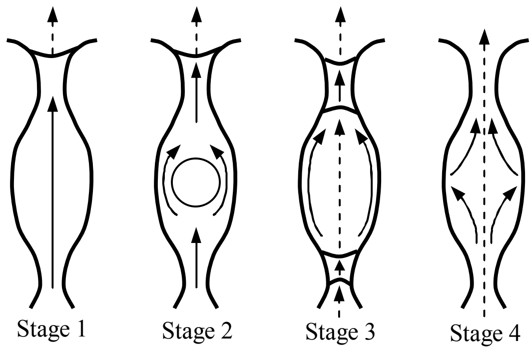
The material can keep water in various ways, both intra and intercellular. In these materials, the intercellular water can move easily and thus it is known as "free water" while intracellular it is less free and often known as "bound water". The free and free bound water can be normally discharged through evaporation at, or almost at the boiling point, while the bound water requires higher temperatures, of some hundred degrees , to break the connections , as well as in the burning procedure.

In the drying procedure, we are normally interested only in the unbound water and subsequently a factor that needs to be taken into consideration is the hygroscopic property of the material[2]. It is more advantageous / convenient to take into consideration the material with the size of pores higher than 0.1μm separated from the materials with the size of pores under 0.1μm

If a liquid is continuously distributed through the pores of a material with pores higher than the 0.1 μm radius is called "the funicular state", and the liquid's state of movement towards an exterior surface can take place if the pores are not too rough. As the movement of humidity progresses, under the influence of surface evaporation, the continuity of liquid in the pores in interrupted, displaying humid isolated cavities and the capillary flow is possible only at a local level. Under these conditions, the liquid is in the "pendular state".

In these states, the humidity will exercise its entire steam pressure, which is a function proper only to the temperature of a solid object, and the material is called non hygroscopic.

As the material reaches the total drying, typically less than 1% of humidity molecules are maintained as a monomolecular layer on the pores wall and the body will have hygroscopic properties. The different states are illustrated in Figure 1.



1-2 Funicular water movement phase
3 Pendular condensing and evaporation
4 Steam movement in the monomolecular layer

Fig.1. Phases of drying

In the materials having the size of pores lower than 0.1 µm radius, the area of internal surface can be large. Over the area of the humidity content typical for these materials, the humidity can be stores by/on the pores walls like a thick film of only a few molecules. In materials like the ones where the solid and liquid are in interaction, for example, by connecting the hydrogen, the liquid does not exercise its entire vaporising pressure[2]. These materials are called hygroscopic. It is possible to further classify the materials as poorly, moderately or strongly hygroscopic. In addition to the latent heating of evaporation, energy must be still applied in order to discharge the bound water. The method in which the water is stored and the nature of capillaries or pores leads to the characteristic drying curves of material, as indicated in Figure 2.

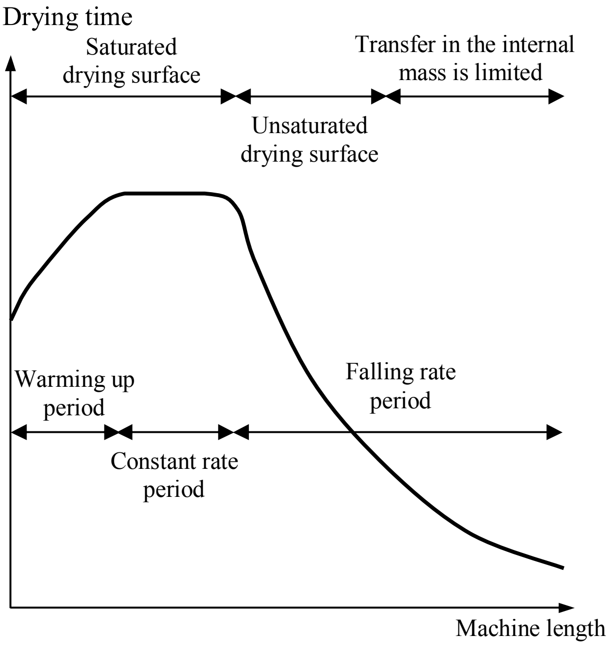
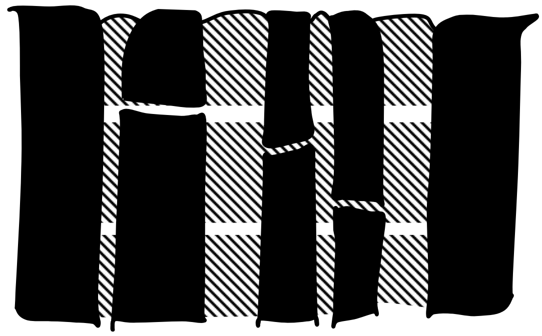


Fig.2. Typical drying curve

Typically, when a wet uniform material is placed in a drying environment, the water freely evaporates from the surface, at an equal rate per the time unit, the machine's length or the energy applied, being known as the period of constant drying rate. Provided that the loss of water at surface could be replaced by liquid's phase of internal movement, this evaporation at the physical surface will continue.

However, in certain stages from the drying process, it will cease, and the drying will take place on a wet retracting surface or on a surface effectively reduced. The first means that an increasing exterior thick dry layer is formed, which represents a thermal insulator through which the heat must be led to cause other /further evaporation [5].

The later results from the fact that the largest capillaries cease to carry water to surface and these capillaries will be dried by the smaller ones, according to Figure 3, subsequently only a part of the available surface for evaporation, and the rate decreases.



Constant rate of drying when all the capillaries are active. High evaporation surface.

Rate of drying when only the small capillaries are active. Reduced evaporation surface.

Fig.3. Rate of drying, according to the width of capillaries

This stage, known as the period of decreasing rate, can be extended and will progressively worsen as the dry exterior layer increases in width. The increase in time, length of mechanism and energy per evaporation unit is a clear indication regarding the decrease of efficient usage and the lack of results concerning the basic equipment [2].

The transition between the constant and the decreasing rate us often gradual, and for some materials, we can argue that there is no constant rate in the strict sense. Typical for these materials are the textiles under the form of packages where the highly opened structure of fibres and their extraordinary thermal properties mean that the driest layer is established very fast.

A fundamental aspect regarding the conventional heat transfer is that the temperature and humidity gradients have opposite signs, the highest temperature is registered at the surface, and the humidity in the lowest point [1].

Using the conventional heat transfer for drying a capillary porous body at the atmospheric pressure, the internal movement of humidity is due to the flow of liquid through the capillary action and the flow of steam through molecular diffusion. The phase of liquid movement is connected to the gradient by the humidity and temperature, while the phase of vaporization is due to a partial pressure or temperature gradient.

The main attraction of dielectric heating results from the fact that water, as selective and volumetric technique, in most of the circumstances is directly heated, regardless the place and means of dispersion in a body. Thus, the substrate's thermal conductivity is no longer a limitative factor of the rate where the heat can be introduced in its humid areas, and since this form of heating does not depend on the transfer through a surface, we can achieve significant improvements in the heating and drying rates by the massive elimination of temperature and humidity gradients and subsequently, in most of the cases, improving the quality of product [3].

The mechanism of dielectric heating is sometimes explained to a laic/non-specialized individual with reference to the polar nature of water molecules, which react to the high frequency electrical fields and compared to the non-polar molecules of the substratum / base can only be indirectly heated from the hot water.

However, this is an incorrect view and it can lead to difficulties when we consider various frequencies for a certain application. Obviously, at microwaves frequencies, the dipoles highly contribute to the heating mechanism, while the lower radiofrequencies are dominating the ionic conductivity. If perfectly pure, deionised water is placed into a radiofrequency field, there will be no heating or a reduced heating.

However, since in any industrial process the water used will present some ionic species, this is not usually a condition. Thus, taking into consideration the relative values of dipoles components and the ionic conductivity there is, at least potentially, a way of determining if a process is better approached through one or another frequency band, despite the fact that in most of the cases there is the possibility that no one will be used [2].

In the relationship regarding the heat transfer, the power transferred to a body P is given by:

$$- P = 2 \Pi \ f \ \varepsilon_O \varepsilon_R \ E^2 \ [\text{watts} / m^3]$$

where f is the supply frequency in MHz

E is the power of electrical field in volts/meters

ε_R is the relative permittivity or the "loss factor"

ε_O is the permittivity /dielectric constant of free space

Transferred it is possibly to chose a frequency from the bands available, which would establish a value for E for a given loss factor. If the loss factor is very low, it is recommended to use a higher frequency (microwaves) in order to prevent E to exceed a level where an electric discharge or a thunder would take place.

The most important term from the expression for the absorption of volumetric power is the loss factor, a parameter with no dimension determined by the electrical properties of the material . The value of this loss factor decides whether the dielectric methods are feasible, it dictates the frequencies that can be used and it establishes the superior limit of the power absorbed.

There is a direct relationship between the humidity content and the loss factor of a material, according to Figure 4. The research was made in our laboratories from the University Oradea.

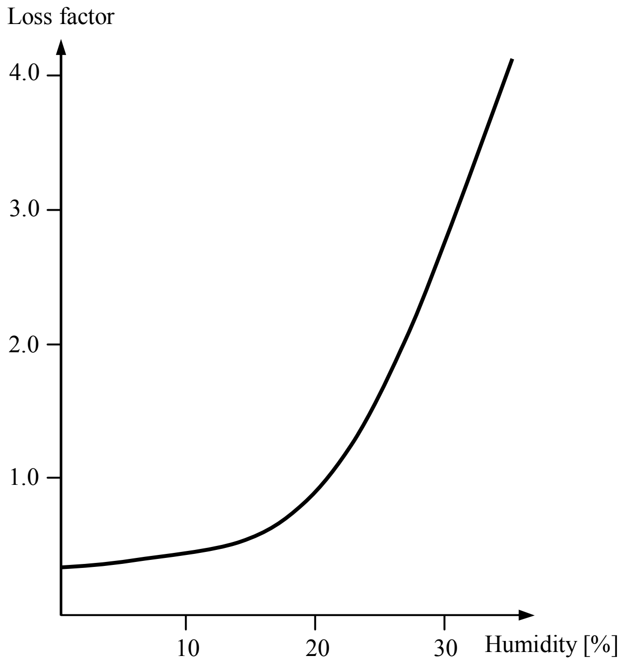


Fig.4. The loss factor for paper at 27.12 MHz

It can be also shown that the loss factor increases with the ascending temperature and as drying takes place at high temperatures, this can be perceived as important [3]. Nevertheless, once the temperature rises, the water is lost through evaporation and there is an auto-limiting control.

This is the reason for which the RF is so efficient for correcting the humidity's profile.

The main usage and interest source in terms of microwave heating was the food. An example would be the transformation of a solid product into a liquid one through microwave heating. Butter melting is a good example. For instance, in order to prepare meat, the microwaves, at about 896 MHz, rise the temperature from -18° C to -4° C. While melting, the butter goes from -14° C to +2° C in 5 minutes.

There are some examples of drying through microwaves, but they are not significant. An exception from this rule is the drying of pastures, where microwaves are used. This method uses the effect of microwaves and air humidity volumetric heating in order to prevent their cracking [1].

The result was a reduction of drying time of 8 hours for one hour. The advantages of boiling to a reduced pressure are visible for the materials destroyed or decomposing at temperatures of 40°C or even 15°C. This technique was used in the conventional heating for many years, but it is very slow due to the fact that there is no convection into an empty oven and the only mechanism for transferring the heat is through conduction.

Drying by Radiofrequency

There are certain opinions of some unspecialized individuals, according to which due to the reaction of a dipole to microwave frequencies compared to radiofrequencies, the higher will be preferred in water heating or even drying operations[5].

In the simple relationship of power equation, the highest values of frequencies associated with microwaves are advantageous when a system choice is performed. In reality, as it was already proved, the loss factor RF is does not depend on the dipole, but on the ionic conductivity of water into a sublayer. These include capital costs and a compatibility line.

In general terms, it is easy to create and cheaper build a piece of equipment for the radiofrequency. For microwaves we must considerate in the first place the electrical engineering of the equipment with microwaves. The shape and dimensions are important, but complex arrangements from a continuous are needed in order to allow the product to be introduced and removed from the appliance without causing too much energy losses.

Microwaves are shorter than the radiofrequencies, namely 13 cm to 2.45 GHz compared to 11.2 m to 27.12 MHz. On the radiofrequencies, the design of input and output ports , as well as the buffers is more simple and can be executed from various materials, from the thickest to large three-dimensional objects.

An analysis of dielectric dryers will reveal that the radiofrequency dominates the market. Microwaves will be used only in special cases. For example, as the power of the electrical field necessary to heat the microwaves is lower than the radiofrequency, the risk of an electric discharge is eliminated, subsequently the microwaves are used in the pharmaceutical industry or in other specialized industries that require drying at temperatures less than 100^0 in void space [3].

It was demonstrated [1] that the variation of content losses for a certain material is higher at the radiofrequency than in the microwaves.

As a number of plants, the largest usage of radiofrequency is for PVC welding, in industrial products, pneumatic rescue boards, engines and paper articles [3]. However, the fastest growth is within the drying industrial field. There are several drying processes, and the dielectric heating processes are used with a technical and economical justification.

Biscuit drying is a classical example for the usage of radiofrequencies. The baking process begins by forming a dough, placed on a metal band and conveyed through a mineral fuel into a 100 m hot oven. During the passage through the oven, several processes take place, like flavouring, shaping. These processes assume the loss of humidity [5].

Drying is executed though the collection of wet part in a narrow portion, which will be subsequently redistributed. This is essentially for keeping the quality of product. The usage of radiofrequencies in the drying process improves the quality of product. Radiofrequencies reduce the excess of humidity, making it uniform. This standardization of product considerably increases its quality. The products than can benefit from this operation are crispy cookies, biscuits and toast.

With the increase in quality demands, textile producers used drying through radiofrequencies more and more often. By their nature, radiofrequencies limit the product's temperature to 100° C or even less, because the evaporation takes place at the temperature of the humid protected thermometer.

Textile drying is usually associated with dying or other treatments. Since there are so many dying methods, drying must be performed in different forms. From dismounted fibres to strains. Radiofrequencies can be used in all stages. The arguments for using the radiofrequencies in drying the textiles are important [3]. It was demonstrated that the high temperature associated with conventional drying causes the deterioration of fibres. Drying by radiofrequency does not deteriorate the fibre. Subsequently, for an adequate quality of products it is recommended to use this method. Fast drying with less material manoeuvres also represents an advantage. Since the fibres are different, they retain water in a different way, the conveyance capacity of a certain dryer depends on the type of fibres being handled. Thus it is justified the usage of radiofrequencies for drying the fibres, it is easier for fibres that do not retain water and more difficult for fibres as wool and even difficult for materials with a strong water retention, as viscose silk. The specialized application, as drying the ready-to-wear products or the laundry, proved to be efficient [3].

There are two aspects of paper industry for which drying by radiofrequency can be advantageous. For the fabrication of paper, it was demonstrated that radiofrequencies are an efficient means of correcting the unequal humidity of paper. These were installed on paper machines, with the purpose retracting the humidity and make the paper uniform.

This technique became quite difficult to be justified, due to the fact that IR emitters became sophisticated, and the control of computer over the paper machine allowed the assembly of some cheaper IR systems.

It was demonstrated that in terms of humidity retraction, radiofrequencies are more efficient than the microwaves. They represent an advantage over the IR because they no longer need an external intelligence.

However, due to the relatively small quantity of water present in a row of electrodes, for the production of paper (a 80 grams per square meter, with a speed 500 meters per minute) radiofrequencies have a much too high power to prevent the paper breakage. Still, for the production of larger objects, like the cardboard, the usage of radiofrequencies is justified [3].

The most important usage of radiofrequencies in the paper industry is for the transformation of paper in finished goods, like envelopes, agenda, or books. For instance, when producing paper as support for coating, which already covers another dry paper. Sticking bands, in envelopes, cover only 5% from the total surface. This varies, in position, from one product to another.

Thus, any other drying method would dry the entire surface of paper. This not only means an energy loss, but it would also affect the quality of already dried paper. Radiofrequency can be used with almost all adhesive types, including PVA, dextrin, latex and acrylic.

One of the most successful application of radiofrequency is for processing the adhesive used to stick the wooden blocks. It was first used during the Second World War, for the construction of a bombardier. Since then, it was used for the production of furniture and within the fitting industry, cabinets, door frames and beams.

The usage of radiofrequencies to dry wood was highly debated. There are some problems, because wood drying is limited, not by the heat rate to which it is submitted to, but by the rate of evaporated water that can be conveyed in the surrounding air of work environment. If the temperature rises, the risks concerning the damage of material also rise[1].

It was demonstrated that the usage of radiofrequencies for drying some thinner products, as the laminated woods, is not as limited as for some ticker materials. For the later, additional measures must be taken into consideration, measures that imply more costs. As additional measures, you can use rooms that allow a reduced atmospheric pressure or a clamping mechanism. Another measure would be the reduction of power density to a level where the diffusion could take place without destroying the material. This method is not justifiable from the economic point of view.

The usage of radiofrequency for drying certain products has both advantages and disadvantages. It can also be used in other industries, not only in the ones already mentioned, for example, in the processing of tobacco and others.

In addition to the commercial examples presented above, there are other processes where radiofrequencies and microwaves can be used, but which have not been accepted by the industry yet. Not due to the technical restraints, but due to the economical ones. All kind of strategies were suggested in order to reduce the costs related to the usage of radiofrequencies. The more expensive being the generator. The changes provided will grant a smaller importance to the generator, which will only have a marginal role in the total cost of the plant. The establishment of frequency and control are the main factors to succeed.

The mass production is not compatible with this type of application. As we already shown, most of the applications involving drying by radiofrequencies were used after the conventional drying methods (convective or conductive) have failed. For instance, in the paper industry, biscuit production, etc. Nevertheless, if we take into consideration the entire drying process, it seems that as long as the processed product can maintain a certain humidity, drying through conventional methods can also be efficient.

III. CONCLUSIONS

The authors of this article are involved in researches regarding the efficient use of drying methods Microwaves and radiofrequencies have attributes that make them attractive for several types of industries. However, due to various reasons, they do not represent a universal solution. Since the final decision regarding the purchase of a dryer will be taken according to the financial perspective, it is important to know that they still are in an incipient stage of usage. Despite the fact that this method requires supplementary costs, the quality of final product must be also taken into consideration.

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