COMBINED MICROWAVE–CONVECTIVE DRYING OF *SACCHAROMYCES CEREVISIAE* BASED YEAST

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Attention is paid to drying as a downstream processing of foodstuff as it is used finally for human consumption. In some cases the conventional (convective, contact or infrared) drying processes can damage the quality of food due to crusting phenomena, overheating or protein denaturation. Better results can be obtained using combined microwave–convective dehydration.

The paper mainly focuses on the investigation of drying *Saccharomyces cerevisiae* pulp using the method of dielectric dehydration. A dried product with a residual fermentative activity of over 80% was produced with the application of a microwave–convective drying system. As a result the moisture content was lower than 10% calculated on dry basis. We permanently regulated the incident microwave power manually in order to eliminate the mentioned disadvantageous effects. This type of regulation was applied when the surface temperature reached 45 °C.

Keywords: microwave–convective drying, *Saccharomyces cerevisiae*

The rise of temperature of a dielectric material being exposed to an electromagnetic field can be explained by the conversion of electromagnetic energy into heat. This new heating method was discovered about 40 years ago, although the magnetron, which is used to make it, was already used in radar equipment during World War II.

The microwave radiation ranges from 300 MHz frequency up to 300 GHz, which corresponds to wavelength 1 mm–1 m. From this range 2.45 GHz frequency was selected for the household microwave ovens.

Microwave heating and drying differ from the conventional heating methods essentially. The latter methods are based on the internal friction between weakly bound electrons and molecules. Microwave energy transmission in wet solids can be explained by polarisation of randomly oriented water dipoles. In the 2.45 GHz alternating field the dipoles are forced to change their direction 4.9×10^9 times per second. A part of the

input energy is converted into heat and results in a very rapid heating. ZAGROUBA and co-workers (1993) found that electromagnetic energy at a frequency of 2.45 GHz can penetrate an object with a thickness of 100 mm uniformly.

The power dissipated and converted into heat in a unit volume of the material can be expressed by:

$$P_v = 2\pi\, f\, E^2\, \varepsilon_0\, \varepsilon'' \tag{1}$$

were f: frequency, E: electric field strength, ε_0: permittivity of free space, ε'': dielectric loss factor. The higher the frequency and the electric field strength the higher the amount of energy converted into heat in the material. The dielectric loss factor is a material parameter, which indicates the amount of input microwave loss throughout the volume of the material. The values of dielectric loss factor of water was compiled by ZAGROUBA and co-workers (1993) at frequency 2.45 GHz in function of the temperature (Table 1). It obviously depends on the temperature.

One of the most important applications of the microwave technology is drying. In convective drying the heat gradient is of the opposite direction compared to the mass gradient. Consequently, if the material is dried too rapidly, an impermeable outer crust can form and will not permit moisture diffusion. Moreover, this crust can result in overheating of the surface. Since the direction of the heat gradient is the same as the mass gradient during microwave drying, the mentioned undesirable phenomena can be avoided, therefore the microwave technology is ideal for drying thermosensitive materials. Thermosensitive materials can be favourably dried by combining convective and microwave methods. In this case the moisture migration inside the material can be influenced by the microwave power mainly, and the evaporated water is carried out by the air ventilation at a moderate temperature.

ZAGROUBA and co-workers (1993) investigated the behaviour of a gelatine film and a polyacrylamid sphere during microwave-convective drying. Analysing the obtained drying characteristics, they found the presence of an over pressure drying period owing to the microwave energy, which can seriously damage the product by bursting it.

Table 1

Dielectric loss factor of water at different temperatures

Temperature (°C)	0	20	40	60	80	100
Dielectric loss factor	20	12	7	4.5	2.7	2

AYAPPA and co-workers (1991) determined the conditions of the approximate applicability of Lambert's law which was conventionally used to model the microwave heating of finite slabs. The correct power dissipation was computed from Maxwell's equations. They determined the critical slab thickness, above which the Lambert's law is valid. They compiled a wide range of dielectric properties of foods.

BODOR and co-workers (1993) carried out experiments applying microwave treatment to concentrate L-ascorbic acid solutions. They stimulated the crystallisation process using infrared and microwave energy. With special regard to the thermodegradable material, they did not heat it over 50 °C.

TURNER and co-workers (1998) built up a mathematical model for convective and microwave enhanced convective drying of pine wood. Drying periods, rate, moisture profiles and temperature profiles, effective diffusivity were modelled and analysed. They found that the use of combined microwave and convective drying can reduce time and increase drying rate as compared to the convective equivalent. The reduction of drying time depends on the level of incident microwave power.

Combined microwave–convective investigations were carried out on baker's yeast suspension by SZALAY and co-workers (1993). They found that the critical time and critical moisture content were reduced compared to the convective method. They emphasized the importance of the accurate temperature control of the material during the process.

BERECZ and NEMÉNYI (1996) investigated the internal temperature profile of baker's yeast during infrared drying. They determined the critical moisture content of the material, at which crust formation started, by means of temperature profiles and weight changes.

1. Materials and methods

Commercial compressed *Saccharomyces cerevisiae* based yeast was used in the experiments as model material. Its moisture content varied from 200% to 300% on dry basis. The purpose of the work was to produce dried yeast with
– maximum 10% moisture content according to GINZBURG (1979)
– at least 80% of its original fermentative activity retained (BÉNDEK, 1987).

In the case of yeast drying it is essential to preserve the fermentative activity, which refers to its biological value and characterizes the drying method used. To determine a value for the fermentative activity, the dried yeast was dissolved in a 10% (w/w) glucose solution and poured into a test tube. After closing the tube with a plug pierced with a capillary tube, the test tube was vertically turned by 180°. Then it was put into a water bath of 20 °C to assure the necessary temperature for fermentation. Then the fermentation, namely the evolution of carbon dioxide started. The solution was

forced by carbon dioxide to drop out of the tube and its weight was registered and plotted at intervals by means of a PC. The slope of this line represented the rate of evolution of CO_2 (Fig. 1). There were three typical periods: first the "lag" period of microbes, second the exponential growing period and third the falling-rate period of growing when the decrease of substrate molecules began to limit fermentation. The fermentation capacity was characterized by the maximal rate of evolution of CO_2 (v_1). It is obvious that the rate of gas evolution was in direct proportion to the rate of measured weight.

After t_1 time passed a peak of rate of gas evolution could be observed, then the falling-rate period began. Each fermentation experiment was carried out twice, first using a dehydrated material, then a fresh material without drying with the same dry matter. Maximal rates of gas evolution of dried material (v_{1d}) and fresh material (v_{1f}) were then determined. The residual fermentative activity of dried material was given by

$$A = v_{1d}/v_{1f} \tag{2}$$

The drying apparatus (ENSGTI, France) was a convective drying tunnel (Fig. 2) equipped with a magnetron (2.45 GHz) with a modulable power between 0 and 800 W.

The convective drying parameters could be varied in the following ranges:
- the air velocity between 0.5 m s^{-1} and 2.5 m s^{-1},
- the temperature between the ambient one and 155 °C,
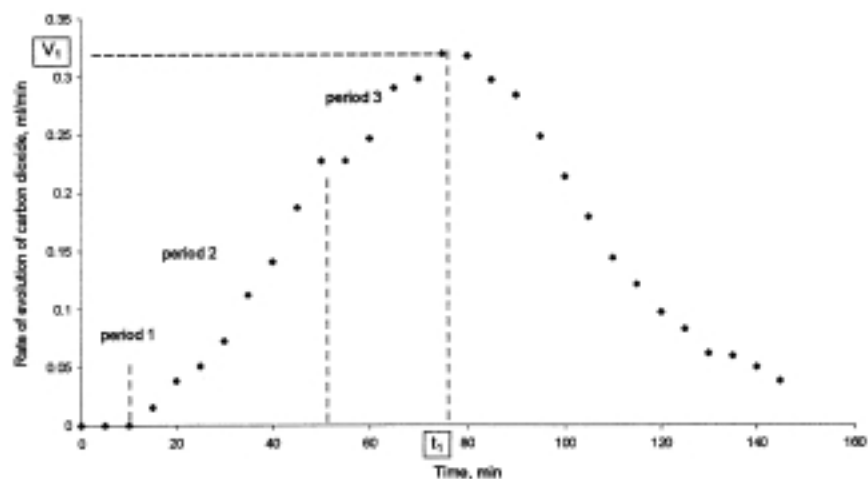- the relative air humidity between 12 and 99%.

Fig. 1. Evolution rate of carbon dioxide during fermentation

An example drying rate curve is presented in Fig. 3 in order to get a better insight into the process of drying achieved by means of the mentioned drying tunnel. It describes convective drying. Moisture content is indicated on the abscissa. The process is started at point No. 1 and finished at point No. 4, which is the equilibrium state. The following generalities can be noted: curve of mass flux (right ordinate) can be divided into three principal sections: the constant-rate drying section (A) and the first and second section of falling-rate drying (B, C). The first section of falling-rate drying extends from point No. 2 (as it is the first critical moisture content) to point No. 3 (as it is the second critical moisture content) and the second section of falling-rate drying extends from point No. 3 to point No. 4. The drying rate is controlled by the surrounding drying air during constant-rate period. The surface temperature (left ordinate) of the material is the same as that of the wet bulb temperature of the drying air.
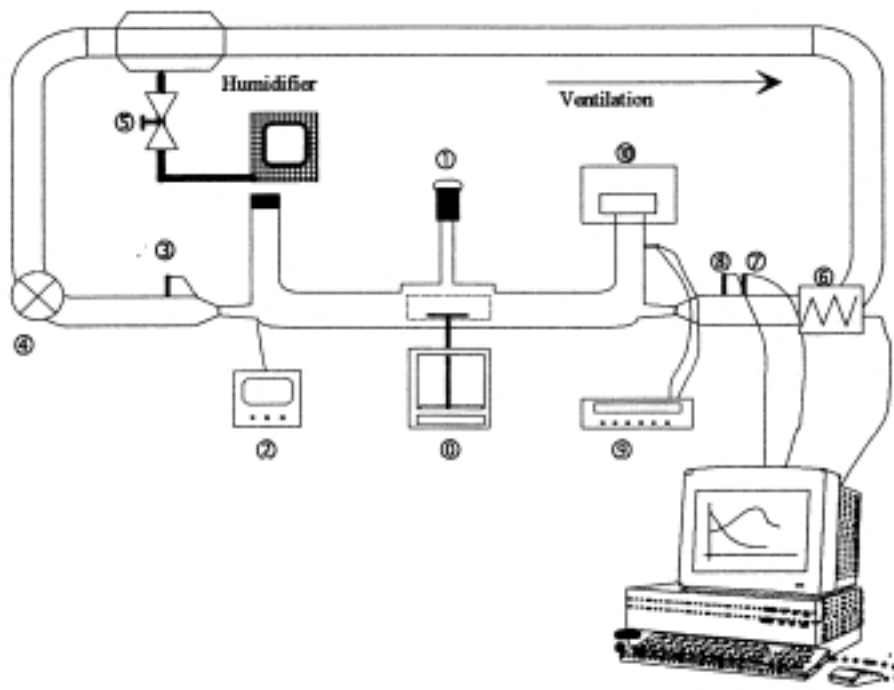

Fig. 2. Experimental drying tunnel. 0: Balance, 1: optic pyrometer, 2: powermeter, 3, 8: thermohygrometer, 4: fan, 5: valve, 6: heater, 7: anemometer, 9: optic thermometer, 10: generator
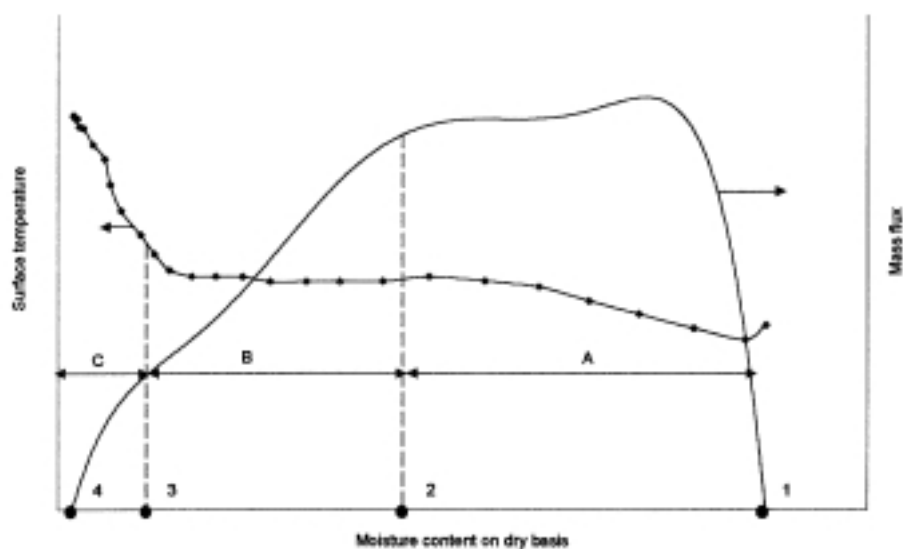
Fig. 3. Drying rate curve with the surface temperature curve. A: constant-rate period, B: first falling-rate period, C: second falling-rate period

The process is controlled by the resistance of the product to heat and mass flows in the falling-rate stages. Most of the undesirable quality deficiencies (e.g. shrinkage, protein denaturation) can occur during these periods. Surface temperature exceeds the wet-bulb temperature and reaches the dry-bulb temperature.

During the completed drying experiments the layer thickness, air velocity and relative humidity of inlet air remained constant (1 mm, 1.2 m s^{-1} 20%, respectively). The effect of drying temperature on the fermentative activity was investigated at four inlet air temperatures: 39 °C, 45 °C, 48 °C and 54 °C.

In combined experiments incident microwave power amounted to 1 W and 3 W. The samples were disc shaped with 0.1 cm thickness and 2.5 cm radius, so the volumetric power was calculated as 0.509 W cm^{-3} and 2.036 W cm^{-3}, respectively.

2. Results

2.1. Convective method

The results of fermentation after convective drying process are represented in Fig. 4. The activity after drying at 45 °C was close to the required value (74% and 80%, respectively). Drying at 48 °C and 54 °C resulted in a product, which retained 37% of

the original fermentative activity. Degradation, denaturation of enzymatically active proteins started at a temperature of 45–48 °C. The yeast cells preserved their fermentative nature at 39 °C well. The lower drying temperature provided good circumstances for the viability of microbes, but at atmospheric pressure the drying time could be longer.

2.2. Combined convective–microwave method

A possible way to shorten drying time is to combine convective method with microwave power. The drying curves and surface temperature values are shown in Fig. 5. Chapter 2.1. indicates that the ideal inlet air temperature should be 39 °C. Incident microwave power of 0.509 W cm^{-3} and 2.032 W cm^{-3} was added to the convective process. Figure 6 represents the calculated fermentative activity levels which did not reach the required minimum activity value. According to Fig. 5, surface temperatures did not exceed 46.7 °C, therefore this considerable activity loss (more than 30%) demands an explanation. The possible reason is that oscillated microwave power took effect on the material within the sampled time and resulted in a brief and undetected overheating.
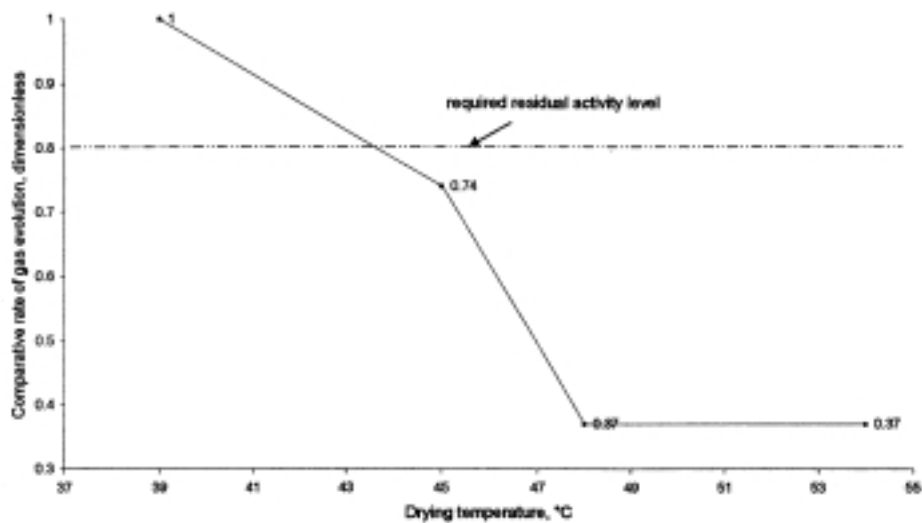

Fig. 4. Fermentation activity of yeast after convective drying at different temperatures
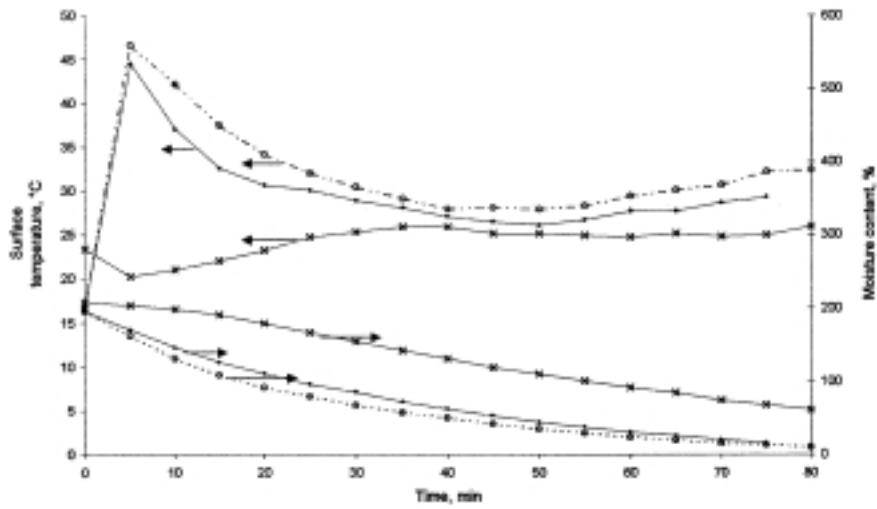
Fig. 5. Convective and microwave enhanced convective drying curves and surface temperatures curves of yeast. X: pure convection at 39 °C ●: convection at 39 °C with 0.509 W cm^{-3} microwave power
O: convection at 39 °C with 2.032 W cm^{-3} microwave power
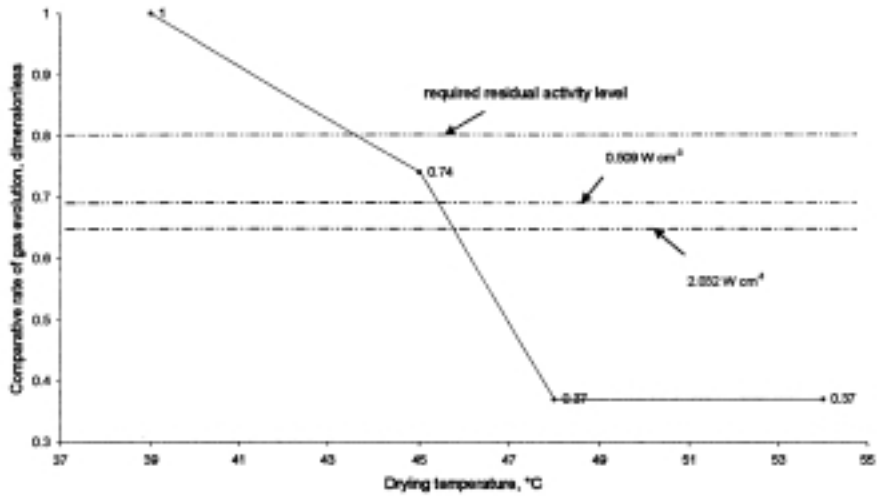

Fig. 6. Fermentation activity of yeast after convective drying at different temperatures (solid line) and combined drying at 39 °C (dashed line)
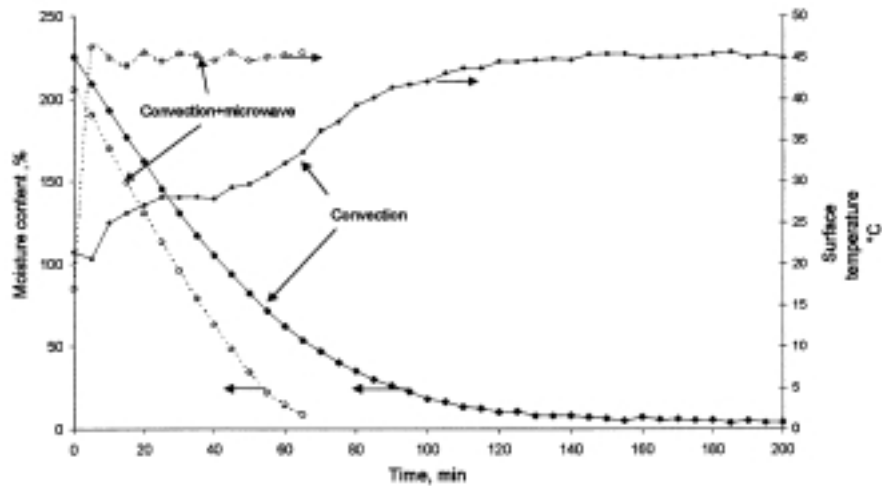
Fig. 7. Convective and enhanced convective drying curves with manual regulation of the incident microwave power

2.3. Combined convective-microwave method with manual regulation of incident microwave power

In order to avoid overheating phenomena permanent manual regulation of incident microwave power was performed taking the surface temperature as a basis. The regulation was set into action when the surface temperature attained 45 °C, and the inlet air temperature was 39 °C.

In Fig. 7 a comparison is shown between pure convection (temperature level was 45 °C) and the convection method enhanced by microwave. During pure convective process 10% moisture content was reached after 130 min whereas manual regulation of the indicent microwave power resulted in the same moisture level after 65 min.

The results of the gas evolution experiments for determining the biological value are shown in Table 2. The maximal rate of carbon dioxide formation (0.205 g min^{-1}) in the dried material was reached after 130 min. Using fresh material we got values of 0.235 g min^{-1} after 75 min. In order to compare the results, the specific rate of carbon dioxide evolution was introduced, which means the maximal rate of gas evolution divided by the dry matter. In this way the rate of gas evolution can be calculated per unit of dry matter. The final fermentative activity referring to the biological activity of the material can be obtained by dividing the specific gas evolution rate of the dried material

by the specific gas evolution rate of the fresh material. For getting a percentage, the results are to be multiplied by 100:

$$0.447/0.550 \times 100 = 81.27\%$$

Table 2

Results of yeast fermentation after manually regulated convective-microwave drying

	Dried material	Fresh material
t_1 (min)	130	75
v_1 (g min^{-1})	0.205	0.235
Dry matter (g)	0.429	0.427
Specific rate evolution of carbon dioxide (min^{-1})	0.447	0.550

This value met 80% of the residual activity level, as required.

3. Conclusions

Our study indicated the effect of microwave enhanced convective drying on the activity of *Saccharomyces cerevisiae* based yeast. The drying time shortened and the drying intensity increased.

The temperature profiles of the material are of primary importance because of the presence of thermosensitive enzymes. The use of constant incident microwave power could be the cause of either overheating of the material or inefficient dehydration during the process. Consequently, the incident microwave power had to be regulated on the basis of the material temperature. A dried product with a moisture content of 8% was produced, which retained 81% of its original fermentative activity.

Further investigations are needed to be able to determine the yeast's dielectric properties being essential to calculate some process parameters.

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