DRYING 2002

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Editors: C.W. Cao Y.K. Pan
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Series editors: A S Mujumdar

IDS 2002 BEIJING CHINA

Volume ABC

Drying' 2002-Proceedings of the 13th International Drying Symposium (IDS' 2002)
Beijing, China, 27-30 August' 2002, vol. A, pp. 319

MODELLING OF COMBINED HOT-AIR CONVECTIVE DRYING OF MUSHROOM (AGARICUS BISPORUS)

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SUMMARY

We investigated mushroom (*Agaricus Bisporus)* as a model material to verify the thesis that capillary-porous colloidal materials can be dried at desired quality with well-planned drying strategy considering properties of the drying material as contrasted with classical combined dehydration processes.

The experiments have justified that there is no possibility to produce satisfactory products by using only microwave or only convective drying. At the same time suitable combined drying could produce easy eatable, i.e., snack-like products, but instant ones, which can be rehydrated perfectly, could not.

Our investigations proved that the most effective drying strategy was the following:

1. convective predrying at the period of the constant drying rate,
2. microwave drying at the beginning period of the decreasing drying rate,
3. convective drying again at the final period of the decreasing drying rate to be homogeneous dispersion of the moisture content.

The most important benefits of the recommended drying strategy are decreasing the drying time, homogeneous dispersion of temperature and moisture as well as puffing possibility of the product.

INTRODUCTION

Keeping the biological properties, taste and nutritional value of the raw materials the considerate drying technologies are of interest in the market and the alternating drying methods become more and more important (Szabó et al. 2002; Szabó és Rigó, 1998; Tulasidas et al., 1995).

The convective-microwave alternating drying gives possibility to change the mechanism of the moisture transport with which ordering and controlling the inner processes of the material can be possible to produce the desired product (Szabó et al., 1998; Hodúr et al., 1998).

The drying technology producing the desired products depends on both the pretreatment of the raw materials, and the mechanism of the moisture transport in liquid form to the surface.

The liquid form transport is much more powerful if the directions of the transport induced by the moisture conductivity and the heat-moisture conductivity are the same. This can be assured using microwave drying.

It is well known that the combined convective-microwave drying guarantees the control of the moisture transport and thus the quality of the drying material (Baker, 1997; Toledo, 1994). The combined technique means that the convective heat treatment is suitable for certain moisture linkage (removing free water, polimolecular and partly the monomolecular moisture amount), while in the final period of the drying the microwave heat treatment is suitable, because of the increased moisture linkage energy. Our experiments led to a little bit different results from that.

MATERIALS AND METHODS

The mushroom has high biological value. It can be makeable exquisitely; it can be additive for instant desiccated soups, meat and rice meals, stew. In snack form customers also love it. Today the largest part of the cultivated varieties of mushrooms in Hungary belongs to the champignon, which gives 60-65% of the harvest and 90-95% of the export of mushroom. The small amount of the dehydrated mushroom export (about 1%) can be explained by the slightly elaborated drying technology producing good quality products.

Several drying techniques, i.e., convective heat, combined convective-microwave, vacuum microwave, and freeze-drying can produce dried mushroom. Among them freeze-drying can make the top grade products. However, the combined convective-microwave treatment does not always meet the prescribed quality demands because of the imperfection in the applied dehydration technology.

Essentially the mushroom is a colloidal, disperse material, and capillary-porous considering the structure. The liquid is in the cells as cell fluid on the one part, and is in other colloidal gels of periblast and cells on the other. The combined convective-microwave treatment is manageable successfully for this kind of materials

Efficiency of the microwave treatments depends greatly on the raw materials and the treatment is influenced by several other facts, i.e., the geometrical, thermal, physical etc. properties of the material, but mostly the temperature distribution in it**.** Fig. 1 shows the heating profile in mushroom caused by microwave impingement. We can improve this inhomogeneous distribution using pretreatment processes (blanching, antioxidant additive agent) and the proper setting the operational parameters of the alternating drying.

Fig. 1. Measured two-dimensional heating profile in mushroom (dark: lowest temperature, light: highest temperature)
Ponne, C. T. (1966). Interaction of electromagnetic energy with vegetable food constituents. Ph.D. Thesis, Technical University Eindhoven, NL.)

The experimental schedule was:

- investigation of the drying properties of mushroom (moisture content determination, taking drying and drying rate curves),
- modeling convective drying with unit heater (thermo-ventilator),
- investigation of the effects of blanching and antioxidants,
- investigation of the combined drying (convective pre-drying and conditioning, pulsed system microwave drying, convective post-drying for temperature homogenizing).

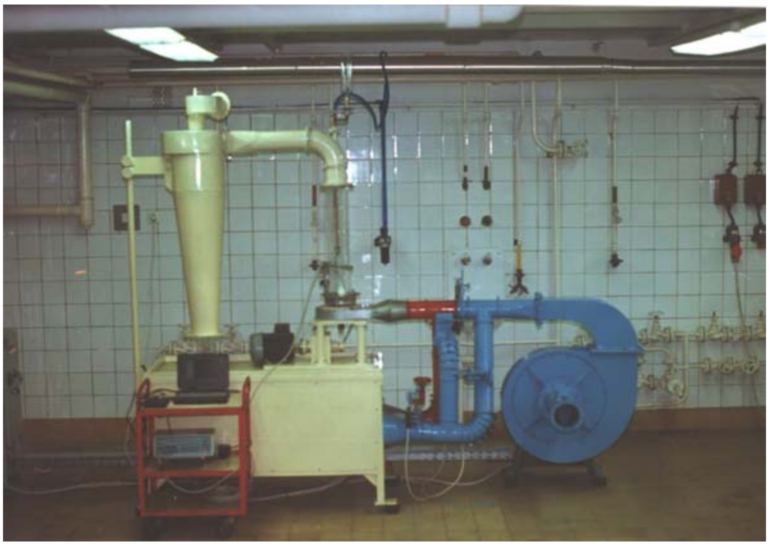

Fig. 2 Aero-vibro-fluidized bed dryer

Fig. 3 Professional microwave equipment LABOTRON-500-type

The convective pre-heating was carried out by the aero-vibro-fluidized bed dryer (Fig. 2). Pretreatment: washing cold water, getting off the leg of mushroom at alignment of the head. Slicing chips with 5 mm thick. Airflow rate was 2 m/s. The temperature of the drying air was 80 °C. Thickness of layer: 60 mm. Sampling rate: 20 min.

The pulsed system microwave treatment was carried out by the Bucher manufactured LABOTRON 500-type professional equipment with vacuum possibility and center plate (Fig. 3). Different samples of mass were treated by the microwave until mass constant with 1 min treatment – 30 sec conditioning (in the meantime the mass decrement was weighed). The residual moisture content was determined with rapid moisture-content measuring equipment.

In the alternating drying the samples were dried with convective treatment for 20, 40, 60, 80 min, the treatment and the conditioning time was 1 min. After the pre-drying the microwave treatment followed for 1, 2, 3, 4, 5 min. The process was finished with post-drying with convective heat treatment again until the equilibrium moisture content for homogenization of the moisture content.

RESULTS AND DISCUSSIONS

Kinetics of the drying of mushroom was investigated and the operational times were determined for the different drying periods of the alternating dehydration. The drying curves (kinetics curves, Fig. 4) and the drying rate curves (Fig. 5) were admeasured with OHAUS infrared weighing machine.

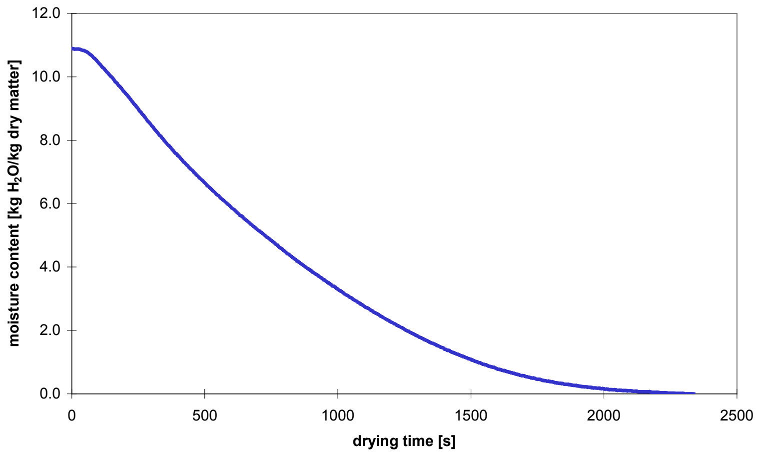

Fig. 4 Drying curve of the champignon measured by OHAUS infrared weighing machine

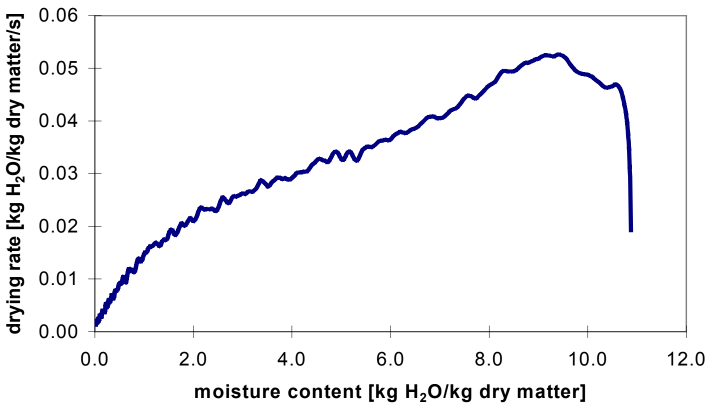

Fig. 5 Drying rate curve of the champignon measured by OHAUS infrared weighing machine

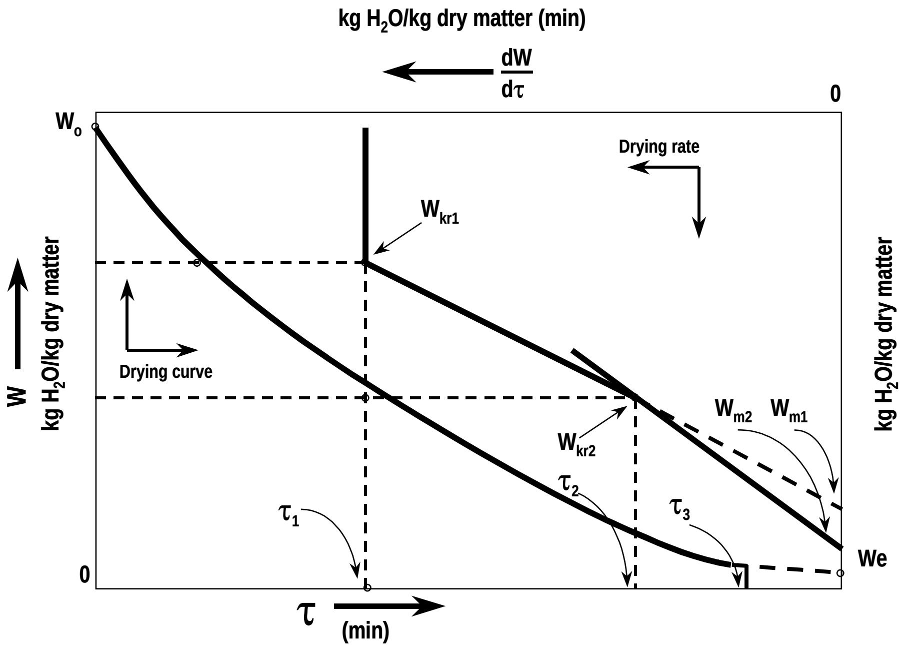

Fig. 6 Idealized drying curve and linearized drying rate curve

The champignon has the typical drying periods as the colloidal-capillary porous materials have based on and proved by the drying rate curve 100of Fig 5. The rapid warming-up period is followed by the constant drying rate period until the first critical moisture content W_{kr1} attained, then the inflection point of the decreasing drying rate curve W_{kr2} can be explained by the changes in the moisture conduction mechanism (Fig. 5 and 6).

In the first, i.e., constant drying rate period we used convective heat treatment, in the second, i.e., the initial section of the decreasing rate period we used microwave treatment, while in the third, i.e., the terminal section of the decreasing rate period we used convective treatment again. For this alternating drying process we had to calculate the drying times with different equations reckoned with the W_0-W_{kr1}, W_{kr1}-W_{kr2} and W_{kr2}-W_e periods, respectively (Fig. 6).

THE THEORETICAL MODEL OF THE ALTERNATING DRYING PROCESS

In Fig. 7 the flowchart for model developing of the alternating drying process can be seen, which can be used in general for the same processes.

In our work we have made an attempt to develop a considerate procedure combining convective and microwave drying for producing products with novel consumer goods properties, i.e., to be instant and/or snack-like. One of the criterions was that the rehydrated product should be similar to the fresh yield, especially considering its eatable properties, as far as possible.

Firstly we constructed the initial verbal model. After that we gave a very general mathematical model formulated by differential equations with the unicity conditions. We plotted the drying curve and the drying rate curve similar to Fig. 6. The next step was the simplification and giving the solution of the equations (Szabó et. al. 2002). We investigated the sensitivity of the operational parameters for different drying strategies, and then we worked out the experiments.

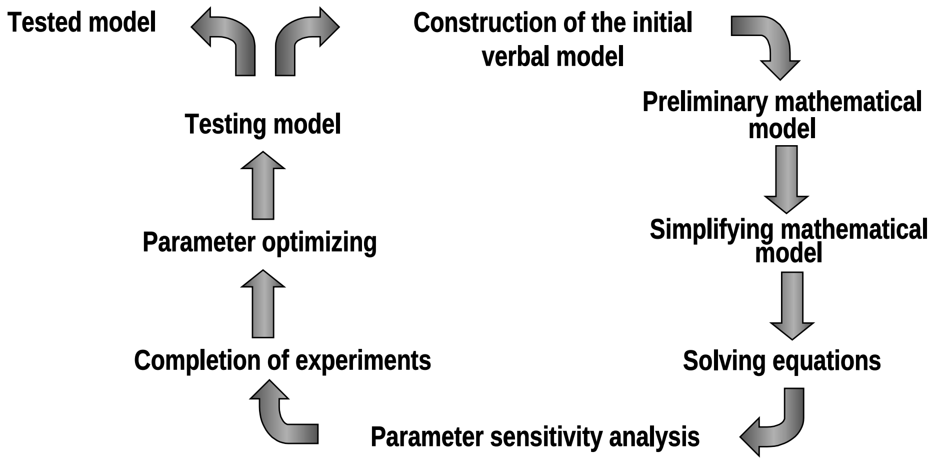

Fig. 7 Flowchart of the model development

We optimized the parameters, evaluated the quality of yields, and made the proper corrections.

To test the model was based on the curves of Fig 6. In the figure the residual moisture contents W_{m1}, W_{m2} are the intersections of the null rate curves and the axis of abscissa on the right side. The simplification of the model was elaborated (Szabó et. al. 2002) and the determination of the drying times was put in based on Toledo (1994).

Drying time for the constant rate period (convective predrying):

$$\tau_1 = \frac{W_0 - W_{kr1}}{R} \tag{1}$$

Drying time for the initial section of the decreasing rate period (microwave treatment):

$$\tau_2 - \tau_1 = \frac{W_{kr1} - W_{m1}}{R} \ln \frac{W_{kr1} - W_{m1}}{W_{kr2} - W_{m1}} \tag{2}$$

Drying time for the terminal section of the decreasing rate period (convective treatment again):

$$\tau_3 - \tau_2 = \left(\frac{W_{kr1} - W_{m1}}{R} \right) \left(\frac{W_{kr2} - W_{m2}}{W_{kr2} - W_{m1}} \right) \ln \left(\frac{W_{kr2} - W_{m2}}{W_e - W_{m2}} \right) \tag{3}$$

The total drying time for the alternating drying process:

$$\begin{aligned} \tau = \tau_1 + (\tau_2 - \tau_1) + (\tau_3 - \tau_2) &= \left(\frac{W_0 - W_{kr1}}{R} \right) + \left[\frac{W_{kr1} - W_{m1}}{R} \ln \left(\frac{W_{kr1} - W_{m1}}{W_{kr2} - W_{m1}} \right) \right] \\ &+ \left(\frac{W_{kr1} - W_{m1}}{R} \right) \left(\frac{W_{kr2} - W_{m2}}{W_{kr2} - W_{m1}} \right) \ln \left(\frac{W_{kr2} - W_{m2}}{W_e - W_{m2}} \right) \end{aligned} \tag{4}$$

TESTED MODEL OF THE ALTERNATING DRYING PROCESS

The accurate values of the drying time for the different periods can be determined after the theoretical calculations only to do experiments, i.e., under empirical way (Beke, 1997; Rajkó et al. 1997; Szabó et al. 2002).

The microwave treatment was carried out with 1 min treatment – 1 min conditioning after 20, 40, 60 and 80 min convective predrying, the results are in Table 1. These results buttress up the argument that there is no possibility to decrease the damp with microwave treatment after predrying of 60 and 80 min because of the thick stratification.

Table 1 Mass decrement during convective predrying and microwave treatment of different operational time

Microwave drying time [min]	Mass decrement [g] Depends on the convective predrying time				
	Raw material	20 min	40 min	60 min	80 min
Initial mass →	8.27	9.05	5.61	4.64	6.51
0	8.27	4.99	1.35	0.57	0.63
1	6.92	4.72	1.22	0.57	0.63
2	4.50	4.06	1.08	0.57	0.63
3	3.29	3.43	0.98	0.57	0.63
4	2.78	2.97	0.92		
5	2.50	2.60	0.88		
Residual moist. cont.	W=73.15[%]	W=71.71[%]	W=48.15[%]	W=33.77[%]	W=15.97[%]

Two typical drying strategies follow to illustrate the case that the desired properties of the production were attainable adjusting the proper operational parameters of the alternating drying processes.

S1 drying strategy (*$W_{init.}$=90%, <u>t=70^{0}C</u>, v=2m/s, 2 min blanching with 0.1% citric acid + 0.1% potassium metabisulphite + 0.1% NaCl in water solution*)

- convective predrying until moisture content of <u>50 %</u>
- 1 min conditioning in vacuum (20 mbar)
- 500 W microwave treatment of <u>7 min</u> – 1,5 min conditioning in vacuum
- convective postdrying – moisture balancing

<u>Quality of the product</u>: drab colored sponged structure, brownish skin, and thick stratification during rehydration.

S1 drying strategy (*$W_{init.}$=90%, <u>t=60^{0}C</u>, v=2m/s, 2 min blanching with 0.3% citric acid + 0.1% potassium metabisulphite + 0.1% NaCl in water solution*)

- convective predrying until moisture content of <u>40 %</u>
- 1 min conditioning in vacuum (20 mbar)
- 500 W microwave treatment of <u>5 min</u> – 1,5 min conditioning in vacuum
- convective postdrying – moisture balancing

<u>Quality of the product</u>: sponged structure, brownish skin, arid and crispy, i.e., and snack-like, thick stratification during rehydration.

CONCLUSIONS

The experiments have justified that there is no possibility to produce satisfactory products by using only microwave or only convective drying. At the same time easy eatable, i.e., suitable combined drying could produce snack-like products, but instant products, which can be rehydrated perfectly, could not.

Iinitial section of the decreasing rate period could improve the quality of the end product. We stated that the use of blanching and antioxidants could be advantageous for homogenizing the temperature distribution.

Snack-like end-product can be produced from champignon with the recommended drying strategy, i.e., convective predrying until 40 % moisture content, conditioning, pulsed system microwave drying (500 W nominal power, 20 mbar vacuum, 5-6 min microwave treatment), end finally convective post-drying of 1-2 min for temperature homogenizing.

ACKNOWLEDGEMENTS

This research was supported by the Research and Development in Higher Education Foundation of Ministry of Education (No. FKFP-0261/2000) and by the Hungarian Science Foundation (No. OTKA T035125 and T037480).

REFERENCES

Baker C.G.J. (1997) *Industrial Drying of Foods*. Chapman & Hall, New York.

Beke J. (1997) *Terményszárítás*. [Crop-drying] Agroinform, Budapest. *in Hungarian*

Hodúr C., Szabó G., Rajkó R. (1998) Agglomeration-drying by microwave. *Bulletins for Applied Computer Mathematics. BAM* – 1532/'98 – LXXXVI –A, pp. 215-223.

Neményi M., Czaba I., Jáni T. (2000) Investigation of simultaneous heat and mass transfer within the maize kernels during drying. *Computers and Electronics in Agriculture*. Vol. 26. pp. 123-135.

Ponne, C. T. (1966). Interaction of electromagnetic energy with vegetable food constituents. *Ph.D. Thesis,* Technical University Eindhoven, NL.

Rajkó R., Szabó G., Vidal-Valverde C., Kovács E. (1997) Designed experiments for reducing antinutritive agents in soybean by microwave energy. *Journal of Agricultural and Food Chemistry.* Vol. 45. pp. 3565-3569

Szabó G., Rajkó R., Hodúr C., Papp Gézáné. (2002) A váltakozó rendszerű kombinált szárítás elmélete és gyakorlata. [Theory and practice of the alternating drying] *Szegedi Élelmiszeripari Főiskolai Kar, Tudományos Közlemények.* pp. 122-134. *in Hungarian*

Szabó G., Rajkó R., Hodúr C. (1998) Combined energy transfer (microwave–convective) by drying agriculture materials. *Hungarian Agricultural Engineering.* Vol. 11. pp. 23-25

Szabó G., Rigó K. (2000) Agglomeration-drying of food powders by combined microwave/convectional energy transfer in vibro-fluid layer. *3rd Israeli Conference for Conveying and Handling of Pariculate Solids*. The Dead Sea, Israel. May 29-June 1, 2000. Proceeding Volume 1. pp. 2.20-2.28.

Toledo R.T. (1994) *Fundamentals of Food Process Engineering*. Chapman & Hall, New York.

Torringa. E., Esveld.E., Scheewe.I., Berg.R., Bartels P. (2001). Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. *Journal of Food Engineering* Vol. 49. No. 3-4 pp. 185-191

Tulasidas T.N., Raghavan G.S.V., Mujumdar A.S. (1995) Microwave drying of grapes in a single mode cavity at 2450 MHz. *Drying technology* Vol. 3. No. 8-9. pp. 1949-1971.