SZENT ISTVÁN UNIVERSITY

USE OF INTERMITTENT-MODE MICROWAVE CAVITIES FOR DRYING

Thesis of doctoral dissertation

Dr. Lajos Ludányi

Gödöllő
2004.

Name of the doctoral school: Doctoral School of Technical Science

Discipline: Agricultural technical science

Head of school: Prof. Dr. Péter Szendrő DSc.
professor
SZIE Gödöllő,
Faculty of Mechanical Engineering
Institute of Machinery

Supervisor: Prof. Dr. János Beke CSc.
professor
SZIE Gödöllő
Faculty of Mechanical Engineering
Department of Machinery

Approved by head of school

Approved by supervisor

CONTENS

1. Theoretical background and present objectives 4

2. Instruments and methods 5

3. Results and theses 6

  3.1 Energy distribution in the electromagnetic field in intermittent-mode and in continuous-running microwave drying cavities 6

  3.2 The continuous-running microwave drying cavity 8

  3.3 Effect of the microwave radiation pressure on the material to be dried 9

4. Conclusions and suggestions 11

5. Publications related to the theme of the doctoral dissertation 14

6. Engineering and developmental work of the author in related fields 16

1. THEORETICAL BACKGROUND AND PRESENT OBJECTIVES

For the automatization of the drying process the inner qualities of the material to be dried must be measured. The microwave dissipation field (i.e. the electromagnetic cavity) does not allow the application of traditional sensors.

In convective drying technologies the information-bearing (i.e. the energy transmitting) medium is the drying air. In the microwave drying chamber the main parameters of drying are ensured by the electrical parameters of the electromagnetic fields, and not by the changes of state of the air.

The parameters of drying are not easy to measure due to the inhomogenity of the microwave field, the geometry-depending resonance frequencies and the irregularity of energy distribution. This problem is especially important in the case of large-size, intermittent microwave chambers. Thus investigations have been made using continuous-type, smaller-size dissipation fields, as well. An important point was to test the response of the humid material to microwave radiation by measuring such an electric parameter that is of microwave character, can be measured easily and provides suitable data for analysis.

2. INSTRUMENTS AND METHODS

Investigations have been made concerning drying in intermittent dryers equipped with a stationary conveyor belt and in continuos dryers equipped with a running conveyor belt. Further measurements have been taken concerning the drying of dry material as well as that of material with high input moisture content in an intermittent dryer and in a continuous dryer with running the conveyor belt in different directions and at different rates.

The moisture loss was the same in both types of dryers. In the case of the continuous drying method - with the same moisture elimination - lower output temperature could be observed, caused by the radiation pressure of the microwaves.

In order to prove the above and to determine the radiation pressure a mathematical model was set up and the material to be dried was radiated at the resulting Brewster-angle.

With continuous-running microwave drying the parameters of drying can be measured easily. Since investigations have proved that above a certain value the output temperature is independent of the speed of the conveyor belt and can be taken constant, thus in order to automatize the drying process it is enough to measure only the parameters of the input and output moisture contents.

3. RESULTS AND THESES

In the course of building up an intermittent-running microwave dryer several problems had to be solved. Thus, first the structure of the microwave field and the measurability of the parameters of drying were studied.

Then further investigations were carried out using continuous-type microwave dryers, as well.

Concerning the above unique but closely related two types of microwave dryers the following main conclusions have been reached:

3.1 Energy distribution in the electromagnetic field in intermittent-mode and in continuous-running microwave drying cavities

3.1.1 In microwave drying cavities the electromagnetic field is not homogeneous as energy distribution is concerned. Geometry-dependent energy maxima and energy minima develop in it. To prove this, a measuring device has been made and used.

3.1.2 A mathematical model has been developed for the two-dimensional and three-dimensional visualization of the electromagnetic field. The model has been proved to be similar to the results of measurements (Fig.1).

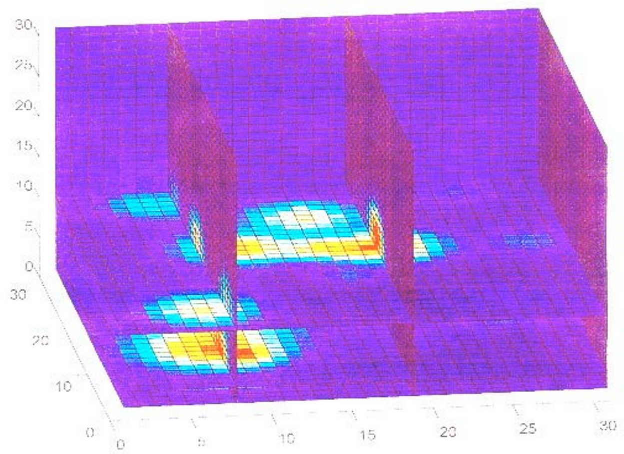

Fig. 1 The 3D visualization of the electromagnetic field - Simultaneous computer graphics of two measurements

The mathematical model is the following:

$$W(x,y,z)=\sum_{j=1}^{m}\sum_{i=1}^{n}P_i\exp\left[-\alpha_{ix}(x-x_i)^2-\alpha_{iy}(y-y_i)^2-\alpha_{jz}(z-z_j)^2\right] \qquad (1)$$

Where P_i is the normalized power determined using colour scale, α is the deviation coefficient, n is the sum of all stains on several sections of the indicating desk, m is the number of axis z measurements, and x_i, y_i and z_j are the coordinates of power maxima.

3.2 The continuous-running microwave drying cavity.

3.2.1 A new-type microwave dryer using a conveyor belt with variable rotational velocity and variable direction of rotation has been developed. It has been concluded that the drying process can be measured and evaluated by means of one microwave parameter, the measured P_r reflected power (Fig. 2).

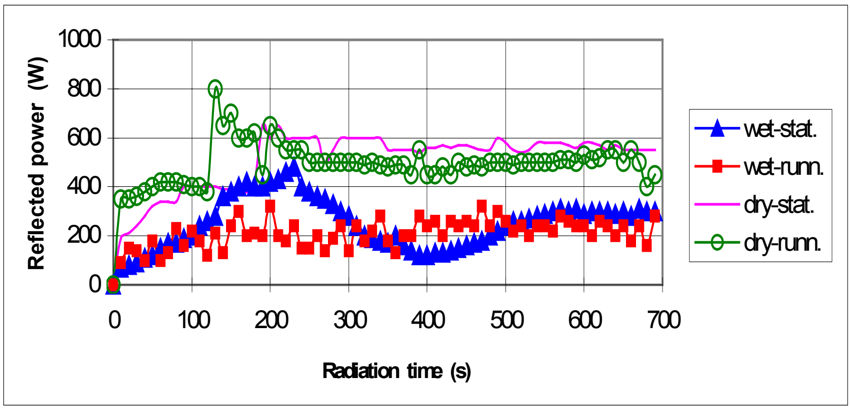

Fig. 2 $P_r(t)$ microwave radiation times of wet, dry, stationary and running belts

3.2.2 In stationary-belt mode the condition of the material to be dried is characterized by the $P_r(t)$ time scale. The oscillation of $P_r(t)$ is of high period time, and this feature is due to discrete changes in the moisture content and the temperature.

3.2.3. In running-belt mode the intense oscillation feature of the measured $P_r(t)$ time scale is independent of the mechanical vibration of the material to be dried. It is influenced by the mass power of the moving dielectric material.

3.3 Effect of the microwave radiation pressure on the material to be dried

3.3.1 In the case of running-belt mode the loss in moisture content is equal to that in stationary-belt mode, but it occurs at a much lower output temperature.

It has been concluded that the microwave field does not only show a thermic effect but a non-thermic effect, i.e. radiation pressure, as well. Thus, in the case of running material an equal amount of moisture loss compared to that in stationary-belt drying is due to the increasing radiation pressure (Fig. 3).

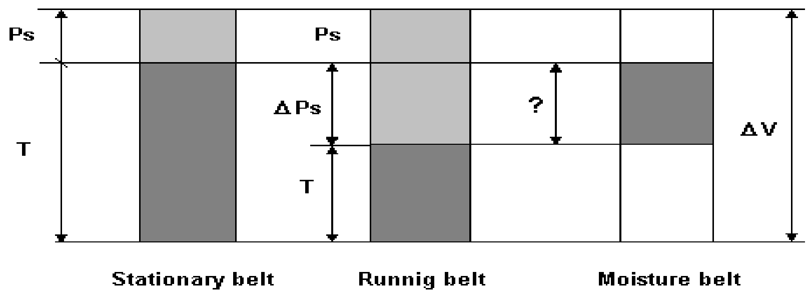

Fig. 3 Analysis of the existence of radiation pressure

3.3.2 In the case of vertical polarization applied in the present dryer the radiation pressure depends on the Θ Brewster-angle, ρ-density and the dielectric coefficient.

3.3.3 For the determination of p_s-radiation pressure at vertical polarization the following equation has been set up:

$$p_s = E_i \cos^2 \Theta_i (1+\Gamma) - E_i \cos\Theta_i \sqrt{\varepsilon_t - \sin^2 \Theta_i}(1-\Gamma) \qquad (2)$$

if $\Theta_i = \Theta_B$ then $\Gamma=0$

where $\Theta_B = ar \text{ ctg} \sqrt{\frac{\rho_t^2 - \varepsilon_t \rho_i^2}{\rho_i^2(\varepsilon_t - 1)}}$ -Brewster-angle, ρ_t is the density of the material to be dried, ε_t is the dielectric constant of the material, Γ is the reflexion coefficient, and E_i is the electric force of the input wave.

3.3.4 The advantages of drying with running mode over stationary mode have been established as follows (Fig. 4):

- Drying is easier to measure and the process can be automatized
- This technology is suitable for drying heat-sensitive materials
- It is energy-saving

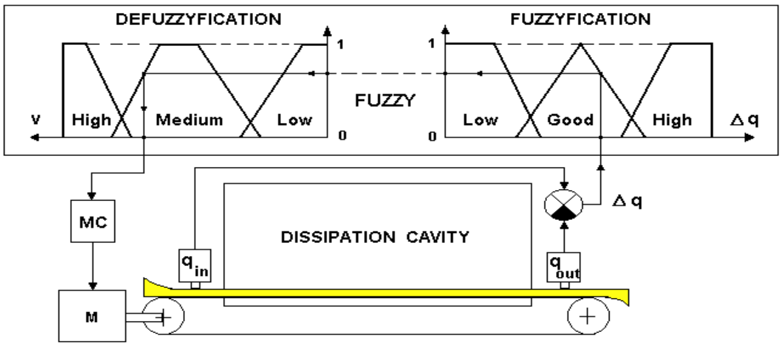

Fig. 4 Microwave drying with Fuzzy control

3.3.5 The output temperature is practically constant in running-mode drying and for the regulation of drying it is enough to measure only the parameters of the moisture content. Accordingly, different practicable regulation principles have been referred to.

4. CONCLUSIONS AND SUGGESTIONS

1. In convective drying technologies the information-bearing, i.e. the energy-transmitting, medium is the drying air. In the microwave-dissipating field, i.e. the drying chamber, however, traditionally used drying sensors cannot be applied.

2. In the microwave drying chamber the main parameters of drying are ensured by the electrical parameters of the electromagnetic field and not by the changes of state of the air.

3. Whereas, in large-size multi-mode dissipating fields the parameters of drying are, in practice, impossible to be measured due to the inhomogeneity of the microwave field, the geometry-depending resonance frequencies as well as the irregularity of energy distribution.
4. The multi-mode feature of the microwave cavity and the difficulties of measurement can be reduced in smaller-size continuous-running dissipating fields.
5. In continuous-running microwave dryers the behaviour of the material to be dried can be studied during irradiation by means of a microwave parameter, i.e. the measurable $P_r(t)$ reflected power.
6. The dry, the wet as well as the drying materials of various temperatures are clearly identified in different modes of drying by means of the measured $P_r(t)$ time scale.
7. In intermittent-mode microwave drying the oscillation of $P_r(t)$ is of high period time and of high amplitude. This is due to a similar kind of change in the dielectric coefficient of the drying material at high output temperature.
8. In continuous-running microwave drying the oscillation of $P_r(t)$ in the time scale of $P_r(t)$ reflected power is increased with low period times and lower mean reflected (as well as higher dissipated) power.
9. The output temperatures are, on an average, by 50% lower in running-belt mode than in intermittent-mode microwave dryers. Whereas, the extent of moisture reduction is, in practice, the same in both modes.

10. The same moisture-reducing effect under lower output temperature is due to the microwave radiation pressure.
11. The radiation pressure and thus the moisture-reducing effect can be increased if vertical polarization is applied in the drying process, and drying is carried out with microwaves reflected in the Brewster-angle.
12. In running-mode microwave drying the output temperature is independent of the speed of the running belt above a certain value of speed, and it can be taken as constant. Thus, for the automatization of the process it is enough to measure the input and output moisture contents only.

5. PUBLICATIONS RELATED TO THE THEME OF THE DOCTORAL DISSERTATION

Publications in journals in Hungarian:

1. Ludányi L. (1988): Nagyteljesítményű mikrohullámú sugárzások élettani hatása, valamint a sugárzásintenzitás lehetséges csökkentési módszerei. Tudományos Kiképzési Közlemények, Szolnoki Repülőműszaki Főiskola, p. 45-51.
2. Ludányi L. (1998): A mikrohullámú technika ipari alkalmazási lehetőségei. Szolnoki Tudományos Közlemények, Szolnok, p. 30-40.
3. Ludányi L. (1999): A mikrohullámú technika, mint a korszerű szárítástechnológia eszköze. Mezőgazdasági Technika, XXXIX. Évfolyam, p. 2-4.
4. Ludányi L. (2001): Az elektromágneses összeférhetőség. Elektrotechnika, MEE központi kiadvány, Budapest, 38. évfolyam 5.sz.p. 65-68.
5. Ludányi L. (2002): Mikrohullámú szárító-mérő berendezés kifejlesztése. Mezőgazdasági Technika, XLIII. Évfolyam, p.5-7.

Publications in journals in foreign language:

6. Ludányi L. (1999): The 3D Visualization of The Electromagnetic Field of the Microwave Cavities., The Pamm's periodical Buletins for Applied & Computer Mathematics (BAM), Budapest, p. 18-26.
7. L. Ludányi - J. Beke (2000): Study of Intermittent and Continuous-mode Microwave Drying. Hungarian Agricultural Engineering, N^{o}13/2000 Periodical of the Committee of Agricultural Engineering of the Hungarian Academy of Sciences, p. 41-43.
8. L. Ludányi - J. Beke (2002): Energetical Problems of Dissipation Heat Transfer by Means of Microwaves. Hungarian Agricultural Engineering, N^{o}18/2002 Periodical of the Committee of Agricultural Engineering of the Hungarian Academy of Sciences, p. 40-43.

Conference proceedings in Hungarian:

9. Ludányi L. (1999): A multimódusú mikrohullámú üregrezonátorok elemzése. Műszaki Kémiai Napok '99, Veszprém, ISBN 963 03 7406 4, p. 74-86.
10. Ludányi L. (1999): A mikrohullámú szárítás hő és nedvességmérési problémái. 3. Magyar Szárítási Szimpózium, Nyíregyháza, p. 10-16.
11. Ludányi L. (2001): Szennyezett aktív szén regenerálása mikrohullámmal. Műszaki Kémiai Napok '01, Veszprém, ISBN 963 00 6467 7, p. 183-187.

12. Ludányi L. (2001): Mikrohullámú szárító-mérő berendezés kifejlesztése. 4. Magyar Szárítási Szimpózium, Mosonmagyaróvár, ISBN 963 9364 355, p. 20-24.
13. Ludányi L., Szabó G., Forgács E. (2002): Aero-vibrofluidizációs agglomeráló berendezés mikrohullámú szárító-mérőegysége. Műszaki Kémiai Napok '02, Veszprém, ISBN 963 7172 95 5, p. 262-270.
14. Pallai I.-né, Göllei A., Ludányi L., Vass A., Szijjártó E. (2003): Mezőgazdasági magvak mikrohullámú energiaabszorpciójának mérése. Műszaki Kémiai Napok '03, Veszprém, ISBN 963 7172 998, p 159-164.
15. Ludányi L., Göllei A., Pallainé V. E., Vass A., Szijjártó E. (2003): A mikrohullámú energia-abszorpció tanulmányozása mezőgazdasági magvak mikrohullámú és kombinált szárítása, hőkezelése kapcsán. 5. Szárítási Szimpózium, Szeged, ISBN 963 482 647 4.
16. Ludányi L., Szabó G., Forgács E., Beszédes S. (2003): Aero-vibrofluidizációs mikrohullámú szárító-mérőegység. 5. Szárítási Szimpózium, Szeged, ISBN 963 482 647 4.
17. Simon E., Ludányi L., Szabó G. (2003): Sterilizálás lehetősége mikrohullámú térben (hőmérséklet-eloszlás meghatározása). 5. Szárítási Szimpózium, Szeged, ISBN 963 482 647 4.

Conference proceedings in foreign language:

18. L. Ludányi (2001): Study of Intermittent and Continuous-mode Microwave Drying. Műszaki Kémiai Napok '01, Veszprém, ISBN 963 00 64677, p. 188-193.
19. I. Pallai, L. Ludányi, A. Vass, A. Göllei (2002): Investigations to Enforce Advantages of the Use of Microwave Energy at Heat Treatments of Food Products.V. Nemzetközi Élelmiszertudományi Konferencia, Szeged, ISBN 963 482 577 5.
20. G. Szabó, L. Ludányi, E. Forgács (2003): Recent Developments of Combined Microwave-Assisted Hot-Air Vibrofluidised Bed Drier with Homogeneous Distribution of Electromagnetic Field. The 4^{th} International Conference for Conveying and Handling of Particulate Solids, Budapest, May 27-30.,ISBN 973 682 3344

6. ENGINEERING AND DEVELOPMENTAL WORK OF THE AUTHOR IN RELATED FIELDS

1. 1992 " A microwave equipment for material shaping", patent applied for at No.23140/1992
2. 1993 OMFB project work design and building of " A microwave chemical reactor with six channels", carried out in collaboration with the ATOMKI Spektrum 3D Kft., Debrecen, by order of the Department of Chemisty, Kossuth Lajos University, Debrecen
3. 1996 Development of "A microwave antenna-measuring system", related to theme No. 12/1996 as registered in the scientific research plan of KGYRMF
4. 1996 Supervisor of microwave measurement techniques in FEFA Project Work No. 2133
5. 1996 Design and building of a microwave dryer for drying wood by order of BOROVI Bt., Szolnok
6. 1997 Study of microwave field indication, design and building of an equipment related to theme No. 492/1996/6 as registered in the scientific research plan of KGYRMF
7. 1997 Design and building of a microwave material processing equipment by order of the JNKSZ Country Foundation for Enterprise Development
8. 2000 Development of a microwave testing chamber in collaboration with the Engineering Chemical Research Institute of Kaposvári University
9. 2001 Design and building of a microwave differential cavity-resonator for the determination of the dielectric coefficient, by order of the Szent István University
10. 2001 Design and building of a microwave drying and measuring unit, by order of the Institute of Agricultural Technology, West-Hungarian University
11. 2002 Design and building of a microwave drying and measuring unit, by order of the Szent István University
12. 2002 Design and building of a microwave drying and measuring unit for an aero-vibrofluidization dryer, by order of the University College of Food Engineering, University of Szeged