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Mathematical Modeling of Potato Slices Drying Kinetics

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ABSTRACT: Food treatment is becoming very important issue in the world due to the environmental pollution and the global growing of the population. This paper is dealing with drying as one among the plenty of methods for food preservation. During the drying process a quite amount of water is removing from the food. Removal of the water is important for preventing bacteria growth which causes deterioration and spoilage of the food. Experimental examination of far infrared vacuum drying of potato slices has been realized for heaters temperatures of 120, 140, 160, 180 and 200°C and pressure in vacuum chamber of 20, 40, 60 and 80 kPa. Experimental setup was made to imitate real dryer. Certain mathematical analysis was undertaken in order to find out the best mathematical models which would predict drying kinetic. Two mathematical models were suggested, logarithmic and trigonometric, and both show excellent correlation with experimental data. Parameters optimization has been done by using Levenberg-Marquardt method to solve non-linear least squares problems.

Keywords: Drying kinetics, mathematical modeling, parameters optimization.

I. AIMS AND BACKGROUND

Since the global population is growing and due to boosting world industrialization, the environmental pollution is increasing and healthy soil and water are decreasing, food production and preservation is becoming essential issue. Considering the fact that, the long time between harvest and consumption could be reason for deterioration and spoilage of the food, its preservation is quite necessary. Beside mechanical, physical and chemical, microbial effects could be cause for food deterioration and spoilage, as well[1].

It is well known that water activity in the food is closely correlated with the bacteria growth[2]. So, it is very important to remove the water from the food, as a media which is suitable for bacteria growth, in order to prevent food of deterioration and spoilage. Basically, preservation should ensure quality, edibility and the nutritive value of the food for future use.

There are many methods for food preservation[1]. Some of them are: drying, freezing, smoking, vacuum packing, salting and pickling, canning and bottling, jellying, pulsed electric field processing, pasteurization, irradiation and many others. The oldest method for food preservation is drying. The quite amount of water could be removed from the food during the drying process. Thermodynamically speaking, drying is simultaneous heat and mass transfer process and its kinetic depends of thermophysical properties of the material. In last decades, many papers are correlated with determination of thermophysical properties in order to predict and calculate drying kinetics[3.4.5.6]. A lot of experimental investigations have been realized about drying different vegetables and fruits, such as: carrot[7], banana[8], onion[9], red pepper[10], potato[11], pear[12], quince[13], apple[14].

The potato is very important staple food in many countries and after maize (corn), wheat and rice, it is fourth largest food crop in the world. Billions of people daily consumed potatoes and their survival depend on it[15]. There are dozens of types of potatoes and they are grown in over the 125 countries. According to FAOSTAT, top 5 potato producing countries for 2017, are: China (99,205,600 tones), India (48,605,000 tones), Russian Federation (29,590,000 tones), Ukraine (22,208,200 tones) and United States (20,017,400 tones)[16].

II. EXPERIMENTAL RESEARCH

On figure 1 is presented experimental setup for far infrared vacuum drying research of 3 mm thick potato slices. It is designed to simulate real dryer. Series of experiments are realized for heaters temperatures of 120, 140, 160, 180 and

200oC and pressure in vacuum chamber of 20, 40, 60 and 80 kPa.

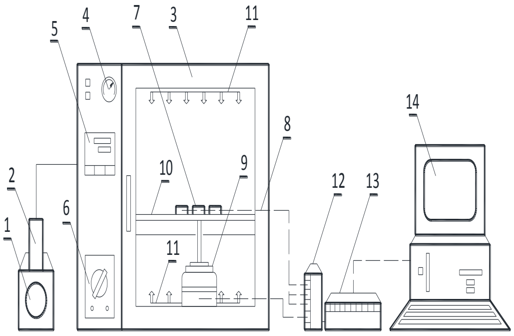

Fig.1.View of experimental far infrared-vacuum drying setup

1 - vacuum pump, 2 - separator, 3 - vacuum chamber, 4 - vacuum-meter, 5 – temperature controller, 6 - vacuum regulator, 7 – samples, 8 - micro thermocouples, 9 – load cell, 10 – tray, 11 – heaters,
12 -computer interface, 13 - A/D converter, 14 - personal computer

It was concluded that decreasing of vacuum pressure in the chamber and increasing of heaters temperature, result on decreasing of drying time. In table 1 and in the diagrams on figures from 2 to 6 are presented the experimental results for heaters temperatures of 120, 140, 160, 180 and 200°C and pressure in vacuum chamber of 80 kPa, where t_h is heaters temperature, p is pressure in vacuum chamber, τ is time, t_0 is initial temperature of the sample, u_0 is initial moisture of the sample and u_f is final moisture of the sample.

Table 1. Experimental conditions for potato slices

Experiment	t_h [^{o}C]	p [kPa]	τ [min]	t_0 [^{o}C]	u_0 [kgkg^{-1}]	u_f [kgkg^{-1}]
E1.4	120	80	260	23.37	5.10	0.01
E1.8	140	80	200	23.53	5.34	0.01
E1.12	160	80	150	23.78	5.30	0.02
E1.16	180	80	110	23.59	5.31	0.02
E1.20	200	80	100	23.74	5.25	0.01

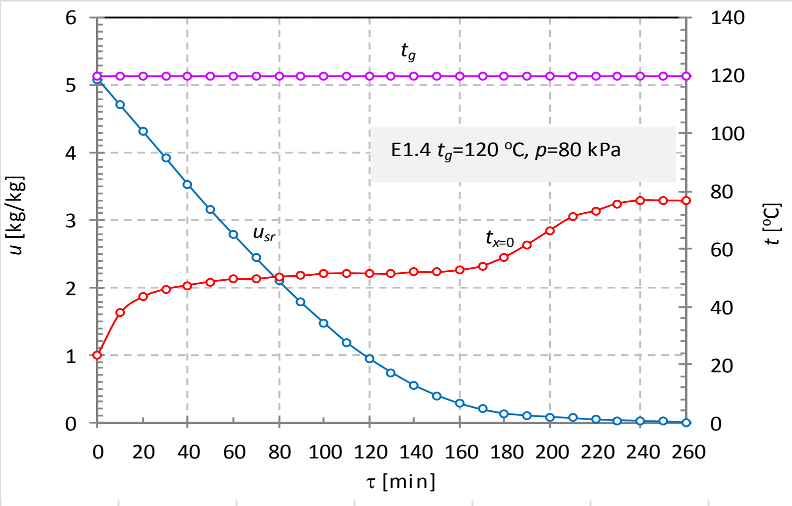

Fig. 2. Experiment E 1.4

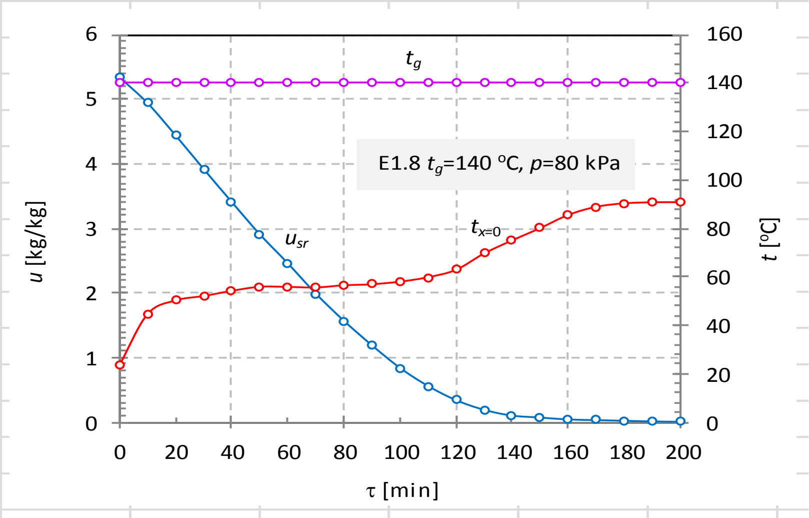

Fig. 3. Experiment E 1.8

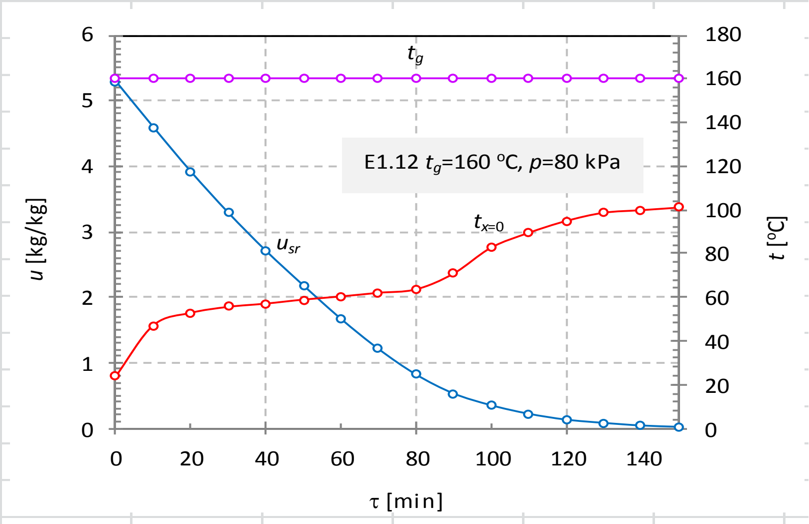

Fig. 4. Experiment E 1.12

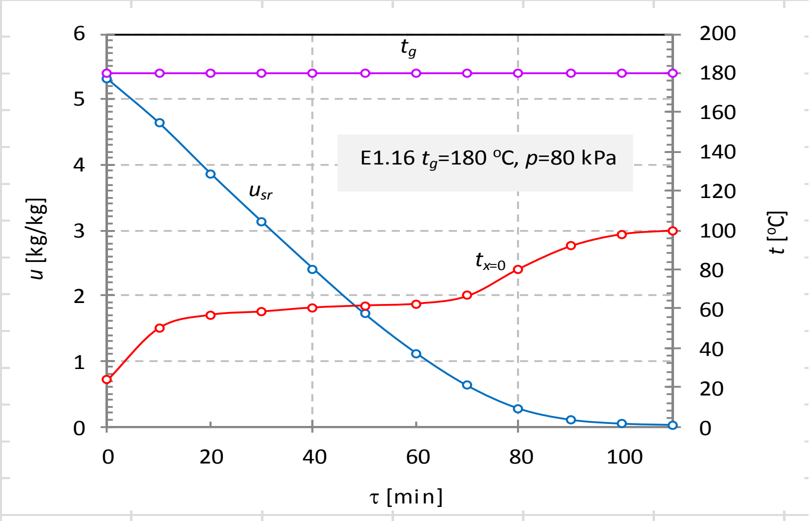

Fig. 5. Experiment E 1.16

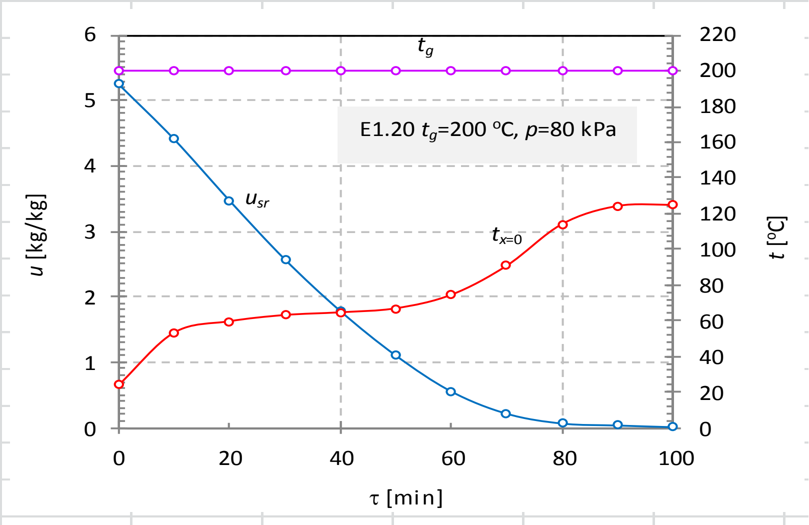

Fig. 6. Experiment E 1.20

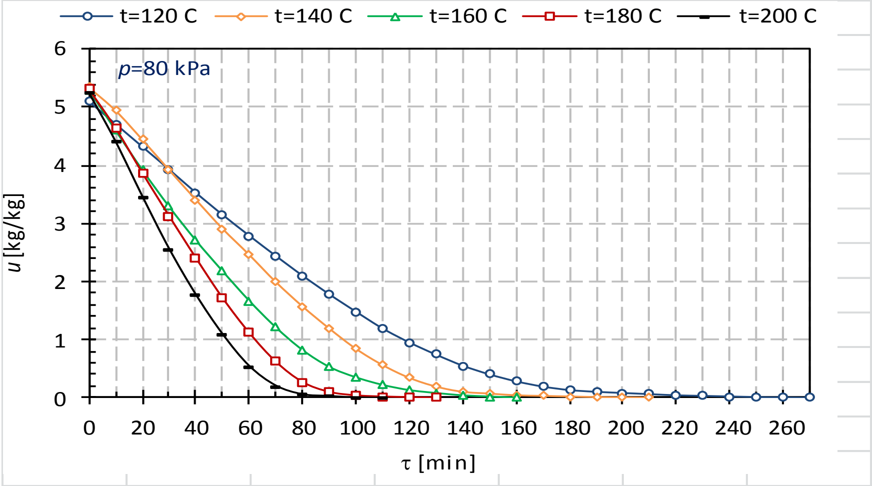

Fig. 7. Change of average moisture content withtime, potato p = 80 kPa, t_h = 120,140,160,180,200 °C

On figure 7 are shown changes of average moisture content of potato slices for different heaters temperatures of 120,140,160,180,200 °C and constant vacuum pressure of 80 kPa and can be concluded that increasing of heaters temperature from 120 to 200 °C results in decreasing of the drying time for 59%.

III. ANALYSIS AND PARAMETER OPTIMIZATION

For better predicting the drying process, a mathematical analysis should be undertaken in order to find out mathematical model of drying kinetic which would show the best fitting with experimental data. For that purpose, it was calculated the change of gradient of moisture (∂u/∂τ) with average moisture (u) and is shown on figure 8. As it could be seen, falling drying rate is dominated generally through all period. So, it could be linear or nonlinear changes.

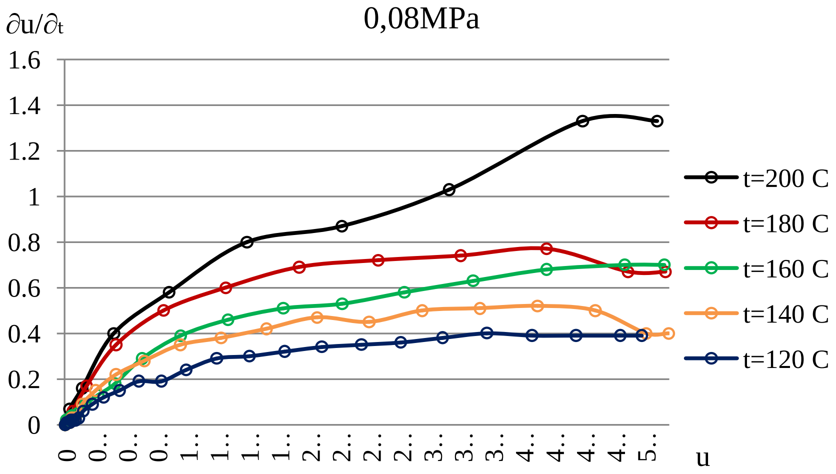

Fig. 8. Change of gradient of moisture with average moisture

Where:

$$\frac{\partial u}{\partial \tau} = \frac{\Delta u}{\Delta \tau} = \frac{u_j - u_{j+1}}{\tau_{j+1} - \tau_j}$$

and:

$$u = \frac{u_j + u_{j+1}}{2}$$

The mathematical analysis will be made by approximating changes as line and as curve.

$$\frac{\partial u}{\partial \tau} = \frac{du}{d\tau} = Au + B$$

$$\int_u^{u_0} \frac{du}{Au + B} = \int_0^{\tau} d\tau$$

After integrating and rearranging the equation above, a transcendental function as mathematical model is obtained:

$$u = k_1 + k_2 e^{k_3 \tau}$$

It is actually a logarithmic model used for drying kinetic modeling of other foods such as apple[14], rough rice[17], pistachios[18], quince[13], pear[12].

$$\frac{\partial u}{\partial \tau} = \frac{du}{d\tau} = Au^2 + Bu + C$$

$$\int_u^{u_0} \frac{du}{Au^2 + Bu + C} = \int_0^{\tau} d\tau$$

In this case, after integrating and rearranging the equation above, a trigonometric function as mathematical model is obtained:

$$u = k_1 tg(k_2 + k_3 \tau)$$

In order to verify the suggested mathematical models, parameters optimization has been done by using Levenberg-Marquardt method to solve non-linear least squares problems. Levenberg-Marquardt method, among others optimization methods, is included in the computer program StatSoftStatistica. The results of optimization and the coefficients of determination, R^2 as well, are shown below in the table 2.

Table 2. Estimated values of parameters

Model	$u=k_1+k_2e^{k_3\tau}$	$u=k_1tg(k_2+k_3\tau)$
Experiment E1.4 t_h=120[°C], p=80[kPa]	k_1=-0,569284 k_2=5,989501 k_3=-0,010707 R^2=0,99476539	k_1=1,973025 k_2=1,228660 k_3=-0,005477 R^2=0,98168455
Experiment E1.8 t_h=140[°C], p=80[kPa]	k_1=-0,736093 k_2=6,479955 k_3=-0,012846 R^2=0,99259378	k_1=2,264372 k_2=1,199159 k_3=-0,006891 R^2=0,97881497
Experiment E1.12 t_h=160[°C], p=80[kPa]	k_1=-0,660806 k_2=6,173398 k_3=-0,016399	k_1=2,192735 k_2=1,197162 k_3=-0,008753

	R^2=0,99637264	R^2=0,98643861
Experiment E1.16 t_h=180[^{o}C], p=80[kPa]	k_1=-0,921660 k_2=6,541363 k_3=-0,018252 R^2=0,99249837	k_1=2,505600 k_2=1,152358 k_3=-0,010508 R^2=0,98075862
Experiment E1.20 t_h=200[^{o}C], p=80[kPa]	k_1=0,421741 k_2=4,492703 k_3=-0,034592 R^2=0,96088246	k_1=2,329897 k_2=1,171463 k_3=-0,012581 R^2=0,98178242

It is obvious that both mathematical models excellent correlate with experimental data. Logarithmic model better correlate with first four experiments (E1.4, E1.8, E1.12 and E1.16) and trigonometric model better correlate with experimental data of last experiment E1.20.

IV. CONCLUSIONS

Considering the phenomena of growth of global population and environmental pollution, food production and preservation is becoming essential issue.

Among of many methods for food preservation, such as: freezing, smoking, vacuum packing, salting and pickling, canning and bottling, jellying, pulsed electric field processing, pasteurization, irradiation, drying is the oldest one which is used for removal of the water from the food. Removal of the water is very important to prevent bacteria growth which causes deterioration and spoilage of the food.

Experimental research of far infrared vacuum drying of 3 mm thick potato slices have been realized in order to predict and calculate drying kinetic. The potato is very important staple food and survival of billions of people in the world depends of it. For that purpose a mathematical analysis has been undertaken and two mathematical models were suggested. One is logarithmic and the other is trigonometric model. After parameter optimization, the coefficients of determination show excellent correlation with experimental data. Logarithmic model better correlate with four experiments and trigonometric model better correlate with one experiment.

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