REGULATING THE MOISTURE OF OILSEED MATERIAL IN A TOASTER FOR VEGETABLE OILS EXTRACTION
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РЕГУЛИРАНЕ НА ВЛАЖНОСТТА НА ЗЪРНЕН МАТЕРИАЛ В ПЕКАЧ ЗА ИЗВЛИЧАНЕ НА РАСТИТЕЛНИ МАСЛА

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ABSTRACT

The influence of the moisture in the process of thermal-moisture treatment of oilseed material has been determined. The behaviour of the electronic system for adjustment of oilseed moisture has been investigated. For this purpose, experimental data on the current moisture values have been obtained in treatment period via grain sample method. The obtained experimental data have been statistically compared with the simulation results from a model, which describes the thermal-moisture process.

РЕЗЮМЕ

Определено е влиянието на влажността на зърнения материал в процеса на добиване на растително масло. Изследвано е поведението на електронна система за регулиране влажността на зърнения материал. За целта са получени експериментални данни за моментната стойност на влажността в периода на обработка чрез зърнена проба. Тези данни са статистически съпоставени със симулационни резултати от предварително разработен модел, описващ влаготоплинния процес.

INTRODUCTION

The first operation after harvesting the oilseeds involves grinding, and then heat and moisture treatment. Decortication or shelling separates the oil-bearing portion of the raw material and eliminates the parts that have little or no nutritional value. Small-scale mechanical shellers are available for kernels and nuts although manual cracking is still prevalent. Most oil seeds and nuts are heat-treated by roasting to liquify the oil in the plant cells and facilitate its release during extraction. To increase the surface area and maximize oil yield, the oil-bearing part of groundnuts, sunflower, sesame, coconut, palm kernel and shea nuts is reduced in size. Mechanical disc attrition mills are commonly used in rural operations *(Kabutey et al, 2011; Kadirova S., Manukova A., 2009b; Manukova A., Kadirova S., 2009; Sigalingging R. et al, 2014)*.

Moreover, mechanical pressing is most popular method in the world to separate oil from vegetable seeds crops. Thus, the impact of several variables on oil recovery, oil quality, rupture force of seeds, deformation, and energy cost for pressing is essential for an adequate design of equipment for pressing seeds crops *(Sigalingging R., et al, 2014).* Heat treatment before extrusion is necessary for improvement of the amount of recovered oil. Pre-treatment has a significant impact on the efficiency of pressing *(Sayyar S., et al 2009; Willems P. et al, 2008; Kadirova S., 2008; Kadirova S., Manukova A., 2009a; Kadirova S., Manukova A., 2009b; Sigalingging R et al, 2014; Herák D., et al 2013; Kabutey A., et al, 2012).*

The main point of thermal-moisture processing of meal is accomplished in the simultaneous action of water vapour and heat to the cells of the milled mass. Oleaginous cells consist of two main parts - a hydrophilic, which is associated with the water (carbohydrates, proteins and other nitrogen-containing substances) and hydrophobic, which is not associated with the water (oil and other substances dissolved therein). During the heating of the meal, the water contained in the cells, is associated with the hydrophilic portion that swells and intersects - coagulate. It is thus a sharp demarcation between hydrophilic and hydrophobic phase. To suppress the hydrophilic phase it is necessary a precisely defined amount of water. If naturally the water content of meal is insufficient, then it has to be additionally moistened by water or by wet steam *(Sigalingging R et al, 2014; Herák D., et al, 2013; Kabutey A., et al, 2012)*.

The dynamics of variation of meal moisture and temperature as a function of time depends on many interdependent factors. The main parameters are the temperature values of the heating fluid and the incoming meal, the initial moisture content of meal, the relative weight of dry basis, thermal conductivity, heat exchange etc. The recognition of their influence during the thermal-moisture processing of the meal is possible based on the simulation model *(Kadirova S., 2008; Herák D., et al 2013; Kabutey A., et al, 2012)*.

The moisture content of the meal is necessary to be controlled in each stage of the process. It significantly affects the quality of the treatment, which is necessary for the next operation, for extrusion. This requires control of meal moisture variation in all stages of the process (*Herák D., et al, 2013, Kadirova S., 2008).*

The aim of the publication is to investigate the efficiency of the developed electronic system for control of moisture content in the thermal-moisture treatment of meal the preliminary substantiated control points of the treatment process.

MATERIAL AND METHOD

Object of investigation

The structure of the investigated system is presented in Fig. 1. In the current research the parameters of corn-germ meal are investigated. Starting of the system begins with entering of initial conditions - kind of oilseed material and kind of treatment depending on the next stage of the technological process for oil extraction. The initial moisture and specific density of incoming meal are determined by grain sample method, as there is a possibility for process interruption to enter data and to change the treatment parameters. The opportunity for simulation of the process for two main technological operations is provided in the developed software. They respectively are thermal-moisture treatment of meal for full pressing, and treatment for pre-pressing and next chemical extraction *(Manukova A., Kadirova S., 2009a).*

Because of the continuous character of the process the meal in the toaster passes through the sections for exact duration, which depends on the current values of temperature and moisture content of the treated meal. The heating of the material is done indirectly by energy exchange between the meal and heating fluid through the metal wall of the toaster. The surface of the toaster is heated by the fluid circulating in the heating chamber. The meal is processed as it contacts with the heated surface of the section and receives its heating energy via heat exchange.

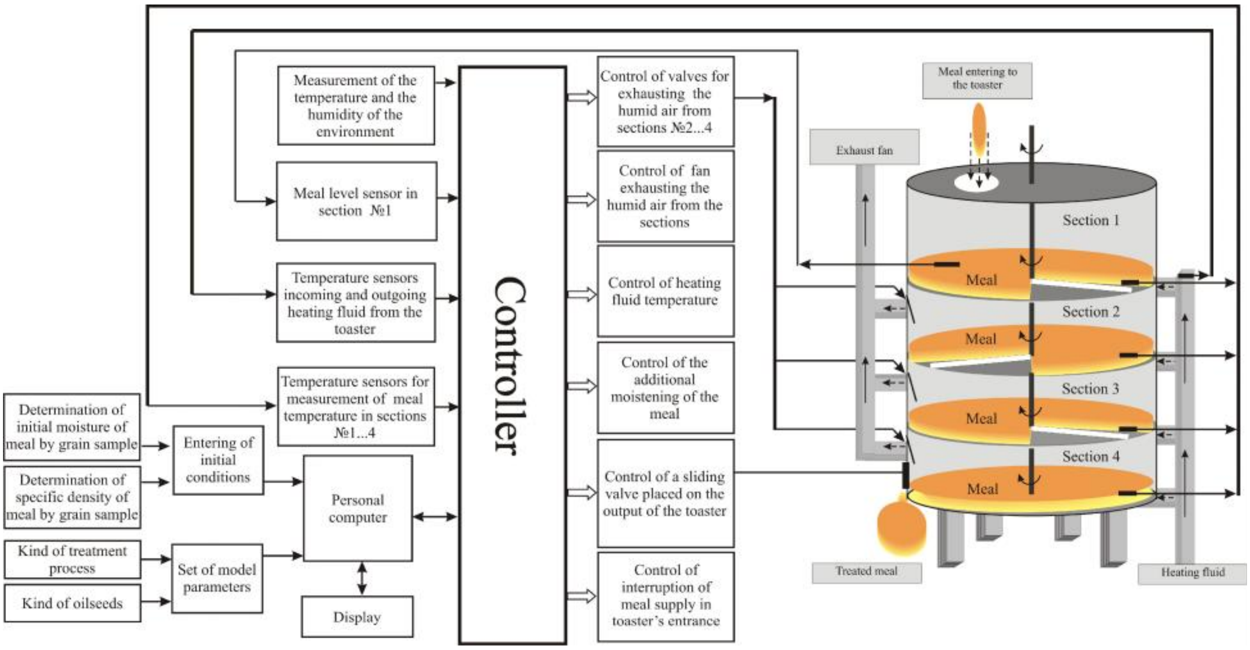


Fig.1 - Structure of the electronic system for control of thermal-moisture processing of oilseeds in a toaster for extraction of vegetable oils

The temperature and humidity of the ambient air are important input data for the environment parameters and they influence the processes' control. The steam saturated air from the section is exhausted by external vent pipe with exhaust fan, as at the output of each section are installed control valves. The initial moisture content of treated oilseeds is determined by grain sample method before it enters into the toaster. The current moisture content of meal is calculated by the proposed model at each stage of the processing. In case of not corresponding to moisture requirements, proposed in the criteria, the electronic system controls the operating mechanisms *(Kadirova S., A. Manukova, 2009a)*.

Toaster's sections are closed vessels containing free airspace intended to absorb the moisture evaporated from meal during heating. This provides a better moisture exchange between the air and the processed material, which helps to intensive the evaporation process of the material and leading away the humid air from the toaster. The movement of meal from one section of the toaster to the other one is realized by cross valves, connected to a mechanical system. It provides constant and uniform passing of meal in the toaster by an exact preliminary defined step in time as well as the quantity of treated meal. In each section are placed temperature sensors for control of the meal temperature in real time.

The amount of the discharging meal is controlled by a sliding valve, placed in section №4. The sliding valve is controlled by the electronic system based on the results obtained from process simulation via the developed model compared with the measured values of parameters at the current time. The position device helps to position the operating mechanism of a sliding valve to a desired position. Thereby, the treated material is being discharged from the toaster at the exact time which leads to a significant increase in system efficiency by reducing the material's duration of stay in the toaster and reduces the energy consumption.

RESULTS

For investigation of the efficiency of the developed electronic control system some experimental studies are implemented. They are based on the variance of the meal moisture. During the experiment the values of the meal moistures at the exit of each section have been measured at each 10 minutes because the process has a significant inertness.

The results are presented in tabular and graphic form. In the control points of the technological scheme, the current values of the meal moisture of the experimentally obtained results are compared with simulation data from developed software. The software is based on literary and experimental data. The root-mean-square deviation, the absolute error and relative error of experimentally obtained moisture data to simulation data, are estimated. The root-mean-square deviation of the current values of meal moisture at the control points is calculated by the following expression:

$$\pm = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}} \text{ , [-]} \tag{1}$$

Experimental investigation at various moisture contents has been conducted and the observed data is summarized in Tables 1 to 4. In Figures 2 to 7 are presented graphical parities of change of meal moisture content in time. Studies, based on developed software model in MATLAB environment, have been conducted as the results are summarized in Tables 1 to 4.

<u>Comparison of the experimental data with the simulation results of the meal moisture at the output of section 1 of the toaster.</u>

Table 1 presents the data for current values of the meal moisture at the output of section 1.

Table 1

Values of the meal moisture at the output of section 1

Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error	Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error
[min]	[%]	[%]	[-]	[%]	[%]	[min]	[%]	[%]	[-]	[%]	[%]
10	9.5	10.5	0.81	0.9	2.26	110	9.4	10.2	0.64	0.8	2.04
20	9.7	9.9	0.04	0.2	0.51	120	10.3	9.1	1.44	1.2	3.09
30	9.3	10.1	0.64	0.8	2.06	130	9.7	10.1	0.16	0.4	1.01
40	9.9	9.1	0.64	0.8	2.11	140	10.2	8.8	1.96	1.4	3.68
50	10.1	10.2	0.01	0.1	0.25	150	10.4	9.6	0.64	0.8	2.00
60	9.7	10.4	0.49	0.7	1.74	160	9.7	10.2	0.25	0.5	1.26
70	8.8	9.7	0.81	0.9	2.43	170	9.2	10.1	0.81	0.9	2.33
80	9.6	10.1	0.25	0.5	1.27	180	9.9	9.7	0.04	0.2	0.51
90	10.2	8.9	1.69	1.3	3.40	190	9.8	9.9	0.01	0.1	0.25
100	10.1	9.5	0.36	0.6	1.53	200	10.2	9.6	0.36	0.6	1.52

The root-mean-square deviation of meal moisture at the output of section 1 of the toaster is $\sigma = 0.77\%$. At the current moisture values the calculated average value of the absolute error is $\varepsilon_{abs} = 0.69\%$, as the relative is $\varepsilon_{rel} = 1.76\%$.

Fig. 2 illustrates the change of meal moisture at the output of section 1. The moisture range of the meal is within the field of defined criterion diapason. The results presented in Fig. 2 are obtained from the simulation model, and the experimental ones are measured in the real toaster.

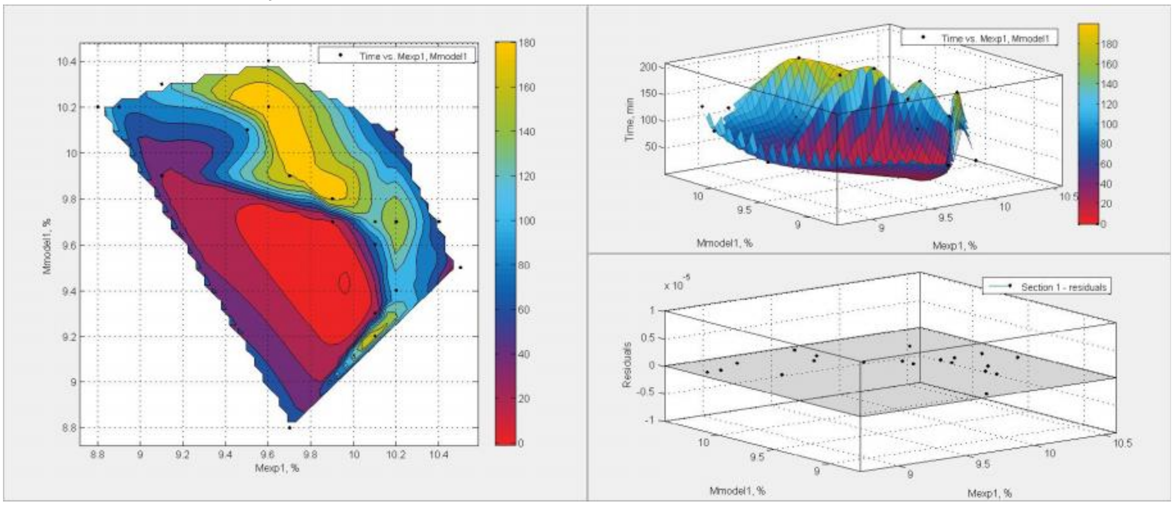


Fig. 2 - Variation of the meal moisture at the output of section 1 in dependence of time

During the model simulation the variation of moisture values is in the range of $M_{meal\_section\_1\_model}$ = (10.4…8.8) %, and the experimentally measured ones in the installation are $M_{meal\_section\_1\_exp}$ = (10.5…8.8) %. For section 1 the diapason of change of the meal moisture is $M_{meal\_section\_1\_criteria}$ = (11…9.5) %. Therefore, the technological requirements for the range of moisture change in section 1 of the toaster are adhered.

Comparison of the experimental data with the simulation results of the meal moisture at the output of section 2 of the toaster.

Table 2 presents the data for current values of the meal moisture at the output of section 2.

Table 2

Values of the meal moisture at the output of section 2

Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error	Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error
[min]	[%]	[%]	[-]	[%]	[%]	[min]	[%]	[%]	[-]	[%]	[%]
10	7.7	7.9	0.04	0.2	0.64	110	7.6	7.8	0.04	0.2	0.65
20	7.4	7.6	0.04	0.2	0.67	120	8	7.6	0.16	0.4	1.28
30	7.8	7.4	0.16	0.4	1.32	130	8.2	8	0.04	0.2	0.62
40	7.7	8.2	0.25	0.5	1.57	140	7.5	8.2	0.49	0.7	2.23
50	7.9	7.7	0.04	0.2	0.64	150	7.6	7.5	0.01	0.1	0.33
60	7.8	7.6	0.04	0.2	0.65	160	7.6	7.9	0.09	0.3	0.97
70	8.1	7.9	0.04	0.2	0.62	170	7.9	7.8	0.01	0.1	0.32
80	8	7.6	0.16	0.4	1.28	180	7.6	8.1	0.25	0.5	1.59
90	7.8	8.1	0.09	0.3	0.94	190	8.1	7.6	0.25	0.5	1.59
100	7.5	8.3	0.64	0.8	2.53	200	7.9	7.8	0.01	0.1	0.32

The root-mean-square deviation of meal moisture at the output of section 2 of the toaster is $\sigma = 0.38°C$. At the current moisture values the calculated average value of the absolute error is $\varepsilon_{abs} = 0.33\%$, as the relative is $\varepsilon_{rel} = 1.04\%$.

Fig. 3 illustrates the change of meal moisture at the output of section 2. The moisture range of the meal is within the field of defined criterion diapason. The results presented in Fig. 3 are obtained from the simulation model, and the experimental ones are measured in the real toaster.

During the model simulation, the variation of moisture values is in the range of $M_{meal\_section\_1\_model}$ = (8.2…7.4) %, and the experimentally measured in the installation are $M_{meal\_section\_1\_exp}$ = (8.3…7.4) %. For section 2 the diapason of change of the meal moisture is $M_{meal\_section\_1\_criteria}$ = (9.5…7) %. Therefore, the technological requirements for the range of moisture change in section 2 of the toaster are adhered.

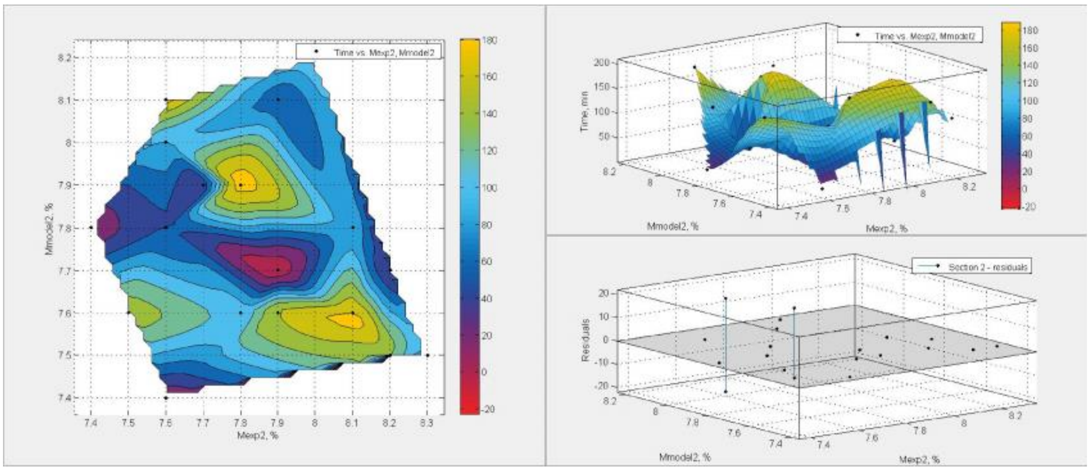


Fig. 3 - Variation of the meal moisture at the output of section 2 in dependence of time

Comparison of the experimental data with the simulation results of the meal moisture at the output of section 3 of the toaster.

Table 3 presents the data for current values of the meal moisture at the output of section 3.

Table 3

Values of the meal moisture at the output of section 3

Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error	Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error
[min]	[%]	[%]	[-]	[%]	[%]	[min]	[%]	[%]	[-]	[%]	[%]
10	5	5.5	0.25	0.5	2.38	110	5.3	5.6	0.09	0.3	1.38
20	5.7	5.6	0.01	0.1	0.44	120	5.2	5.9	0.49	0.7	3.15
30	5.8	5.3	0.25	0.5	2.25	130	5.6	5.7	0.01	0.1	0.44
40	5.4	5.4	0	0	0.00	140	5.1	5.2	0.01	0.1	0.49
50	5.3	5.8	0.25	0.5	2.25	150	5.2	5.4	0.04	0.2	0.94
60	5.5	5.6	0.01	0.1	0.45	160	5.3	5.2	0.01	0.1	0.48
70	5.2	5	0.04	0.2	0.98	170	5.7	5.3	0.16	0.4	1.82
80	5.4	5.2	0.04	0.2	0.94	180	5.3	5.8	0.25	0.5	2.25
90	5.3	5.7	0.16	0.4	1.82	190	5.1	5.5	0.16	0.4	1.89
100	5.6	5.8	0.04	0.2	0.88	200	5.2	5.3	0.01	0.1	0.48

The root-mean-square deviation of meal moisture at the output of section 3 of the toaster is $\sigma = 0.34$. At the current moisture values the calculated average value of the absolute error is $\varepsilon_{abs} = 0.28\%$, as the relative is $\varepsilon_{rel} = 1.29\%$.

Figure 4 illustrates the change of meal moisture at the output of section 3. The moisture range of the meal is within the field of defined criterion diapason. The results presented in Fig. 4 are obtained from the simulation model and the experimental ones are measured in the real toaster.

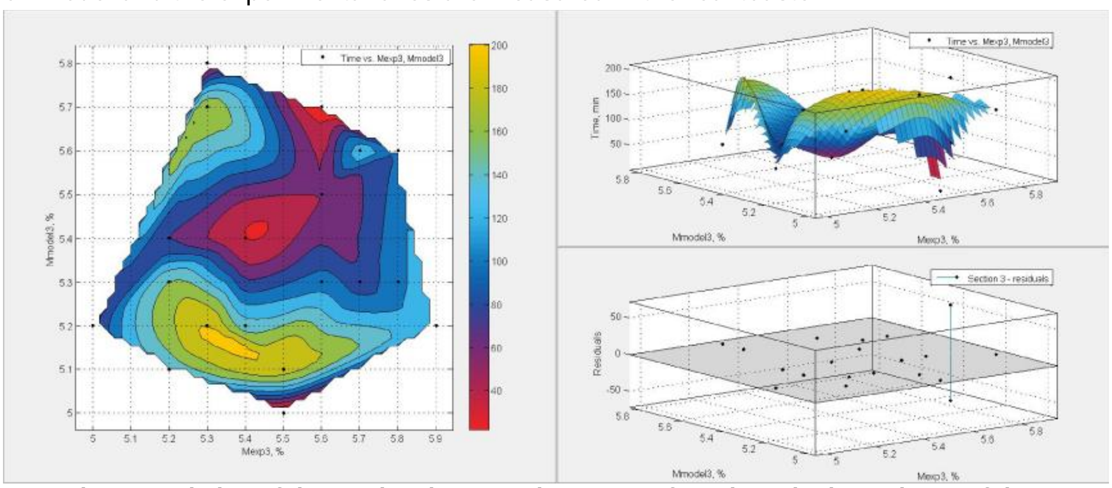


Fig. 4 - Variation of the meal moisture at the output of section 3 in dependence of time

During the model simulation the variation of moisture values is in the range of $M_{meal\_section\_1\_model}$ = (5.8…5.0) %, and the experimentally measured in the installation are $M_{meal\_section\_1\_exp}$ = (5.9…5.0) %. For section 3 the diapason of change of the meal moisture is $M_{meal\_section\_1\_criteria}$ = (7…4.5) %. Therefore, the technological requirements for the range of moisture change in section 3 of the toaster are adhered.

Comparison of the experimental data with the simulation results of the meal moisture at the output of section 4 of the toaster.

Table 4 presents the data for current values of the meal moisture at the output of section 4 (output of the toaster).

Table 4

Values of the meal moisture at the output of the toaster

Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error	Time	M_{ml}, model	M_{ml}, exp	Root-mean-square deviation	Absolute error	Relative error
[min]	[%]	[%]	[-]	[%]	[%]	[min]	[%]	[%]	[-]	[%]	[%]
10	3.2	2.9	0.09	0.3	2.46	110	2.8	3.1	0.09	0.3	2.54
20	2.5	2.7	0.04	0.2	1.92	120	3.1	2.8	0.09	0.3	2.54
30	2.7	2.6	0.01	0.1	0.94	130	3	2.9	0.01	0.1	0.85
40	2.8	2.9	0.01	0.1	0.88	140	2.5	2.6	0.01	0.1	0.98
50	2.6	3.1	0.25	0.5	4.39	150	2.9	2.6	0.09	0.3	2.73
60	2.9	2.7	0.04	0.2	1.79	160	2.8	2.9	0.01	0.1	0.88
70	3.1	2.5	0.36	0.6	5.36	170	2.9	3.1	0.04	0.2	1.67
80	3.2	2.7	0.25	0.5	4.24	180	2.6	2.9	0.09	0.3	2.73
90	3.2	2.9	0.09	0.3	2.46	190	2.5	2.9	0.16	0.4	3.70
100	2.9	2.8	0.01	0.1	0.88	200	2.6	2.8	0.04	0.2	1.85

The root-mean-square deviation of meal moisture at the output of section 3 of the toaster is $\sigma = 0.3$. At the current moisture values the calculated average value of the absolute error is $\varepsilon_{abs} = 0.26°C$, as the relative is $\varepsilon_{rel} = 2.29\%$.

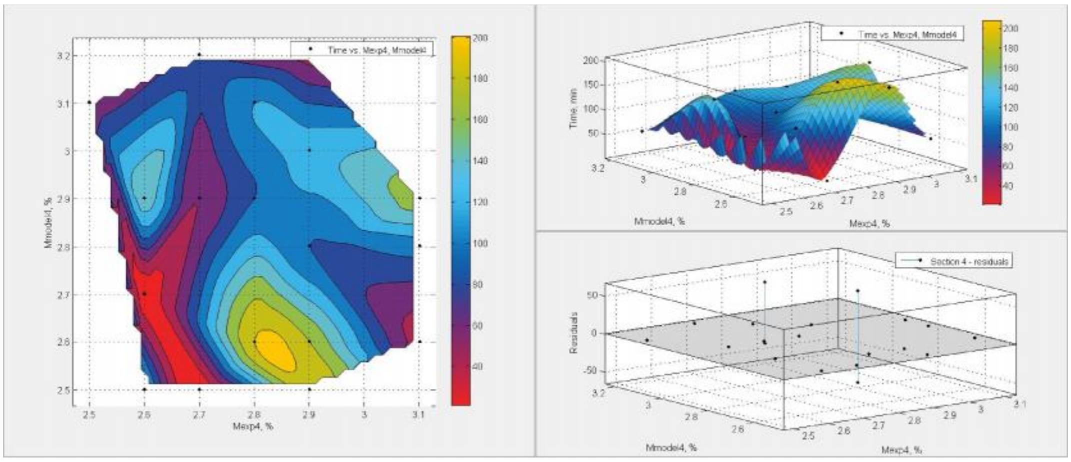
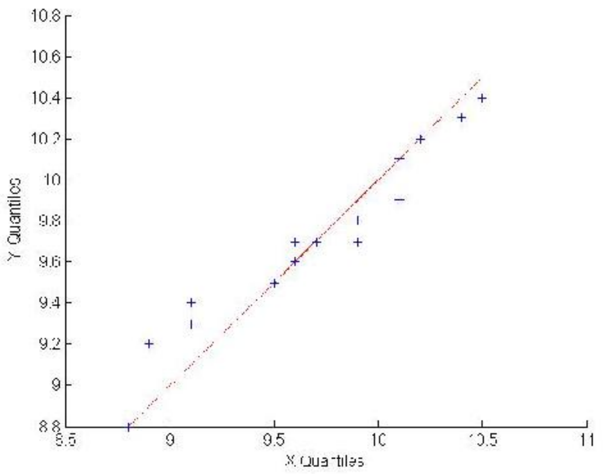


Fig. 5 - Variation of the meal moisture at the output of section 4 in dependence of time

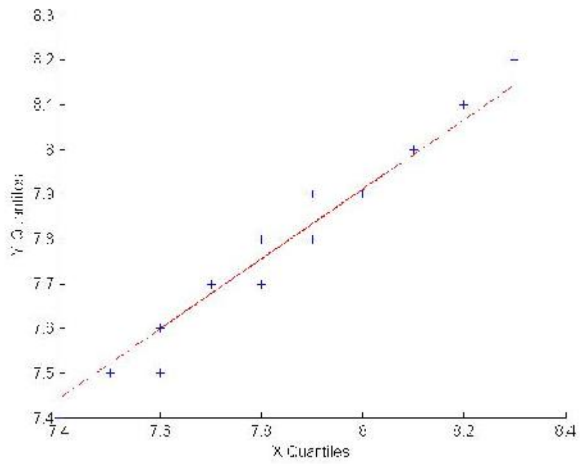
Fig. 5 illustrates the change of meal moisture at the output of section 4. The moisture range of the meal is within the field of defined criterion diapason. The results presented in Fig. 5 are obtained from the simulation model, and the experimental ones are measured in the real toaster.

During the model simulation the variation of moisture values is in the range of $M_{meal\_section\_4\_model}$ = (5.8…5.0) %, and the experimentally measured in the installation are $M_{meal\_section\_4\_exp}$ = (5.9…5.0) %. For section 4 the diapason of change of the meal moisture is $M_{meal\_section\_4\_criteria}$ = (4.5…2.5) %.Therefore, the technological requirements for the range of moisture change in section 4 of the toaster are adhered.

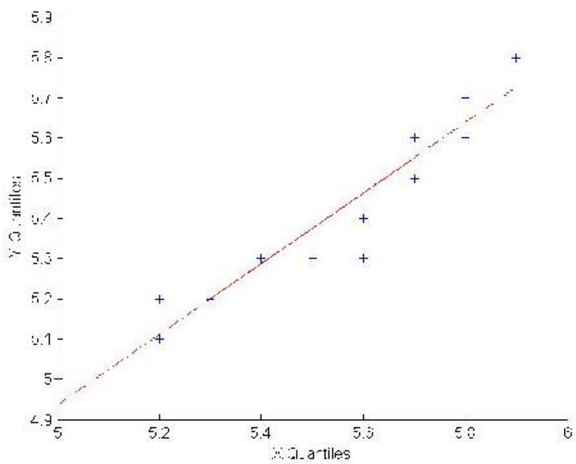
The graphical interpretation of the evaluation of the adequacy of the software model is presented in Fig. 6. The comparative assessment of function $M_{(ml\_model)}=f(M_{ml\_exp)})$ presents a linear distribution of results which provides a high accuracy of the effectiveness of the model. The deviation of the values of the model to experimental data can be read from Figures 2 to 5, where dependence is presented in time, and the character of the results surface is flat.



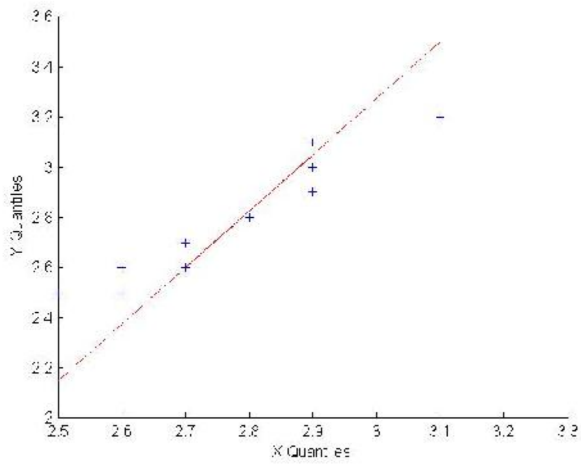
Section 1



Section 2



Section 3



Section 4

Fig. 6 - Variation of the meal moisture at the output of sections – model vs. experiment

The values of relative errors are around the permissible value of 2 %. It is highest at the last section (2.29 %) because the absolute value of the meal moisture is low and closed to 0. Although the variation of the values of the relative errors, the electronic system applies adequate control to the process and the thermal-moisture treated meal is together with parameters substantiated in the criteria.

CONCLUSIONS

The absolute and relative errors for the variation of meal moisture obtained in all control points are lower than the maximum allowable. This is an indicator for the effectiveness of the electronic system for control of meal moisture in the toaster.

The amount of the extracted corn oil increases with a decrease of moisture and increased the processing time. Results of experimental studies present that the electronic system has applied the appropriate variation of control parameters, which affects on the observing of a meal with the exact physicochemical changes and decreasing the effectiveness of the system.

The treated for pressing meal has sufficiently plastic and elastic structure. These properties of the cooked meal are achieved by precise grinding of the oilseeds, and also by applying the most appropriate regime of thermal-moisture treatment that provides the required temperature and moisture properties.

The regulation of the thermal-moisture treatment process via the proposed criteria for assessment of the effectiveness of the developed electronic system based on adequate control, ensuring the reduction of technological processing time of the oilseed material and energy as it guarantees the quality of the final product.

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REFERENCES

[1] Herák D., Kabutey A., Divisova M., (2013), Analysis of tangential curve equation describing mechanical behaviour of rapeseeds (*Brassica napus L.*) mixture under compression loading, *Research in Agricultural Engineering*, vol.59 (1), pp.9–15;

[2] Kabutey A., Herák, D., Sedláþ ek A., (2011), Behaviour of different moisture contents of Jatropha curcas L. seeds under compression loading, *Research in Agricultural Engineering,* vol.57 (2), pp.72–77;

[3] Kabutey A., Herak D., Choteborsky R., Divisova M., (2012), Model for energy and deformation determination of selected oilseeds under compression loading–Short communication, *Research in Agricultural Engineering*, vol.58, pp.155–158;

[4] Kabutey A., Sedláþ ek, A., Divišová M., Svato Ėová T., (2012), Heat treatment of Jatropha Curcas L. seeds under compression loading, *Scientia Agriculturae Bohemica*, vol.43 (3), pp.116–121;

[5] Kadirova S., (2008), Electronic system for control of oil boiler for meal pretreatment in vegetable oil pressing, *Food science, engineering and technologies*, University of food technologies, Plovdiv, pp.273-278;

[6] Kadirova S., Manukova A., (2009a), Criteria for assessment of the quality of thermal–moisture treatment of meal in oil extraction processes by means of electronic control of a toaster, *Agricultural engineering*, Volume XLVI, 4/2009, Sofia, pp. 8-14;

[7] Kadirova S., Manukova A., (2009b), Computer-based model simulating the thermal-moisture processes in a toaster controlled by an electronic system, *Proceeding of the Union of Scientists-Rousse, the 4th International Conference EE&AE'2009*, Ruse, pp. 457-463;

[8] Manukova A., Kadirova S., (2009), Electronic control for high efficient process in thermal-moisture pretreatment of meal, *Elektronika – konstrukcje, technologie, zastosowania*, No 9, pp.162-168;

[9] Sayyar S., Abidin Z.Z., Yunus R., Muhammad A., (2009), Extraction of Oil from Jatropha Seeds-Optimization and Kinetics, *American Journal of Applied Sciences* 6, pp.1390–1395;

[10] Sigalingging R., Herak D., Kabutey A., Mizera C., Divisova M., (2014), Tangent curve function description of mechanical behaviour of bulk oilseeds: A review, *Scientia Agriculturae Bohemica*, vol.45, pp.259–264;

[11] Willems P., Kuipers N.J.M., De Haan A.B., (2008), Hydraulic pressing of oilseeds: Experimental determination and modelling of yield and pressing rates, *Journal of Food Engineering*, vol.89, pp.8–16.