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KINETICS OF OSMOTIC SOLUTION REGENERATION IN THE EVAPORATOR IUR 20

KINETIKA REGENERACIJE OSMOTSKOG RASTVORA U UPARIVAČU IUR 20

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ABSTRACT

A team of researchers from the *Faculty of Agriculture in Novi Sad designed an original device for the regeneration of osmotic solution used in the process of osmotic drying.*

The effects of two types of ceramic (porcelain) fillings and air temperature on the regeneration process were studied.

On the basis of Fisher's criterion, it was concluded that air temperature affects the specific energy consumption for a probability of 95 %. Moreover, it was also concluded (on the basis of Fisher's criterion and for a probability of 95 %) that a type of a porcelain filler has no impact on the specific energy consumption.

In addition, a mathematical model of the functional dependence of regeneration kinetics on regeneration temperature and duration was also established.

The regression analysis resulted in the functional dependence of regeneration kinetics and energy efficiency on the air temperature and the type of examined fillers.

Key words: *sugar solution, osmotic drying, regeneration of osmotic solution, evaporation.*

REZIME

U Laboratoriji za biosistemsko inženjerstvo, na Poljoprivrednom fakultetu u Novom Sadu, konstruisan je originalan uređaj za regeneraciju rastvora koji se koristi u tehnologiji osmotskog sušenja biomaterijala. Princip regeneracije rastvora zasniva se na ishlapljivanju molekula vode iz korišćenog osmotskog rastvora pomoću zagrejanog vazduha.

Prilikom rada regenerisan je šećerni rastvor od koncentracije 50°Bx do 65°Bx.

Ispitan je uticaj temperature vazduha kojim se obavlja regeneracija rastvora i uticaj vrste ispune u reaktoru uređaja na kinetiku regeneracije i energetsku efikasnost uređaja tokom regeneracije.

Obavljeni su eksperimenti sa dva nivoa temperature vazduha (50°C i 70°C) kao prvog uticajnog faktora i dve vrste ispuna u reaktoru uređaja kao drugog uticajnog faktora. Ispitane ispune su porcelanski "Rašig"- ovi prstenovi i porcelanske pletenice proizvođača "Elektroporcelan" iz Aranđelovca.

Disperzionom analizom ispitan je uticaj vrste porcelanskih ispuna i temperature vazduha kojim se obavlja regeneracija rastvora, na specifičnu potrošnju energije.

Na osnovu Fišerovog kriterijuma zaključeno je da temperatura vazduha utiče na specifičnu potrošnju energije, za verovatnoću od 95%. Međutim, na osnovu Fišerovog kriterijuma zaključeno je za verovatnoću od 95%, da vrsta porcelanske ispune ne utiče na specifičnu potrošnju energije.

Pored ovoga ustanovljen je i matematički model funkcionalne zavisnosti kinetike regeneracije od temperature i vremena trajanja regeneracije.

Regresionom analizom došlo se do funkcionalne zavisnosti kinetike regeneracije i energetske efikasnosti regeneracije od temperature vazduha i vrste ispitavanih ispuna.

Ključne reči: *sećerni rastvor, osmotsko sušenje, regeneracija osmotskog rastvora, uparavanje.*

INTRODUCTION

Combined drying technology

The most significant item among the costs of dried fruit production refers to the costs of energy generating products. Due to a constant tendency to cut the costs of production, and at the same time to improve the quality of dried product, a combined technology of osmotic and convective drying of fruit has been developed at the Faculty of Agriculture in Novi Sad since 2001. Combined technology comprises osmotic drying as a pretreatment prior to convective drying. Osmotic dehydration can be used as a pretreatment prior to air drying in order to reduce the water content of food from 70 % to 30 % *(Lenart and Lewicki, 1988)*. Osmotic dehydration has received greater attention in recent years as an effective method for fruit and vegetable preservation. It is less energy-intensive than air or vacuum drying processes because it can be conducted at low or ambient temperatures *(Chavan and Amarowicz, 2012)*. According to the research, osmotic drying as a pretreatment reduces the total consumption of thermal energy by approximately 30 *% (Babić et al., 2005)*. The combined technology of fruit drying, which comprises the osmotic and convective drying, has a chance of mass application in practice *(Kudra and Mujumdar, 2002).*

Osmotic drying

The osmotic drying of fruit and vegetables is performed on the basis of the difference in moisture concentration potential between the biomaterial that is dried and the solution the material is soaked in.

During the osmotic drying of fruit and vegetables, plants are constructed where the environment with a lower concentration of water molecules consists of solutions, i.e. syrups. The choice of the type and concentration of osmotic solution plays an important role. In the case of fruit and vegetables dehydration, the solutions primarily used are sucrose or salt solutions *(Romero et al., 2001)*. In this process, water flows from fruit or vegetables to solution accompanied by such components as minerals, vitamins, fruit acids, etc. The sugar and salt migrate towards the fruit and vegetables. The acid removal and the sugar uptake by the fruit pieces give a sweeter product in comparison with conventionally dried products *(Ashok and Satya, 2014)*.

Requirement for osmotic solution regeneration

Physical and chemical values, structural values and values in use of the solution are constantly changed during the process of osmotic drying. An issue of using osmotic solution is very important *(Dalla Rosa and Girouk, 2001; Courel et al., 2000)*. A useful fact that a solution accepts a certain amount of water in the course of the process requires a special attention since sustainability of combined technology of drying fruit depends on the efficiency of solution regeneration *(Babić et al., 2009)*. In other words, in order to achieve the cost effectiveness of the combined drying method, the solution should be used several times. *Dalla Rosa and Giroux (2001)* studied the issues related to the solution management in osmotic treatments. They examined the following factors: solution mass and dilution loss of solutes and particles from food, concentration restoring and solution recycling, reconditioning of solution, microbial contamination of the solution, microbial contamination of foodstuffs due to food/solution contact, sanitation of the solution, resistance of the solution to the thermal treatments, condition to determine the end-point of the working solution, possible utilisation of spent solutions for different use and problems related to the discharge of the spent solutions.

Due to the requirement of solution regeneration, different technologies and technical solutions have been developed. An original device for regeneration of osmotic solution has been designed and developed at the Faculty of Agriculture in Novi Sad.

MATERIAL AND METHOD

Material

Technical description of the evaporation device

The device for solution regeneration is a result of several years of examination and research carried out in the Biosystems Engineering Laboratory at the Department of Agricultural Engineering, the Faculty of Agriculture in Novi Sad (fig. 1).

Basic requirements of the evaporation process that the device needs to meet are: an adequate air temperature that is used in the evaporation process, an adequate speed and flow of air, as well as an adequate surface of the syrup where water evaporation process takes place. There is a large number of various available technical systems that can meet the set forth technology requirements, however, the question is which of these systems provides market advantage from the point of view of investment and exploitation costs.

The solution of sucrose and water was used during the examination of the regeneration process. The changes in humid air conditions used to regenerate the solution were also examined as changes in solution parameters during the regeneration process. The IUR 20 device consists of: a base, two cylindrical vessels set one above the other, and the accompanying elements. The accompanying elements are: dividing elastic tubes, a wing pump used for syrup circulation, and a ventilator that brings heated air into the reactor of the device *(Stamenković, 2012)*.

Fig. 1. IUR 20 The device for solution regeneration

Osmotic solution

Osmotic drying process is intensified if the solution with a high concentration (60 % – 70 %) of dried matter is used. The solution of sugar and water is either transparent or bright yellow, odour-neutral and sweet in taste.

At the temperature of 160 °C, sugar melts with no change into a clear liquid state, and at the temperature of 200 °C it turns into a brown coloured caramel. An important technical feature of sugar is its capacity to ferment as a result of fungi reaction, i.e. to dissolve into alcohol (ethanol) and carbon-dioxide (alcoholic fermentation).

Porcelain filler of the device for osmotic solution regeneration

The examined porcelain fillers are ’Raschig’ rings and porcelain plaits (fig. 2 and fig. 3). Porcelain ’Raschig’ rings and porcelain plaits are used as fillers of the device reactor’s space in chemical and similar industries. ’Raschig’ rings and porcelain plaits are made of hard porcelain.

Fig. 2. “Raschig” rings

This material has good mechanical features; it is almost entirely chemically resistant to the effect of any acid, with the exception of hydrofluoric acid *(www.epa.rs)*.

The physical features of porcelain fillers were also examined in the paper and the obtained values were compared to the values in the technical documentation of the manufacturer (Table 1)

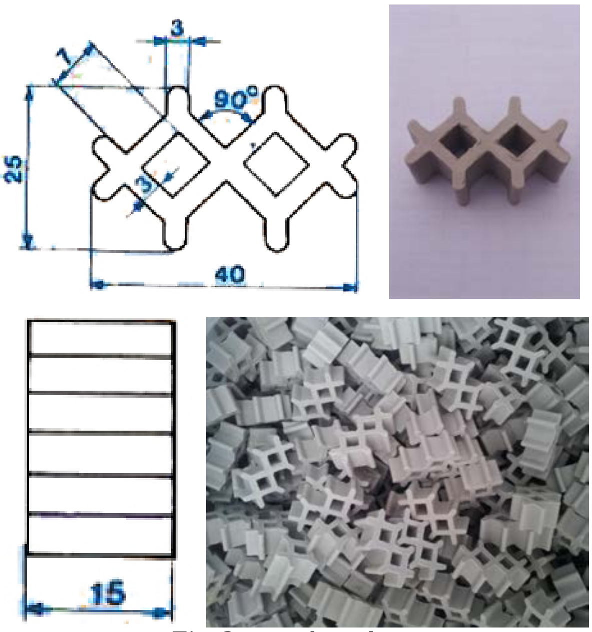

Fig. 3. Porcelain plaits

Technical documentation of the manufacturer of porcelain 'Raschig' rings and porcelain plaits of 'Elektroporcelan' producer from Aranđelovac are not in accordance with the results obtained by the measuring performed at Biosystems Engineering Laboratory.

Table 1. Preview of physical features of porcelain fillers

Measured feature	Label and unit	Porcelain 'Raschig' rings		Porcelain plaits	
		Technical document.	Measured at Biosystems Engineering Laboratory	Technical document.	Measured at Biosystems Engineering Laboratory
Mid mass Of a single piece	m [g]	-	3.30	-	13.26
Length	h [mm]	-	15	-	40
Exterior diameter /width	d [mm]	-	15	-	25
Interior diam./thickness	d_1 [mm]	-	10	-	15
Number of pieces per m^3	N [kom/ m^3]	295,000	225,480	64,000	45,020
Dike thickness	ρ [kg/ m^3]	1,160	744.8	800	596.9
Porosity	P [%]	49	66.8	65	74.5
Active surface per m^3	A [m^2/ m^3]	-	309.75	-	117.15
Volume of a single piece	V [m^3]	-	0.0000014718	-	0.0000056741
Active surface of a single piece	A_{kom} [m^2/ m^3]	-	0.00137375	-	0.003935

Method

A two-factor experiment was conducted with air temperature and a filler type as experimental factors of drying kinetics. Air temperature, as a quantitative factor, was at two levels 50 °C and 70 °C. Two types of fillers were examined as qualitative factors. The combination of these factor levels resulted in 4 experimental units. The experiment was repeated three times. In addition to the examined porcelain fillers, a control measurement was also performed with the filler of stainless steel chips. Stainless steel chips were the original solution of the examined device for osmotic solution regeneration. The measurements were made under equal initial conditions and similar weather conditions. Prior to the beginning of each experimental unit, a filler of the regeneration device was heated by air at the temperature of 60 °C for half an hour. The temperature of the solution at the beginning of each experimental unit was 45 °C, the initial concentration of the solution was 50 °Bx, and the initial quantity of the solution was 25 l. The solution was regenerated up to the concentration of 65 °Bx. The humid air and solution parameters were measured every 20 minutes during the experiment. The speed of humid air prior to entering the regeneration device was maintained and controlled at a constant value of approximately 5 m/s during all experimental units. The air temperature control was carried out by means of laboratory plant controllers.

Parameters of the regeneration process obtained on the basis of the measurements of Lab VIEW instruments include adequate temperatures of air and solution by means of thermocouples. The data measured by computer acquisition are collected in the computer in interval of one minute and are subsequently processed with a view to obtain the following parameters of the regeneration process:

1. The condition of surrounding humid air is obtained by psychometric method, by measuring temperature of dry and humid thermometer (thermocouple).

2. The condition of humid air at the entrance of the device is obtained by measuring the air temperature after heating the surrounding humid air that is prior to entering the examined device. The temperature of the heated air was also measured by means of thermocouples (type K) and it was maintained at the set level of 50 °C or 70 °C.

3. The condition of humid air at the exit of the examined device was determined by measuring the temperature of dry and humid thermocouple at the exit point of the air from the device. The knowledge of the condition of humid air at the exit point is necessary for determining the quantity of humidity evaporated from the solution. The evaporated quantity of humidity compared to the input of energy in the evaporation process provides the value of energy efficiency of the device.

4. The temperature of the solution during regeneration process was also measured by a thermocouple that was immersed in the solution.

The preview of measurements of all physical dimensions during the experiment is provided in table 2.

RESULTS AND DISCUSSION

The measured data were processed by a regression and dispersion analysis. A non-dimensional parameter of the concentration *c* was used in the regression analysis of functional dependence of the solution concentration and the duration of regeneration process. The introduced non-dimensional parameter of concentration of the solution *c* is an indicator of the solution

Table 2. Preview of measurements of all physical dimensions during the experiment (Pavkov, 2012)

Ord. No.	Measured dimension	Unit	Instrument name, Manufacturer and model	Measuring range, resolution and accurateness of the instrument
1.	Temperature of dry thermometer – surrounding air	°C	Thermocouple Type K non-isolated, Mantel, Germany	-40 °C-375 °C, ±0.5 °C
2.	Temperature of humid thermometer – surrounding air	°C	Thermocouple Type K non-isolated with conditioner – moisture cloth, Mantel, Germany	-40 °C-375 °C, ±0.5 °C
3.	Air temperature upon heating	°C	Thermocouple Type K non-isolated, Mantel, Germany	-40 °C-375 °C, ±0.5 °C
4.	Temperature of dry thermometer – upon exiting the device	°C	Thermocouple Type K non-isolated, Mantel, Germany	-40 °C-375 °C, ±0.5 °C
5.	Temperature of humid thermometer – upon exiting the device	°C	Thermocouple Type K non-isolated with conditioner – moisture cloth, Mantel, Germany	-40 °C-375 °C, ±0.5 °C
6.	Solution temperature	°C	Thermocouple Type K non-isolated, Mantel, Germany	-40 °C-375 °C, ±0.5 °C
7.	Concentration of Osmotic solution	°Bx	Digital refract meter, „Atago“ – Japan, model PAL - α	0-85 °Bx; 0.1 °Bx; ±0.1 °Bx
8.	Dynamic air pressure	Pa	Pittot tube, ϕ 4 mm, Digital differential micro manometer Testo 521 with the addition of sensor for precise measuring No: 06381447	0-1000 Pa; 0.1 Pa; ±0.2 Pa
9.	Mass flow of solution	kg/s	Coriolis flow meter „Micro Motion“, model R025	1-60 kg/s; 0.1 – 0.2 % *(Bikić, 2010)*

concentration change. The parameter *c* represents a ratio of the currently measured concentration of solution *C* and the initial concentration of solution C_0, [$c=C/C_0$]. The impact of air temperature and a filler type as experimental factors onto the kinetics of solution regeneration and specific consumption of the solution during regeneration were examined by a dispersion analysis.

Filler made of porcelain Raschig rings

The regression analysis examined the functional dependence of the solution concentration change and duration of regeneration process. The chart in fig. 4 indicates the kinetics of osmotic solution regeneration process with the filler made of porcelain Raschig rings at both air temperatures of regeneration. The regression analysis determined a linear dependence of the change in the concentration of osmotic solution and duration of regeneration process. At both air temperatures, the determination coefficient is high and exceeds the amount of 0. 98. The regeneration at the air temperature of 70 °C lasts 160 minutes, which is significantly shorter than the process of regeneration at the air temperature of 50 °C which lasts 260 minutes.

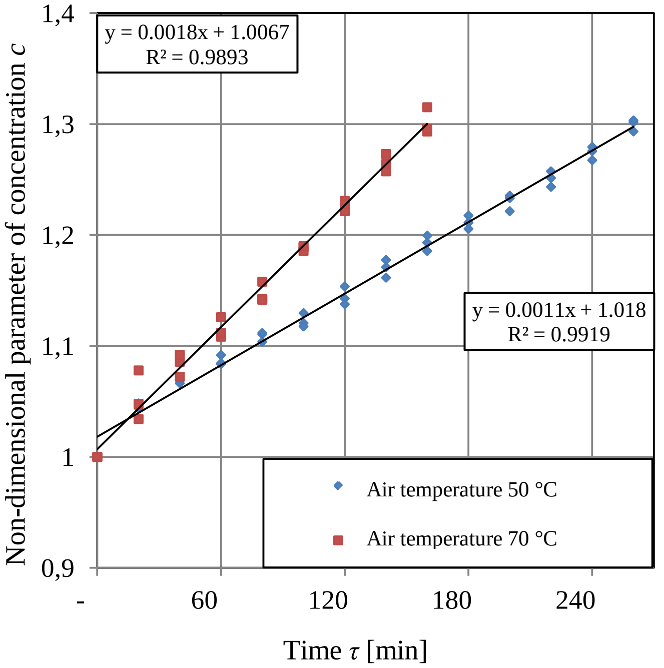

Fig. 4. Dependence of non-dimensional parameter of concentration c (ratio of current and initial concentration of solution) and duration of the process τ - porcelain 'Raschig' rings

Filler made of porcelain plaits

The kinetics of osmotic solution regeneration process is presented in the chart in fig. 5 with a filler made of porcelain

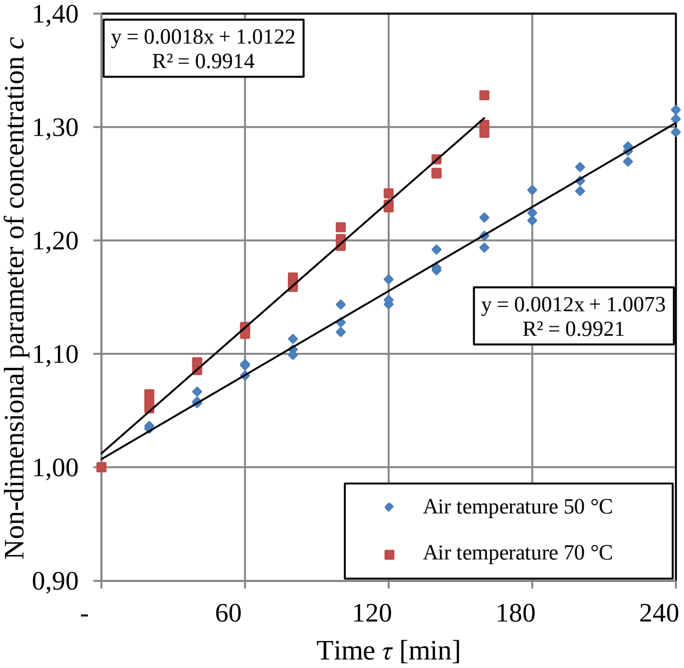

Fig. 5. Dependence of non-dimensional parameter of concentration c (ratio of current and initial concentration of solution) and duration of the process τ - porcelain plaits

plaits. The analysis of the chart in fig. shows that the regeneration of osmotic solution at the air temperature of 70 °C lasts 160 minutes, and the regeneration at the air temperature of 50 °C lasts 240 minutes. The regression analysis determined a linear dependence of the change in the concentration of osmotic solution and duration of regeneration process. At both air temperatures, the determination coefficient is high and exceeds the amount of 0.99.

The analysis of the charts in fig. 4 and 5 indicates a significant difference in terms of the duration of regeneration process at the air temperature of 70 °C, whereat the regeneration process with a filler of porcelain plaits is 20 minutes shorter than with a filler of porcelain 'Raschig' rings.

The chart in fig. 6 indicates a functional dependence of the specific energy consumption *q* [kJ/kg$_{evapo.\ wat.}$] and the concentration of osmotic solution *C* [°Bx].

The chart in fig. 6 indicates the results of measuring during the solution regeneration at the air temperature of 50 °C for both examined porcelain fillers as well as the original filler of stainless steel chips. The regression analysis determined a stepwise dependence of the change in the specific energy consumption q [kJ/kg $_{eva.\ wat.}$] and the concentration of osmotic solution C [°Bx]. The determination coefficient is satisfactory in all three cases.

The analysis of the chart in fig. 6 determines that the specific energy consumption with porcelain fillers is also very close, whereas a significantly higher specific energy consumption was noted during the regeneration with the filler of stainless steel chips.

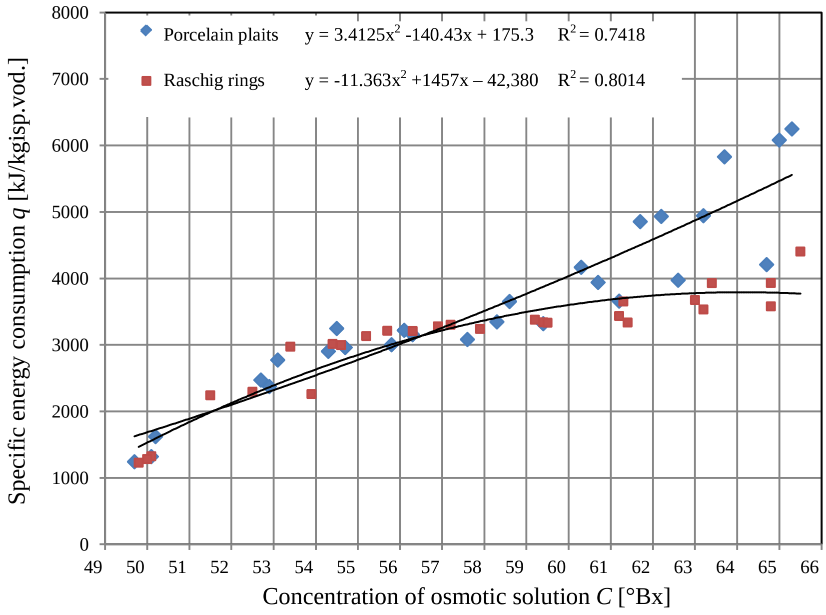

Fig. 7. Dependence of specific energy consumption q [kJ/kg$_{isp.vod.}$] and concentration of osmotic solution C [°Bx] – Air temperature 70 °C

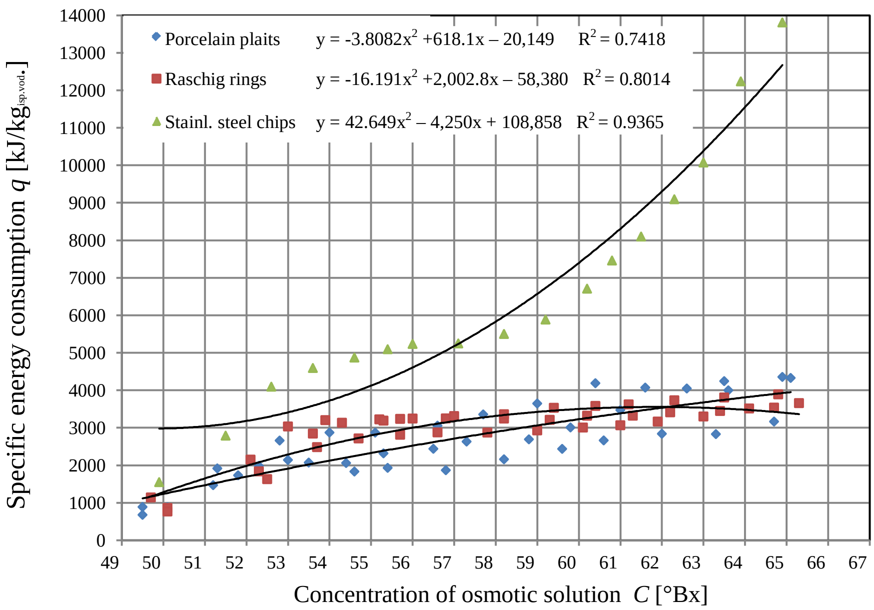

Fig. 6. Dependence of the specific energy consumption q [kJ/kg$_{isp.vod.}$] and The concentration of osmotic solution C [°Bx] – The air temperature 50 °C

The specific energy consumption for both porcelain fillers is within the limits of 800-5,000 kJ/kg $_{evapo.\ wat.}$, whereas these limits of 1,200-14,000 kJ/kg$_{evapo.\ wat.}$ are for the filler made of chips. It is important to note that the duration of solution regeneration process with stainless steel chips is significantly longer and it amounts to 320 minutes. The chart in fig. 7 indicates a dependence of the specific energy consumption q [kJ/kg $_{evapo.\ wat.}$] and the concentration of osmotic solution C [°Bx] during the solution regeneration at the air temperature of 70 °C for both examined porcelain fillers. The regression analysis has determined a stepwise dependence of the specific energy consumption q [kJ/kg $_{evapo.\ wat.}$] and the concentration of osmotic solution C [°Bx]. The determination coefficient is satisfactory in both cases. The specific energy consumption during regeneration with the filler of porcelain plaits is within the limits of 1,000-6,500 kJ/kg$_{eva.\ wat.}$ and with porcelain rings within the limits of 1,000-4,500 kJ/kg $_{evapo.\ wat.}$

Dispersion analysis (variance analysis)

The tables suitable for dispersion analysis in the Statistica 12 software package were formed on the basis of draft tables. The dispersion analysis examined impact of the process duration, air temperature and types of fillers, as experimental factors, on the kinetics of solution regeneration and specific energy consumption during the regeneration process. The results of dispersion analysis are presented in Tables 3 and 4.

The calculated value of Fisher's criterion for every factor of the experiment is higher than the table value. It can be concluded on such basis that air temperature, process duration and filler type impact the change of solution concentration for a probability of 95 %. Furthermore, Fisher's criterion for interaction of factors of process duration and air temperature is higher than the table value, which means that there is a statistically significant interaction of these two factors for a probability of 95 %.

On the basis of Fisher's criterion, it can be concluded that there is no statistically significant impact of interaction of other factors of the experiment for a probability of 95 %. The dispersion analysis shows the impact of both types of porcelain fillers and air temperature used for solution regeneration on the specific energy consumption. The results of dispersion analysis are presented in Table 4. In this case, the calculated value of Fisher's criterion for the impact of air temperature on specific energy consumption is higher than the table value. It can be concluded on such basis that air temperatures impact the specific energy consumption for a probability of 95 %.

curve of dependence of the solution concentration on time. The linear equations for porcelain 'Raschig' ring filler are:

for the air temperature of 50 ⁰C.
$c = 0.0011\tau + 1.018$; $R^2 = 0.9919$
for the air temperature of 70 ⁰C.
$c = 0.0018\tau + 1.0067$; $R^2 = 0.9893$
The linear equations for porcelain plait filler are:
for the air temperature of 50 ⁰C.
$c = 0.0012\tau + 1.0073$; $R^2 = 0.9921$
for the air temperature of 70 ⁰C
$c = 0.0018\tau + 1.0122$; R^2 0.9914

Table 3. Results of dispersion analysis of the impact of air temperature, process duration and fillers type on the kinetics of solution regeneration

Effect	Sum of squares	Degree of freedom	Mid value of the square	F value	Table F-value
Process duration	0.6565	8	0.0821	**1177**	2.07
Air temperature	0.0710	1	0.0710	**1019**	3.98
Filler type	0.0005	1	0.0005	**7**	3.98
Process duration / Air temperature	0.0325	8	0.0041	**58**	2.07
Process duration / Filler type	0.0006	8	0.0001	1	2.07
Air temperature./ Filler type	0.0002	1	0.0002	2	3.98
Process duration / Air temperature / Filler type	0.0007	8	0.0001	1	2.07
Error	0.005020254	72	0.0000697257591		

A non-dimensional factor of air temperature on an exponent was introduced in previous linear equations: $c = a \cdot \tau\,(t/20)^n + b$, where: *c* – stands for a non-dimensional concentration parameter, τ stands for regeneration duration, *t* stands for air temperature, an *a*, *b* and *n* stand for constants. Statistica 12 programme was used for the mathematical model examination. The analysis of the examined mathematical form produced a functional dependence of non-dimensional parameter of the concentration *c* on the process duration and air temperature in the form of:

$$c = 0.000299 \cdot \tau(t/20)^{1.420814} + 1.013423$$

With reference to porcelain 'Raschig' ring filler, the determination coefficient is R^2=0.9897.

With reference to porcelain plait filler, the obtained mathematical model has the following form:

$$c = 0.000382 \cdot \tau(t/20)^{1.268446} + 1.009393$$

Table 4. Results of dispersion analysis of the impact that filler types and air temperature through which solution regeneration is performed have on specific energy consumption

Effect	Sum of squares	Degree of freedom	Mid value of the square	F value	Table F-value
Air temperature	7.115250E+06	1	7.115250E+06	**7.720**	3.92
Filler type	4.498619E+05	1	4.498619E+05	0.488	3.92
Air temperature/ Filler type	5.176811E+06	1	5.176811E+06	**5.617**	3.92
Error	1.207379E+08	131	9.216634E+05		

However, the value of Fisher's criterion for impact of the type of porcelain fillers on specific energy consumption is lower than the table value. It can be concluded on such basis that a type of porcelain filler has no impact on the specific energy consumption for a probability of 95 %. The interaction of examined factors has an impact on the specific energy consumption during the process of osmotic solution regeneration for a probability of 95 %.

Regression analysis of solution regeneration kinetics and research of an adequate mathematical model

The regression analysis determined a mathematical form of dependence of the solution concentration change during the regeneration process. Since three repetitions were performed in terms of solution regeneration at the air temperature of 50 °C, as well as at the temperature of 70 °C, the data were put together, regarding each air temperature and regression analysis for both types of porcelain fillers. The results of regression analysis are presented both graphically as regression curves (fig. 4 and fig. 5) and analytically. The greatest values of the determination coefficient are obtained if a linear equation is set for a regression

The determination coefficient is R^2=0. 9915912.

The obtained mathematical models are reliable and have a high determination coefficient.

CONCLUSION

Two types of porcelain fillers in the osmotic solution regeneration devices designed at the Faculty of Agriculture in Novi Sad are presented and examined. The examined porcelain fillers are 'Raschig' rings and porcelain plaits. The dispersion analysis determined a statistically significant impact of air temperature, duration of the regeneration process and types of fillers on the change of solution concentration for a probability of 95 %. The dispersion analysis also served to examine the impact of types of porcelain fillers and air temperature used for solution regeneration on the specific energy consumption. Air temperature has an impact on the specific energy consumption for a probability of 95 %. However, it was established that in terms of a probability of 95 %, the type of porcelain filler has no impact on the specific energy consumption. The regression analysis determined a linear dependence of the change of osmotic solution concentration and duration of regeneration process for both air temperatures at which osmotic solution regeneration is performed and both examined porcelain fillers. The determination coefficient of all determined linear equations is high and exceeds the amount of 0. 98. The functional dependence of specific energy consumption q [kJ/kg$_{evapo.\ wat.}$] and concentration of osmotic solution C [°Bx] is also presented in the paper.

The analysis of the examined mathematical form resulted in a functional dependence of non-dimensional parameter of the concentration c on the process duration and air temperature in the form of - $c = 0.000299 \cdot \tau(t/20)1.420814 + 1.013423$, for a filler made of porcelain 'Raschig' rings. The determination coefficient is R^2=0. 9897. In terms of the filler made of porcelain plaits, the obtained mathematical model has a form of $c = 0.000382 \cdot \tau(t/20)1.268446 + 1.009393$, and the determination coefficient is R^2 = 0. 9915912.

The specific thermal energy consumption in the case of 'Raschig' rings is in the range of 800-5,000 kJ/kg$_{evapo.\ wat.}$ in the case of porcelain plaits is in the range of 800-5,000 kJ/kg$_{evapo.\ wat.}$ and in the case of stainless steel chips is in the range of 1,200-14,000 kJ/kg$_{evapo.\ wat.}$ at the air temperature of 50 °C. The specific thermal energy consumption in the course of regeneration with a filler made of porcelain plaits is in the range of 1,000-6,500 kJ/kg$_{isp.vode}$, and in terms of porcelain rings it is in the range of 1,000-4,500 kJ/kg$_{evapo.\ wat.}$ at the air temperature of 70 °C.

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