RESEARCH ARTICLE | NOVEMBER 27 2024

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AIP Conf. Proc. 3244, 060007 (2024)
https://doi.org/10.1063/5.0241534

Determination and Mathematical Modeling of the Optimal Modes of Cotton Oiling Process with Electrical Impulse Operation

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Abstract. In the article, in order to speed up the process of extracting oil from the technical seed, press the method to fully squeeze the extracted oil and increase the press productivity, the moisture level of the product, the thickness of the processed product, and the capacitor capacity of the electric pulse processing device and the number of pulses, the discharge voltage The degree of damage to seed cells and tissues has been theoretically investigated. In order to increase the amount of oil obtained from seed pulp, functional relationships between the parameters of the electric impulse treatment device and the amount of oil output during the pressing process are presented.

INTRODUCTION

Cottonseed oil holds a significant position in global consumption, ranking eighth worldwide. Its nutritional profile, enriched with phospholipids, essential oils, omega-3 fatty acids, and vitamin e, renders it advantageous for human health compared to other vegetable oils. With an annual production of 23 million tons of cotton raw materials, where 30-35 percent comprises seeds, and 5.5 million tons yield oil, there arises a pressing need to develop energy-efficient methodologies and technical apparatus for oil extraction [1,2].

Among the primary processing techniques for oil extraction from oilseed products, mechanical, chemical, and electrophysical methods stand prominent. Electrophysical processing emerges as an energy-conserving, high-quality technological avenue [3]. Specifically, electric impulse processing presents itself as an eco-friendly, efficient means to produce superior food products without subjecting them to heat. This method operates through pulsed electric discharge applied to the processed material, inducing cracks on cell membranes, facilitating the swift release of oil from plant material into cells.

Contemporary research highlights the efficacy of primary treatment of plant materials and agricultural products using electrical methods, particularly electric impulse discharge. This approach proves superior in terms of energy efficiency compared to other electrical methods, expediting the oil extraction process while concurrently reducing energy consumption. In light of these advancements, exploring the applicability of electric impulse operation in cotton

International Scientific Conference on Modern Problems of Applied Science and Engineering
AIP Conf. Proc. 3244, 060007-1–060007-7; https://doi.org/10.1063/5.0241534
Published under an exclusive license by AIP Publishing. 978-0-7354-5085-1/$30.00

oiling processes stands as a promising endeavor, aligning with the global quest for sustainable, resource-efficient practices in oil extraction [4,5].

Mathematical Modeling of Oil Extraction Process by Dimensional Analysis: The study by Ionescu et al. provides valuable insights into the mathematical modeling of oil extraction processes, particularly through dimensional analysis. They highlight the significance of the vegetable oil industry and the prevalent methods of oil extraction, with a special focus on mechanical pressing [6,7]. By developing a mathematical model validated through experimental data, the researchers shed light on the factors influencing oil recovery efficiency.

Actual Methods for Obtaining Vegetable Oil from Oilseeds: The comprehensive review by Ionescu, Ungureanu, Biriş, Voicu, and Dilea provides an overview of the methods employed in obtaining vegetable oil from oilseeds [8,9]. By addressing the challenges and necessities of efficient oil extraction, the article underscores the importance of optimizing extraction processes [10]. As the demand for vegetable oil rises, the need for faster and more efficient extraction methods becomes imperative.[11,12]. This article sets the stage for exploring novel approaches such as electrical impulse operation in cotton oiling, building upon established methods while aiming for greater efficiency and sustainability. In conducting experimental studies, the method of mathematical planning of studies is used to obtain the necessary information about the studied process with less time and effort. Experimental research is faced with the task of building a mathematical model of the process connecting external influences and object parameters with processing quality.[13,14].

METHODS.

Taking into account the requirements for the development of a mathematical model of the process of damage to cells and tissues by electric pulse treatment of seed extract, it is necessary to determine the factors and determine their variation intervals.

Mathematical planning issues include:

- preliminary study of the process;
- selection of optimal parameters;
- selection of variation factors;
- selection of variation ranges and variations;
- choosing a planning matrix;
- conducting research;
- processing of research results;
- obtaining equations in the process of mathematical handwriting;
- coefficient indicators;
- values of the model;
- statistical evaluation of processing [15].

In the results of monitoring the process of product processing and damage, the results of optimal processing indicators and variation factors were selected. Based on the results of studies of electroimpulse processing of seed pulp, the range of variation factors of quantity change was selected.

Work was carried out using the mathematical theory of planning experiments to reduce the number of experiments and increase accuracy, to obtain the equations of mathematical descriptions of the process, to set the mode parameters in the optimal field of research [16,17].

RESULTS AND DISCUSSIONS.

In order to construct the experimental planning matrix, the conversion of the factors from their actual values to their coded value was performed using the following expression.

$$x_i = \frac{x_i - x_{io}}{\varepsilon} \quad (1)$$

Here: - x_i – i is the coded value of the factor;

x_i - i the control value of the i factor;

x_{io}- i is the zero-level control value of the factor;

ε is the change interval of this factor.

For each factor, we first code the zero level and change interval.

We select the following type of mathematical model:

$$y = b_0 + \sum_{i=1}^{n} b_i x_i + \sum_{i<1}^{n} b_{ij} x_i x_j + \sum_{n=1}^{n} b_{ij} x_i^2 \quad (2)$$

We use the method of planning a second-order experiment of type Vn.

From the initial experiments, the following were determined as the main parameters affecting the degree of damage (S) of the oil-holding tissues in the seed extract:

x_1 – discharge voltage, kV;

x_2 – number of pulses, units;

x_3 – capacitor capacity, μF;

x_4 - humidity of the solution, %

x_5 - The thickness of the material to be processed, mm [18,19].

During the experiments, three experiments were conducted at each point of the spectrum of the B_5 plan. The order numbers of the experiments were carried out according to the given table.

The determined factors, their change intervals and levels are presented in table 1.

TABLE 1. Intervals and levels of factor studies.

Identification of factors		**Factors**	**Interval**	**Degrees**		
Encoded	Natural			-1	0	+1
X_1	U	Discharge generating voltage, kV	2	4	6	8
X_2	n	Number of pulses, pc	8	10	18	26
X_3	C	Capacitor capacity, μF	0,2	0,6	0,8	1
X_4	f	Liquid moisture %	3	6	9	12
X_5	h	Thickness, mm	5	5	10	15

The matrix of key functions for this plan is presented in Table 2.

In Table 2, the average values and variances of n parallel experiments were calculated using the following formulas:

$$\overline{y}_g = \frac{1}{m} \sum_{i=1}^{m} y_{gi} \quad (3)$$

$$S_g^2 = \frac{1}{m-1} \sum_{i=1}^{m} \left(y_{gi} - \overline{y}_g \right)^2$$

In order to check the expression of the experiment according to the Cochrane criterion for q=0.05:

$$G = 0{,}8563 < G_{1-q}(v_1 = 2, \quad v_2 = 42) = 0{,}1131$$

The hypothesis that this value represents the experience does not contradict the observational results.

We calculate the degree of dispersion expression using the following formula [20,21]

$$S^2\{y\} = \frac{1}{N} \sum_{g=1}^{N} S_g^2 = \frac{1}{N_1 + 2n + N_0} \sum_{g=1}^{N} S_g^2 = \frac{142{,}07}{42} = 3{,}38 \quad (4)$$

We calculate the average variance as follows:

$$S^2\{\overline{y}\} = \frac{S^2\{y\}}{m} = \frac{3{,}38}{3} = 1{,}127 \quad (5)$$

To determine the regression coefficients, we calculate the following sum:

$$z_j = \sum_{g=1}^{N} f_{gj} \overline{y}_g, \ j = 0 \ldots 20. \quad (6)$$

Here: $j = 0$ for $f_{g0} = 1$; $j = 1 \ldots 5$ for $f_{gj} = (x_i)_g$; $j = 6 \ldots 15$ for $f_{gj} = (x_i x_j)_g$ $(ij = 1 \ldots 5, \quad i = f)$; $j = 16 \ldots 20$ for $f_{gj} = (x_i^2)_g$ $(i = 1 \ldots 5$.

TABLE 2. t_j – criteria and b_j – coefficients calculation results.

basis function	j	z_j	b_j	$S^2(b_j)$	$S(b_j)$	t_j
1	0	2820,40	43,65	0,44527	0,66728	65,42
x_1	1	76,00	4,22	0,24952	0,49952	8,45
x_2	2	67,10	3,73	0,24952	0,49952	7,46
x_3	3	23,80	1,32	0,24952	0,49952	2,65
x_4	4	18,10	1,01	0,24952	0,49952	2,01
x_5	5	73,20	4,07	0,24952	0,49952	8,14
x_1x_2	6	-10,20	-0,64	0,28068	0,52980	-1,20
x_1x_3	7	-24,40	-1,53	0,28068	0,52980	-2,88
x_1x_4	8	-11,00	-0,69	0,28068	0,52980	-1,30
x_1x_5	9	-2,60	-0,16	0,28068	0,52980	-0,31
x_2x_3	10	61,20	3,83	0,28068	0,52980	7,22
x_2x_4	11	30,60	1,91	0,28068	0,52980	3,61
x_2x_5	12	-55,00	-3,44	0,28068	0,52980	-6,49
x_3x_4	13	27,20	1,70	0,28068	0,52980	3,21
x_3x_5	14	44,00	2,75	0,28068	0,52980	5,19
x_4x_5	15	-8,60	-0,54	0,28068	0,52980	-1,01
x_1^2	16	2156,80	3,21	1,14029	1,06784	3,31
x_2^2	17	2173,10	8,26	1,14029	1,06784	8,73
x_3^2	18	2169,40	7,11	1,14029	1,06784	7,66
x_4^2	19	2167,50	6,52	1,14029	1,06784	6,61
x_5^2	20	2175,20	8,91	1,14029	1,06784	9,34

Using the calculated sum values $Z_j (j = 0 \ldots 14)$, we calculate the regression coefficients using the following formulas.

$$b_0 = \frac{a}{N}\sum_{i=1}^{N}\bar{y}_g - \frac{b}{N}\sum_{i=1}^{n}\cdot\sum_{g=1}^{N}(x_i^2)_g\bar{y}_g; \quad (7)$$

$$b_i = \frac{1}{\lambda_2\cdot N}\cdot\sum_{g=1}^{N}(x_i)_g\bar{y}_g; \quad (8)$$

$$b_{ij} = \frac{1}{\lambda_3\cdot N}\cdot\sum_{g=1}^{N}(x_i x_j)\bar{y}_g; \quad (9)$$

$$b_{ij} = \frac{c}{N}\cdot\sum_{i=1}^{N}(x_i^2)\bar{y}_g - \frac{d}{N}\cdot\sum_{i=1}^{n}\cdot\sum_{g=1}^{N}(x_i^2)\bar{y}_g - \frac{b}{N}\cdot\sum_{g=1}^{N}\bar{y}_g; \quad (10)$$

Here:
a,b,c,d $(\lambda_{\cdot 2}\cdot N)^{-1}$, $(\lambda_3\cdot N)^{-1}$ auxiliary constructions for calculating constants, model coefficients.

When the number of coefficients in n=5 is equal to five, the value of the constants is as follows: [22,23]

a = 4,1642; b= 0,91416; c= 13; d= 2,33584; $(\lambda_{\cdot 2}\cdot N)^{-1} = 0{,}05556$; $(\lambda_3 N)^{-1} = 0{,}0625$.

The variances of the coefficients are calculated using the following expressions:

$$S^2(b_0) = \frac{a}{N} S^2\{\bar{y}\}; \tag{11}$$

$$S^2\{b_i\} = (\lambda_2 \cdot N)^{-1} S^2\{\bar{y}\}; \tag{12}$$

$$S^2\{b_{ij}\} = (\lambda_3 \cdot N)^{-1} S^2\{\bar{y}\}; \tag{13}$$

$$S^2\{b_{ii}\} = \frac{C-OC}{N} S^2\{\bar{y}\}; \tag{14}$$

t_j- we calculate the criterion values using the following expression:

$$t_i = \frac{|b_j|}{S\{b_j\}} \tag{15}$$

Here: $S\{b_j\} = \sqrt{S^2\{b_j\}}$ sample mean square deviation.

To check the significance of the estimation of the regression coefficients, we compare the null hypothesis with the alternative value of the Student's t-criterion by the following inequality:[24]

$$t_j > t_{1-\frac{g}{2}}(v = N(m-1)) \tag{16}$$

here: $t_{1-\frac{g}{2}}(v)$ - B = H (m-1) of Stewdent's for the number of degrees of freedom $(1-\frac{g}{2})$ % quantile distribution, null hypothesis $H_0 \cdot \beta = 0$ is rejected and the corresponding estimate of b_i is considered statistically significant.

In this case $q = 0{,}05$ quantile of the Stewdent distribution for $t_{1-\frac{g}{2}}(84) = 1{,}987$ is equal.

b_5, b_6, b_8, b_9, b_{10}, b_{12}, $б_{13}$ (3.19) is not satisfied for the coefficients, so these coefficients are not significant.

Thus, we get the mathematical model in the following form:

$$Y = 43{,}65 + 3{,}21x_1^2 + 8{,}26x_2^2 + 7{,}11x_3^2 + 6{,}52x_4^2 + 8{,}91x_5^2 + 4{,}22x_1 + 3{,}73x_2 + 1{,}32x_3 + 1{,}01x_4 + 4{,}07x_5 - \\ -0{,}64x_1x_2 - 1{,}53x_1x_3 - 0{,}69x_1x_4 - 0{,}16x_1x_5 + 3{,}83x_2x_3 + 1{,}91x_2x_4 - 3{,}44x_2x_5 + \\ +1{,}70x_3x_4 + 2{,}75x_3x_5 - 0{,}54x_4x_5$$

The next step in processing the experimental results is to check the hypothesis about the adequacy of the mathematical model and the response function. After the regression analysis method, this selection is done by comparing variance and adequacy variance [25].

The test of the hypothesis about the adequacy of the hypothesis about the homogeneity of the two specified variances is carried out using Fisher's criterion:

$$F = \frac{S_{OTK}^2}{S^2\{\bar{y}\}} \tag{17}$$

The sample variance S_{OTK}^2 is found using the following formula:

$$S_{OTK}^2 = \frac{\sum_{g=1}^{N}(\bar{y}_g - \hat{y}_g)^2}{N-d} \tag{18}$$

Based on the value in the table, we calculate [26]:

$$S_{OTK}^2 = \frac{1875{,}9}{21} = 89{,}32$$

Taking $S_{OTK}^2 < S_{\{\bar{y}\}}^2$ into account, we calculate as follows::

$$F = \frac{S^2\{\bar{y}\}}{S_{OTK}^2} = \frac{1{,}127}{89{,}32} = 0{,}0126$$

B_1=Nd=42-21=21; B_2=N(h-1)=42(3-1)=84

q=0,05 The tabular value of Fisher's criterion at is equal to:

F= 0,0126 <F_{1-q}(21,84) = 1,8425

Therefore, the hypothesis about the compatibility of the mathematical model and the response function does not contradict the observational results [27].

Excluding insignificant coefficients and calculating the obtained data, the mathematical model in coded form is as follows:

$$Y = 43{,}65 + 3{,}21x_1^2 + 8{,}26x_2^2 + 7{,}11x_3^2 + 6{,}52x_4^2 + 8{,}91x_5^2 + 4{,}22x_1 + 3{,}73x_2 + 1{,}32x_3 + 1{,}01x_4 + 4{,}07x_5 \\ - -0{,}64x_1x_2 - 1{,}53x_1x_3 - 0{,}69x_1x_4 - 0{,}16x_1x_5 + 3{,}83x_2x_3 + 1{,}91x_2x_4 - 3{,}44x_2x_5 \\ + +1{,}70x_3x_4 + 2{,}75x_3x_5 - 0{,}54x_4x_5$$

The conversion of variables from the coded form to their natural values is done by the following expression:

$$x_i = \frac{X_i - X_{i0}}{\varepsilon} \tag{19}$$

Based on the expression (19), the value of the variables in the equation of the process of damage to fat cells and tissues is as follows:

$$x_1 = \frac{U-6}{2};\ x_2 = \frac{n-18}{8};\ x_3 = \frac{C-0{,}8}{0{,}2};\ x_4 = \frac{f-9}{3};\ x_5 = \frac{h-10}{5};$$

CONCLUSION.

After transferring the coded values to natural values and appropriate changes, the mathematical model of the process of cutting the oil-retaining tissues by electrical impulse treatment of the seed is as follows:

To find the optimal value of the mathematical model, we calculate in the PascalABC computer program. The figure shows the block diagram of the algorithm for calculating seed cell fragmentation [27].

As a result of the research, the following optimal parameters of the process of damaging the seed cell and extracting oil by electric pulse processing were determined: the voltage of the discharge for processing the pulp is 6 kV, the number of pulses is 18, the capacitor capacity is 0.8 µF, the humidity of the pulp is 9%; The thickness of the treated material is 10 mm.

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