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ENERGETIC AND TECHNOLOGICAL ANALYSIS OF THE PROCESS OF OIL PRESSING FROM WINTER RAPE

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Summary. There were carried out energetic and technical analysis of technology for winter rapeseed oil extraction designer for RME production in the farm. The technological process was subjected to optimization in respect to maximization of process productivity, minimization of energy demand, and maximization of rapeseed oil output.

The developed model of winter rape seed production in the farm is a tool that facilitates decision making on advisability of production undertaking or abandonment under conditions of the farm. It would facilitate a direct selection of machines and equipment for the defined production scale.

Key words: rapeseed oil, oil extraction, process energy consumption, winter rape, biofuels, raw material for RME production.

INTRODUCTION

An increase in prices and petroleum shortage caused the interest in renewable fuels (biofuel) originated also from the oil plants. Biofuels for engine fuel systems should be, first of all, used in agriculture, since raw materials for biofuel production come mainly from agricultural production as a main crop or its by-products. The opinion that satisfaction of agricultural energetic needs should be achieved with the use of farm raw materials becomes more and more common [Drosio and Klimkiewicz 2009]. The efforts in this direction will enhance activity and restructuring of rural areas and allow for utilization of biofuel and its by-products directly by the producers. Fulfillment of this postulate can enhance stabilization of agricultural production and prices of agricultural products; it can also assure the energetic and food security of the country.

European Union maintains the agrarian policy that supports production of plant raw materials to be used in biofuel production [Kupczyk 2008]. These materials should not compete with food production and should be utilized directly on the farm; this will greatly reduce the logistic costs and technical infrastructure development, and improve energetic security in particular countries and UE.

The rapeseed oil can be widely used, since it can be fed to the self-ignition engines after minor modifications of fuel system [Bocheński and Bocheńska, 2008, Jakóbiec et al. 2009, Mruk 2006]. Striving at common application of rapeseed oil as a self-contained fuel (particularly in agriculture) is justified with its beneficial effect on natural environment and also with lower energy inputs in its production when compared to rapeseed methyl esters (RME).

Actuating the rapeseed oil extraction proves in farms can enhance the full use of production potential of seeds, straw and by-products (oil cakes). Part of seed crop can be used for food purposes, and the second part for biofuel production. The rape straw can be used for fabrication of highly-energetic fuel in the form of briquettes or pellets.

The oil output from the classical technology application can be high, which is a strong advantage of that method. However, it has some disadvantages also, namely the poor quality of post-extraction oil meal due to solvent residue and denatured protein content. Additionally, extraction equipment affects adversely the environment by emitting the aliphatic hydrocarbons into atmosphere (Tys et al. 2003).

During oil extraction with the use of screw presses the oil is not fully extracted, and its substantial part 8 – 14% remains in the oil cake (Jaswant and Bargale 2000).

Possibility of management of oil cake obtained in the oil extraction process, as an animal feed component, if very important; it enables to obtain a high-protein and high-energetic animal feed at reduced production costs.

Parameters of obtained oil, its chemical composition and the content of contaminants greatly depend on pressing parameters (Klimkiewicz and Wiechetek 2008, Klimkiewicz et al. 2010, Panasiewicz et al. 2009).

PURPOSE AND METHODS

The scientific aim was to analyze effectiveness of oil extraction from winter rape seeds in a small farm, and evaluation of energy demand and oil output in this process. The process optimization affects directly effectiveness of oil extraction process, in respect of energetic and economic considerations.

The basic tool used in the work was process modeling that allowed for analysis and making variants. The developed optimization models were used in decision-making on selection of the best variant. The effect of press technical parameters on energy consumption and energetic effectiveness of the process was investigated (Gach, 2009; Jaros and Pabis 2007; Chmielecki 2006). Then, the process optimization for the assumed production scale was performed. The working parameters of equipment were taken according to manufacturer’s recommendations.

The utility aim was to develop the information models for particular variants of oil extraction process that can be used by framers to verify justification of a given variant application, together with determination of its effectiveness.

The process model developed for the farm is a tool facilitating decision making on undertaking production or its abandonment under the farm conditions. It would facilitate a direct selection of machines and equipment for the defined production scale and would allow for evaluation of effectiveness at assumed process parameters.

Numerical methods implemented in MatLab program were used in the modeling process. The active experiment on rapeseed oil extraction was aided by LabView program.

Methodology of investigations

Each farm where the technological process is realized is characterized by different and specific production-site conditions and different activity aims. Therefore, evaluation criteria for technological processes are usually quite different (Banasiak 2008).

With respect to rapeseed oil extraction technology there were determined parameters of decision variables and constants for particular process variants. Then, there was performed the modeling of oil extraction process basing on the results obtained from oil seed extraction process with the use of the press of exchangeable die with various diameter of outlet hole. The change in screw rotational speed of press screw was considered also. There were developed three independent optimization models of the following objective functions: process productivity, energy demand and oil output.

Equipment of various design is available in the market; therefore, devices of output suitable for small farm conditions have been selected. The optimization process was carried out with the use of MATLAB program and function library **OptimizationToolbox**.

In optimization there were assumed the exemplary organization-site parameters for the farm of area 60 ha. It allows for agricultural commodity production under EU market position and is determined by technological, economic and social conditions. The 4-year rape succession and its 25% share in the crop structure were assumed in the farm. The remaining 75% were left for cereals.

The liquid fuel demand in the farm was assumed as 86 l/ha of diesel oil according to Council of Ministers' Decree of 8 Dec. 2009 on the excise tax refund included in diesel oil price used in agricultural production. No excise tax refund included in biofuels was considered in the Decree (Waszkiewicz, 2009). For such conditions there was proposed the machine fleet that allowed for execution of oil extraction process and biodiesel production to satisfy the fuel demand of own agricultural farm.

In investigations the screw press Farmet PSL UNO 7 (Farmet, 2010) was used; the 1.1 kW motor parameters were controlled with the inverter Hitachi SJ100 (Hitachi 2001) that allowed for current frequency adjustment with accuracy $\Delta f \pm 0{,}01$Hz.

Besides screw rotational speed n_w, the diameter of oil cake output die was changed; the die diameters of ø 6 [mm], ø 8 [mm] and ø 10 [mm] were used.

RESULTS AND DISCUSSION

Own investigations – optimization of rapeseed oil extraction process in small farm.

In agricultural activity of commodity production scale the manager follows the principle of rational farming. The resources of a given farm are limited, therefore, they should be utilized in the way that provides the maximal realization of assumed economic objectives. This principle applies to situation when both the means and objective can be determined in terms of quantity. It can be then called the principle of highest effectiveness (Tarnowski, 2009).

Realization of this principle can be twofold. In the first manner, the maximal objective can be obtained at a given input of resources or means. In the second one, the level of resources or means is maximized at the assumed objective.

Development of production system mathematical model to follow the above principles is possible with application of optimization methods (Tarnowski 1998; Tarnowski 1999, Kiczkowiak 2005; Tarnowski, 2001).

There was developed the optimization model for exemplary model agricultural farm that aims at winter rapeseed extraction for own internal needs.

Analysis of the obtained material and evaluation of objective function variability with consideration to the set of decision variables showed that particular optimization iteration processes correctly found the local minima for defined combination of decision variables.

To illustrate clearly the obtained results, the full set of optimization results for particular iterations and the selected objective function surfaces related to extreme values were marked on diagrams.

Investigations on objective function course with consideration to oil extraction productivity

The Farmet PSL UNO 7 press oil extraction productivity were measured at 1 second intervals with the use of LabVIEW computer program. Duration of experiment depended on the press productivity. The oil extraction of rapeseeds of moisture content 7% was executed for seed sample of 1 kg.

Basing on the obtained results there was developed the model that determined the press productivity with consideration to die diameter variability and changes in the screw rotational speed:

$$W_w = A_1\phi_b^2 + A_2\phi_b + A_3 n_w^2 + A_4 n_w + A_5\phi \cdot n_w + A_6, \quad (1)$$

W_w – productivity [kg/h],
$A_1, \ldots, A_6$ – model coefficient [-],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

As a result of regression model development there was obtained the equation of fitting degree R^2=0.956 [-] of the form:

$$W_w = 0{,}128\phi_b + 0{,}685 n_w - 4{,}53, \quad (2)$$

W_w – productivity [kg/h],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

The model of mathematical course of changes in productivity according to screw rotational speed and die diameter is presented in Figure 1.

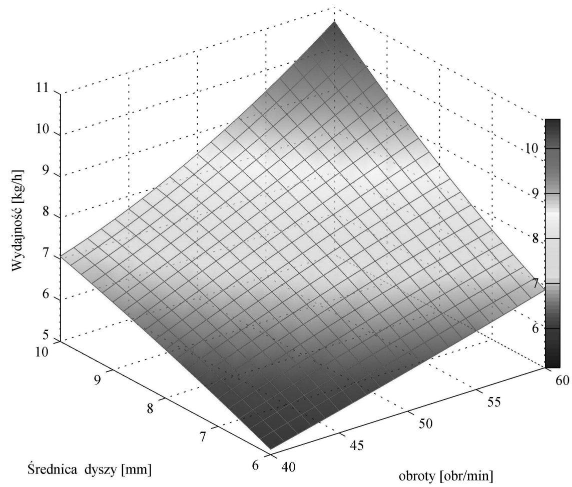

Fig. 1. Model determining press productivity at various screw rotational speed [rpm] and various die outlet hole diameter [mm

The change in screw rotational speed n_w ranged from 40 to 60 [rpm], while in die diameter from 6 to 10 [mm].

Results of extraction optimization process with respect to productivity

Basing on carried out experiment and the obtained results of rapeseed oil extraction, there was performed the process optimization with respect to productivity.

Strukture of modeling process:

1. **The optimization subject** is productivity of technological process of winter rapeseed oil extraction.
2. **The optimization scope** takes into consideration changes in:
   - rotational speed.
   - die diameter.
3. **Criteria –** in optimization process the following criteria were assumed:
   W_w – process productivity [kg/h].
4. **Determination of decision variables:**
   - *ø* – die diameter (from 6 to 10 [mm]).
   - *n* – screw rotational speed (from 40 to 60 [rpm]),
5. **Inequality limitations:**
   - *n* – $40 \leq n \leq 60$ [rpm].
   - *ø* – $6 \leq$ **ø** ≤ 10 [mm]).

Objective function:

$$W_{wcelu} = A_1\phi_b^2 + A_2\phi_b + A_3 n_w^2 + A_4 n_w + A_5\phi \cdot n_w + A_6, \tag{3}$$

W_{wcelu} – objective function of oil extraction process productivity [kg/h],
$A_1, \ldots, A_6$ – model coefficients [-],
$ø$ – die diameter [mm],
n_w – screw rotational speed [rpm].

The subject of worked out optimization is searching for maximal values of objective function according to dependence:

$$\max\left(W_{wcelu}\left(n_w, \phi\right)\right), \tag{4}$$

W_{wcelu} – objective function of oil extraction process productivity [kg/h],
$ø$ – die diameter [mm],
n_w – screw rotational speed [rpm].

Optimization results for extraction process productivity are presented in Figure 2 as averages of measurement series.

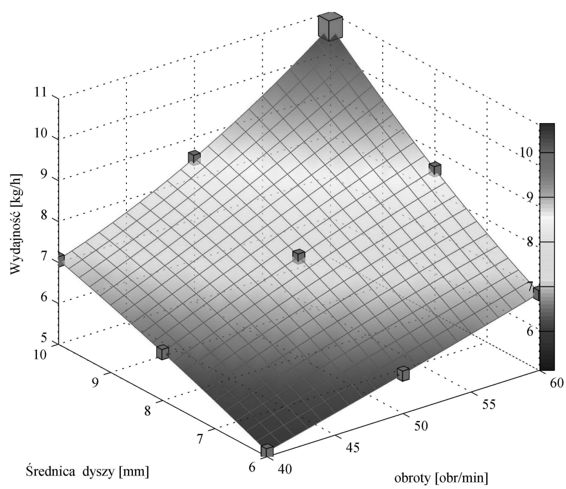

Fig. 2. Productivity [kg/h] according to die diameter- ø [mm] and screw rotational speed [rpm]).

For the sample of parameters: die diameter ø - 10 mm and rotational speed n_w - 60 rpm there was obtained the highest productivity, thus, the optimal value of technical parameters for the process on investigated device. This value is distinguished on diagram as the cube of magenta colour. The lowest productivity was obtained at technical parameters: die diameter ø - 6 mm and rotational speed 40 rpm.

Extraction process productivity with the use of exemplary press increases with an increase in die diameter ø – from 6 mm to 10 mm, and also with an increase in screw rotational speed n_w - from 40 to 60 rpm.

Investigations on objective function course with consideration to energy demand

The Farmet PSL UNO 7 press energy demand was also measured at 1 second intervals with the use of LabView computer program. The results are presented in Figure 3 as the specific electric energy consumption [kJ/kg].

Basing on the obtained results there was developed the model that determined the extraction process energy consumption with consideration to die diameter variability and changes in the screw rotational speed.

$$E_w = A_1\phi_b^2 + A_2\phi_b + A_3n_w^2 + A_4n_w + A_5\phi \cdot n_w + A_6, \tag{5}$$

E_w – energy demand [kg/h],
$A_1, \ldots, A_6$ – model coefficients [-],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

As a result of regression model development there was obtained the equation of fitting degree R^2=0.909 [-] of the form:

$$E_w = -1{,}82\phi_b + 2{,}02n_w^2 - 54{,}7n_w - 0{,}612\phi \cdot n_w + 1240, \tag{6}$$

E_w – energy demand [kg/h],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

Figure 3 presents changes in energy demand of oil extraction process.

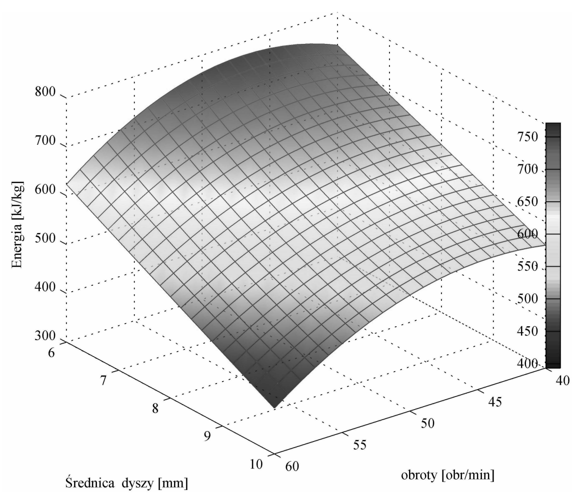

Fig. 3. Model of energy demand of rapeseed oil extraction
with Farmet PSL UNO 7 press at various working parameters of device

As it is evident from the above model, the energy inputs are not directly proportional to the values of working parameters of the device: screw rotational speed [rpm] and die diameter [mm].

Results of extraction optimization process with respect to energy demand

Basing on carried out experiment and the obtained results of rapeseed oil extraction, there was performed the process optimization with respect to process energy consumption.

Structure of modeling process:

1. **The optimization subject** is energy consumption in technological process of winter rapeseed oil extraction.
2. **The optimization scope** takes into consideration changes in:
   - rotational speed,
   - die diameter.
3. **Criteria -** in optimization process the following criteria were assumed:
   E_w – energy inputs in rapeseed oil extraction process [kJ/h].
4. **Determination of decision variables** of oil extraction process
   - ***ø*** – die diameter (from 6 to 10 [mm]),
   - $\boldsymbol{n_w}$ – screw rotational speed (from 40 to 60 [rpm]).
5. **Inequality limitations:**
   - n_w – 40 ≤ n ≤ 60 [rpm],
   - ø – 6 ≤ ø ≤ 10 [mm]).

Objective function:

$$E_{wcelu} = A_1\phi_b^2 + A_2\phi_b + A_3n_w^2 + A_4n_w + A_5\phi \cdot n_w + A_6, \tag{7}$$

E_{wcelu} – objective function of energy demand [kg/h],
$A_1, \ldots, A_6$ – model coefficients [-],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

The subject of worked out optimization is searching for minimal values of objective function according to dependence:

$$\min\left(E_{wcelu}\left(n_w,\phi\right)\right), \tag{8}$$

E_{wcelu} – objective function of energy demand [kg/h],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

The lowest energy consumption was found at n_w - 60 rpm. This value is marked on Fig. 4 with the cube of magenta colour.

There is also another cube on the diagram 4 marked by magenta colour for technical parameters: die diameter *ø* - 10 mm and rotational speed n_w - 40 obr/min, however, the value of that point is higher than optimal. For the sample of parameters: die diameter *ø* - 6 mm and rotational speed n_w 40 rpm, the highest energy consumption per 1 kg of pressed rapeseeds was obtained.

The energy consumption of extraction process with the use of exemplary press increases with a decrease in die diameter *ø* – from 10 mm to 6 mm, and also with a decrease in screw rotational speed n_w - from 60 to 40 rpm.

Distribution of energy consumption values is marked with a net; its filling colour changes from dark blue to dark red along with an increase in energy demand.

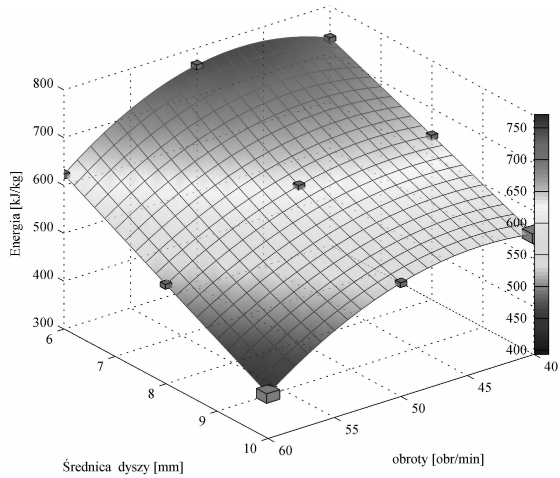

Fig. 4. Electric energy consumption [kJ/kg] according to die diameter [ø] and screw rotational speed n_w [rpm].

As it is evident from Fig. 4, the process energy inputs are not directly proportional to the values of technical parameters of the device.

Investigations on objective function with consideration to oil output

During measurements on energy demand and device productivity, its effectiveness was also verified by the measurements of rapeseed oil output.

Basing on the obtained results there was developed the model that determined the oil output at various press working parameters with consideration to die diameter variability and changes in the screw rotational speed:

$$U_w = A_1\phi_b^2 + A_2\phi_b + A_3n_w^2 + A_4n_w + A_5\phi \cdot n_w + A_6, \tag{9}$$

U_w – oil output [kg/kg],
$A_1, \ldots, A_6$ – model coefficients [-],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

As a result of regression model development there was obtained the equation of fitting degree R^2=0.987 [-] of the form:

$$U_w = 0{,}0300\phi_b^2 - 2{,}97\phi_b + 2{,}00n_w^2 - 30{,}5n_w + 0{,}100\phi \cdot n_w + 420, \qquad (10)$$

U_w – oil output [kg/kg],
$ø$ – die diameter [mm],
n_w – screw rotational speed [rpm].

Various amount of oil was obtained at different press adjustments. The obtained values related to changes in press working parameters are presented in Figure 5.

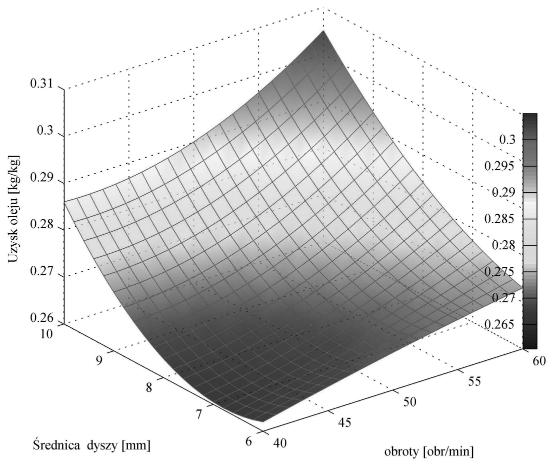

Fig. 5. Model of extraction process effectiveness expressed by oil output

The oil output value is not directly proportional to particular press parameters, but the growing trend can be found.

Results of extraction optimization process with respect to oil output

Basing on carried out experiment and the obtained results of rapeseed oil extraction, there was performed the process optimization with respect to oil output.

Particular samples were obtained at defined settings of press working parameters. The sample mass was determined by weighing. Basing on this active experiments, the optimization process was carried out.

Structure of modeling process:

1. **The optimization subject** is oil output in technological process of winter rapeseed oil extraction.
2. **The optimization scope** takes into consideration changes in:
   - rotational speed,
   - die diameter.
3. **Criteria -** in optimization process the following criteria were assumed:
   U_w – oil output in rapeseed oil extraction process [kg/kg],
4. **Determination of decision variables:**

- *ø* – die diameter (from 6 to 10 [mm]),
- n_w – screw rotational speed (from 40 to 60 [rpm]).

5. **Inequality limitations:**
   - n_w – $40 \le n \le 60$ [rpm],
   - ø – $6 \le ø \le 10$ [mm]).

Objective function:

$$U_{wcelu} = A_1\phi_b^2 + A_2\phi_b + A_3n_w^2 + A_4n_w + A_5\phi \cdot n_w + A_6, \tag{11}$$

U_{wcelu} – objective function of oil output [kg/h],
$A_1, \ldots, A_6$ – model coefficients [-],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

The subject of worked out optimization is searching for maximal values of objective function according to dependence:

$$\max\left(U_{wcelu}\left(n_w,\phi\right)\right), \tag{12}$$

U_{wcelu} – objective function of oil output [kg/kg],
ø – die diameter [mm],
n_w – screw rotational speed [rpm].

The highest oil output was obtained for the sample at press working parameters: die diameter *ø* -10 mm and crew rotational speed n_w - 60 rpm. This value is marked on the diagram with magenta colour. The minimal oil output value was found for the sample at parameters: die diameter *ø* - 6 mm and screw rotational speed n_w - 40 rpm.

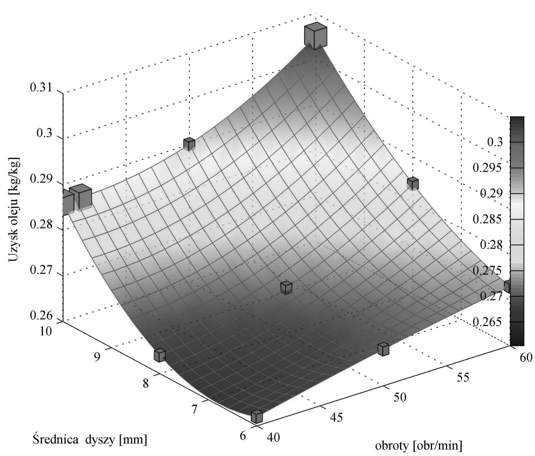

Fig. 6. Oil output [kg/kg] according to die diameter [ø] and screw rotational speed [rpm]

The effect of rapeseed oil extraction experiment with the use of Farmet PSL UNO 7 press is determination of press setting optimal parameters of in respect to productivity, energy inputs and oil output (Table 1), that amount to: die diameter *ø* - 10 mm and screw rotational speed n_w - 60 rpm.

Table 1. Criteria of optimization and criteria of rapeseed oil extraction process

Criteria of optimization	Values	Unit
Productivity- maximal	10.65	kg/h
Energy consumption - minimal	0.393	MJ/kg
Oil output - maximal	0.305	kg/kg

Considering the investigated parameters: productivity, process energy consumption and oil output one can find that the optimization process points out at the need for proper selection of parameters (the increased screw rotational speed and die diameter), since working parameters recommended by manufacturer differ from the results obtained in optimization process.

CONCLUSIONS

Basing on carried out optimization process of winter rapeseed oil extraction (at assumed limitations) and on the basis of performed active experiment one can find that:

- maximal possible process productivity amounts to 10.65 [kg/h],
- minimal energy demand amounts to 393 [kJ/kg],
- maximal rapeseed oil output amounts to 305 [g/kg].

To reach these results one should apply the press die diameter *ø* - 10 [mm] and screw rotational speed n_w - 60 [rpm].

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ANALIZA ENERGETYCZNO-TECHNICZNA TECHNOLOGII WYTŁACZANIA OLEJU Z NASION RZEPAKU OZIMEGO.

Streszczenie. Przeprowadzono analizę energetyczną i ocenę technologii wytłaczania nasion rzepaku z przeznaczeniem na produkcję RME w gospodarstwie rolnym. Proces technologiczny poddano optymalizacji ze względu na: maksymalizację wydajności procesu, minimalizację zapotrzebowania na energię, maksymalizację uzysk oleju rzepakowego.

Opracowany model procesu wytłaczania oleju z nasion rzepaku ozimego w gospodarstwie rolnym jest narzędziem ułatwiającym podejmowanie decyzji o celowości podjęcia produkcji lub zaniechania jej w warunkach gospodarstwa rolnego. Ułatwi on bezpośredni dobór maszyn i urządzeń dla określonej skali produkcji.

Słowa kluczowe: olej rzepakowy, wytłaczanie oleju, energochłonność procesu, rzepak ozimy, biopaliwa, surowiec do produkcji RME.