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*Article*

## **The efficiency rise of the feeds grinding process by optimizing its parameters**

**Tatyana B. Stankevich<sup>1</sup>, Olga A. Anpilogova<sup>1</sup>, Gennady I. Malinov<sup>1</sup> and Timmo A. Gavrilov<sup>1,\*</sup>**

<sup>1</sup> Petrozavodsk State University, Lenin Str. 33, 185910 Petrozavodsk, Russia; E-Mails: [gladiolus@list.ru](mailto:gladiolus@list.ru) (T.B.S.), [anpilogova@petsru.ru](mailto:anpilogova@petsru.ru) (O.A.A.), [malinov@petsru.ru](mailto:malinov@petsru.ru) (G.I.M.), [gavrilov@petsru.ru](mailto:gavrilov@petsru.ru) (T.A.G.)

\* Author to whom correspondence should be addressed; E-Mail: [gavrilov@petsru.ru](mailto:gavrilov@petsru.ru) (T.A.G.); Tel.: +7(8142)711046; Fax: +7(8142)711000.

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**Abstract:** Grinding is one of the most complicated and energy-intensive processes in the technology of making feeds for fur-bearing animals. That is why the most important nowadays is the research of the parameters influencing energy consumption during the grinding process. These parameters are: the slip angle of the knife blade and the temperature of the grinding material. The influence of the parameters on energy consumption has not been studied enough yet which prevents the increasing of the efficiency of the grinding process. The aim of the article is to increase the efficiency of the grinding process by optimizing its parameters according to the minimum criterion of energy consumption. The method of multifactorial experiment planning has been considered as a means of the research. During the research the samples of meat-fish feeds were grinding on a laboratory-scale plant at different slip angles of the knife blade and temperatures according to the plan of the experiment. The analysis of the experimental data has been resulted in a mathematical model describing the changes in energy consumption of the grinding process depending on the slip angle of the knife blade and the temperature of the grinding material. The recommendations on the decreasing of energy consumption of the feeds grinding process allowing the increasing the efficiency of the process have been explained.

**Keywords:** grinding, the temperature of the grinding material, the slip angle of the knife blade, energy consumption, model, meat-fish feeds

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## 1. Introduction

While preparing feeds for fur-bearing animals the main energy consumption (up to 50 % of the whole energy consumption) is taken by the grinding process [1]. At the same time the grinding process leads to the extending of the active surface of the feeds particles which assists the acceleration of the digestion process and the accessibility of the nutrients. Therefore the research of this process and its higher efficiency are essential.

The base of the feeding diet of fur-bearing animals is meat-fish feed the grinding of which is the most efficient according to the minimum criterion of energy consumption if a blade cutting is used [2]. The energy consumption of the grinding process by blade cutting depends on a numbers of parameters: cutting velocity, type of a cutting tool and its arrangement, geometrical parameters of the cutting tool, the temperature of the grinding material. The influence of these parameters on energy consumption of the grinding process is the subject of investigation by some Russian [1–4] and foreign authors [5–15]. The analysis of these articles shows that the problems of the influence of such parameters as the temperature of the grinding material and the slip angle of the knife blade on energy consumption of the grinding process have not been studied enough yet, the results of the research are very contradictory and there is no common opinion on the subject. All these factors prevent higher efficiency of the grinding process of meat-fish feeds, which is an important problem to be solved.

The aim of this work therefore is higher efficiency of meat-fish feeds grinding process obtained by optimizing its parameters (the temperature of the grinding material and the slip angle of the knife blade) according to the minimum criterion of energy consumption.

In accordance with the formulated aim and the theoretical background the tasks to be solved are the following:

- 1) to carry out an experimental research into the influence of the temperature of the grinding material and the slip angle of the knife blade on energy consumption of the grinding process;
- 2) to optimize the parameters (the slip angle of the knife blade and the temperature of the grinding material) of the grinding process according to the minimum criterion of energy consumption;
- 3) to analyze the obtained results and offer some recommendations on the choice of the slip angle of the knife blade and the temperature of the grinding material.

## 2. Materials and Methods

According to the method of multifactorial experiment planning the temperature of the grinding material  $T$  (°C) and the slip angle of the knife blade  $\tau$  (°) have been accepted as varied factors and energy consumption of the grinding process  $N$  (BТ) – as optimization criterion.

The level of factors variation (Table 1) have been chosen on the base of the analysis of the present theoretical and experimental research, listed in scientific literature [1–15].

**Table 1.** The levels of variation factors

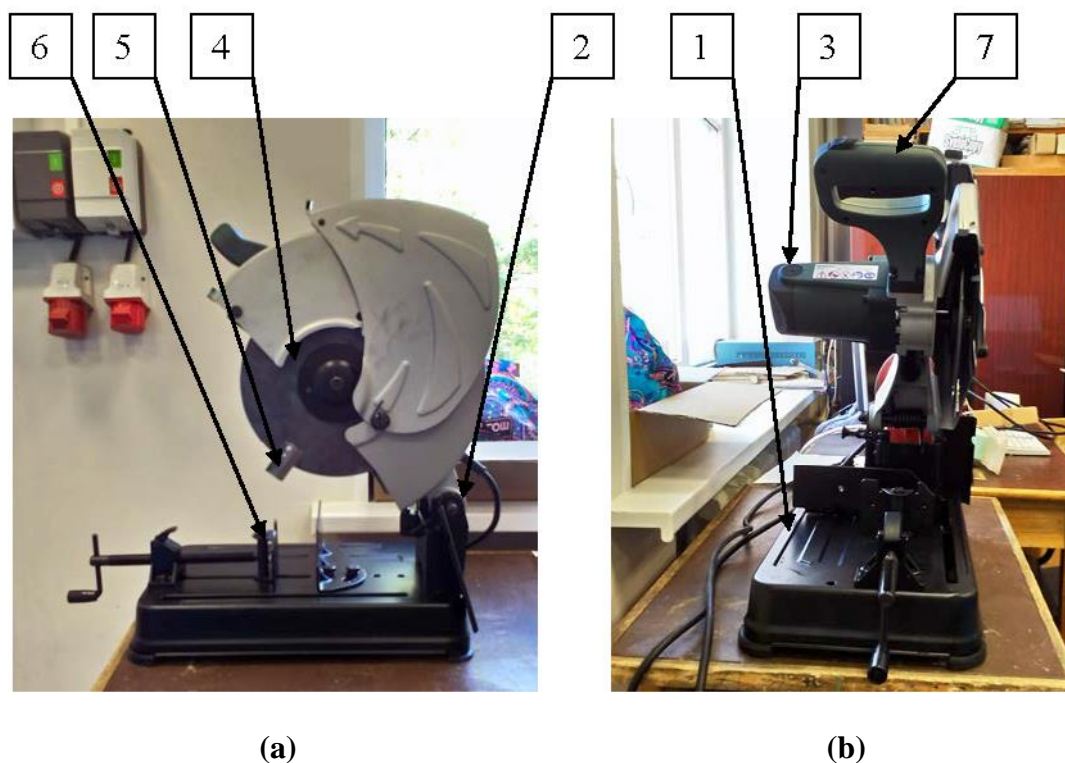
Factors	$T, ^\circ\text{C}$	$\tau, ^\circ$
The upper level (+1)	0	60
The main level (0)	-1	45
The lower level (-1)	-2	30
The variability interval	1	15

The realization of the multifactorial experiment has been done in accordance with the full factorial experiment  $3^2$  plan (Table 2) at three variation levels. The sequence of the experiments has been randomized with the use of a random numbers table. The experiments replication is fivefold.

**Table 2.** The planning matrix of the full factorial experiment  $3^2$

The experiment number	$T$	$\tau$
1	+1	-1
2	0	-1
3	0	+1
4	0	0
5	-1	-1
6	+1	0
7	+1	+1
8	-1	+1
9	-1	0

To carry out a multifactorial experiment concerning the influence of the slip angle of the knife blade  $\tau$  and the temperature of the grinding material  $T$  on energy consumption of the grinding process  $N$  as well as for the optimization of these parameters a laboratory – scale plant (Figure 1) with an energy meter «Neva MT 123» engaged to it has been used (the energy meter measures and displays capacity values with an error of 1 watt).

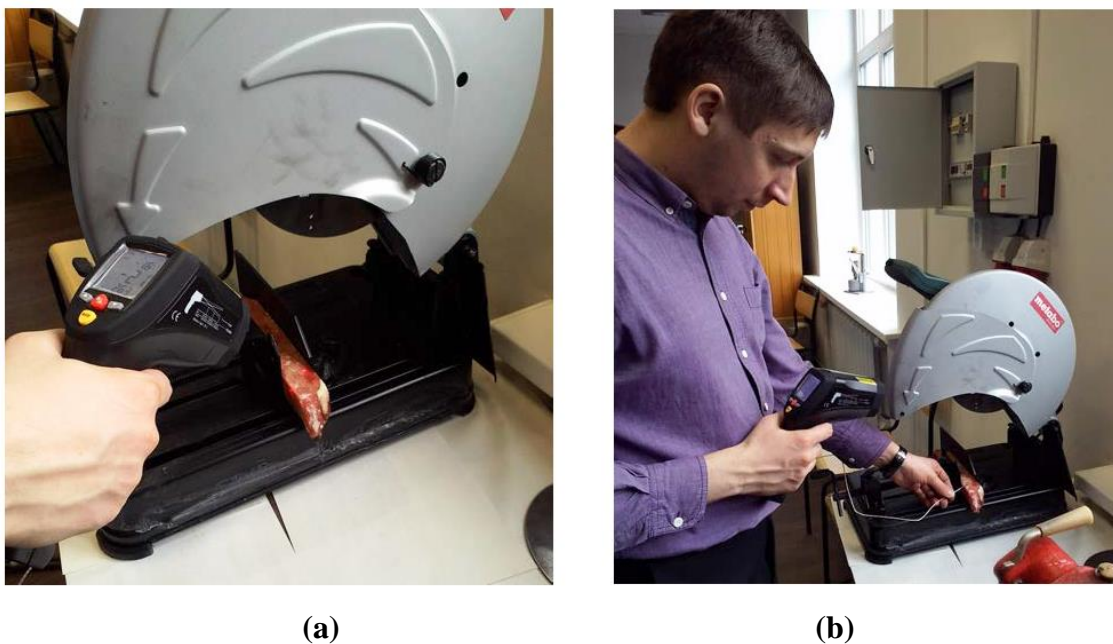


**Figure 1.** The laboratory-scale plant: (a) front view, (b) end-view

1 – base, 2 – strut, 3 – electric motor, 4 – disk, 5 – knife, 6 – vice, 7 – the handle with push switch

Meat-fish feeds – beef and offal (moisture 72,1...72,9 % and density 1160...1180 kg/m<sup>3</sup>) have been used as grinding material.

The methods of the conducting the research is the following. The material to be grinded was cut into pieces with equal cross section of 30×30 mm<sup>2</sup>. After that they were defrosted to the desired temperature which was measured with the help of the infrared thermometer ADA TemPro 1200 (with the margin of error 0,1 °C). Temperature measurements were made on the pieces surface by the noncontact method (by the infrared detector of the thermometer, Figure 2 (a)) and inside the pieces in the depth of 10...15 mm by the contact method (by the thermometer thermocouple Figure 2 (b)). Average temperature value was taken as the unknown quantity.



**Figure 2.** The methods of temperature measurement: **(a)** noncontact, **(b)** contact

After that blades were fixed on the disk of the laboratory scale plant under the given angle  $\tau$  and grinding was made. The data from the energy meter «Neva MT 123» were taken by a digital camera. The values of the energy consumed by the grinding process  $N$  were determined according to these video recordings. And then the values of the examined factors were changed according to the experiment plan (Table 2) and the research was repeated.

### 3. Results

According to the results of the research data retrieval of the capacity  $N$  consumed on the grinding process of meat-fish feeds was received. Statistical analysis was made for the received data by the generally accepted methods of mathematical statistics for the 5 % variation levels using software packages STATGRAPHICS Centurion XVI and Microsoft Office Excel 2007.

As the result of the processing the regression equation (model) of the second order for capacity  $N$  consumed on the grinding process of meat-fish feeds was received

$$N = 60,25 + 0,42 \cdot T - 2,71 \cdot \tau + 0,02 \cdot T \cdot \tau + 2,50 \cdot T^2 + 0,03 \cdot \tau^2 \quad (1)$$

The adequacy of the model was checked with the usage of Fisher's variance ratio

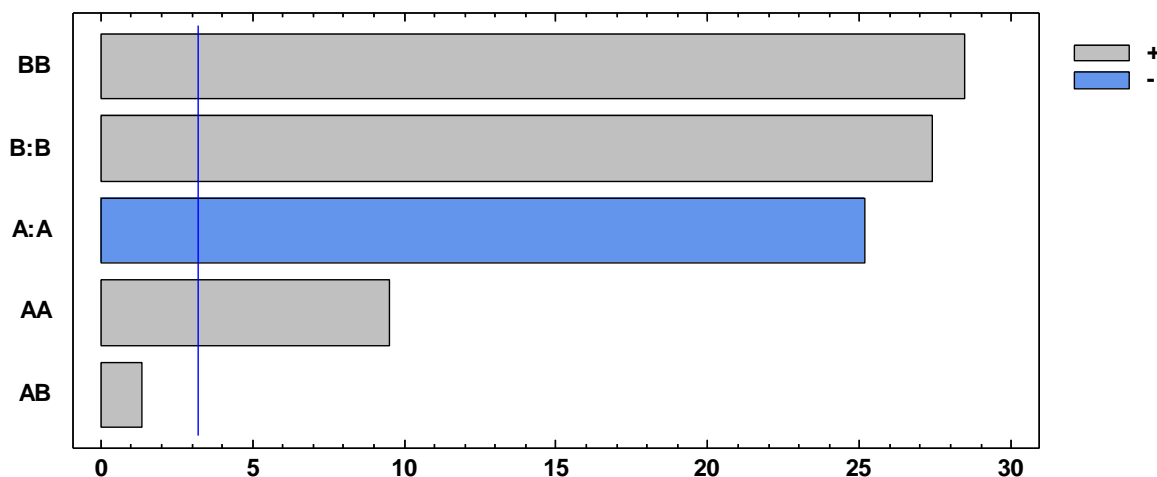
$$F = S_{LF}^2 / S_y^2 = 0,24 / 1,33 = 0,18 \quad (2)$$

where  $S_{LF}^2$  is the inadequacy dispersion of the mathematical model and  $S_y^2$  is the dispersion of the experiment error.

The table value of Fisher's variance ratio for 5 % significance level  $F_{0,05} = 2,66$  with the degree of freedom  $f_1 = 6$  and  $f_2 = 18$  exceeds the measure of this criterion experiment value. Thus the hypothesis about the adequacy of the experiment results presentation can be accepted.

Model processing showed that the model approximation certainty by the second order polynomial was  $R^2 = 97,87 \%$ .

Pareto chart was used to find regression coefficient significance. The results of the calculations with relation to the table value of Student's test for the 5 % level of significance  $t_{\text{tabl}} = 3,18$  are shown in Figure 3.



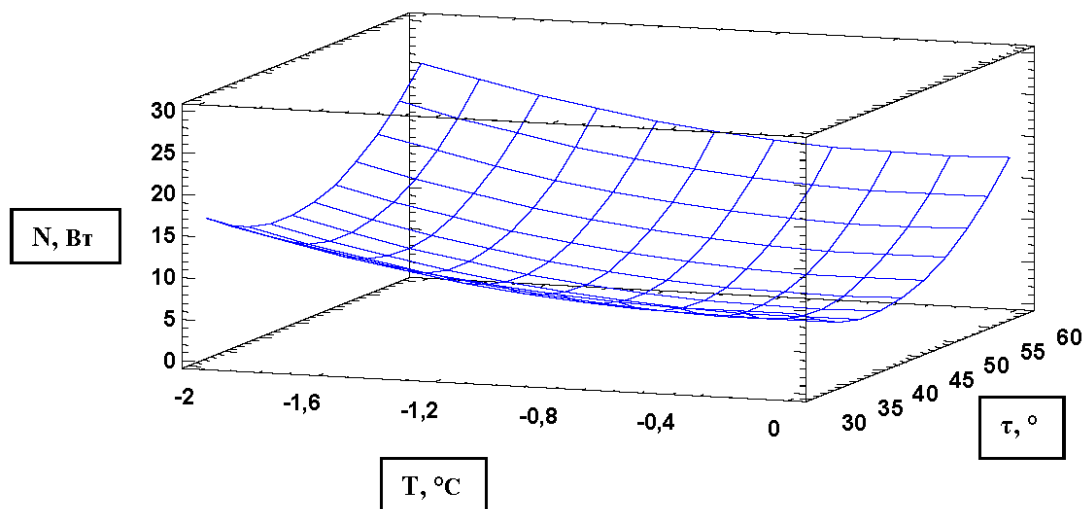
**Figure 3.** Pareto chart

In the Pareto chart it is quite well seen that the regression coefficient  $A$ ,  $B$ ,  $AA$ ,  $BB$  of the linear and quadratic terms of the model have probable significant phenomena. The fact that the corresponding columns cut the vertical presenting 95<sup>th</sup> % test for significance determination denotes this. Wherefrom both factors  $-T$  and  $\tau$  – influence greatly optimization criteria  $N$ . Regression coefficient  $AB$  of factor coupling  $T$  and  $\tau$  turned out to be not significant, and therefore was excluded from the model. At that, the adequacy of the model went down negligibly  $R^2 = 96,34 \%$ . In the result the model is as follows

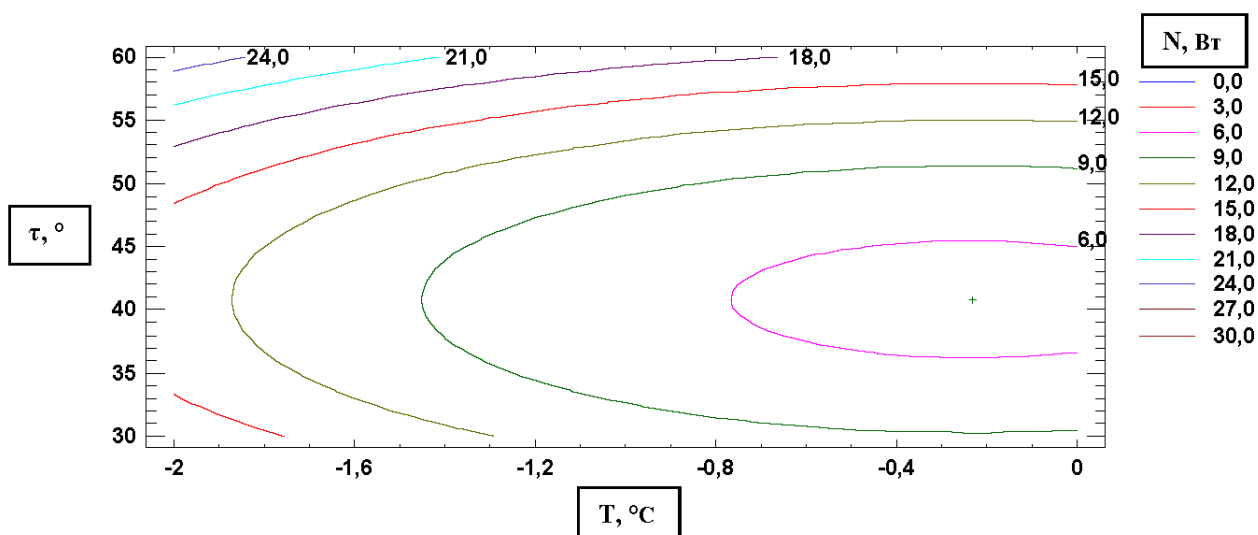
$$N = 61,00 + 1,17 \cdot T - 2,72 \cdot \tau + 2,50 \cdot T^2 + 0,03 \cdot \tau^2 \quad (3)$$

Further function minimum incremental search at the factors combination with the help of built-in function STATGRAPHICS Centurion XVI was made.

The response surface charts of optimization criterion  $N$  and its projection in relation to the factors  $T$  and  $\tau$  which clearly demonstrate factors optimal region are shown in Figure 4 and Figure 5.



**Figure 4.** The response surface chart



**Figure 5.** The projection of the response surface chart

The optimum values of factors  $T$  and  $\tau$  with function minimum are shown in Table 3.

**Table 3.** The optimum values of the factors with a minimum of functions

Parameters	Values
The optimization criterion $N, W$	5,29
The factor $T, ^\circ C$	-0,23
The factor $\tau, ^\circ$	40,83

Further a replication experiment at the optimum values of the factors was made. In the result the optimization criterion  $N$  was 5,58 W.

#### 4. Discussion and Conclusions

Model analysis (3) shows that both factors –  $T$  and  $\tau$  – influence greatly the change of the optimization criterion  $N$ . At that, factor  $T$  increase drives at the rise of optimization criterion value  $N$ , and factor  $\tau$  increase drives at its fall. The character of  $T$  and  $\tau$  factors influence on optimization criterion is fully enough described by model (3). The results of the replication experiment ( $N = 5,58$  W) with the factors optimal values received according model (3) correspond to the results of the calculations according this model ( $N = 5,29$  W). The model itself describes the process of meat-fish feeds grinding for certain.

Optimal factor values were  $T = -0,23$  °C and  $\tau = 40,83$  ° (Table 3). The values received correspond the results of the research on grinding both plant and meat-fish feeds made by a number of authors. This fact points the patterns commonality of the process of plant and meat-fish feeds grinding.

To decrease energy consumption of the fish-meat feeds grinding process is recommended to take the slip angle of the knife blade and the temperature of the grinding material from the intervals  $T = -1 \dots 0$  °C and  $\tau = 40 \dots 41$  °.

Thus, optimal values of the factors, allowing decreasing energy consumption of the fish-meat feeds grinding process and hence increasing the efficiency of this process were received with the use of the methods of multifactorial experiment planning.

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