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MODELING OF INFLUENCE OF ORE SUPPLY DYNAMICS ON ENERGY CONSUMPTION IN MINING AND PROCESSING ENTERPRISE IN TERMS OF CONTROL

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Summary. *Models of influence of supply dynamics and response time of the bin on energy consumption in mining and processing enterprise is investigated. The factors and parameters of the model of influence of ore supply parameters on the amount of energy consumption are analyzed. The modeling scheme according to proposed models is presented. The idea to develop a decision support system with a criterion of minimum specific energy consumption is substantiated.*

Key words*: ore supply dynamics, energy consumption, mining and processing enterprise, modeling.*

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Formulation the problem. Due to the fast increase in energy prices, the question of energy saving is raised, which is one of the main aspects in the course on production efficiency increase in mining industry.

Balanced use of electricity is strongly associated with the introduction of technically based consumption standards. They are determined by taking into account the specificity of mining production and accepted technological processes which are based on the use of scientifically grounded energy consumption regulation and planning methods. Effective cost management requires the knowledge of energy consumption patterns and its dependence on technological factors.

Research results analysis. Among the studies aimed to examine the mining production energy efficiency improvement, we would like to point out the research by N. Fedunets and O. Liakhomskoi [1], who conducted factor analysis and identified the most influential technological factors on energy consumption in the ore processing. In research [2] a complex scheme to solve the problem of high level energy consumption in mining enterprises is reviewed.

Among the studies of the dynamics of ore passing through technological branches of mining and processing enterprise, attention should be focused on the research by I. Mladetskyi. In the research by I. Belkina [3] the dependence of revenue and profit on the ore supply management at an enterprise is identified, and not only ore supply dynamics, but also the changing of quality characteristics are examined. But the problem of energy consumption at mining and processing enterprises in the framework of this research has not been considered.

Accordingly, an important stage of energy efficiency improving is to determine the degree of influence of ore supply parameters, in particular – the period, duration of supply and the constant of bin time response on energy intensity of production process. Another important step is to create the model of influence of ore supply dynamics on energy consumption in mining and processing enterprise to continue further research on practicability of control action implementation.

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Purpose of the article. The purpose of this article is to create an influence model of ore supply dynamics on specific energy consumption and analyze the possibility of implementing energy saving management system in mining and processing enterprise.

The main part.

1.1 Model construction

Ore supply from the open-cast to the crushing plant of the mining and processing enterprise runs on a round-the-clock basis. Ore flow dynamics depends on many factors, including the effectiveness of the ore supply rhythm stimulation mechanism. The following elements should be highlighted as the main reasons for not following a rhythm of ore supply: the conditions of ore output in open-cast, weather conditions, organization of mining transport complex work, the level in which workers are interested in the work performance, provision of spare parts and other [4].

During the ore transportation process from the place of production to the first production branch of mining and processing enterprise its quality characteristics are changing, due to the mix of ore from different open-casts or levels. Thus, in this research, the dynamics of ore quality during ore supply to the crushing plant is considered as an impulse process. Therefore, according to the impulse process, each supply corresponds to some impulse whose amplitude is the level of iron content in the ore batch and impulse duration corresponds to the time of the ore batch processing [3].

The influence modeling of ore supply dynamics on energy consumption is based on the economic and mathematical methods, which were developed in research [3]. The factors and parameters of the model of ore supply dynamics influence on performance effectiveness of the mining and processing enterprises by energy consumption are shown in the scheme in Figure 1.

The crushing and processing plants are considered as stable aperiodic factor with delay, so according to [5] transfer function and frequency response of plants are as follows:

$$K(p) = \frac{k_1 k_2}{t_1 p + 1} \cdot e^{-t_2 p}, \qquad (1)$$

$$\left| K_д(i\omega) \right| = \frac{k_1 k_2}{\sqrt{t_1^{\,2} \omega^2 + 1}}, \qquad (2)$$

where p – is Laplace operator, t_1 – is time response, t_2 – is the delay time of the transition process start, k_1, k_2 – are conversion coefficients according to aperiodic component and component of delay.

Transfer function and frequency response for bin are:

$$K_б(p) = \frac{1}{T_б p + 1}\ , \qquad (3)$$

$$\left| K_б(i\omega) \right| = \frac{1}{\sqrt{T_б^2 \omega^2 + 1}} \qquad (4)$$

where T_b – is the time response of the bin.

According to [3], ore supply period T and its duration τ are not random values, spectral density (energy spectrum) of iron ore output in the open-cast can be described by the following impulse process spectral density function:

$$S_0(\omega) = \frac{2\tau^2}{T} \frac{\sin^2 \frac{\omega\tau}{2}}{(\frac{\omega\tau}{2})^2} \left[\sigma^2 + \frac{2\pi}{T} \alpha^2 \sum_{r=-\infty}^{\infty} \delta\left(\omega - \frac{2\pi r}{T} \right) \right] \tag{5}$$

$$\delta(x) = \frac{du(x)}{dx}, \; u(x) = \begin{cases} 1, x \geq 0 \\ 0, x < 0 \end{cases} \tag{6}$$

where $u(x)$ – is a single leap, σ – is standard pulse amplitude deviation, α – is average impulses amplitude (average content of magnetite iron in the ore).

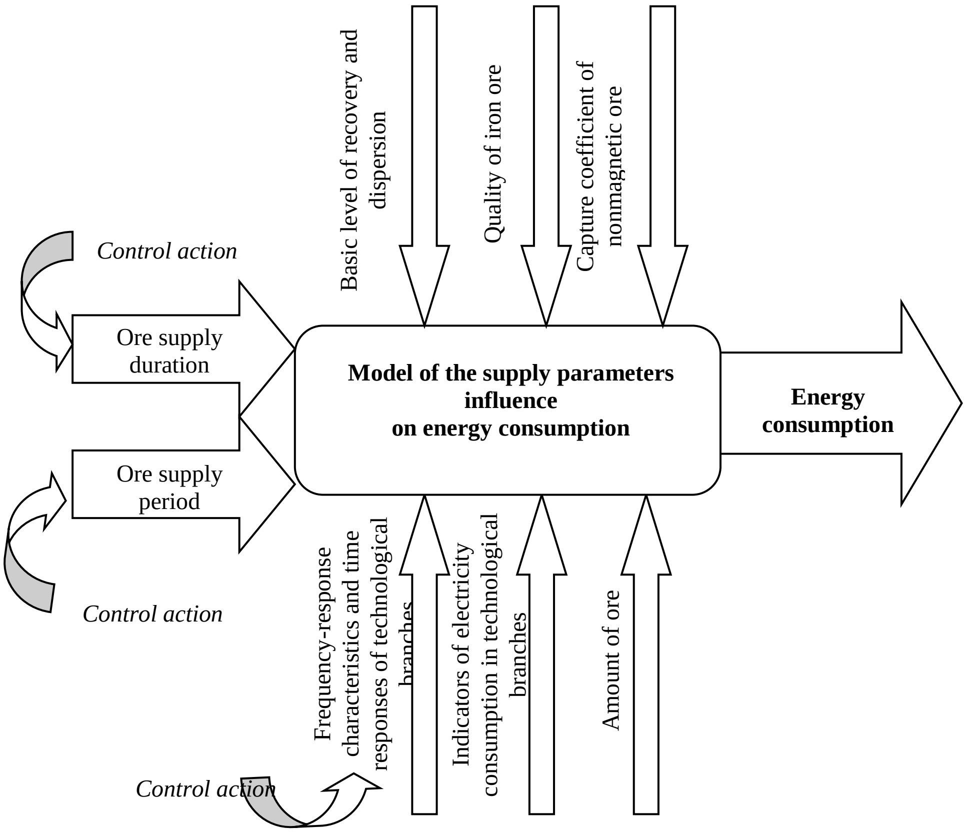


Figure 1. Factors and parameters of the model of supply parameters influence on the amount of energy consumption

Knowing the frequency characteristics of each technological branch, it is enough to know the function of spectral density at the input of the first branch using formula (7) to describe the spectral density at the output of the last technological branch – the processing plant.

The function of spectral density at the input of the processing line corresponds to the function of spectral density at the output of the processing plant's collecting bins:

$$S(\omega) = S_0(\omega) \cdot \left| K_{\text{д}}(i\omega) \cdot K_{\text{б}}(i\omega) \cdot K_{\text{зб}}(i\omega) \right|^2 \tag{7}$$

where $S(\omega)$ – is function of spectral density at the output of the processing plant's collecting bins;

$S_0(\omega)$ – is function of spectral density of iron content in ore at the output of the open-cast (dump of the open-cast).

In this research it is proposed to use the relative coefficient of iron content oscillation reduction and the methodology of determining the amount of concentrate which is used in the simulation in research [3].

Energy consumption amount is determined using the average value of electricity consumption per 1 ton concentrate production according to [6]:

$$E = \gamma \cdot ke \tag{8}$$

where γ – is ore concentrate yield,

E – is amount of energy consumption, kW,

ke – is amount of energy consumption per 1 ton concentrate production, kWh.

The mechanism for determining the influence of ore supply dynamics parameters on the amount of specific energy consumption, as it is mentioned above, it is intended for consistent calculation of power consumption function for each pair of the indicators. Consistent scheme of modeling the influence of ore supply dynamics on the amount of specific energy consumption is shown in Figure 2.

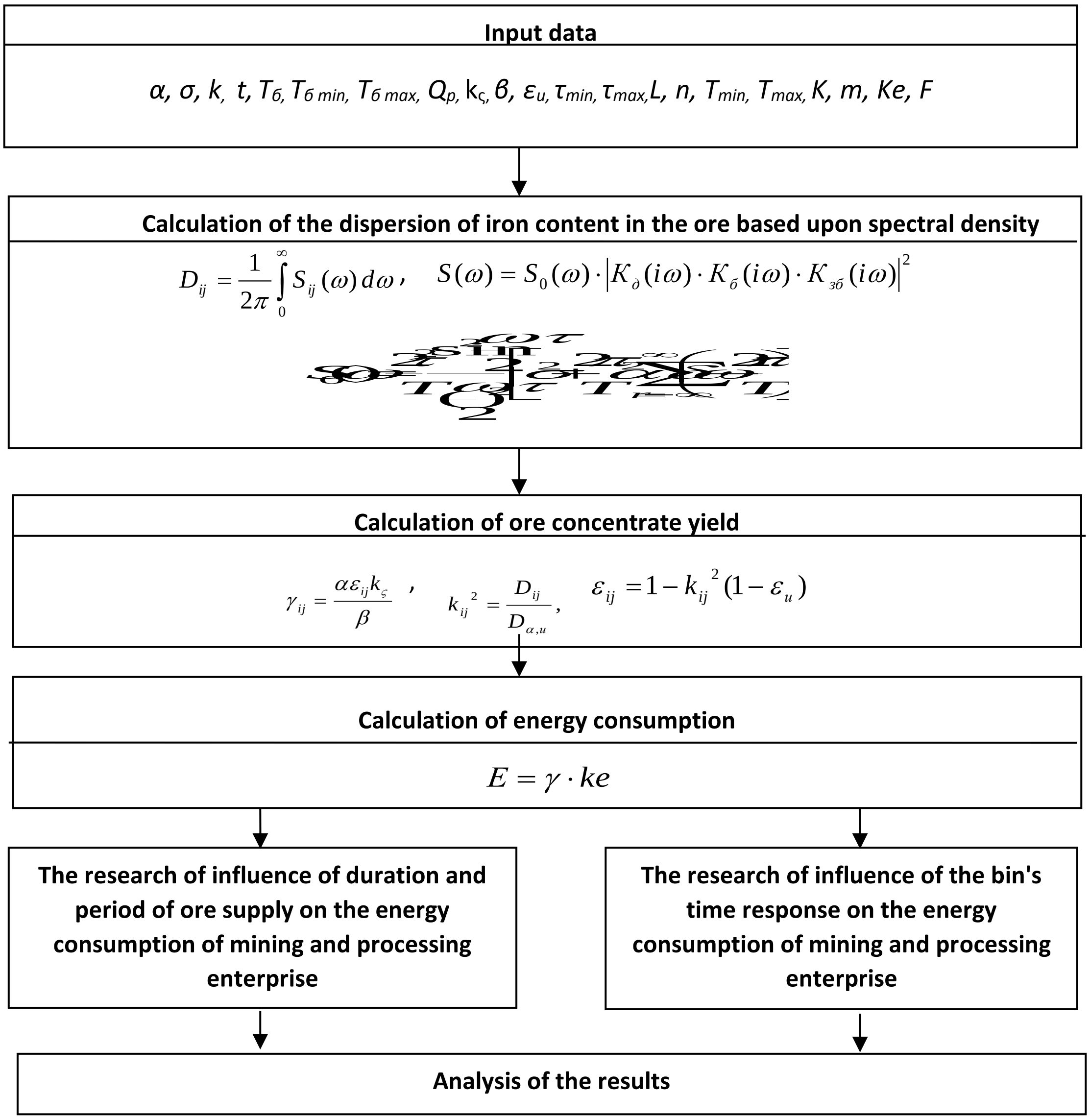


Figure 2. Scheme of modeling the influence of ore supply dynamics on the energy consumption in mining and processing enterprises

It is the first time that the time response of the bin, which is the part of the frequency-response characteristic, is investigated as a management factor of the bin's functionality and the dynamics of ore supply to the processing branch.

Management of the bin's functionality can be implemented by adjusting the required stocks number in the bin at the time point, which in turn affects the rhythm of ore supply to the processing plan, which is the most energy-intensive branch of mining and processing enterprise. Thus, management of the bin's time response, which is equal to ratio of the ore stock in it to the output stream from the ore bin [7], is considered as an energy saving method for mining and processing enterprise.

Thanks to implementation of this model we are able to get some results about the influence of the ore supply parameters on energy consumption in mining and processing enterprise, which is shown in Figure 2.

Input data for calculations are presented in Table 1.

Table 1

Input data for calculations and information about variables models

Parameter	**Value**
Content of total iron in the ore	$\alpha = 33.3\%$
Mean-square deviation of the iron content in the ore	$\sigma=15\%$
Frequency-response characteristics of crushing plant conversion factor	$k_1=1$
Frequency-response characteristics of processing plant conversion factor	$k_3=0.75$
Conversion factor of delay	$k_2=1$
Time response for Frequency-response characteristics of crushing plant	t_1 = 180 min
Time response for Frequency-response processing of crushing plant	t_1 = 240 min
Time response of the bin	T_b= 360 min
Minimum value of the bin's time response	$T_{b\ min}$= 25 min
Measurement pitch of the bin's time response	F= 20 min
Capture coefficient of nonmagnetic ore	$k_{ς}=1.067$
Iron content in the concentrate	$\beta=63.3\%$
Removal of iron to concentrate as a basis of comparing	$\varepsilon_u=0.9442$
Minimum value of ore supply duration τ	τ_{min} =11 min
Measurement pitch of ore supply duration τ	L=1 min
The number of values of ore supply duration τ	$n=30$
Maximum value of ore supply duration τ	τ_{max}=40 min
Minimum value of ore supply period T	T_{min}=40 min
Measurement pitch of ore supply period T	K =10 min
The number of points of ore supply period T	m = 30
Maximum value of ore supply period T	T_{max}=330 min
Amount of energy consumption for 1 ton concentrate production	Ke=93 kWh

1.2 The results of modeling ore supply period and duration influence on specific energy consumption in mining and processing enterprise.

The dependence of ore supply parameters on the specific energy consumption obtained as a result of the first model implementation is shown in Figures 3 – 5.

The amount of specific energy consumption is directly proportional to the period of ore supply. But it should be noted that this dependence is nonlinear with point of extremum.

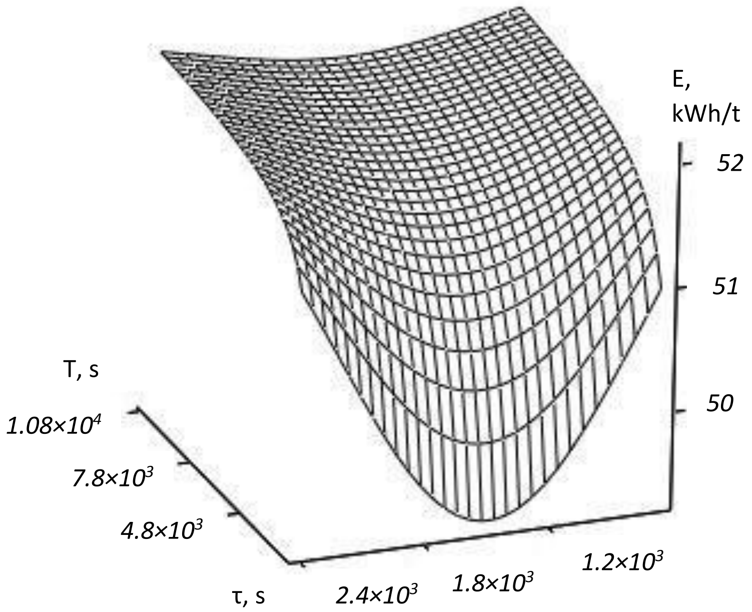
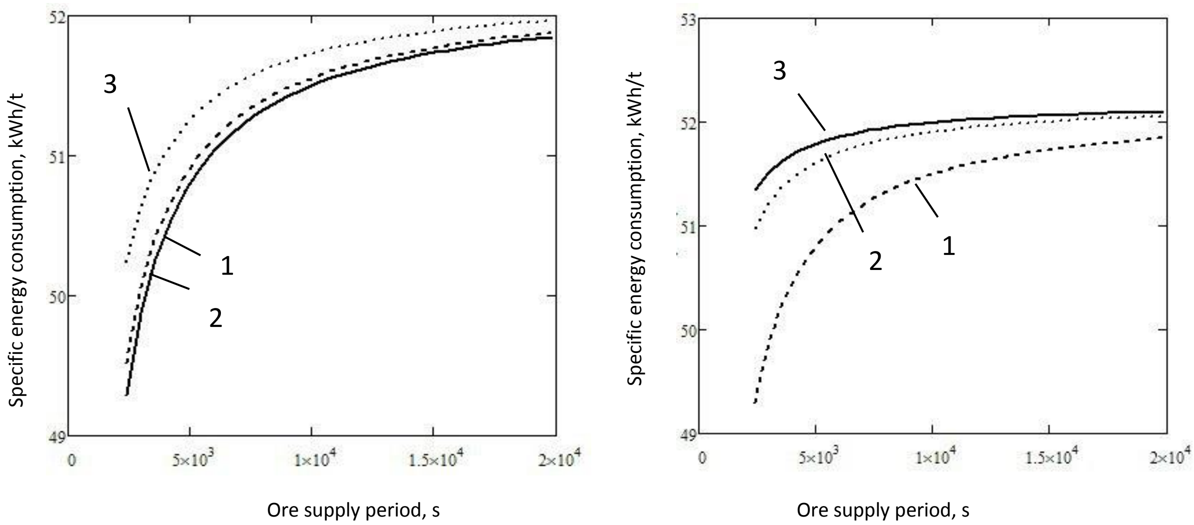
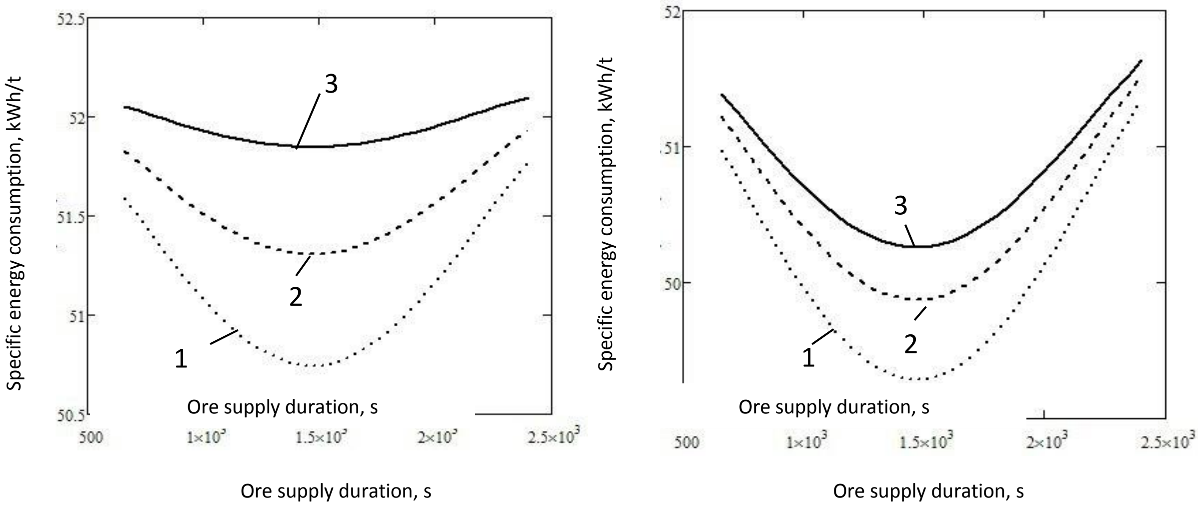


Figure 3. Three dimensions graph of influence of ore supply parameters on the specific energy consumption



a) b)

Figure 4. Influence of ore supply period on the specific energy consumption:
a) 1) τ = 25 min; 2) τ = 11 min; 3) τ = 40 min;
b) 1) τ = 25 min; 2) τ = 20 min; 3) τ = 15 min



a) b)

Figure 5. Influence of ore supply duration on the specific energy consumption:
a) 1) T = 80 min; 2) T = 130 min; 3) T = 330 min;
b) 1) T = 40 min; 2) T = 50 min; 3) T = 60 min

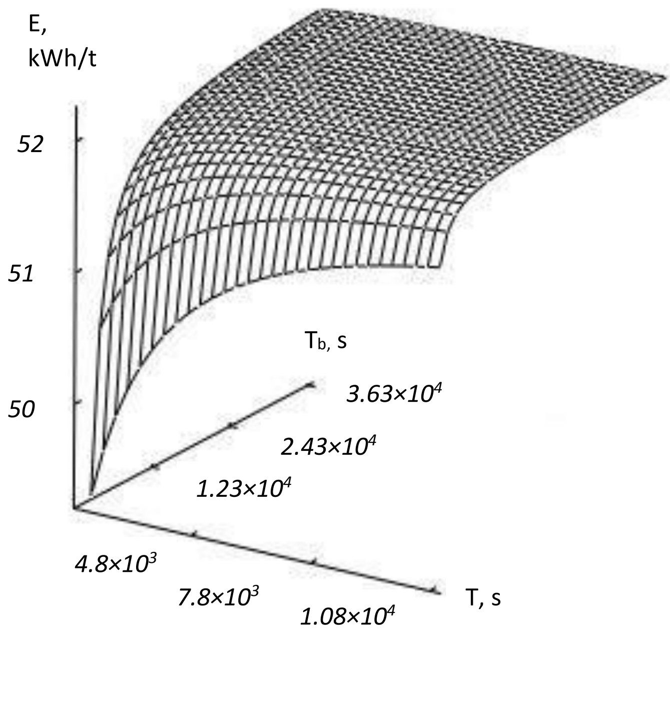


Figure 6. Three dimensions graph of the influence of bin's time response
on the specific energy consumption

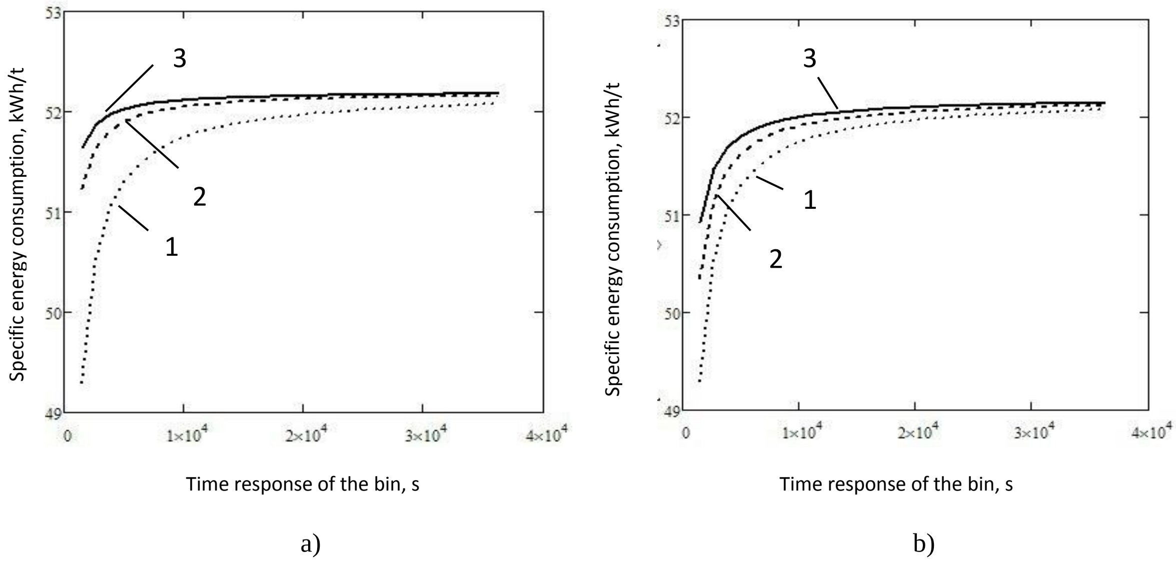


Figure 7. The influence of bin's time response on the specific energy consumption:
a) 1) T = 35 min; 2) T = 105 min; 3) T = 180 min;
b) 1) T = 35 min; 2) T = 55 min; 3) T = 80 min

1.3 The results of modeling of the bin's time response influence on specific energy consumption in mining and processing enterprise.

In the Figures 6 – 7, the influence of bin's time response on specific energy consumption of concentrate production is shown.

The dependence between bin's time response and specific energy consumption is non-linear. With the grow of bin's time response to more than 300 min, the growth of specific energy consumption is minimal, which makes it possible to form a range of effective management for this parameter.

Conclusions. Thus, there is an opportunity to influence energy intensity of production process in mining and processing enterprise managing ore supply dynamics parameters. The determined influence of bin's time response, as parameter of bin functionality, on the specific energy consumption confirm the practicability of ore amount management in bin by changing the parameters of the loading equipment. Availability of extremum point in the graph of influence of ore supply duration parameter on the specific energy consumption indicates the possibility of process optimization.

Model of ore supply dynamics influence on energy consumption can be used in further research on the topics of energy saving and energy efficiency automation in mining and processing enterprise to develop a decision support system with a criterion of minimum specific energy consumption.

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МОДЕЛЮВАННЯ ВПЛИВУ ДИНАМІКИ РУДОПОСТАЧАННЯ НА ЕНЕРГОСПОЖИВАННЯ ГІРНИЧО-ЗБАГАЧУВАЛЬНОГО КОМБІНАТУ З ПОЗИЦІЇ КЕРУВАННЯ

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Резюме. *Досліджено моделі впливу динаміки поставок руди і постійної часу бункера на споживання енергії гірничо-збагачувального комбінату. Проаналізовано фактори і параметри моделі впливу динаміки поставок руди і постійної часу бункера на споживання енергії гірничо-збагачувального комбінату. Наведено схему моделювання відповідно до запропонованих моделей. Обґрунтовано ідею розробити систему підтримки прийняття рішень з критерієм мінімуму питомих витрат електроенергії.*

Ключові слова: *динаміка рудоподачі, енергоспоживання, гірничо-збагачувальний комбінат, моделювання.*

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