

Cost price reduction is one of the ways to improve the competitiveness of products. It is possible by establishing the set of factors affecting the production costs at an industrial enterprise and building on this basis a mathematical model of in-house cost management.

The study objective was to develop and substantiate an economic-and-mathematical model of management to minimize the enterprise costs taking into account the utilization of secondary resources obtained in the production of basic products. The model consists of two stages. At the first stage, full costs of production of basic and additional products are determined. The peculiarity of this production implies the generation of significant amounts of secondary resources that have both independent value and opportunities for their use in the main technological process. This leads to complex material flows within the production process, which were accounted for in the study with the help of an adapted "cost-output" balance model.

A plant can function with the use of a variety of raw materials which differ in both prices and rates of the output of basic products and secondary resources. This brings about the problem of finding an optimal combination of input resources to minimize costs or maximize profits. The problem is solved in the second stage. It is formalized as a linear programming problem. It features the provision of the ability to establish indicative plans of production of both main products and by-products.

The model was tested on the example of coke-chemical plants producing coke of KDM-2 grade with 6 % humidity content and KDM-1 grade coke of improved quality as the main products. Coke oven gas, coke fines, beans, and sludge are produced as by-products. After purifying the coke oven gas, it is further used in the production of heat and electricity, compressed air, and a fuel for coke ovens. Thus, the produced fuel and energy, utilizable material resources, and circulating water supply are secondary resources. A certain portion of by-products is sold to third parties.

When applied, the model will make it possible to improve the efficiency of cost management at enterprises

Keywords: industrial enterprise, cost management, secondary resources, cost optimization, linear programming

Received date 13.05.2020

Accepted date 14.07.2020

Published date 31.08.2020

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1. Introduction

Product cost price is one of the most important factors influencing the profitability, solvency, and competitiveness of an industrial enterprise, its positioning in the target market of industrial goods.

Industrial production is material- and energy-intensive and costly, so the efficiency of plants directly depends on the economical use of material resources and energy.

Limited amount of material resources increases supply costs, so industrial plants are forced to make management decisions on the use of returnable waste as secondary resources. Formation of management decisions requires an assessment of technological features of obtaining and use of secondary material resources.

The use of primary energy resources (fuel, heat and electricity, steam, compressed air, etc.) has a negative impact on

the cost of industrial products. The main problem for enterprise management is searching for technological processes based on the utilization of secondary energy resources.

Any metallurgical complex which includes coke and mechanical engineering plants capable to produce foundry goods, chemicals, etc., has every opportunity to use secondary energy sources.

Both technical and technological issues of utilization, purification, production of energy carriers, and economic issues of cost optimization and substantiation of in-house prices for secondary energy resources remain relevant. At the same time, the utilization of coke oven gas generated in the process of coke production solves two issues: reduction of the cost price of coke-chemical products and harmful emissions into the atmosphere.

Recently, the construction of optimization models to maximize profits or minimize costs is scarcely considered in

UDC 658.1:338.3

DOI: 10.15587/1729-4061.2020.208764

MANAGING COSTS OF AN INDUSTRIAL ENTERPRISE WHEN USING SECONDARY RESOURCES

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information sources. However, practice shows that models of mathematical forecasting are in demand in activities of industrial plants as they make it possible to establish both volumes of products and energy resources and their cost price. However, each branch of the processing industry has its in-house characteristics regarding the formation and use of secondary resources.

Thus, there is a need to improve the cost management of industrial enterprises by construction and testing an economic-and-mathematical model of minimizing production costs taking into account secondary resources.

2. Literature review and problem statement

Many scientific papers are devoted to the issue of cost management of industrial enterprises since profits, innovation, social security of employees, etc. depend on the cost price level.

The method of “cost-output” or Leontiev’s method of intersectoral balance [1] based on the use of direct production costs is the most common method of cost analysis at enterprises.

A model of cost optimization for multi-node construction projects was presented in [2] based on the model of mathematical programming and taking into account direct and indirect costs, cost of missed deadlines and breaks in the working group. The objective function is the total cost of the project.

This study feature consists in that the search for solutions is combined with a metaheuristic algorithm simulator at a simultaneous solution of the linear optimization problem using the Simplex method [2].

The authors simultaneously address the issue of minimizing construction costs and deadlines. The advantage of the scientific approach implies the formation of an algorithm for a gradual making an optimal decision to minimize the cost of the construction project. The lack of cost optimization according to the established classification is its disadvantage.

The authors of [3] emphasize that the production of electricity at the in-house plant is an effective reserve for cost savings. The paper proposes a model of mixed-integer non-linear programming (MINLP) for the system’s production plan and minimization of total energy costs.

To solve the MINLP problem, the paper proposes a linearization strategy and a metaheuristic algorithm at reasonable computational costs. However, the problem is time-consuming to use in an industrial plant and features a large error.

The paper [4] presents a model of regression analysis to assess the factors influencing the operating income of the plant. Only two factors are taken into account: production assets and labor resources. The authors do not analyze the impact of such important factors as material and fuel-energy resources. Correlation-regression analysis enables identification of factors of influence but does not optimize the cost price, so it is inapplicable to planning full enterprise costs.

It was found in [5] that environmental aspects are not considered in the system of management accounting as a part of direct or indirect production costs. Therefore, the authors of [5] proposed a model that takes into account various aspects of impact on the environment that results in limitations and changes factors of direct cost in the objective function. Sensitivity analysis and parametric programming make it possible to use in-house prices in terms of sharing environmental costs while paying attention to pricing for emissions, resources, production, and reprocessing activities. However, the authors of [5] do not show how the model takes

into account the cost of utilization of harmful emissions and makes use of wastes and emissions as fuels, electricity, and other energy resources.

The model of dynamic programming is used in [6] where cost reduction is planned due to an optimal amount of production in accordance with the market demands. The advantage of dynamic programming implies the optimization with taking into account the time factor. However, costs are minimized only through reducing the product volume and the impact of other expenses on the cost price is not studied.

In contrast to the previous work, paper [7] presents a method of cost planning (dynamic programming) which considers environment-related costs as internal costs. These costs include hydrocarbon emissions, the cost of energy consumption and the costs associated with the wastes of material resources. The authors divide the environment-related costs into direct and indirect. The direct costs include those related to emissions, wastes, and energy consumption. Indirect costs include the cost of air purification services and preventive measures for soil and water conservation, which can be attributed to return material resources and considered as direct costs.

Flexibility and adaptability of the behavior of variables are the advantages of dynamic cost programming but high planning overheads are its disadvantage. Therefore, in further studies, it is expedient to combine static and dynamic programming of expenses for industrial plants.

In [8], attention is paid to medium-term production planning in conditions of discrete time. The authors point out that it is advisable to move from a linear to a circular (waste-free) economy paying attention to the processing of raw materials, emission utilization, energy consumption, and obtaining of by-products. However, this study only systematizes existing publications on the issues of linear and circular economics and does not search for the problem solution.

The study [9] is devoted to the circular economy as well. It states that the interaction of energy, water and environmental systems plays an important role in industrial production. There is a need to integrate activities of plants where a by-product of one entity becomes a resource for another.

However, [9] does not analyze the organization of the cost management process through the use of secondary resources as an in-house circular economy of the industrial plant (use for in-house needs) and products sold to third parties.

The authors of [10] note that industrial plants consume a multitude of material and energy resources. Given the scarcity of resources and production of zero emissions, it is proposed to introduce a methodology of “rational behavior” of the consumer. “Rational behavior” is the intention to maximize the use of benefits and potentials of energy markets in order to reduce energy costs, raise the level of electrification in industrial production and use the opportunities of their in-house energy carrier production. The operation of a power plant and a combined heat power plant (CHPP) at large metallurgical plants is analyzed in [10] but no modeling of costs for different options of use of secondary material and energy resources is proposed.

An important issue of determining the costs of converting waste into energy and material resources in conditions of industrial symbiosis is considered in [11]. Industrial symbiosis is considered in a regional aspect. The authors solve the problem in two stages. A problem of optimal management intended for choosing the best waste conversion technology for companies is proposed for the first stage. The greatest benefit for the symbiosis participants is determined at the second stage based on the theory of joint games and a core.

The core-based approach allows symbiosis participants to gain additional income. Its use helps to increase the interest of the symbiosis participants. However, for some industries, the use of secondary resources for cleaning or preparation for reuse requires additional investments which is a hard task.

In the problems of optimizing the cost price of products of a concrete industrial plant taking into account secondary resources, it is impractical to apply the game theory but it is purposeful to consider it in a further study for selling by-products.

Thus, the cost price of the plant products is planned in [1, 2, 5, 7] in terms of direct and indirect costs. The reduction of the cost price requires an analysis of factors (economic items) in relation to the impact on the level of costs and the operating income [4]. Studies [5, 7, 10, 11] are devoted to improving the composition of costs. These studies established the relevance of the use of waste and emissions as secondary material and fuel-energy resources. The authors of [8, 9] propose by-products that arise as a result of the utilization of production waste to third-party plants (circular economy) which are parts of the industrial symbiosis. However, it is proposed in [10] to use most of the waste in its own production as a secondary resource. The analysis has shown that the publications on the plant cost optimization use various economic and mathematical methods: regression analysis [4], linear [2], nonlinear [3], and dynamic programming [6, 7] and the game theory [11]. However, each of the above methods has certain disadvantages. Only linear programming can be used when planning costs by taking into account secondary material and fuel-energy resources since it enables calculation of full production and sale costs taking into account savings from the use of secondary resources.

Thus, there is a necessity of statement of an economic-and-mathematical problem of optimizing costs of an industrial plant which takes into account:

- utilization of secondary material and fuel-energy resources;
- use of secondary resources in the production of basic products;
- sale of secondary resources to third parties as by-products.

3. The aim and objectives of the study

The study objective is to construct an economic-and-mathematical model of managing minimization of costs for the production of industrial products in conditions of use of secondary resources which will make it possible to determine in-house prices for fuel, heat, electricity and water resources.

To achieve this objective, the following tasks were set:

- analyze the technological features of production and use of secondary resources on examples of coke plants;
- develop an economic-and-mathematical model for optimizing costs of an industrial plant taking into account variance of material aggregates concerning the production of basic products and yield of by-products used as secondary resources;
- test the cost minimization model on examples of coke plants as this model represents the problem

of linear programming and takes into account secondary material, fuel-energy, and water resources.

4. Construction of a model of minimizing the costs of an industrial plant under the use of secondary resources

4. 1. Analysis of technological features of production and use of secondary resources of coke plants

Secondary resources mean by-products or additional products that are used in the main technological process as material, fuel-energy, or water resources.

Coke production is an important component of the metallurgy complex since it is used in the blast furnace operation as a reducing agent for iron ore, the source of cast iron used in the production of steel and steel products. Besides the basic product, coke oven gas and by-products are produced at coke plants (CP) (Table 1, Fig. 1).

Table 1

Analysis of production of coke, coke oven gas, and additional products [12–16]

Indices	Years				
	2014	2015	2016	2017	2018
Total coke production, thousand t	7,055.38	5,944.094	6,757.266	5,154.255	5,690.170
Index of production growth for coke	–	0.84	1.137	0.76	1.10
Production of coke gas, thousand m ³	3,152,519.8	2,590,949.92	3,080,491.33	2,318,503.2	25,33,942.8
Index of production growth for coke gas	–	0.82	1.19	0.75	1.09
Coke beans, thousand t	333.621	249.885	292.692	244.646	287.261
Index of production growth for coke bean	–	0.74	1.17	0.84	1.18
Coke fines, thousand t	768.528	630.119	734.291	620.197	652.066
Index of production growth for coke fines	–	0.82	1.17	1.17	1.05

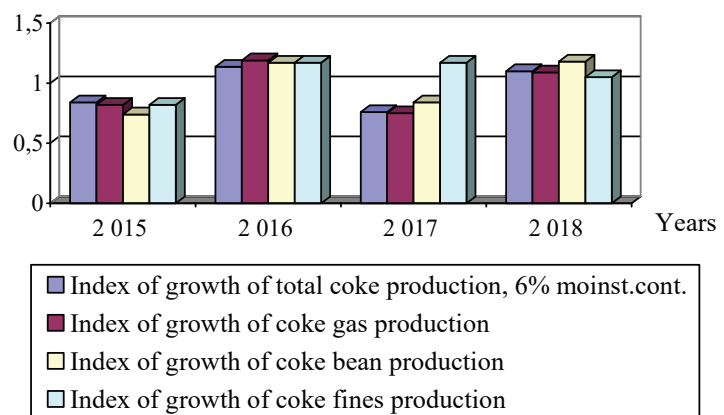


Fig. 1. Dynamics of the production growth index for coke, coke oven gas and additional products at coke plants

The study of the growth of coke and coke oven gas production dynamics has shown (Table 1, Fig. 1) instability of CP activities and direct dependence of coke oven gas production on coke, or more precisely, on the charge.

Coke oven gas is a product of the thermal decomposition of coal molecules. It is formed simultaneously with coke during coal distillation in chamber ovens. This process is realized at 900–1,200 °C. The amount of gas produced directly depends on the set temperature and the cycle duration [17]. Coke oven gas has a high calorific value of 14–18 MJ/m³ which makes it the most efficient gaseous fuel [18]. 40 % of the gas is used to heat coke batteries in coke production and production of steam and compressed air for technological needs. Gas is directed converted into electricity by turbines installed at coke plants. In the process of coal decomposition, 330 m³ of coke oven gas per each ton of coal is obtained and used for the generation of electricity [17].

In normal operation, Avdiivsky KHZ PJSC (Ukraine) sells electricity to Donbasenergo JSC (Ukraine) twice cheaper than power plants. In normal operation, Yuzhkoks PJSC (Ukraine) and Dniprokoks PJSC (Ukraine) are fully self-sufficient as concerns electrical energy. To use coke oven gas, it should be cleaned (Fig. 2, Table 2).

Thus, coke oven gas provides the CP with advantages in terms of energy resources: fuel (natural gas), electricity (in-house production), heat (in-house utilization), steam and compressed air (in-house production). Therefore, coke oven gas purification allows the CP to save on fuel and energy resources. In addition to the use of coke oven gas for in-house needs, the CP sell it to third parties (Table 3).

It can be seen from Table 3 that the coke oven gas from the CP is used in different ways. Avdiivsky KHZ PJSC transfers 0.002 % of produced coke oven gas to third parties and does not use 25.78 % at all. Zaporizhkoks PJSC transfers 32.3 % and does not use only 0.14 %. Yuzhkoks PJSC does not transfer coke oven gas at all and does not use 0.53 % in coke production.

In addition to saving on material and energy resources, the CP use circulating water supply.

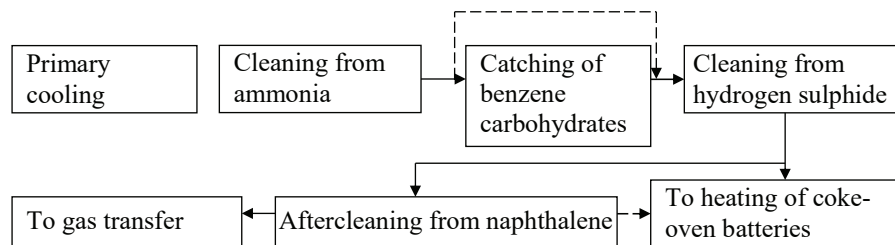


Fig. 2. Diagram of coke gas processing [18]

Table 2

Composition of coke gas and its cleaning [18]

Coke gas composition	Cleaning parameters	Cleaning operations
hydrogen H ₂ : 50–60 %	300–500 g/nm ³ of water vapor	Cleaning by condensation or freezing-out
methane CH ₄ : 20–30 %	100–125 g/nm ³ of tar	Tar residues are precipitated on electric filters
carbon oxide CO: 5–7 %	30–40 g/nm ³ of benzene carbohydrates	Benzene is absorbed by resin oil or solar oil
carbon dioxide CO ₂ : 2–3 %	7–1 g/nm ³ of ammonia	Ammonia and sulfur are caught for further reprocessing into medicines
nitrogen N ₂ : 2–3.5 %	5–20 g/nm ³ of hydrogen sulfate and partial inclusions of carbon bisulfide, nitrogen oxides, cyanogen	The capture of other impurities is primarily determined by the preservation of equipment and pipelines, as the excess content of these substances can cause equipment failure, clogging of pipes and hydraulic shocks

Table 3

Balance of production and consumption of coke oven gas in 2018 [15]

Plant name	Gas evolved from the charge, thousand m ³	Consumption, thousand m ³			Transfer to the third parties, thousand m ³	Non-consumed gas, thousand m ³
		For heating coke oven batteries	For heating boilers	Other consumers		
Avdiivsky KHZ PJSC	1,645,147.703	819,892.64	352,445.18	48,718.362	30.308	424,061.213
Zaporizhkoks PJSC	381,425	209,177	41,316	7,225	123,182	525
Yuzhkoks PJSC	233,684.619	150,051.892	81,948.664	442.698	0	1,241.365

Thus, the technological features of coke production allow companies to reduce cost prices through the use of secondary energy resources and circulating water supply. Also, they obtain additional incomes from the sale of coke oven gas to third parties.

4. 2. Statement of the problem of optimizing costs of an industrial enterprise under the use of secondary resources

In the course of operation of full-cycle industrial plants, such as coke-chemical, metallurgical, machine-building, etc., by-products or additional products are obtained besides the basic products. Additional products can be used as secondary resources, some of which are sold to final consumers, and others are returned to the technological process.

Coke production should be considered as a multicommodity production and the “cost-output” model should be used for accounting in-house consumption of secondary resources. In this case, each resource involved is considered

an economic sector in Leontiev’s model of intersectoral balance [1].

The nomenclature of resources used and produced at the plant is indexed as $i=1, \dots, n$. It is advisable to divide this set into three subgroups: a set of input resources I , a set of sold products O and a set of secondary resources S ; $I \cup O \cup S = \{1, \dots, n\}$. Denote volumes of product deliveries to final consumers by $y_i, i=1, \dots, n; y_i=0$ for $i \in I$.

Denote the i -th resource volume spent on the production of the j -th resource by x_{ij} , $i=1, \dots, n$, $j=1, \dots, n$. Then the volume of gross output of the i -th resource is given by the formula:

$$x_i = \sum_{j=1}^n x_{ij} + y_i, \quad i=1, \dots, n. \quad (1)$$

Denote price of the i -th resource by p_i , $i=1, \dots, n$. The plant income from sales of the i -th resource is:

$$\pi_j = p_j y_j - \sum_{i=1}^n p_i x_{ij}, \quad (2)$$

and the total profit of the plant is:

$$\pi = \sum_{j=1}^n \pi_j. \quad (3)$$

The use of secondary resources generated as a result of the production of basic products is accounted for as follows. If the secondary resource $s \in S$ is transferred directly for selling to final consumers, the volume of this sale is included in the vector y as an element y_s . If the secondary resource is returned to the technological process for the production of the main product $o \in O$, then the volume of its consumption is reflected as elements x_{so} of the matrix X .

Current data (per day or per shift) are the source of information on the technological preparation of production activities of the plant taking into account utilization and distribution of secondary resources between material resources (matrix X) and final products (vector y).

Like in V. Leontiev's model, an assumption was made on the constancy of proportions of resource use when the scale of production is changed and coefficients of direct costs were introduced as follows:

$$a_{ij} = \frac{x_{ij}}{x_j}. \quad (4)$$

The coefficient a_{ij} was interpreted as the amount of the i -th resource required to produce a unit of the j -th resource. Using these coefficients, equations (1) and (3) take the form:

$$x_i = \sum_{j=1}^n a_{ij} x_j + y_i, \quad i=1, \dots, n; \quad (5)$$

$$\pi = \sum_{i=1}^n p_i y_i - \sum_{i=1}^n p_i \sum_{j=1}^n a_{ij} x_j. \quad (6)$$

After combining the indexed variables in vectors and matrices, equations (5), (6) are written as:

$$x = Ax + y; \quad (7)$$

$$\pi = \underbrace{p^T y}_{\text{income}} - \underbrace{p^T A x}_{\text{costs}} = p^T (y - Ax). \quad (8)$$

where

$$y = \begin{pmatrix} y_1 \\ \dots \\ y_n \end{pmatrix}; \quad x = \begin{pmatrix} x_1 \\ \dots \\ x_n \end{pmatrix}; \quad p = \begin{pmatrix} p_1 \\ \dots \\ p_n \end{pmatrix}; \quad A = \begin{pmatrix} a_{11} & \dots & a_{1n} \\ \dots & \dots & \dots \\ a_{n1} & \dots & a_{nn} \end{pmatrix}. \quad (9)$$

Using relation (7), formulas for expressing the relationship between sold and gross products are as follows:

$$y = (I - A)x; \quad (10)$$

$$x = (I - A)^{-1} y; \quad (11)$$

where I is a unit matrix of dimension $n \times n$. Elements of the matrix $B = (I - A)^{-1}$ represent coefficients of total (direct and indirect) consumption of the i -th resource for the production of a unit of the j -th resource taking into account the return of secondary resources to production.

Analysis of costs and incomes of the plant using the "costs-output" model is reduced to performing the following steps:

– construct a matrix of coefficients of direct costs A based on current data of production activities of the plant (a report on the use of raw materials for the production of basic products);

– using formula (11), determine the vector of gross output x for the planned volumes of output of the main types of products and secondary resources given by the vector y ;

– calculate gross income, costs and profit from formula (8).

By changing components of the vector y , the established steps can be used to assess the impact of changes in the production plan on the financial results of the plant activities.

For the production of industrial products, raw materials of various types differing in cost and yield of primary and secondary resources can be used. Volumes of consumption of various raw materials are limited by volumes of their supply. Therefore, a problem appears to find such an optimal mixture of raw materials which will lead to minimum costs (or a maximum profit) with restrictions on the available amount of input resources.

Each option of the mixture of raw materials, $k=1, \dots, l$, corresponds to a certain matrix of direct costs A^k which is associated with the use of a certain technology of production and output of secondary resources. Denote by λ_k the specific weight of the k -th mixture in the plant plan of procurements ($0 \leq \lambda_k \leq 1$). The input resource requirements associated with the use of the k -th technology are determined by the elements x_i^k , $i \in I$ of the vector $x^k(y) = (I - A^k)^{-1} y$, that is, the gross resource requirements associated with the production plan when using the k -th mixture. Then we can consider the following optimization problems which are parameterized by the planned production vector y :

$$\sum_{k=1}^l \lambda_k p^T A^k x^k(y) \rightarrow \min \quad (12)$$

to minimize costs, or

$$\sum_{k=1}^l \lambda_k p^T (y - A^k x^k(y)) \rightarrow \max \quad (13)$$

to maximize profits, with restrictions:

$$M_i^k \leq \lambda_k x_i^k(y) \leq R_i^k, \quad k=1, \dots, l, \quad i \in I, \quad (14)$$

$$\sum_{k=1}^l \lambda_k = 1, \quad (15)$$

$$0 \leq \lambda_k \leq 1, \quad k=1, \dots, l, \quad (16)$$

where R_i^k is the maximum available number of variants of raw materials (mixtures) and other input resources associated with the use of the k -th technology; M_i^k is the minimum amount of raw materials (mixtures) and other resources required to ensure a smooth production process.

There may be other restrictions due to the specifics of a particular plant.

4. 3. Methodical recommendations for minimizing direct production costs (on the example of coke plants)

Due to the use of secondary resources, the company reduces the cost of coke production. As a result, CPs have the opportunity to save by reducing variable costs.

The problem of optimizing the costs of coke production is solved in several stages (Fig. 3).

At the first stage, input information is collected on the volume of production, resources used for production, the cost of resources in the previous period, the volume of sales of basic products at an actual cost price. It should be noted that different types of coal are used in coke production. This affects the quality characteristics of products. In this case, the enterprise has different yields of secondary resources depending on the coal rank and the mines from which it is supplied, as well as the composition of the charge (mixture).

Therefore, the product structure in terms of actual cost price and specific weight of yield (use) of secondary resources according to the charge options are found in the second stage. At the third stage, costs are calculated according to the coefficients of direct costs with no use of secondary resources, and the need for coal reserves by ranks (mines) and other resources is established. The volumes of secondary resources are calculated at the fourth stage. Monthly cost savings obtained due to the use of secondary material and fuel-energy resources are determined at the fifth stage. Overall savings from minimizing the CP costs at the expense of secondary resources are established at the sixth stage.

The methodological recommendations concerning the process of minimizing direct costs are given in Table 4.

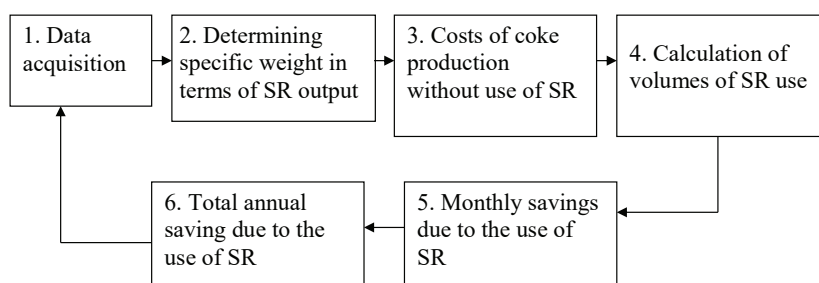
Thus, when elaborating methodological recommendations for minimizing costs of KDM-1 and KDM-2 coke production, various charge compositions by coal ranks and mines, the technology of utilization and use of secondary resources are taken into account.

Table 4

Methodological recommendations for minimizing direct costs of the CP

No.	Stage of calculation of cost minimization	Indicators	Calculation procedure
1	Data acquisition	1. 1. Production volume	1. KDM-1 (Q_{KDM-1}), KDM-2 (Q_{KDM-2}), coke gas (Q_{CG}), coke beans (Q_{CB}), coke sludge (Q_{CSL}), coke fines (Q_{CF})
		1. 2. Coal amount, t	1. 2. Coal amount by ranks ($V_G, V_C, V_F, V_{CF}, V_{LC(CL+CLC)}$) and mines
		1. 3. Actual cost price of the product unit	1. 3. Average cost of KDM-1 (CPa_{KDM-1}), KDM-2 (CPa_{KDM-2}), coke gas (CPa_{CG}), coke beans (CPa_{CB}), coke sludge (CPa_{CSL}), coke fines (CPa_{CF})
		1. 4. Actual cost price of secondary resources	1.4. Average cost of coke gas (SRa_{CG}), coke bean (SRa_{CB}), coke sludge (SRa_{CSL}), coke fines (SRa_{CF}) in the previous period
		1. 5. Actual cost price of electrical energy of in-house production for technological purposes	1.5. Average cost of 1 kWh of in-house production (CPa_{EE})
		1. 6. Actual cost price of 1 m ³ of water	1. 6. Cost of 1 m ³ of water taking into account circulating water supply (CPa_W)
		1. 7. Sale volumes of main products at actual cost price: KDM-1 (SV_{KDM-1}) and KDM-2 (SV_{KDM-2})	$SV_{KDM-1} = Q_{KDM-1} \times CPa_{KDM-1};$ (17) $SV_{KDM-2} = Q_{KDM-2} \times CPa_{KDM-2}$ (18)
2	Determining unit weight of SR yield		
2. 1	Establishing the structure (unit weight) in a sold product at actual cost price of the product	2. 1. Unit weight of KDM-1 (UW_{KDM-1}), KDM-2 (UW_{KDM-2}), coke gas (UW_{CG}), coke bean (UW_{CB}), coke sludge (UW_{CSL}), coke fines (UW_{CF}) in the structure of the sold products.	$UW_{KDM-1} = (Q_{KDM-1} \times CPa_{KDM-1}) / TC_{CPa};$ (19) where TC_{CPa} is total cost of the products at actual cost price; $UW_{KDM-2} = (Q_{KDM-2} \times CPa_{KDM-2}) / TC_{CPa};$ (20) $UW_{CG} = (Q_{CG} \times CPa_{CG}) / TC_{CPa};$ (21) $UW_{CB} = (Q_{CB} \times CPa_{CB}) / TC_{CPa};$ (22) $UW_{CSL} = (Q_{CSL} \times CPa_{CSL}) / TC_{CPa};$ (23) $UW_{CF} = (Q_{CF} \times CPa_{CF}) / TC_{CPa}$ (24)
		2. 2. 1. Unit weight of use of SR (coke gas) for production of KDM-1 and KDM-2 ($UWsr_{CG}$)	$UWsr_{CG} = (SRa_{CG} \times UW_{CG}) / (Q_{CG} \times 100);$ (25)
		2. 2. 2. Unit weight of use of SR (coke bean) for production of KDM-1 and KDM-2 ($UWsr_{CB}$)	$UWsr_{CB} = (SRa_{CB} \times UW_{CB}) / (Q_{CB} \times 100);$ (26)
		2. 2. 3. Unit weight of use of SR (coke sludge) for production of KDM-1 and KDM-2 ($UWsr_{CSL}$)	$UWsr_{CSL} = (SRa_{CSL} \times UW_{CSL}) / (Q_{CSL} \times 100);$ (27)
		2. 2. 4. Unit weight of use of SR (coke fines) for production of KDM-1 and KDM-2 ($UWsr_{CF}$)	$UWsr_{CF} = (SRa_{CF} \times UW_{CF}) / (Q_{CF} \times 100);$ (28)
2. 2	Establishing the structure (unit weight) in terms of use of secondary resources		

3		Costs of coke production with no use of SR	
3.1	Calculating coefficients of direct material costs	3.1. Coefficients of direct costs by ranks of coal, coke gas, water and electrical energy	$Kdc_{KDM-1}=(V_G \times UW_{KDM-1}) / (Q_{KDM-1} \times 100);$ (29)
			$Kdc_{KDM-2}=(V_G \times UW_{KDM-2}) / (Q_{KDM-2} \times 100);$ (30)
			$Kdc_{CG}=(V_G \times UW_{CG}) / (Q_{CG} \times 100);$ (31)
			$Kdc_{CB}=(V_G \times UW_{CB}) / (Q_{CB} \times 100);$ (32)
			$Kdc_{CSL}=(V_G \times UW_{CSL}) / (Q_{CSL} \times 100);$ (33)
			$Kdc_{CF}=(V_G \times UW_{CF}) / (Q_{CF} \times 100);$ (34)
etc.			
3.2	Calculation of necessary reserves of coal and other resources	3.2. Necessary reserves of coal by ranks, coke gas, water, and electrical energy	$NR_{KDM-1}=Q_{KDM-1} \times Kdc_{KDM-1};$ (35)
			$NRg_{KDM-2}=Q_{KDM-2} \times Kdc_{KDM-2};$ (36)
			$NRg_{CG}=Q_{CG} \times Kdc_{CG};$ (37)
			$NRg_{CB}=Q_{CB} \times Kdc_{CB};$ (38)
			$NRg_{CSL}=Q_{CSL} \times Kdc_{CSL};$ (39)
			$NRg_{CF}=Q_{CF} \times Kdc_{CF};$ (40)
			$NRg=NRg_{KDM-1}+NRg_{KDM-2}+NRg_{CG}+NRg_{CB}+NRg_{CSL}+NRg_{CF}$ (41)
etc.			
4	Calculating volumes of SR use	4. Volumes of secondary resources (coke gas, coke bean, coke sludge, coke fines)	$SR_{CG}=[(Q_{KDM-1}+Q_{KDM-2}) \times UWsr_{CG}] / 100;$ (42)
			$SR_{CB}=[(Q_{KDM-1}+Q_{KDM-2}) \times UWsr_{CB}] / 100;$ (43)
			$SR_{CSL}=[(Q_{KDM-1}+Q_{KDM-2}) \times UWsr_{CSL}] / 100;$ (44)
			$SR_{CF}=[(Q_{KDM-1}+Q_{KDM-2}) \times UWsr_{CF}] / 100$ (45)
5	Monthly savings due to the use of SR	5.1. Cost of material and other resources per month with no taking into account SR (C_M)	$C_M=NRg \times P_g+NR_C \times P_C+NR_F \times P_F+NR_{CF} \times P_{CF}+$ $+NR_{LC} \times P_{LC}+NR_{CL} \times P_{CL}+NR_{CLC} \times P_{CLC},$ (46)
		where P is procurement price for coal and other material resources	
		5.2. Costs of SR by types (CSR_M)	$CSR_{CG}=SRa_{CG} \times CPa_{CG};$ (47)
			$CSR_{CB}=SRa_{CB} \times CPa_{CB};$ (48)
			$CSR_{CSL}=SRa_{CSL} \times CPa_{CSL};$ (49)
$CSR_{CF}=SRa_{CF} \times CPa_{CF}$ (50)			
5.3. Savings due to the use of SR (SSR_M)	$SSR_M = \sum_{i=1}^n C_M - \sum_{j=1}^m CSR_M,$ (51)		
where $i...n$ is the number of types of material and other resources; $j...m$ is the number of SR types			
6	Total annual savings due to the use of SR	6. Total costs for material resources: coal of rank G (SSR_{YEAR})	$SSR_{YEAR} = \sum_{k=1}^{12} SSR_M,$ (52)
			where $k...12$ is number of months in a year



5. Testing the economic-and-mathematical model of minimization of coke production cost

The problem of optimizing coke production is solved in several stages. The first stage is the collection of initial information on the amount of resources spent on production and their costs. It should be noted that various types of coal are used in the production of coke.

Fig. 3. Stages of calculation of total savings due to the use of secondary resources (SR)

This makes it possible to obtain coke with various quality characteristics. Three types of the mixture (charge) of input materials are used at the plant which was taken for the model testing. Table 5 shows the costs of resources for the production of other resources for the technology of coke production using the charge 1 (technology 1).

Coefficients of direct costs were calculated from formula (4) at the next step. They are given below (Table 6) for technology 1.

Using the data from Table 5, values of gross income, expenses, and profits related to the implementation of the established production plan for the three technologies which became the initial data for the optimization problem were obtained.

Next, solve the problem of minimizing the costs of coke production. The objective function (12) for this problem takes the following form:

$$863.12\lambda_1 + 1721.84\lambda_2 + 127.34\lambda_3 \Rightarrow \min, \tag{53}$$

and the constraints (14) take the form:

$$\begin{aligned} 57,000 \leq 286,926\lambda_1 \leq 258,000, \\ 122,000 \leq 612,090\lambda_2 \leq 550,000, \end{aligned} \tag{54}$$

$$74,000 \leq 370,706\lambda_3 \leq 333,000.$$

The obtained model of linear programming with objective function (53) and constraints (15), (16) and (54) was solved using the built-in function “Solution search” in MS Excel.

As a result of solving the problem of cost minimization, optimal proportions of the use of various types of charge were obtained. Therefore, according to the model (15), (16), (53), (54) it is necessary to adhere to the following proportions of mixtures (charges): 3:2:5, that is, it is necessary to use mixture 3 in larger quantities because the gross costs for this resource are the lowest (Fig. 4).

It should be noted that the third charge has the smallest number of different types of coal and no run-of-mine coal at all. This leads to the fact that the smallest amount of coke oven gas is obtained in the production process. A plant can use this gas in own production or sell it to metallurgical and other plants. This use of secondary resources allows the company not only to reduce the cost price of final products (coke) but also to obtain additional income from the sale of coke oven gas to third parties.

The use of mixture (charge) 2 makes it possible to obtain the largest amount of coke oven gas in the production process, namely twice as much as when using a mixture 1 or 3. However, production costs are the largest when using mixture 2.

Table 5

Costs of resources for technology, 1 mon. unit

	Run-of-mine coal	Coal concentrate	Coke	Coke gas	Process electrical energy	Process steam	Compressed air	Dry coke quenching	Coke fines	Coke beans	Coke sludge
Run-of-mine coal	0	0	4,013.9	1,037.1	0	0	0	0	103.7	20.7	10.3
Coal concentrate	0	0	7,941.3	2,052	0	0	0	0	205.2	41	20.5
Coke	0	0	0	0	0	0	0	0	0	0	0
Coke gas	0	0	0	211.8	0	1165	317.7	423.6	0	0	0
Process electrical energy	0	0	180.1	0	0	0	0	0	0	0	0
Process steam	0	0	65.9	0	0	16.4	0	0	0	0	0
Compressed air	0	0	150.3	0	0	0	0	0	0	0	0
Dry coke quenching	0	0	1453.5	0	0	0	0	0	0	0	0
Coke fines	0	0	0	0	0	0	0	0	0	0	0
Coke beans	0	0	0	0	0	0	0	0	0	0	0
Coke sludge	0	0	0	0	0	0	0	0	0	0	0

Table 6

Calculated direct costs

	Run-of-mine coal	Coal concentrate	Coke	Coke gas	Process electrical energy	Process steam	Compressed air	Dry coke quenching	Coke fines	Coke bean	Coke sludge
Run-of-mine coal	0	0	0.4815	0.1642	0	0	0	0	0.2177	0.0742	0.1543
Coal concentrate	0	0	0.9526	0.3249	0	0	0	0	0.4306	0.1467	0.3053
Coke	0	0	0	0	0	0	0	0	0	0	0
Coke gas	0	0	0	0.0335	0	14.129	2.114	0.2915	0	0	0
Process electrical energy	0	0	0.0216	0	0	0	0	0	0	0	0
Process steam	0	0	0.0079	0	0	0,2	0	0	0	0	0
Process steam	0	0	0.018	0	0	0	0	0	0	0	0
Process steam	0	0	0.1744	0	0	0	0	0	0	0	0
Coke fines	0	0	0	0	0	0	0	0	0	0	0
Coke beans	0	0	0	0	0	0	0	0	0	0	0
Coke sludge	0	0	0	0	0	0	0	0	0	0	0

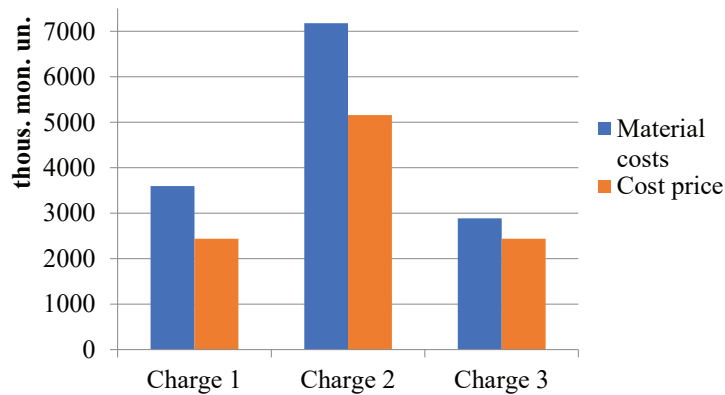


Fig. 4. Resource costs

The use of different types of charges in the proposed proportions will allow the company to reduce production costs to 39,560,358 mon. un. which in comparison with the option of using charges at the plant before optimization makes it possible to reduce production costs by 18 %.

Therefore, the proposed cost reduction of 18 % is achieved by redistributing the proportions of coal mixtures in production. This should lead to lower production costs and higher outputs of coke oven gas. Its use as a secondary resource reduces the cost price of coke and the surplus resources sold to metallurgical or machine-building plants make it possible to obtain additional income which in turn increases the company's profits.

Thus, the application of the optimization model (15) to (18) reduces the plant gross costs by 18 % including those due to the use of the coke oven gas as a secondary resource in own production.

Let us consider what cost savings will allow a company to implement the obtained modeling results on an example of the work of Avdiivsky KHZ PJSC and Zaporizhkok PJSC.

To forecast the costs of production of coke of two ranks (KDM-1 and KDM-2), by-products (coke oven gas, sludge, beans, and fines), the structure of sales at the actual cost of material costs is established (Table 7).

It is seen from Table 7 that the largest share in the structure of sales at Avdiivsky KHZ PJSC is occupied by coke of KDM-2 grade (6 % moisture content). KDM-1 (coke of improved quality) and coke oven gas occupy the second and the third places, respectively.

Avdiivsky KHZ PJSC produced coke in January based on the charge characteristic of grade KDM-2, and additionally, starting from February, based on the grade KDM-2; therefore, the calculation of materials costs for the two coke types in February is given in Tables 8–10.

The total expenses without using SR in February (Table 9) were equal to 22,942,109 monetary units, the cost of using secondary resources was 3,568,958 monetary units. The cost of material and other expenses considering secondary resources in February was 19373151 monetary units.

The results of minimizing the expenses by using secondary resources, achieved by the enterprise over 12 months of 2019, are compared to the actual costs associated with the production of basic and related products over the same period (Table 11).

The total savings by Avdiivsky KHZ PJSC as a result of using SR in February are 208,700.43 monetary units, and the total (annual) savings (Table 11) are 28,846,895.30 monetary units.

The basic product of Zaporizhkok PJSC is KDM-1 – the coke of improved quality whose production yields a lesser output of coke gas (Tables 12–14).

The total savings by Zaporizhkok PJSC in January (Table 11) are 9,758,477.59 monetary units, and the annual savings (Table 15) are 87,933,390.65 monetary units.

Table 7

Average monthly structure of sold main products and by-products at Avdiivsky KHZ PJSC

Index name	Amount, t	Actual cost price of the sold products, mon. un.	Sum, thousand mon. un.	Structure of the sold products, %	Unit weight of SR in the production of coke, %
KDM-1, t	209,738	166.67	34,957.03	29.97	–
KDM-2, t	360,439.5	174.07	62,741.70	53.80	–
Coke gas, m ³	286,227.3	48.82	13,973.62	11.98	14.31
Coke sludge, t	5,079	66.13	335.87	0.29	0.34
Coke beans, t	18,649	94.47	1,761.77	1.51	1.80
Coke fines, t	39,254	72.61	2,850.23	2.44	2.92
Total income from the product sales			116,620.22	100.00	19.37

Table 8

Calculation of the coefficients of direct costs to produce coke of grades KDM-1 and KDM-2 by Avdiivsky KHZ PJSC in February

Material cost	Coefficients of direct costs					
	KDM-1	KDM-2	Coke gas	Coke sludge	Coke beans	Coke fines
Coal, G, t	0.8377	0.3196	0.8696	0.1214	0.1734	0.1333
Coal, C, t	0.6071	0.3677	0.1032	0.1397	0.1996	0.1534
Coal, E, t	0.6088	0.2722	0.0764	0.1034	0.1477	0.1135
Coal, CF, t	0.000	0.0107	0.0030	0.0041	0.0058	0.0045
LC (CL+CLC), t	0.5999	0.0016	0.0004	0.0006	0.0009	0.0007
Coke gas, thousand m ³ /t	0.2108	0.2202	0.0618	0.0836	0.1195	0.0918
Water, thousand m ³ /t	0.0014	0.0015	0.0004	0.0006	0.0008	0.0006
Electricity, thousand kWh/t	0.0103	0.0107	0.0030	0.0041	0.0058	0.0045

Table 9

Calculation of the need for material resources to produce coke of the grades KDM-1 and KDM-2 by Avdiivsky KHZ PJSC in February

Material cost	Price, monetary units	Need for resources	Required resources considering remaining stock
Coal, G, t	26.7	266,099.69	2,170,513
Coal, C, t	21.3	174,488.0	174,488
Coal, F, t	21.3	194,520.16	196,858
Coal, CF, t	29.3	11,426.0	11,426
LC (CL+CLC), t	24.59	140,128.05	147,224
Coke gas, thousand m ³ /t	53.74	73,919.77	130,450
Water, thousand m ³ /t	0.5	491.07	125,740
Electricity, thousand kWh/t	62.2	3,603.69	185,400

Table 10

Minimizing the costs of material and other resources to produce coke of the grades KDM-1 and KDM-2 by Avdiivsky KHZ PJSC in February

Indicator	KDM-1, t	KDM-2, t	Volume of secondary resources				Expenses, monetary units
			Coke gas, thousand m ³ /t	Coke sludge, t	Coke beans, t	Coke fines, t	
Production volume	193,557.1	129,887.44	46,268.85	1111.91	5,832.28	9,435.94	22,942,109
Cost per product unit, monetary units			48.83	66.13	94.47	72.61	
Price of secondary resources, monetary units			2,259,308.07	73,530.78	550,975.34	685,143.39	3,568,958
Expenses based on the difference in secondary resources, monetary units							19,373,151

Table 11

Calculation of the total amount achieved by saving the expenses by Avdiivsky KHZ PJSC over one year

Month	Expenses, monetary units		Total saved, monetary units
	Estimated	Actual	
January	9,435,512	25,010,630	-15,575,117.83
February	19,373,151	19,581,852	-208,700.43
March	17,521,584	15,300,556	2,221,028.33
April	15,866,562	17,196,370	-1,329,808.85
May	17,222,808	19,115,556	-1,892,747.26
June	15,818,030	17,818,259	-1,999,229.43
July	17,475,006	16,973,704	501,302.27
August	18,277,739	21,952,074	-3,674,334.75
September	16,840,736	17,570,481	-729,745.55
October	15,761,673	13,086,037	2,675,636.35
November	14,336,942	22,806,741	-8,469,798.71
December	9,688,991	10,054,370	-365,379.44
Total	187,618,734	216,465,630	-28,846,895.3

Table 12

Calculation of the coefficients of direct costs to produce coke of grade KDM-1 by Zaporizhkoks PJSC in January

Material cost	Coefficients of direct costs				
	KDM-1	Coke gas	Coke sludge	Coke beans	Coke fines
Coal, G, t	0.130	0.0896	0.1214	0.1734	0.1333
Coal, C, t	0.00	0.1032	0.1397	0.1996	0.1534
Coal, F, t	0.102	0.0764	0.1034	0.1477	0.1135
Coal, CF, t	0.183	0.0030	0.0041	0.0058	0.0045
LC (CL+CLC), t	0.167	0.0004	0.0006	0.0009	0.0007
Coke gas, thousand m ³ /t	0.2108	0.0618	0.0836	0.1195	0.0918
Water, thousand m ³ /t	0.0014	0.0004	0.0006	0.0008	0.0006
Electricity, thousand kWh/t	0.0103	0.0030	0.0041	0.0058	0.0045

The dynamics of cost savings by months of the year at Avdiivsky KHZ PJSC and Zaporizhkoks PJSC are shown in Fig. 5.

Thus, Avdiivsky KHZ PJSC has overspent in March, July, and October 2019 because of instability in supplies of

high-quality coal at reasonable prices. Zaporizhkoks PJSC had almost stable (except in February and December) savings of direct costs due to the use of secondary resources while there were also disruptions in the supply of coal of required quality.

Table 13

Calculation of the need for material resources to produce coke of the grade KDM-1 by Zaporizhkoks PJSC in January

Material cost	Price, monetary units	Need for resources	Required resources considering remaining stock
Coal, G, t	26.7	9,305.28	9,424.60
Coal, C, t	21.3	1,446.68	1,446.68
Coal, F, t	21.3	7,433.21	7,437.45
Coal, CF, t	29.3	11,426.00	11,740.39
LC (CL+CLC), t	24.59	10,361.39	29,034.0
Coke gas, thousand m ³ /t	53.74	13,952.58	17,915.53
Water, thousand m ³ /t	0.5	39.69	0
Electricity, thousand kWh/t	62.2	292.93	1,555.70

Table 14

Minimizing the costs of material and other resources to produce coke of the grades KDM-1 and KDM-2 by Zaporizhkoks PJSC in February

Indicator	KDM-1, t	Volume of secondary resources				Expenses, monetary units
		Coke gas, thousand m ³ /t	Coke sludge, t	Coke beans, t	Coke fines, t	
Production volume	62,073.13	8,879.58	213.39	1,119.29	1,810.88	1,819,332
Cost per product unit, monetary units		48.83	66.13	94.47	72.61	
Price of secondary resources, monetary units		43,358.98	14,111.49	105,739.18	131,487.74	684,928
Expenses based on the difference in secondary resources, monetary units						1,134,404

Table 15

Calculation of the total amount achieved by saving the expenses by Zaporizhkoks PJSC over one year

Month	Expenses, monetary units		Total saved, monetary units
	Estimated	Actual	
January	1,134,403.89	10,892,881.48	-9,758,477.59
February	3,976,234.97	10,708,977.78	-6,732,742.81
March	11,834,208.45	14,005,755.56	-2,171,547.11
April	3,330,659.82	11,200,407.41	-7,869,747.59
May	2,938,718.85	11,168,618.52	-8,229,899.67
June	2,257,891.73	10,005,740.74	-7,747,849.01
July	2,295,309.33	9,287,225.93	-6,991,916.59
August	1,711,291.95	10,709,044.44	-8,997,752.50
September	1,795,500.88	11,213,914.81	-9,418,413.93
October	1,261,533.45	11,306,942.67	-10,045,409.21
November	1,323,601.22	6,859,435.26	-5,535,834.04
December	2,434,818.66	6,868,619.26	-4,433,800.60
Total	36,294,173.20	124,227,563.85	-87,933,390.65

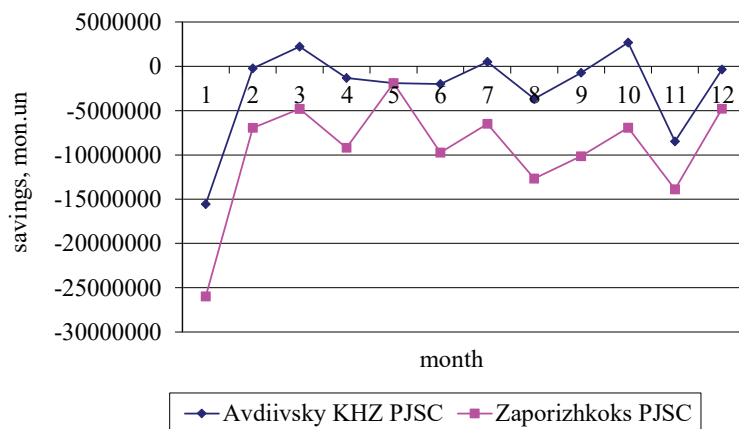


Fig. 5. Savings (-), overspending (+) by months of the year at Avdiivsky KHZ PJSC and Zaporizhkoks PJSC

Thus, the proposed economic-and-mathematical model allows industrial plants to choose the best option for the technological process through the use of secondary resources.

6. Discussion of the results of minimizing costs at an industrial plant under the use of secondary resources

Today, machine-building, coke-chemical, metallurgical plants take measures for the utilization of harmful substances and their further use as secondary resources. For example, Fig. 2 shows a diagram of coke oven gas processing and purification steps are given in Table 2. The purified gas is further used in in-house production of heat

and electricity, compressed air, steam and heating of coke batteries. The rest of the unused gas in a form of additional products (by-products) is sold to third parties for technological needs and residents of the region for room heating. The technology of coke production is based on the use of coal of various ranks which taken together form a charge. The coking process is carried out at high temperatures (over 1,000 °C), which leads to the appearance of by-products: coke oven gas and coke beans, sludge, and fines.

Thus, utilization and use of coke oven gas allow the coke plants to replace natural gas, produce electrical energy and use by-products as secondary resources. However, different compositions of the charge have different yields of by-products and different costs of coke production. Therefore, there is a problem of prompt calculation of material, fuel-energy, and other direct material costs in the production of coke of a given grade (KDM-1 and KDM-2) in required volumes. That is, an economic-and-mathematical model is needed to minimize direct costs of coke production taking into account the use of secondary resources. The economic-and-mathematical model is a linear programming problem based on the use of direct cost coefficients and solved using the MS Excel software package.

To calculate the coefficients of direct costs, the average monthly structure of sold main products and by-products was calculated on the example of Avdiivsky KHZ PJSC (Table 7). According to the methodological recommendations (Table 4), the coefficients of direct costs are set according to coal ranks, coke oven gas, water, and electricity, as well as secondary resources generated in the coke production (Tables 8, 9, 11).

When constructing an economic-mathematical model of cost minimization for the production of KDM-1 and KDM-2 coke grades, several charge options were used. They differed in combinations of coal of different ranks and volumes of secondary resources (Tables 8, 9, 11). Thus, the coke plants producing KDM-2 will obtain maximum amounts of coke oven gas which will be partly used for their in-house needs and partly sold to third parties, however, the coke quality will be lower. Costs for in-house fuel and energy resources are calculated at an actual cost price (Tables 7–9, 11). The amount of monthly savings is calculated as a difference between the costs for production of primary and secondary products and the cost of secondary resources which is the rationale for choosing the optimal composition of the charge by the coke grade. Annual savings (Tables 10, 12) are calculated as the total amount of cost savings in the months of the year.

Thus, the proposed model of linear programming allows coke plants to conduct:

- selection of an optimal charge option in terms of coal composition and obtaining the maximum volume of coke oven gas utilization;
- use of secondary material (coke fines, beans, sludge) and fuel-energy (coke oven gas, electrical energy, compressed air and steam of in-house production) and water resources (circulating water supply);
- minimization of costs under the use of secondary resources;
- maximization of gross profit by minimizing costs.

The proposed model has certain limitations. For example, in accordance with the logic of the “cost-output” models, an assumption was made about the constancy of proportions

between volumes of production of primary products and secondary resources. In practice, the introduction of new production technologies is accompanied by improved efficiency of processing the input resources but in conditions of shortage of material resources of the required quality, it is optimal to justify the use of secondary resources to reduce production costs. The issues related to the choice of the plan of production of main products and by-products taking into account the impact on the environment remain outside the model. Solution to these issues requires further studies.

6. Conclusions

1. Studies have shown that the technological features of coke-chemical production make it possible to utilize coke oven gas which, after cleaning, is sent to heat the ovens, produce electricity, compressed air and steam. In the process of coke production, plants obtain by-products: coke fines, beans, sludge. By-products are partly used for in-house needs. They reduce the costs of material and fuel-energy resources and are partly sold to metallurgical plants.

A concept of “secondary resources” is used in this paper. It indicates the ability of plants to utilize resources such as coke oven gas, fines, beans, circulating water supply and others in their technological processes.

2. The proposed economic-and-mathematical model features the follows:

- it enables a prompt calculation of manufacturing costs taking into account secondary material and fuel-energy resources including those of in-house production;
- it determines savings from the use of optimal production technologies (mixtures of material resources) by coke grades (KDM-1 and KDM-2) and by-products;
- calculations are performed using the standard MS Excel package.

The model is based on Leontiev’s theory of intersectoral balance. It enables prompt calculation of variable costs which can be reduced due to the use of secondary resources and determination of monthly and annual savings.

3. The model of cost minimization was tested on the example of Avdiivsky KHZ PJSC and Zaporizhkoks PJSC coke-chemical plants. Stages of calculation of total savings due to the use of secondary resources were determined and methodical recommendations on the use of the model presented. Based on the structure of sold products and yield of secondary resources in the production of coke of KDM-1 and KDM-2 grades, a matrix of direct costs was built. With the help of direct cost coefficients, monthly savings obtained due to the secondary resources were calculated.

Thus, the costs of the coke plant were minimized by selecting an optimal combination of input resources (coal) and thus establishing the option of the charge with the lowest costs of using primary and secondary resources. Due to the optimization of material costs, Avdiivsky KHZ PJSC and Zaporizhkoks PJSC had annual savings of 28,846,895.30 and 87,933,390.65 mon. un., respectively.

The proposed approach tested on the example of coke-chemical plants can be applied to other plants where the technological processes associated with the production of basic products are accompanied by the generation of significant amounts of secondary resources that can be sold or utilized.

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