ECONOMIC AND TECHNOLOGICAL CONDITIONS OF DEVELOPMENT IN EXTRACTIVE INDUSTRIES

Edited by Izabela JONEK-KOWALSKA

ISBN 978-83-7880-498-7
Wydawnictwo Politechniki Śląskiej
44-100 Gliwice, ul. Akademicka 5
tel. (32) 237-13-81, faks (32) 237-15-02
www.wydawnictwopolitechniki.pl
Dział Sprzedaży i Reklamy
tel. (32) 237-18-48
e-mail: wydawnictwo_mark@polsl.pl
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Proceedings of 3rd International Conference on Management – Economics – Ethics – Technology (MEET 2017)
21-22 September 2017
Faculty of Organization and Management, Silesian University of Technology, Zabrze, Poland

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Knowledge has to be improved, challenged,
and increased constantly, or it vanishes.
Peter Drucker

FOREWORD

The papers included in this Research Bulletin result from the Polish-Russian collaboration in the field of traditional industries management. The management in this field requires special attention and care, because of the specific natural resource profile, natural and technical risk intensification and a wide range of negative environmental and local society impacts. All the publications included in the bulletin were presented at the 3rd International Scientific Conference MEET 2017 (Management, Economics, Ethics, Technics) organized by the Faculty of Organization and Management of the Silesian University of Technology and Saint-Petersburg Mining University (Russian Federation) in Zabrze (Poland) on 21-22 September 2017.

The purpose of the conference was to exchange the scientific and research experience connected with the globalization processes, in particular, with the problem of resource and energy security in the contemporary societies, rational natural resources management as well as natural environment protection, economic, social and ecological risk assessment, sustainable development and corporate social responsibility (CSR) in mining industry.

The scope of the conference included the following issues:

1. Opportunities and threats of globalization in mining enterprises in regional, national and international context.
2. Identification of managerial, social, economic and ecological problems and priorities in the sustainable development of mining enterprises.
3. Indicating theoretical and practical standards of reporting and implementing of Corporate Social Responsibility in mining enterprises.
4. Defining the current and future role of traditional industries in economy, especially in maintaining the regional and national energy safety.
5. Risk management in mining enterprises and energy sector.

In the current market conditions, the extractive industry in Poland and worldwide is in a very difficult situation, because the extraction of natural resources raises a lot of environmental and social controversies and does not fully fit into the concept of sustainable development and corporate social responsibility that is being promoted at the moment. Moreover, due to the deepening of production and deteriorating geological and mining conditions, operations in the mining sector are becoming more and more difficult and less effective. In addition, mining companies as traditional industry representatives are not innovative enough to meet the needs of industry 4.0. The abovementioned circumstances give rise to the necessity of seeking answers to the following research problems: How to manage mining companies in crisis situations? How to increase their efficiency and competitiveness? and How to make them more innovative?

The answer to these questions is attempted in this post-conference monograph in subsequent scientific and research articles divided into two areas: economics and technology. Thus, the first area presents methods of managing hard coal mines in a crisis situation (*Jolanta Bijańska, Krzysztof Wodarski*). Next, the price risk in hard coal mining is analysed in globalised economic conditions (*Izabela Jonek-Kowalska, Tatyana Ponomarenko, Oksana Marinina*), which becomes a prerequisite for considerations devoted to improving the competitiveness of the mining industry in a turbulent environment (*Alina Ilinova, Diana Dmitrieva*) and the production competitiveness conditions of hard coal production (*Yurii Vasilev*). The analysis of the importance of reserves of raw materials in the existence and development of the mining industry concludes the deliberations in this area (*Anna Tsvetkova*).

The link between the economic and technological part is two articles devoted to the use of project management in the mining industry. The first one is aimed at gaining competitive advantage (*Sergey Yur'evich Avksentiev, Sergey Leonidovich Serzhan*) and the other one at improving efficiency (*Olga Olegovna Evseeva, Alexey Evgenevich Cherepovitsyn*).

In the technological area containing three articles, methods of increasing innovativeness and productivity in the extractive industry in the context of improving efficiency of mining machinery and equipment are sought (*Victor Aleksandrov, Pavel Makharatkin; Pavel Shishkin, Inna Trufanova; Paul Shcherban, S. Razumovich, A. Eliseev*).

Jolanta BIJAŃSKA, Krzysztof WODARSKI
Silesian University of Technology, Poland
jolanta.bijanska@polsl.pl, krzysztof.wodarski@polsl.pl

Use of AHP method in strategic decision - making in hard coal mines in a crisis situation

Abstract

This article describes the results of an analysis of the Analytic Hierarchy Process (AHP) used to support decision-making regarding the choice of strategic option in hard coal mines in a crisis situation. In particular, the developed model of the decision problem, the results of its analysis and the method of identifying the best decision-making option were presented. The characterized AHP procedure was used in practice to indicate a strategic option for 10 Silesian mines in a crisis situation.

JEL: E31, G30, L16, L25

Keywords: *coal mines, crisis situation, strategic choices*

Introduction

Strategic decision-making is one of the key issues of business management in today's environment. This problem must also be faced by the managerial staff of Silesian mining companies, including coal mines in a crisis situation. This situation implies the need to make decisions on the choice of strategic options that should be appropriate to the ability of mines to overcome the crisis, to restructure and to be economically efficient in the future. Because of the consequences of these decisions, it is important that they are rational based on multi-criteria evaluation of possible decision options and choosing the best one.

Rational decision-making is supported by the use of Multiple Criteria Decision Making Methods. Of these, the most commonly used in practice is the Analytic Hierarchy Process (AHP) to choose the best decision option. This method is often described, among others, in the publications of its creator, Thomas L. Saaty (Satty, 2000; Satty, 2008). Hence, the article omits the description of AHP, but presents the results of studies conducted for its use in decision making on the choice of strategic option in Silesian hard coal mines in a crisis situation.

The essence of AHP in the context of strategic decision making in coal mines

The AHP is characterized by a small number of specific decision-making options from which you choose the best one from the point of view of accepted assessment criteria, both quantitative and qualitative. In general, we can assume that the AHP procedure includes (Prusak & Stefanów, 2014): 1) developing a model of the decision - making problem in the form of a hierarchical structure, 2) analyzing the model of decision - making problem, 3) identifying the best decision option.

Using the AHP procedure to support decision-making process regarding the choice of strategic options for the Silesian coal mines in crisis, required solving 6 research topics (Table 1).

Table 1. Research issues for the use of AHP to assist strategic decision making in coal mines

AHP procedure	Research issues
1) Development a model of the decision - making problem	▪ Defining the decision problem ▪ Identifying the elements of the model of the decision - making problem ▪ Developing a hierarchical structure
2) Analysis of the model of decision - making problem	▪ Estimation and aggregation of weighting factors
3) Indication of the best decision option	▪ Determining the overriding decision criterion ▪ Developing the standards supporting the decision – making basing on the main decisive criteria

Source: own study.

Developing a model of the decision - making problem

The basis for developing a model of a decision - making problem is to define such. It was assumed that the essence of problem considered in this article is the choice of a strategic option for Silesian coal mines operating in mining enterprises. Due to the crisis situation of the mines, the choice of a strategic option should depend on their ability to overcome the crisis, renew and become economically effective in the future. Basing on the literature (Urbanowska-Sojkin et al., 2007) it is assumed that this capacity is determined by the assessment of development potential. Taking this into account, the problem of decision - making was defined as the choice of a strategic option for hard coal mines in a crisis situation, appropriately to assessment of their development potential.

The projection of decision - making problem in a model of a hierarchical structure requires identifying the components of the problem and then placing them at the levels of this structure according to their relationships (Fig. 1).

The main feature of this model is the aim resulting from the decision - making problem. It is the overriding decision criterion, which is placed at the first level of the hierarchical structure. In the decision-making problem in question, the overriding decision criterion is to assess the development potential of hard coal mines (O_{pr}).

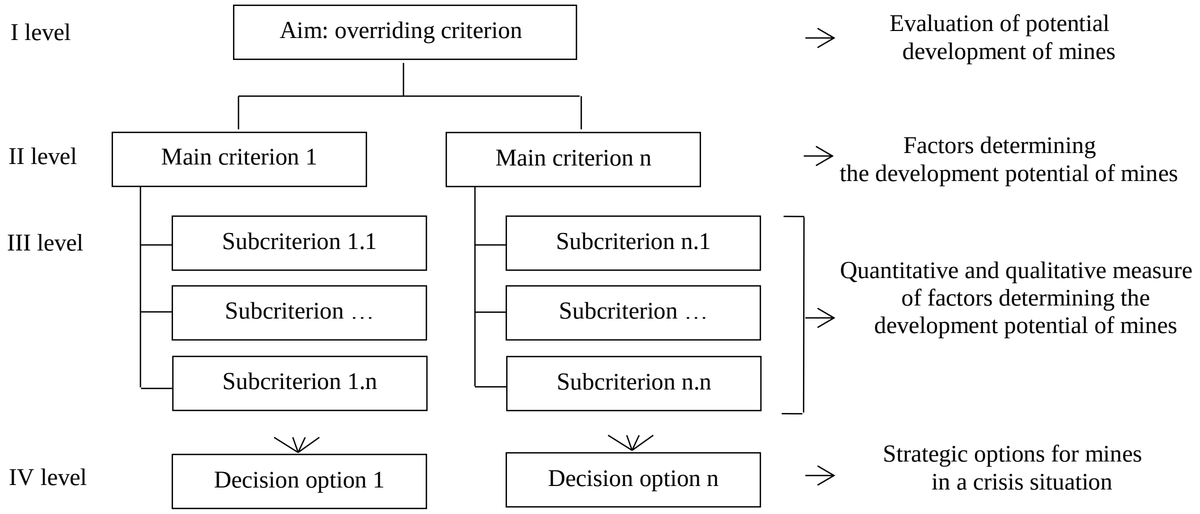


Figure 1. Elements of the model of the decision - making problem in the form of hierarchical structure
Source: own study.

Another element of the model, placed on the second level of the hierarchical structure, is the main criteria for assessing the development potential of mines, i.e. the factors that determine such. Identification of these factors required research involving experts (Bijańska, 2016) in the management of mining companies, selected from their managerial staff and research staff. On the basis of the opinion of 25 experts, using the relative importance of the facilities, among the 78 factors influencing the development potential of the mines 14 have been identified, which determine their development potential. The first group of factors is related to resources (Z) and includes: Z1) the amount of coal resources, Z2) mining and geological conditions, Z3) development investment, Z4) the degree of debt, Z5) employees' competences, Z6) work efficiency, Z7) share in the market, Z8) relationship with local community. The second group of factors is related to activities (D) and includes: D1) preparing the exploitation front, D2) performance of machines and devices, D3) performance of the exploitation front, D4) profitability of coal mining, D5) safety due to existing hazards, D6) environmental protection.

The next element of the model, placed on the level III of the hierarchical structure, are the sub-criteria for assessing the development potential of mines, i.e. quantitative and qualitative measures of 14 identified factors determining their development potential (Table 2). These sub-criteria were adopted on the basis of literature (Karbownik & Wodarski, 2010; Urbanowska-Sojkin et al., 2007) and interviews with 3 employees of the mines.

Table 2. Sub - criteria for assessing the development potential of hard coal mines

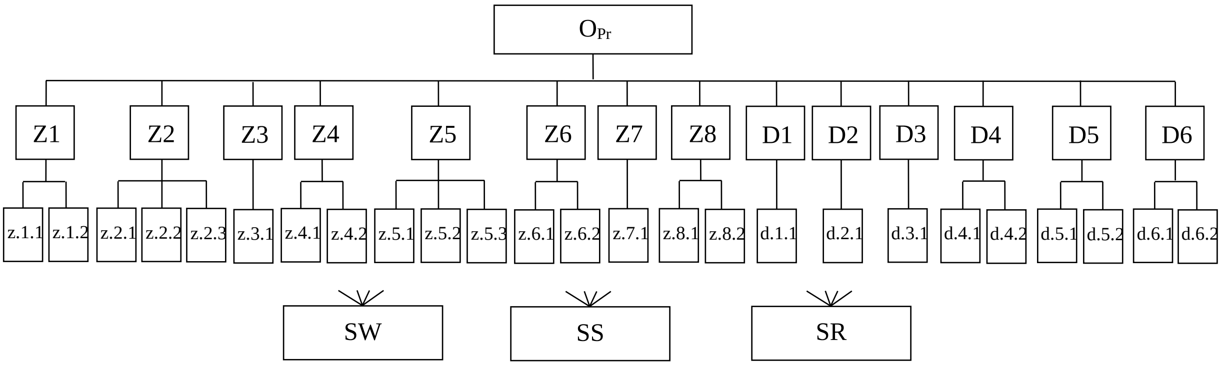
Symbol		Name of a sub- criterion	How to evaluate a sub-criterion
Main criterion	Sub - criterion		
Z1	z.1.1	Viability of the mine considering resources made available	Quantitative assessment, measured by the ratio of the volume of operating resources at the active and under - construction levels to the average gross mining output of the mine during the assessment period; [years].
	z.1.2	Viability of the mine considering resources made possibly available	Quantitative assessment, the measure of which is the ratio of the volume of operating resources at active levels and those under construction and planned to be made available, to the average gross mining output of the mine during the assessment period; [years].
Z2	z.2.1	Density of coal	Quantitative assessment, measured by the share of operational resources in coal layers over 1.5 m thick, at active and under-construction levels relative to the operational resources included in the registry; [m].
	z.2.2	Tectonics	Qualitative assessment that takes into account tectonic disturbances, bed slope, thill and ceiling conditions, and rock mass capability for energy accumulation. Assessments should be in the range of 0 to 1 (very difficult conditions to favourable conditions).
	z.2.3	Depth of sediments	Quantitative assessment, the measure of which is the maximum depth of exploitation at active levels; [m].
Z3	z.3.1	The input for the maintenance and development of production capacity	Quantitative assessment, measured by the amount of expenditures required to maintain or increase the mine's production capacity in relation to net mining output during the assessment period; [PLN / t].
Z4	z.4.1	Debt of the capital base	Quantitative assessment, which measure is the average ratio of the amount of foreign capital to the amount of own finances in the period of assessment; [-].
	z.4.2	General debt	Quantitative assessment, measured in terms of the mean ratio of foreign capital (total liabilities and reserves for the liability) to total assets during the assessment period; [-].
Z5	z.5.1	Know-how	Qualitative assessment, which is based on the professional qualifications and licenses of the crew and the management. Assessments should be done in the range from 0 to 1 (very low to very high level of knowledge and skills).
	z.5.2	Experience	Qualitative assessment, which is based on the years of employment of the crew and the management. Assessments should be done in the range of 0 to 1 (very low level of experience, which is less than 15% of workers with less than 15 years of work experience to the very high levels of experience, with more than 30% of employees with approximately 15 years of work experience).

Symbol		Name of a sub- criterion	How to evaluate a sub-criterion
Main criterion	**Sub - criterion**		
	z.5.3	Education	Qualitative assessment, which is based on the level of education of the crew and the management. Assessments should range from 0 (very low level of education - 10% and lower proportion of employees with higher education) to 1 (very high level of education - more than 20% of employees with higher education).
Z6	z.6.1	Work efficiency of 1 employee	Quantitative assessment, measured by the ratio of average net production to average employment during the assessment period; [T / work].
	z.6.2	Work efficacy	Quantitative assessment, measured by the amount of coal sales to the cost of salaries during the assessment period; [-].
Z7	z.7.1	The amount of coal sales from the mine regarding the market demand	Quantitative assessment, which is measured by the ratio of coal sales from the mine to the market demand for the mining company's products during the assessment period; [%].
Z8	z.8.1	Cooperation with local community	Qualitative assessment, which is based on opinions of local government councils about the mine, protests of the population, court proceedings, and pro-social initiatives. Assessments should be in the range of 0 to 1 (very low to very high level of cooperation).
	z.8.2	Expenditures on social initiatives	Quantitative assessment, measured by the size of the expenditures for pro-social initiatives during the assessment period; [PLN / t].
D1	d.1.1	Intensity of preparatory works	Quantitative assessment, the measure of which is the ratio of the total length of excavations, completed and prepared to 1,000 tonnes of net mining; [m/ 1000 t]
D2	d.2.1	Effective use of machines and devices	Quantitative evaluation, the measure of which is Overall Equipment Effectiveness - OEE, which is a product of availability, performance and quality;
D3	d.3.1	Exploitation of one wall	Quantitative assessment, which is measured by the average volume of mining from 1 wall in the evaluation period; [t / day]
D4	d.4.1	Cost of sourcing 1GJ	Quantitative assessment, which measure is the level of cost of acquiring 1 GJ of energy contained in commercial coal; [PLN/ GJ]
	d.4.2	Return of sales	Quantitative evaluation, measured by the ratio of the average coal price to the average cost of sold coal; [-].
D5	d.5.1	Level of natural risk	Qualitative assessment, which is based on the categories of natural hazards in the mine. Assessments should be in the range of 0 to 1 (very high to very low levels of natural hazards).
	d.5.2	Number of accidents	Quantitative assessment, the measure of which is the total number of people injured in accidents in relation to 1000 people employed in the mine; [-]
D6	d.6.1	Ecological fees and fines	Quantitative assessment, measured by the amount of fees and ecological fees per ton of commercial coal; [PLN / t]
	d.6.2	Compensation for mining damages	Quantitative assessment, the measure of which is the relationship between the amount of compensation for mining damage and the ton of commercial coal; [PLN / t]

Source: own study.

The final elements of the model, placed on the level IV of the hierarchical structure, are the decision options - strategic options adapted to the mines in a crisis situation: blanking (SW), sanation (SS), development (SR). It was adopted on the basis of literature (Zelek, 2003; Kudełko 2007; Kudełko, 2012) and on interviews with two experts on the restructuring of Polish hard coal mining.

The partial results obtained during the implementation of point 1) of the AHP procedures allowed developing a model of the decision problem in the form of hierarchical structure (Fig. 2).



Symbols: O_{Pr} – main criterion, Z1, …, D6 – main criteria, z.1.1., …, d.6.2 - sub criteria, SW, SS, SR – decisive variants

Figure 2. A model of the decision problem for choosing a strategic option for mines
Source: own study.

Analysis of the model of decision - making problem

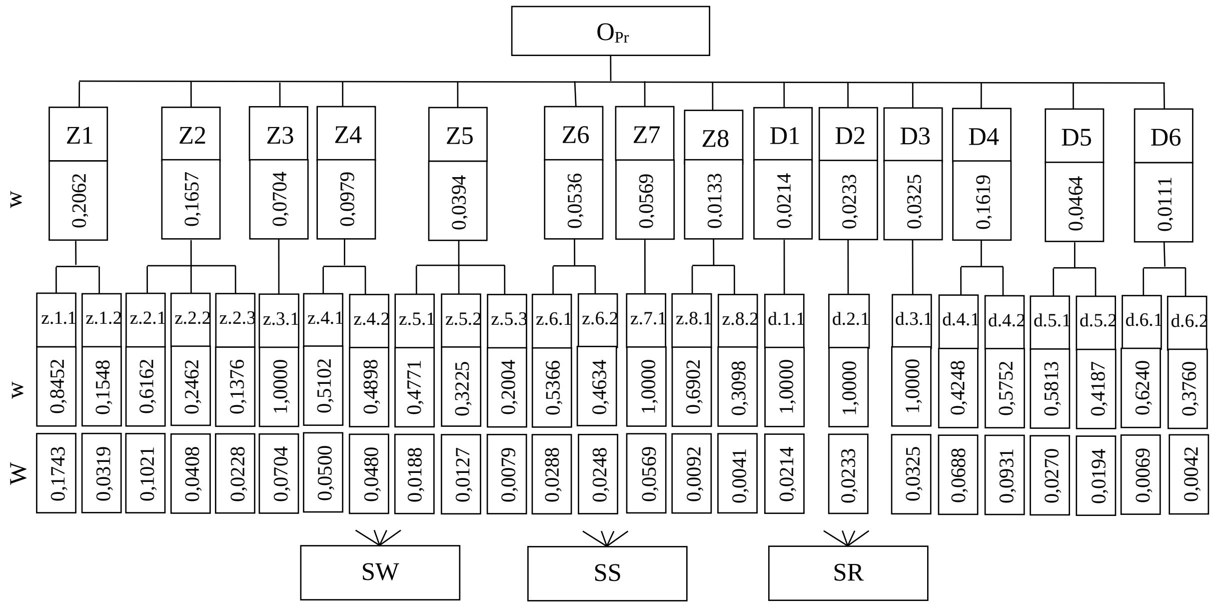
Analysis of the decision - making problem model is aimed at estimating and then aggregating the weighting factors of the individual elements of the hierarchical structure. The basis for this analysis is to compare pairs of specific major criteria and then sub-criteria. For this purpose a survey questionnaire was prepared which included questions about:

- importance (which of the individual criteria is more important?),
- intensity, or degree of importance (to what extent is one criterion more important than another?), according to the nine-level comparison scale of Saaty.

The poll questionnaire was presented to 12 experts in the management of mining companies and mines, who were selected from their managerial staff and researchers. The results obtained from them were introduced into the so-called comparison matrix in pairs. This was the basis for estimating the weighting factors, successively:

- local, which indicate the importance of the given element in relation to the element placed one level higher in the hierarchical structure,
- global, which represent the share of each element in the overriding criterion.

The BPMSG AHP Online System was used to estimate weighting factors. The results of the estimation were then aggregated using a weighted arithmetic mean (the weight was of the experts' competence). In this way, the local (w) and global (W) weighting factors were received and then applied to the model of the decision problem (Fig. 3).



Symbols: O_{Pr} – overriding criterion, Z1, …, D6 – major criteria, z.1.1., …, d.6.2 – sub-criteria, SW, SS, SR – decisive variants, w, W – local and global weighting factors

Figure 3. Weighting factors of the criteria for assessing the development potential of mines

Source: own study.

Indication of the best decision option

In order to indicate the best decisive option - a strategic option for mines in a crisis situation - the first step is to assess their development potential. This requires gathering information on the certain sub-criteria present in the individual mines (Table 2), taking into account anticipated scenarios of environmental change,. Then the unit of measure (Wodarski & Bijańska, 2016) of the sub-criteria[1] should be unified so that the outcome of the assessment of development potential is relative. For this purpose, the zero unitary method should be used. Taking into account the

[1] Refers to the partial criteria, which assessment is quantitative and is in different unit measures.

weighting factors (Fig. 2) and the unified sub-criteria values, the development potential of individual mines can be assessed on the basis of the following aggregation defining the overriding decision criterion:

$$O_{Pr} = \underbrace{(z.1.1 \bullet w_{z.1.1} + z.1.2 \bullet w_{z1.2})}_{Z1} \bullet w_{Z1} + ... + \underbrace{(d.6.1 \bullet w_{d.6.1} + d.6.2 \bullet w_{d.6.2})}_{D6} \bullet w_{D6}, \quad (1)$$

this can be presented as:

$$O_{Pr} = z.1.1 \bullet \underbrace{w_{z.1.1.} \bullet w_{Z1}}_{Wz1.1} + z.1.2 \bullet \underbrace{w_{z.1.2} \bullet w_{Z1}}_{Wz1.2} + ... + d.6.1 \bullet \underbrace{w_{d.6.1} \bullet w_{D6}}_{Wd6.1} + d.6.2 \bullet \underbrace{w_{d.6.2} \bullet w_{D6}}_{Wd6.2}, \quad (2)$$

that is:

$$O_{Pr} = z.1.1 \bullet Wz1.1 + z.1.2 \bullet Wz1.2 + ... + d.6.1 \bullet Wd6.1 + d.6.2 \bullet Wd6.2, \quad (3)$$

where:

O_{Pr} - main decisive criterion,

z.1.1, z.1.2, …, d.6.2 – unified sub-criteria values,

wZ1, …, wD6 – local weighting factors of main criteria,

wz.1.1, …, wd.6.2 – weighting factors of sub-criteria

Wz.1.1, …, Wd.6.2 – global weighting factors of sub-criteria,

Z1, …, D6 – unified values of main criteria.

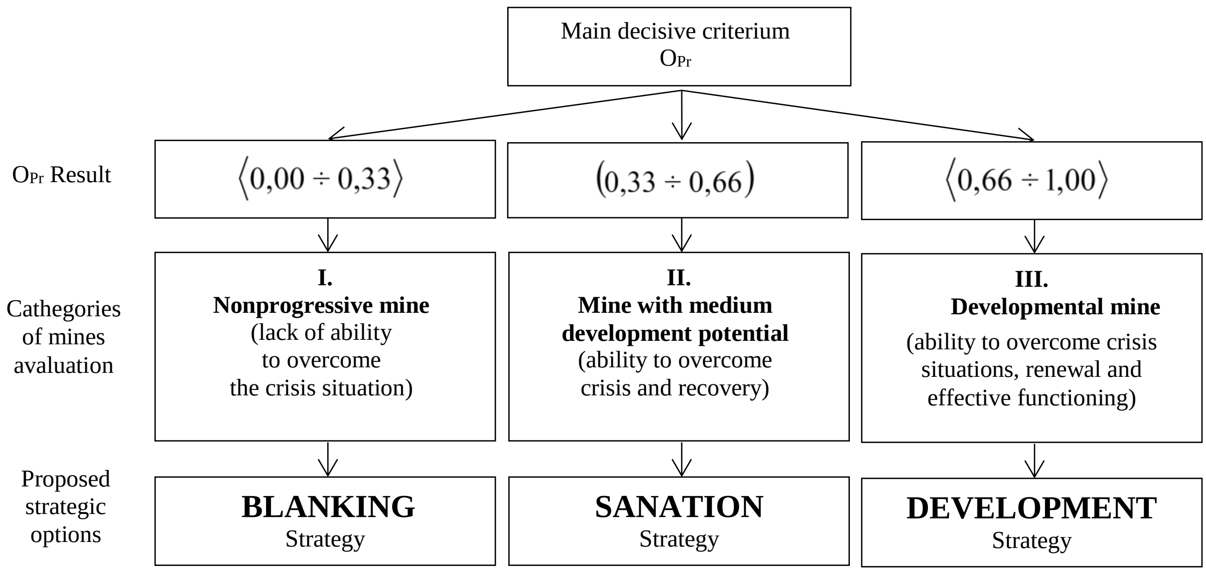


Figure 4. Standards supporting the decision -making to choose the right strategic option based on the overriding decision criterion

Source: own study.

The O_{Pr} result should be applied to certain mining rating categories for which standards have been set to assist in the selection of the best decision option - the appropriate strategic option (Fig. 4). These standards were determined arbitrarily, after consultation with the decision maker influencing the choice of strategic option for mines.

The use of AHP to support the decision to choose strategic options for 10 hard coal mines

The AHP procedure described in point 1 was used to identify the best strategic options for 10 mines included in the mining enterprise in Silesia. The data needed to determine the value of the sub-criteria of the development potential were obtained from the individual mines, taking into account scenarios of expected changes in external factors. The values of these data were unified (Table 3). On this basis, the O_{Pr} values were calculated for individual mines, which were compiled according to decreasing values. This allowed us to present the ranking of mines starting with the best mine - with the greatest development potential. Then, using the standards for each of the mines, an appropriate strategic option was indicated (Fig. 5).

Basing on the results of the calculations, it was found that the best mine among the rated ones is the mine No 5, which was described as developmental (category III), which implies indicating a development strategy for it. On the other hand, the development potential of mines 3, 6, 10, 7, 9, 8, 1 and 4 allows them to qualify for medium-growth mines (category II) for which a sanation strategy is appropriate. In the worst case, mine 2 is defined as non-developmental (category I). For this mine one should adopt a strategy of blanking.

Table 3. Unified values of sub - criteria assessing the development potential of mines

Main criteria	Sub – criteria	Global weight	Unified value for mines									
			1	2	3	4	5	6	7	8	9	10
Z1	z.1.1	0,1743	0,4570	1,0000	0,0349	0,0500	0,0000	0,1716	0,1239	0,6734	0,2083	0,1403
	z.1.2	0,0319	0,9607	0,3768	0,0000	0,2632	0,2428	1,0000	0,7889	0,3326	0,4247	0,6121
Z2	z.2.1	0,1021	0,9520	0,8240	0,0000	0,9360	0,7860	0,8100	0,9000	0,6000	1,0000	0,8300
	z.2.2	0,0408	0,5000	0,0000	0,5000	0,5000	0,0000	0,0000	0,5000	0,0000	1,0000	0,0000
	z.2.3	0,0228	0,4000	0,8000	1,0000	0,4000	0,8000	0,0000	1,0000	0,4000	1,0000	0,8000
Z3	z.3.1	0,0704	0,7951	0,3695	0,9833	0,2179	0,9800	1,0000	0,3633	0,7313	0,0000	0,3850
Z4	z.4.1	0,0500	0,3458	0,8208	1,0000	0,6208	0,2083	0,0000	0,3333	0,3333	0,4167	0,2083
	z.4.2	0,0480	0,8000	1,0000	0,8824	0,9059	0,3765	0,0000	0,2471	0,3529	0,5882	0,3765
Z5	z.5.1	0,0188	1,0000	1,0000	1,0000	1,0000	0,5000	1,0000	1,0000	1,0000	1,0000	1,0000
	z.5.2	0,0127	1,0000	1,0000	1,0000	1,0000	1,0000	0,5000	1,0000	1,0000	1,0000	1,0000
Z5	z.5.3	0,0079	1,0000	1,0000	1,0000	1,0000	0,5000	0,5000	1,0000	0,5000	1,0000	0,5000
Z6	z.6.1	0,0288	0,0000	0,3807	0,9582	0,6771	0,6814	0,5373	0,5972	0,1769	1,0000	0,5476
	z.6.2	0,0248	0,5514	1,0000	0,3021	0,7587	0,0000	0,2822	0,5809	0,5923	0,5047	0,5923
Z7	z.7.1	0,0569	0,3132	1,0000	0,0708	0,4383	0,0000	0,2590	0,4467	0,3226	0,4049	0,3226
Z8	z.8.1	0,0092	0,5000	1,0000	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000

Main criteria	Sub – criteria	Global weight	Unified value for mines									
			1	2	3	4	5	6	7	8	9	10
	z.8.2	0,0041	1,0000	0,6250	1,0000	0,3750	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
D1	d.1.1	0,0214	0,0667	0,1229	0,3667	0,1238	0,1333	0,3333	1,0000	0,6667	0,0000	0,3867
D2	d.2.1	0,0233	0,0000	0,4800	1,0000	0,8000	0,0000	0,6400	0,6400	0,6400	0,6400	0,6400
D3	d.3.1	0,0325	0,5575	0,9928	0,0000	0,6728	0,3633	0,5891	0,6900	0,2545	1,0000	0,7113
D4	d.4.1	0,0688	0,7113	0,4653	0,4747	1,0000	0,0000	0,7352	0,3414	0,7841	0,2617	0,1797
	d.4.2	0,0931	0,5254	0,7592	0,3696	1,0000	0,0000	0,2886	0,6085	0,8230	0,8089	0,7984
D5	d.5.1	0,0270	1,0000	0,0000	0,0000	0,5000	1,0000	1,0000	1,0000	1,0000	0,0000	1,0000
	d.5.2	0,0194	0,0000	0,2799	0,4036	1,0000	0,5486	0,5684	0,6246	0,6509	0,7136	0,5945
D6	d.6.1	0,0069	0,9728	0,0000	0,8850	0,9966	0,9976	1,0000	0,9973	0,9999	0,9992	0,9976
	d.6.2	0,0042	0,7980	0,4069	0,4761	0,4001	0,0000	0,9236	1,0000	0,5134	0,0165	0,9637

Source: own study.

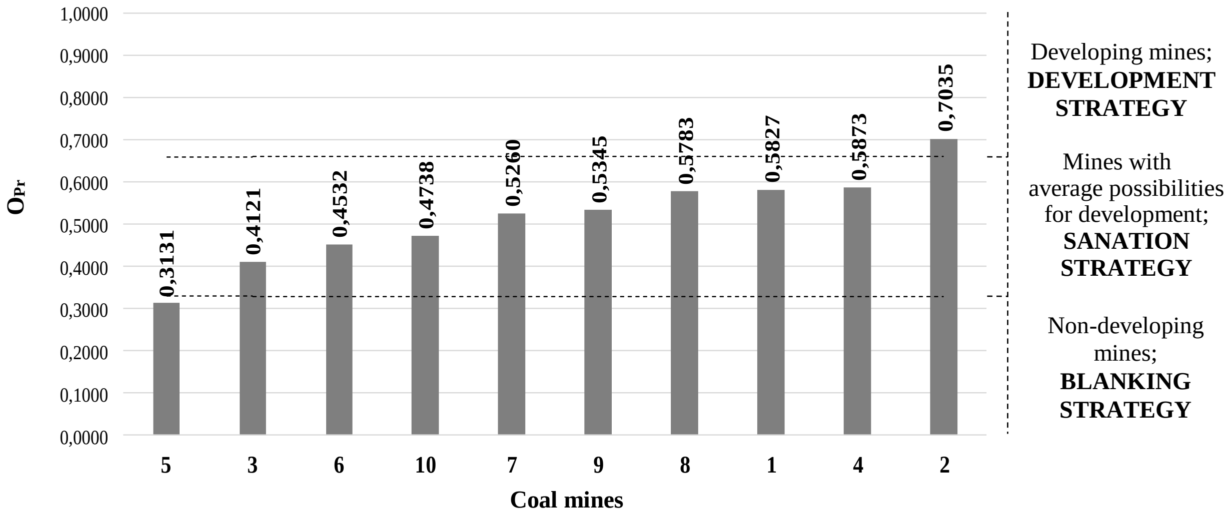


Figure 5. Assessment of the development potential of mines and indication of appropriate strategic options

Source: own study.

Conclusions

The contemporary hard coal market poses difficult challenges for Silesian mining companies which include unprofitable hard coal mines. These companies, in order to adapt to the present conditions of the market and to function in the future, must make difficult decisions about the choices of strategies, that will help overcome the crisis, restore and economically operate in the future, for those mines that have development potential and also to close those that do not have that potential. You can use Analytic Hierarchy Process to help you make those decisions. However, this requires adopting this method to the specifics of Silesian hard coal mines. This article presents the results of research in this field. In particular, the results of a research solution aimed at defining a decision problem, identifying its components and developing a hierarchical model, as well as estimating and aggregation of weighting factors, determining the formula for the overriding decision criterion, and developing decision standards. The solutions obtained within the scope of the presented issues allowed the use of AHP to indicate strategic options for 10 hard coal mines belonging to the Silesian mining company. The results obtained may assist the managerial staff of this company in making strategic decisions about the future of the mines that are part of it.

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Izabela JONEK-KOWALSKA
Silesian University of Technology, Poland
Tatyana PONOMARENKO, Oksana MARININA
Sankt-Petersburg Mining University, Russian Federation
e-mail: izabela.jonek-kowalska@polsl.pl

Mine production in Russia and in Poland in view of the changes of hard coal prices on the global market

Abstract

Hard coal mining is an important industry for the economy and local communities, both in Poland and in Russia. Nevertheless, this industry – especially in Europe – is treated as a declining one, due to high level of this raw material emission used in heat engineering, energy technology and metallurgy. Taking into account the unfavorable image of hard coal as solid fuel, this paper contains comparative analysis of the extraction capacity of hard coal in Poland and Russia and its consumption in the context of rapidly changing price conditions. It is also an attempt to answer the following question: Are the production and consumption levels of hard coal in both countries significantly linked with the price of this raw material on the global market and what is the direction of such potential correlations?

JEL: E31, G30, L16, L25

Keywords: *hard coal mining, mine production, hard coal consumption, hard coal prices on the global market*

Introduction

For years now, Poland and Russia are among the TOP 10 manufacturers of hard coal in the world. According to World Coal Association data, in 2015 Russia ranked 6th with its production amounting to 334 Mt, and Poland was 9th with is production amounting to 137 Mt. Currently, these countries vary significantly in terms of production and market conditions, that greatly influence the amount of production and consumption of coal in the industry. Russia has reserves of coal big enough to last for 420 years and constituting approximately 18% of world resources of this raw material, while Poland has reserves for next 40 years, and its global share in the raw material amounts to only 0.6% (BP Statistical Review of World Energy, 2017). Hard coal production in the European Union takes place in view of growing emission restrictions and increasing support for renewable energy sources, which negatively impacts the demand for hard coal (Turek et al., 2015). At the same time, in 2015 new coal-fired power plants with a total capacity of 4.7 GW have been put into operation in the EU, which will consume 5.8 million tons of coal (Wind in power 2015; Ponomarenko & Vavilina, 2017). In Russia, extraction of hard coal is not being limited by such restrictive legal and environmental conditions, which, along with the growing demand for this raw material in Asia, positively influences the development of mine enterprises (Nevskaya et al., 2016).

In terms of coal exports, Russia ranks third in the world after Indonesia and Australia. In modern conditions, we can state the presence in Russia of an established export-oriented model of the coal market, where the share of exports in production volumes is continuously growing. The main export destinations for Russian coal are the countries of Europe and the Pacific, secondary markets are the markets of the Middle East and CIS countries. In 2015, the structure of coal exports from Russia to the APR countries and Europe was approximately 50:50 (Dagilis, 2016).

Despite differences in production and market conditions, mining companies in both countries operate in similar price conditions due to their geographic proximity, globalization of raw materials markets and correlation between key price indexes for hard coal (Jonek-Kowalska et al., 2014a; Jonek-Kowalska et al., 2014b). In Polish hard coal mining industry the significance of decrease of hard coal global market prices can be observed, being the key reason for lack of competitiveness of mining enterprises and mine closures (Michalak & Turek, 2011). Having in mind the above, this article presents the comparative analysis of correlations between the scale of production and consumption of hard coal in Poland and in Russia and hard coal prices on the global markets. In the course of discussions and research, the authors look for a solution of the following research problem: Are the production and consumption levels of hard coal in both countries significantly linked with the price of this raw material on the global market and what is the direction of such potential correlations?

Research method

As it was mentioned before, the research uses comparative analysis, that was conducted in sections concerning:

- scale of the production and consumption of coal;
- correlations between production and consumption of coal;
- correlations of global price indexes;
- correlations of the scale of production and consumption of coal with particular price indexes.

The analysis was carried out in a long term perspective, retrospective covering the years 1985-2015 on the basis of data contained in BP Statistical Review of World Energy for Poland and Russia, with the use of linear and polynomial trendlines. When assessing the direction and correlation strength between the studied variables, the Pearson linear correlation coefficient was used (1):

$$r_{xy} = \frac{\mathrm{cov}(x, y)}{s(x) \times s(y)} \tag{1}$$

where:

cov(x,y) – covariance of x and y variables,

s(x) – standard variation of x variable,

s(y) – standard variation of y variable.

This coefficient is the measure of straight line relation between two measurable features and takes a value from the range <-1;1>. The more the absolute value of the coefficient is closer to 1, the stronger is the correlative dependency between the studied variables (Bąk et al., 2003).

In the analysis of price indexes, the following indexes characterized by international scale and meaning were used:

- Northwest Europe market price – for prices of hard coal in Europe;
- US Central Appalachian coal spot price index – for prices of hard coal in North and South America;
- Asian market price – for prices of hard coal in Asia.

On the basis of found dependencies the following working theories were verified:

T1: Hard coal price indexes in the world are strongly positively correlated.

T2: Size of coal production in Poland (A) and in Russia (B) is strongly positively correlated with the hard coal prices in the world.

T3: Size of coal consumption in Poland (A) and in Russia (B) is strongly negatively correlated with the hard coal prices in the world.

T4: Decrease of hard coal prices in the world in the decreasing national consumption conditions results in limitation of the production surplus over the total consumption in Poland (A) and Russia (B) and limits the possibility to export hard coal.

Positive verification of the first theory allows to make a statement, that hard coal prices in the world are correlated and their changes have the same direction no matter where in the world the mining production takes place (Bijańska & Wodarski, 2016; Bjańska and Wodarski, 2014). Such claim can be a starting point for verification of the remaining theories. And so, the T2 theory assumes that decreasing prices (with fixed unit cost) contribute to limitation of production profitability and forces its scope limitation, while increasing prices (with fixed unit cost) contribute to the increase of production profitability and encourage the increase of its scope (Michalak & Turek, 2012; Bąk, 2007). As a result, the decrease of hard coal prices we can observe currently and its negative influence on production profitability in view of the decreasing national consumption, should lead to the limitation of export opportunities expressed in part as production surplus over overall consumption (T4 theory) (Bijańska & Wodarski, 2016; Bijańska & Wodarski, 2014). Additionally, it is assumed that the increasing hard coal prices limit the consumption of this raw material, that can be replaced by other energy sources, while the decrease of hard coal prices contributes to the increase of its national consumption (T3) (Bluszcz & Kijewska, 2016; Bluszcz et al. 2015).

Production and consumption of hard coal in Russia and Poland

The analysis of the results starts with trends overview in terms of production and consumption of hard coal in both studied countries (Fig. 1 and 2). According to Graph 1, the extraction of hard coal in Poland and Russia steadily decreases till 1998, while in Poland the steady decrease continues also after 1998 and, as a result, the function of mining production is described by well adjusted decreasing trendline. In Russia, since 1998 the extraction increases, and in the analysed period the mining production is best reflected by parabolic trend. The main reason for production decrease in Poland is the deteriorating price competitiveness of Polish raw material caused by the increase of production unit cost. On the other hand, the opening up to the Asian markets and the possibility to supply hard coal to Europe, where the mining enterprises are being closed and yet still many economies use this raw material in their energy balance, contribute to the increase of production in Russia.

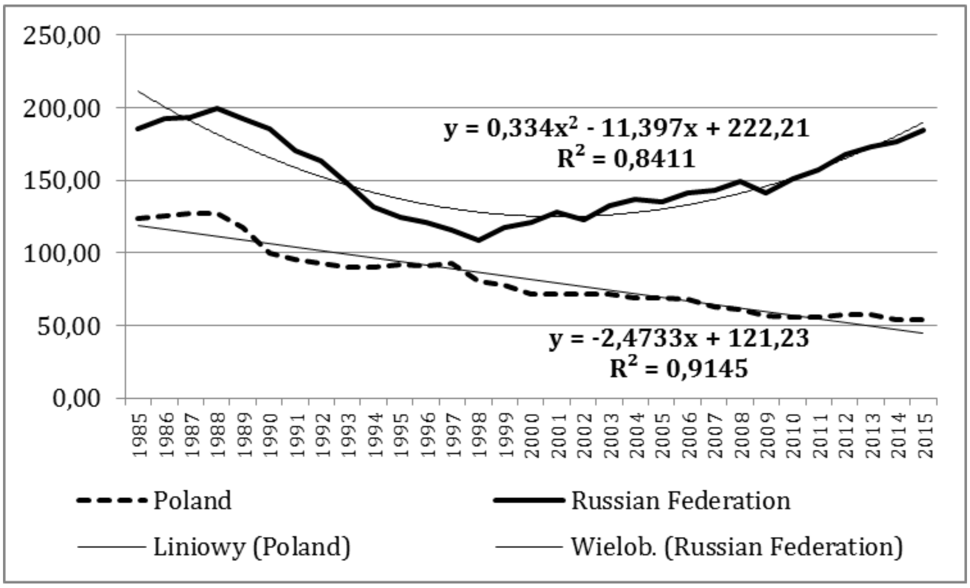

Figure 1. Production of hard coal in Poland and Russia [Mtoe]

Source: Own work on the basis of BP Statistical Review of World Energy.

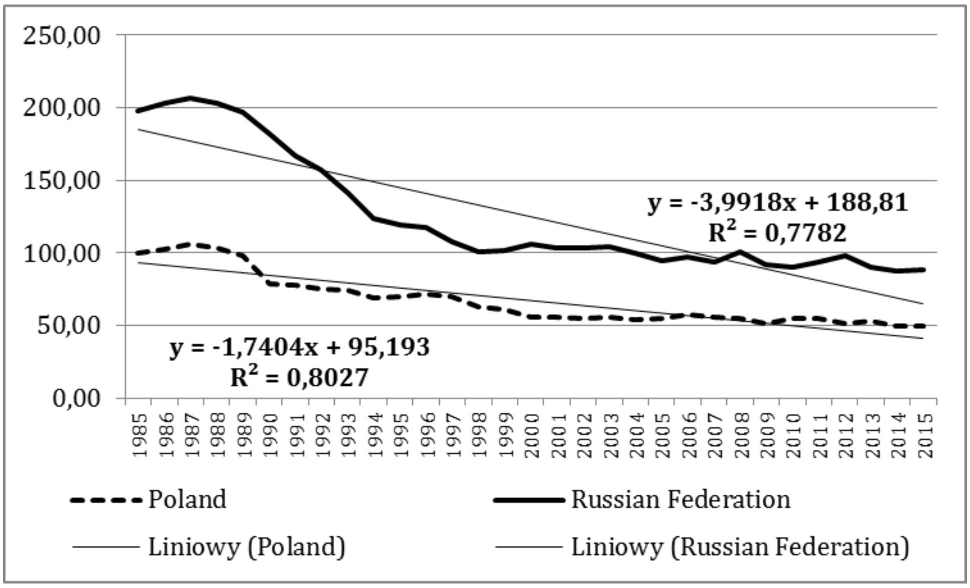

Figure 2. Consumption of hard coal in Poland and Russia [Mtoe]

Source: Own work on the basis of BP Statistical Review of World Energy.

For both countries, the consumption of hard coal is decreasing, while in Poland it is a more evident long-term trend than in Russia (Figure 2). In the Polish energy balance, the share of renewable energy sources (in line with the European Union requirements) and natural gas increases. In Russia, the decreasing consumption of hard coal is supplemented by gas and/or petroleum.

The positive dynamics of exports caused an increase in production, however, domestic consumption stagnates. The main volume of consumption of Russian coal in the country is accounted for by thermal power plants and by-product coke plants. At present, the share of electricity generation using coal is declining, despite state programs for the development of the coal industry and Russia's energy strategy for the period up to 2030. In these programs, there is a tendency to increase coal generation and outstripping the growth of prices for natural gas. It is expected that the consumption of Russian coal in thermal power plants should increase from the current 96 million tons to 120 million tons[2]. According to forecasts of analysts, the increase in coal generation by 2020 will be about 4.7 MW, which will slightly increase the demand (up to 10 million tons). The share of coal-fired TPPs in the electricity production structure will decrease from 17.5% (2010) to 15% by 2030 years (Pisarenko, 2015). The projected growth in the consumption of Russian coal by power plants will occur due to the displacement of imported coal. Compression of the domestic coal market forces coal companies to adhere to the forced export model of development.

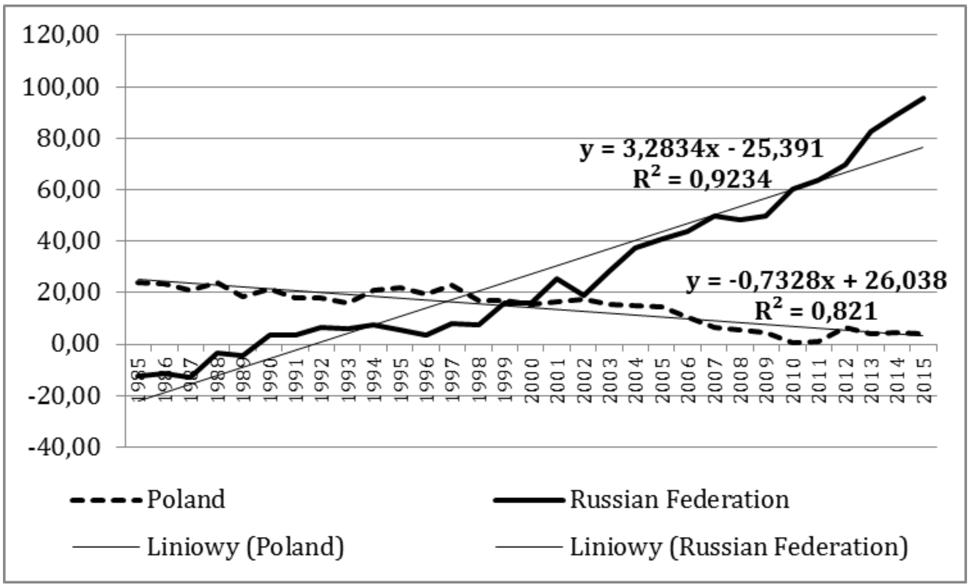

Figure. 3 The difference between production and internal consumption of hard coal in Poland and Russia [Mtoe]

Source: Own work on the basis of BP Statistical Review of World Energy.

In Poland, as a result of decreasing production and consumption, the difference between these values also decreases, reflecting the dwindling export opportunities. In Russia, however, from 1998 this difference steadily increases, which only proves the robust development of external potential customers markets (Figure 3).

To summarize, till 1998 Poland and Russia are characterized by similar, decreasing trends in terms of production and consumption of hard coal, which

[2] Long-term program of development of the Russian coal industry for the period up to 2030. Approved by the Government of the Russian Federation on 24.01.2012. Energy strategy of Russia for the period up to 2030. Approved. Government Decree of 13.11.2009 № 1715-р.

continue to this day in Poland. In case of Russia, after 1998 we can observe a significant increase in production with simultaneous, yet slower decrease of consumption, resulting in greater export opportunities expressed in the production surplus over overall consumption.

Production and consumption of hard coal in Poland and Russia and the prices of this raw material on the global market

In the next part of the analysis, the correlation of price indexes and production and production surplus dependency on the hard coal prices on the global market was defined. Therefore, table 1 contains the value of correlation coefficients for the studied price indexes.

Table 1. Pearson linear correlation coefficient for studied price indexes

Specification	**Coefficient**		
	Northwest Europe market price	US Central Appalachian coal spot price index	Asian market price
Northwest Europe market price	1.0000	-	-
US Central Appalachian coal spot price index	0.9306*	1.0000	-
Asian market price	0.6913*	0.5316*	1.0000

*p<0.05; n=29

Source: own work.

In accordance with data from table 1, all identified relations between the studied hard coal price indexes are positive and important from statistic perspective. Nevertheless, they differ with their relation strength. The European price index is strongly correlated with American index. The relationship between the European and Asian indexes can also be considered as strong. The weakest correlation characterizes the American and Asian indexes. The results presented above allow to make a statement, that hard coal price indexes are correlated and change in the same direction, yet the strength of identified relations vary.

In the next stage, the relations between the production and consumption level of hard coal in the studied countries and the aforementioned price indexes were assessed. The results are presented in Table 2.

Table 2. Pearson linear correlation coefficients for dependencies between the production and consumption of hard coal in Poland and in Russia and price indexes

Specification	Coefficient		
	Northwest Europe market price	US Central Appalachian coal spot price index	Asian market price
Production in Russia	0.1638	0.3461	0.5961*
Production in Poland	-0.6175*	-0.7696*	-0.7271*
Consumption in Russia	-0.4426*	-0.5424*	-0.6596*
Consumption in Poland	-0.4732*	-0.6603*	-0.4522*

*p<0.05; n=29

Source: own work.

The level of production in Russia is not significantly linearly correlated with European and American price index yet it shows dependency on the Asia price index, which is connected with the increasing demand for hard coal in this part of the world. In turn, the size of production in Poland is significantly correlated with all studied price indexes, yet these are negative correlations which makes it difficult to view them as being economically rational and it can be assumed that the production was not adjusted to the changes of prices on global market.

In case of consumption of hard coal, both in Russia and in Poland, together with the increase of prices the consumption was being limited, while the decrease of prices resulted in consumption increase, which is in line with economic market rules. It must be emphasized, that in this scope Poland was depending the most on the European index while Russia on the Asian one, which in turn is related to the geographic localization of both economies.

All these conditions considered together, it can be stated that there are negative and important for statistical purposes relations between consumption and all price indexes in both studied countries and that there is a presence of positive and important for statistical purposes relations between local price indexes and production size in Russia (only for the Asian index) and in Poland (concerns all indexes, but mostly the European one).

In the last stage of the study, the authors referred to the relation between the production surplus and consumption, reflecting in part the export opportunities of hard coal in the studied countries. The results can be found in Table 3.

Table 3. Pearson linear correlation coefficients for dependencies between the production surplus of hard coal in Poland and in Russia and price indexes

Specification	Coefficient		
	Northwest Europe market price	US Central Appalachian coal spot price index	Asian market price
Production surplus in Russia	0.6836*	0.7318*	0.6370*
Production surplus in Poland	-0.7922*	-0.7941*	-0.8138*

*p<0.05; n=29

Source: own work.

In accordance with data in Table 3, all the identified correlations are important for statistical purposes and are characterized by significant correlations between price indexes and production surplus. In Russia, however, these identified relations are positive, which means that the price increase favourably influenced the increase of production surplus, while decrease resulted in its reduction. The production, therefore, was adjusted to the market demand and resulted in profitability maximization. In case of Poland, the constant trend of production decrease resulted in reduction of production surplus and its negative correlation with the changes of hard coal market price. It must be emphasized, that such a situation was linked with the impossibility to allocate any production surplus in the internal and external markets, due to high and increasing unit costs of production reducing the competitiveness of the Polish raw material. Nevertheless, distinct formation of production, consumption and production surplus in Russia allows us to negate the statement, that unprofitability of production in Poland and closures of mines was caused solely by the decrease of hard coal prices on the global market, especially because currently the Polish market is hugely dependent on the import of Russian hard coal.

The specifics of the development of the Russian and Polish coal industry due to differences in imports and exports, geographical location, and orientation to different markets do not allow one to unequivocally interpret the results of the research in terms of linking the performance of companies and price changes. Positive dynamics of indicators of Russian companies is due to a greater degree of competitive advantages due to the availability of coal reserves of various brand names and quality, geographical proximity to the main coal consumption market - Southeast Asia, high competitiveness of coking coal supplies from the Russian Federation in comparison with other exporting countries. However, as practice shows, in the market there are enough sharp changes which any company can use with the purpose of the further development. For example, in 2016, the shortage of global coal supply due to reduced production in China and the problem with the export of coal from Australia led to a jump in prices for coking and energy coal. Due to the insufficient supply in the world market, metallurgical coal has risen in price four times, energy coal - twice. Russian coal companies, in this period, reached high economic indicators of profit and profitability.

However, this is a temporary trend, which, in our opinion, should be used as an opportunity to invest in strategic innovative projects that stimulate the improvement of product quality as a priority for increasing competitiveness in the global coal market.

Conclusions

As an answer to the posed research problem: Are the production and consumption levels of hard coal in both countries significantly linked with the price of this raw material on the global market and what is the direction of such potential correlations? it can be stated that:

- the level of Russian production is significantly positively correlated with the Asian price index, which results in the increase of demand for hard coal in this part of the world,
- the level of Polish production is negatively correlated with price indexes, which is economically irrational and proves, that the production is not adjusted to the market changes, resulting from high unit costs and loss of competitiveness of the Polish raw material.

Consumption of hard coal in both countries is significantly and negatively correlated with price indexes, which necessitates its reduction in case of price increase and its increase in case of price drop.

Due to the above and having in mind the working theories:

T1: Hard coal price indexes in the world are strongly positively correlated.

T2: Size of coal production in Poland (A) and in Russia (B) is strongly positively correlated with the hard coal prices in the world.

T3: Size of coal consumption in Poland (A) and in Russia (B) is strongly negatively correlated with the hard coal prices in the world.

T4: Decrease of hard coal prices in the world in the decreasing national consumption conditions results in limitation of the production surplus over the total consumption in Poland (A) and Russia (B) and limits the possibility to export hard coal.

It must be stated, that the first one can be confirmed, while the strongest correlation exists between the European and American index and the weakest between the Asian and American ones. The second theory was confirmed only in part, in case of Russian production and its relation with Asian price index. The third theory was confirmed for all price indexes and for both countries. The last theory was confirmed for Poland only, which proves, that even in price decrease conditions it is possible to extend production and export if there is a potential consumers market and the level of unit costs still ensures profitability of sales (in case of Russia).

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Yurii VASILEV
Saint-Petersburg Mining University, Russian Federation
e-mail: yur_vas@mail.ru

Coal preparation as the instrument of coal enterprise competitiveness improvement

Abstract

One of the main growth factors and development of the Russian coal industry is the development of coal preparation capacities. The article considers coal preparation as means of increasing coal production competitiveness as well as coal enterprise and coal basin. The data of coal preparation volumes in Russia have been analyzed. It is shown how coal preparation qualitative characteristics can be changed while it is processed at the large coal preparation plants. The method having sufficient impact on coal production preparation at different levels of coal industry competitiveness is given.

JEL: E20, L19, L71

Keywords: *coal preparation; competitiveness; evaluation of competitiveness*

Introduction

Currently it is almost impossible to estimate the role of coal in the world economy from one point of view. On the one hand, the coal share in structure of world fuel and energy resources consumption is 29% (it takes the second place after oil). On the other hand, the coal industry is in the stagnation position in the majority of the countries all over the world as both coal production and its consumption have been reduced in China, the USA, Indonesia, the Republic of South Africa, Germany, Poland. At the same time we can observe reduction of coal prices for a long period of time.

The coal branch of the Russian Federation is characterized by the most provided source of raw materials in comparison with the other branches of fuel and energy complex. In the Russian Federation there are 22 coal-mining fields and 129 separate fields.

The main tendency of coal branch development is accumulation of coal preparation capacities at the present moment. The major stimulating growth factor of coal preparation is increasing export volumes.

The long-term program of the coal industry development of the Russian Federation for the period till 2030 approved by the order of the Government of the RF No. 1099-r from 6/21/2014 (further - the long-term program) within the subprogramme "Ensuring technological branch development and strengthening scientific and technical base of the companies and research centers" provides improving coal preparation technologies, processing and using coal and coal production wastes. One of the purposes of the long-term program is increasing a share of the prepared coal to 60% (Smotrihin, 2016).

There is also the program of development of preparation bituminous steam coal of Russia. It states increasing the volumes of coal preparation to 345 million t by the year of 2030. (increased by 1,9 times in comparison with the level of the year 2015) (Tkacheva, 2015); (Peng, 2016).

The data given in Tab. 1 show that the share of the prepared coal in the total amount of production has been increased for the last 10 years in Russia. At the same time there is a tendency of steam coal share growth in total amount of coal preparation and decrease of a coking coal share. According to the forecasts three fourth of mined coal will be exposed to preparation by 2030.

Table 1. Coal preparation data in the Russian Federation

Year	Coal production, mln. t.	Coal prepared volume, mln. t.			Share in the total volume of prepared coal, %		Share of prepared coal in the total volume production,%
		total	Coking coal	Steam coal	Coking coal	Steam coal	
2007	314,1	114,0	74,9	39,1	65,70	34,3	36,29
2008	328,9	110,6	66,8	43,8	60,40	39,6	33,63
2009	302,6	108,8	62,3	46,5	57,26	42,74	35,96
2010	323,4	124,4	66,8	57,6	53,70	46,30	38,47
2011	336,7	125,8	68,7	57,1	54,61	45,39	37,36
2012	354,6	141,5	77,3	64,2	54,63	45,37	39,9
2013	352,1	156,1	81,5	74,6	52,21	47,79	44,33
2014	358,2	163,6	88,1	75,5	53,85	46,15	45,67
2015	374,0	178,3	88,0	90,3	49,36	50,64	47,67
2016	385,7	184,8	93,3	91,5	50,49	49,51	47,91
2020 (forecast)	425	240	110	130	45,83	54,17	56,47
2025 (forecast)	440	290	120	170	41,37	58,62	65,91
2030 (forecast)	460	345	125	220	36,23	63,77	75,0

Source: own elaboration using datas from: (Efremov, 2016); (Tarazanov, 2016); (Smotrihin, 2016).

There are some sharp evidences proving coal preparation development in the Russian Federation. For example, 85% of the extracted coal of the Pechora basin, 68% of coal of the Rostov region, 60% of coal of Yakutia and Khakassia, 55% of the coal mined in Kuzbass are currently exposed to preparation (Smotrihin, 2016). Thus, we have 97% of coking prepared coal and 40% of steam prepared coal.

So far the Kuznetskiy basin is the leader of coal preparation in the Russian Federation (Tab. 2).

Table 2. Volumes of coal preparation in Russia, thousand tons

Basin, region	Total					
	2015	2014	by 2014, %	2015	2014	by 2014 , %
Total in Russia	169254	163140	103,4	87829	88089	99,7
Pechora basin	13434	11721	114,6	12033	10001	120,3
Donetzk basin	3521	3879	90,8	-	-	-
Chelyabinsk region	1334	1207	110,5	-	-	-
Novosibirsk region	4128	4103	100,6	-	-	-
Kuznetsk basin	110235	106205	103,8	66336	68416	97,0
The Khakassia republic	10560	10464	100,9	-	-	-
Irkutsk region	3114	2652	117,4	-	-	-
Zabaykalsky krai	10308	11111	92,8	-	-	-
The Sakha Yakutia Republic	9460	9672	97,8	9460	9672	97,8
Khabarovsky krai	2181	1880	116,0	-	-	-
Primorsky krai	869	650	133,7	-	-	-
Sakhalin region	110	96	114,0	-	-	-

Source: (Kukushkina, 2015); (Pilov, 2016); (Tarazanov, 2016)

Currently in view of increasing coal branch competitiveness of the Russian Federation and necessity of receiving deep coal prepared products, one of the perspective directions is development of coal chemistry. In the furtherance of this goal the following events are planned (Zaruba, 2016):

- including coal chemistry in the Strategy of chemical and petrochemical complex development of Russia;
- forces and means concentration on development of the Russian coal chemistry in Kuzbass;
- projects development and implementation for creating complexes of deep coal preparation within public-private partnership;
- development of cluster initiatives, etc.

The new 27 coal preparation plants have been put into operation and the 20 operating plants have been reengineered for the last 15 years in the Russian Federation. In the next 10 years the coal companies plan to construct 30 coal preparation plants. There are some factors having impact on raw coal preparation at different plants. Among them there are such factors as (Michael E., 2016):

- qualitative characteristics of raw coal;
- consumers requirements for production;
- the used equipment;
- coal preparation purpose.

The coal preparation is carried out according to the closed-loop water-slurry system at most plants. The raw coal and concentrate qualitative characteristics of some coal preparation plants of Russia are presented in Tab. 3.

Table 3. Coal preparation data in Russia

Company, coal preparation plant	**Coal rank**	**Coal characteristics**		**Prepared coal characteristics**	
		Ash content, %	**Water content, %**	**Ash content, %**	**Water content, %**
“Russian coal” coal pit “Stepnoy”	D	to 22,5	to 15		
	DPK	-	-	8,1-9,1	До 15,6
	DOM	-	-	8,1-9,1	До 15
	DSSh	-	-	19-21	До 16
JSC "SUEK"					
- coal preparation plant “Tugnuiskaya”	DOMSSh	25,9-45	10-17	14-16	9,6-11
- coal preparation plant of mine “name of Kirov”	G	28-40	6-8	7-10	9
- coal preparation plant “Komsomolets”	G	28,1- 32,3	7,5-10	9	6,5
- coal preparation plant of mine “Taldinskaya-Zapadnaya”	DG	20-32,2	8-10	6-8	8-9
JSC "Kuzbassrazrezugol"					
- coal preparation plant “Krasnobrodskaya koksovaya”	KS	20,4	less 7	8,5-9	7,5-8,5
- processing plant “Bachatskaya energeticheskaya”	SS	12,1	less 7	4,5-9	7-10
- processing plant “Bachatskaya koksovaya”	KO	20,4	7	8-8,5	7,5-8,5

Source: own elaboration using data from: (Smotrihin, 2016).

The issues connected with competitiveness of coal production, coal-mining enterprise as well as coal industry in general are considered in the works of Aleshinsky R. E., Davydov M.V., Embulaev V. N., Glinina O., Islamov S.R., Kovalchhuk A. B., Krasnianskii G.L., Martemyanova A. N., Mesyats M. A., Molchanov O. Y., Shafranik Y. K., Tonkih A. I., Zaidenvarg V. E. and the others.

The issues of providing economy of the Russian Federation with high-quality coal fuel and coal prepared products and also coal production development are reflected in the works of such researchers as Aleshinsky R. E., Virula M. A., Delyagina G. N., Zeidenvarg V. E., Linev B. I., Malysheva Yu. N., Puchkova L. A., Rubenstein Yu. B., Sazykin G. P., Shuvalov YU. V. and the others.

It is necessary to give a short review of the research works which are the most important from the point of view investigating coal preparation role in boosting coal branch competitiveness.

Some works of Ponomarenko T. V. are devoted to the issues of strategic assessment methodology of enterprise competitiveness. The author has clarified the terminology in the field of production and enterprise competitiveness and also the parameters, indicators and methods of competitiveness assessment have been proposed. The definition of the operating and dynamic company competitiveness has been also provided (Ponomarenko, 2011).

Syzdykova E.Zh. with her coauthors revealed that the greatest impact on coal production competitiveness can be determined by the following factors:

- production quality (the key factor of competitiveness assessment);
- transportation costs (an important factor in the conditions of remoteness of coal-mining enterprises from external and internal consumers);
- availability of using coal complex (determined by requirements of consumers and level of scientific and technical progress) (Syzdykova, 2016).

The researcher also offers the model of defining coal production competitiveness by calculation of the following indicators:

- output profitability;
- transportation costs;
- coefficient of complex coal use.

In our opinion, the assessment of coal production competitiveness is impossible without characteristics of coal production and it has to be based on calculation of the integrated indicator of production quality.

The matters connected with increasing efficiency of coal consumption in domestic market are considered by such authors as Martemyanova A.N.

It is noted that integration of coal-mining and power generating enterprises by creating power coal company is necessary for increasing steam coal consumption in the domestic market. It is supposed that such a company is based on water coal fuel (WCF) production as highly effective technology of coal preparation. The cumulative (integrated) cost advantages of transfer power plant to WCF consists of the following factors:

- the economic effect of fuel purchasing cost cutting;
- the economic effect due to decreasing payment for emissions of harmful substances in the atmosphere and waste disposal of power plant as well as ecological damage decline;
- additional benefits from ash realization to consumers (Martemyanova, 2010).

According to the results of the overview, most of the researchers studying competitiveness define that firstly production competitiveness has a considerable impact on enterprise competitiveness of the region or basin. As for improving production competitiveness, it directly depends on improving quality production that is provided by coal preparation currently.

Methodology

It is worth mentioning that in spite of numerous literature sources devoted to the coal industry competitiveness, the issue of coal production preparation impact on improving competitiveness of the coal basin, branch and country in general has not been studied sufficiently yet.

The paper is primarily aimed at:

- to distinguish specific features of competitiveness in the coal industry;
- to analyze the data of coal preparation volumes in Russia;
- to give the method having sufficient impact on coal production preparation at different levels of coal industry competitiveness.

In our opinion, Mikhaylov V.V. and Mesyats M.A. have made substantial contribution into the theory and practical assessment development of the coal industry competitiveness (Michailov V.V., 2005).

The researchers defined that the coal branch competitiveness has some specific characteristics which have been reflected at the six levels:

1. Competitiveness of coal production which is defined by such mutually influencing factors as level of scientific and technical progress, production quality and its price.

2. Competitiveness of the coal enterprise which depends on production and management efficiency, the production potential and its product range.
3. Competitiveness of the coal company (association).
4. Competitiveness of coal branch.
5. Competitiveness of the coal basin (region).
6. Competitiveness of the country.

Besides it there are such types of the rivalry as subject and functional, generic; specific, trophic and etc.

To provide assessment of coal preparation impact on coal industry competitiveness, we will use the six-level competitiveness scheme developed by Mikhaylov V.V. and Mesyats M.A. It is noteworthy that competitiveness is determined by indicators of the previous level at each new one. At the same time it has some peculiarities. Earlier we have developed indicators of coal enterprise competitiveness assessment (Tab. 4)

Table 4. Indicators of coal enterprise competitiveness assessment

Estimation criterion	Competitiveness valuation parameter	Competitiveness indicators
Production	Range	Range depth
	Production quality	Integrated quality indicator
	Producibility	A share of prepared coal production
	Production price	Production price
	Volume of production	Volume of production
Marketing	Sales revenue	sales revenue
Sales efficiency	Market share	market share
	A share of exported production	Export share of sold production
	Coal enterprise export share	A share of total export volume of region

Source: (Vasilev, 2016); (Lazarenko, 2016)

It should be noted that coal preparation directly depends on possibility of obtaining more total revenue. In the case of export coal supply there is a comparison between its actual quality with the specified in the foreign trade contract.

According to the export price list of some coal-mining companies (for example, JSC "Kuzbassrazrezugol"):

- for each 1% of ash-content excess the price for supplied coal is reduced by 1,5%;
- for each 1% of coal-humidity excess the price for supplied coal is reduced by 1,3%;
- for each 1% of sulfur content excess the price for supplied coal is reduced by 1%;

These data can be different depending on supplier, however they show coal preparation impact on changing indicators of enterprise activity.

Results

We emphasize the indicator of investments necessity in the fixed-capital assets (coal preparation plant reengineering). It can be considered as one of the consequences of coal preparation.

We can take as an example LLC Vostsibugol Company possessing the only coal preparation asset - Kasyanov coal preparation. This asset was characterized as capital-intensive and inefficient. For changing the situation the plant project stage improvement was approved. It demanded introduction of new technical and engineering solutions. As it is noted that project implementation will allow to increase production by 4,2%, cut costs of coal preparation, get annual benefits of 120 million rubles. Manufacturing expenses are 513 million rubles and a payback period is 6 years (Kalcher, 2016).

Taking into consideration competitiveness at the level of the coal basin, the researchers usually study only coal quality of the particular basin. However in our opinion, the level of competitiveness should be considered from the point of viewing special characteristics of the coal region. Such researchers of region competitiveness as Budeba M. D., Joubert J. W., Webber-Youngman R., Shafiee S. propose the method of calculating integrated indicator of regional competitiveness (Budeba, 2016). This method is based on calculation of such separate indexes as:

1. Index of the region economic potential (it is based on the following indicators: gross regional product; fixed capital investments, etc.).
2. Index of regional efficiency (indicators: volume of industrial production per capita; export volume per capita; gross regional product per capita, etc.).
3. Index of competitive advantages (amount of small enterprises; density of public railway tracks; volume of fixed capital investment per capita, etc.).

Moreover, the condition of improving region productive-economic potential is forming production segments of the coal industry in the region (Efremov E.I., 2016).

For providing assessment of coal preparation impact on competitiveness it is necessary to consider all its levels. Total effect of coal preparation is equal to the sum of all effects at different levels. This effect is determined not only by quantitative but also quality indicators. In particular coal industry competitiveness in general can be assessed by such indicators as: reasonability of coal fuel in comparison with gas; feasibility of the Russian coal in foreign markets.

Conclusions

Currently coal preparation development in the Russian Federation is a growth factor of competitiveness at all levels: from production competitiveness to competitiveness of the country in general (Fig. 1).

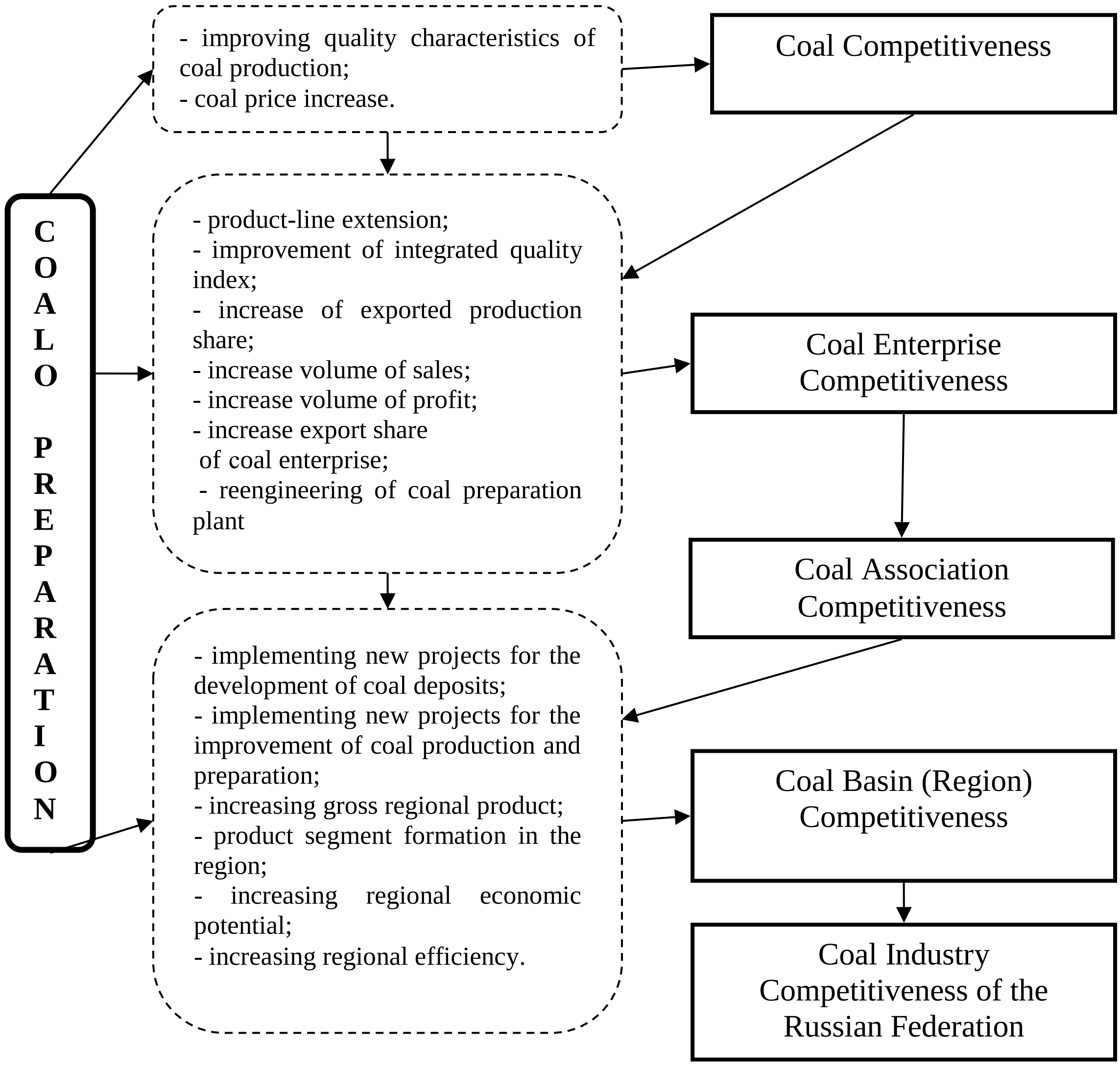

Figure 1. Method of coal preparation impact on different levels of competitiveness

Source: own elaboration

It is noteworthy that different levels of competitiveness are interconnected with each other and development of the lowest levels (coal production and enterprise competitiveness) is the growth factor of higher levels (coal basin and industry competitiveness).

Furthermore the competitiveness assessment of each given level represents a scientific matter. Searching integrated indicator of competitiveness is topical issue. Its problem solution gives a possibility to provide uniform assessment of coal enterprise competitiveness.

The volumes of coal preparation have been growing rapidly for the last 10 years in the Russian Federation. The share of prepared coal in the total production amount approaches 50%. The ultimate target is to increase a share of prepared coal to 75%.

The carried out analysis shows that processing capacity development of coal enterprise is the driver of competitiveness growth for the coal industry and Russian in general at the present moment. For the coal-mining enterprises development of processing capacities is the factor of strategic growth currently.

The main strategic priorities of the Russian coal-mining companies is development of processing capacities. The final strategic objective is to obtain export coal preparation of 100%.

However it should be noted that this situation contradicts the principle provisions of the Energy strategy of Russia. According to its coal-mining branch development has to be based on increasing internal coal supply.

Although the research has reached its aims, there are some limitations which couldn't be avoided. The lack of calculations revealing the impact of coal preparation on improving coal enterprise competitiveness is the main drawback of the research. It was caused by the absence of unified methodology to determine the level of coal enterprise competitiveness.

Moreover, coal production of Russian enterprises is various of quality and there is a demand for it on different markets. The mentioned above drawback can not allow to give any recommendations to improve coal enterprise competitiveness.

One of the most challenging economic issues of the Russian Federation as well as its mineral-resource complex is improving competitiveness. The solution of this issue is impossible without modernization of all branches of economy including the coal one. Currently the Russian Federation gives the problems of increasing volumes of coal mining and its preparation careful consideration.

The paper considers coal preparation issues as instrument for improving competitiveness of coal production. The dynamics of coal preparation volumes has been analyzed for the recent years in the Russian Federation. The main tendencies of development of coal preparation production in the Russian Federation are discussed. The mechanism of coal preparation influencing on the different competitiveness levels has been formed.

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Alina ILINOVA, Diana DMITRIEVA
Saint-Petersburg Mining University, Russian Federation
e-mail: iljinovaaa@mail.ru; diana-dmitrieva@mail.ru

Competitive advantages of mining and chemical companies in high environmental turbulence

Abstract

The unique Russian mineral raw material base - phosphate and potash ore reserves allows domestic mining and chemical companies not only to meet local demand but also to act as significant players on a global scale. Russian fertilizer companies enjoy a significant share of the global fertilizer market and have considerable strategic and social importance to the national economy. At the same time, in condition of tightening of price competition in the fertilizer market, increasing the environmental turbulence and the volatility of global markets the competitive advantages of Russian manufacturers, which are largely resource-based, can be partially or completely lost. Therefore, the purpose of the article is to formulate directions of competitive advantages forming for mining and chemical companies in high environmental turbulence.

In the article, analysis of previous researches on theory of competitive advantages and its application in mining and chemical complex was made. The environmental turbulence level of mining and chemical industry using Ansoff's method was described. Industry peculiarities of the mining and chemical holdings in an oligopolistic market were identified. Comparative analysis of different segments of the mining and chemical industry for the competitive advantage formation was made. As the result, sustainable and non-sustainable competitive advantages of mining and chemical companies in high environmental turbulence were formulated.

Russian mining and chemical companies as well as foreign companies producing mineral fertilizers can use the results of the research for forming their sustainable competitive advantages.

JEL: L11, O13

Key words: *mining and chemical companies, the environmental turbulence, industry and market peculiarities, competitive advantages*

Introduction

Mining and chemical industry is a branch of the mining industry engaged in mining and processing of mining and chemical raw materials - phosphate ores, potassium salts, sulfur ores, etc. In addition, it include the production of final products from these raw materials - mineral fertilizers. The use of fertilizers increased vastly over the twentieth century, and fertilizer use is forecasted to continue growing also in the near future (Enger, 2010).

Due to the global scope of the of mineral fertilizers production industry the main competitive environment for it is a global market, the development of which is subject to a number of macroeconomic factors, ensuring a steady growth in demand for fertilizers. Some of these factors are:

- population growth;
- reduction of arable land per capita;
- growth of GDP per capita and purchasing power in developing countries;
- increasing demand for alternative energy sources (biofuels).

Also limited supply caused by resource exhaustibility influence the situation on the market. Thus, attractive industry fundamentals determine the steady growth in demand for fertilizers in the long term.

Products of the Russian fertilizer industry (due to the unique natural resources) are characterized by high quality and competitive price as a whole (Dmitrieva, 2016). However, the competitive advantages of Russian manufacturers, which are largely resource-based, can be partially or completely lost. Tightening of price competition in the fertilizer market, increasing the environmental turbulence and the volatility of global markets forced mining and chemical companies around the world to focus on managing costs, improve the efficiency of strategic management and marketing activities that were sustainable competitive advantages (Barney, 1991) until recently.

Nowadays many factors which influence the global mineral fertilizers market (including dynamic and multidirectional), generates high turbulence of the external environment and difficulties for creating scientifically grounded strategy for companies in order to gain competitive advantages (Dmitrieva & Ilinova, 2016). The environmental turbulence (Bruno, 2015) should be understood as "a measure of the degree of changeability and predictability of the companies' environment" (Ansoff, 1993). The faster the changes occur, the higher the degree of turbulence (Dmitrieva, 2016).

So nowadays, it is important for companies to form and develop competitive advantages, which could remain sustainable even in high environmental turbulence that would be the purpose of the research.

Literature studies

The founder of the concept of competitive advantages of companies is M. Porter (Porter, 1980; Porter, 1985). In Porter's opinion, "competitive advantage is at the heart of a firm's performance in competitive markets" (Porter, 1985). Nowadays there are a lot of theoretical and methodological researches devoted to competitive advantages: its formation and maintaining. In traditional approach in strategic management, competitive advantage is determined as something that helps company consistently earn a higher rate of return than its competitors (Grant, 1991; Schoemaker, 1990). Some authors define competitive advantage as a characteristic that distinguishes the company from others and keeps it existing and growing (Smith and Flanagan, 2006).

Nowadays, especially taking into account high environmental turbulence companies should not only increase its adaptability and flexibility (Nilson & Rapp, 2005), but also to develop the strategy the main goal of which is gaining and enhancing competitive advantages (Švárová & Vrchota, 2014).

However, in condition of globalization and high business struggle intensity it becomes more and more difficult to gain and maintain competitive advantages (Brown & Eisenhardt, 1998; D'Aveni, 1994; Eisenhardt & Martin, 2000; Hamel, 2000). It is because almost all of them (resources, technologies, information etc.) could be copied and repeated by competitors (Goldsmith 2013; Singh 2012).

In scientific researches concerning strategic management, the problem of competitive advantages' achieving is often raised, but still there are many doubts about conceptualization and measurability of the advantage (Sołoducho-Pelc, 2014).

There are many classifications of competitive advantages by different characteristics, but in our research, the most interesting is classification by the character of dynamics. According to such characteristic competitive advantages could be sustainable and non-sustainable (unsustainable) (Beal, 2001). Sustainable competitive advantages are determined as "above-average performance in the long run" (Porter, 1985, Ghemewat, 1986).

Barney (1997) suggest two definitions of sustainable competitive advantages: the first takes place when a company continues to improve its effectiveness and efficiency and competitors do not copy what the company do. The second one takes place when a company consistently earns returns exceeding its stockholders expectations. Unsustainable competitive advantages could be completely or particularly lost by the company in a short-term (Beal, 2001).

Previous studies, devoted to mineral fertilizers market, have addressed fertilizer markets and forecasts of fertilizer consumption (Al Rawashdeh, 2011; Al Rawashdeh, 2016; Geman, 2013), demand and supply sides of the fertilizer industry (Al Rawashdeh, 2014), the role of fertilizers in the global food system (Cordell, 2015), and also the development of phosphate and potash resources and reserves (Mew, 2016; Ciceri, 2015; Cooper, 2011). Previous research has also addressed recent evolution of the fertilizers market and has assessed likely developments in the coming decades (Al Rawashdeh, 2014), as well as questions concerning fertilizer availability in a resource-limited world (Dawson, 2011).

In addition, papers have considered capital investment in fertilizer companies (Geman, 2013), the supply behavior of state mining enterprises (Al Rawashdeh, 2008), and efficiency performance of the world leading corporations in phosphate rock mining (Geissler, 2015).

Practically all phosphate and potash resources used for fertilizer production originate from exploitable deposits concentrated in a rather small number of countries and mined predominantly by a limited number of global enterprises (Geissler, 2015). These enterprises differ by size, types of fertilizers they produce, degree of vertical and horizontal integration, access to raw materials, and legal form or type of ownership. Their overall goal is to get leading position on the market through using its competitive advantages.

Methodology and methods

As it was already said the mineral fertilizers market is characterized by high dynamics. In such situation, it is important to understand the level of such dynamism. Therefore, we can apply approach of I. Ansoff who selected different levels of the environmental turbulence - from repetitive to unpredictable.

Each turbulence level is described by four characteristics: complexity of the environment, the familiarity of events, the rapidity of the changes and the possibility of predicting their consequences (Ansoff, 1993; Bolotov, 2010; Dmitrieva, 2016).

The fertilizer market is constantly undergoing rapid, poorly defined changes and events that require a special approach to the management of companies. After the analysis of the Russian mining and chemical companies' environment, it was found that the degree of turbulence can be set at forth, and occasionally even on the fifth level (Dmitrieva, 2016).

So, the high level of environmental turbulence, increasingly tough competition and current world economic situation demands that mining and chemical companies monitor the global environment and exhibit flexibility in their actions (Dmitrieva et. al, 2017). Foreign and domestic experience shows that such demands can only be met with advanced and effective strategic management that allows gaining competitive advantages and maintaining it for a long time.

To form competitive advantages and understand if they are sustainable or not, it is necessary to study the peculiarities of the mining and chemical industry.

The characteristic features of an oligopoly and industry peculiarities of the mining and chemical holdings in an oligopolistic market are presented in Table 1.

Table 1. Industry peculiarities of the mining and chemical holdings in an oligopolistic market

Characteristic features	**Industry peculiarities**
Limited number of sellers	The presence of large firm's market power. The high degree of concentration in the market determines the strong competition. Market share of phosphate mining and chemical company OCP - about 14%, the share of 8 largest mining companies - about 40%. The total share of the four main world exporters of P2O5 is about 60%. Potash market is controlled only by 11 companies; the total share of the four producers of the world is about 70%.[3]
Huge amount of customers	Customers of products in most cases are the final consumers (several hundred thousand farms). In operating countries, production is realized through its own sales divisions and international traders. None of the customers can affect the market transactions and the level of competition in the market.
Standardized product	Mineral fertilizers from different manufacturers are identical and completely interchangeable. The consumer buys product from any seller provided the same price. There are no substitute products.
The presence of barriers in industry	Entry into a market requires considerable costs related primarily to the necessity to capture a significant share of the oligopolistic market for part of the industry profits. In addition, there is very high capital intensity of production.
The presence of interaction and interdependence of companies	Decision of each mining and chemical company affects the market situation and at the same time depends on the decisions of its competitors: making a decision, the company takes into account the possible reaction of other market participants. There is the possibility of collusion.

Source: (Dmitrieva et al., 2017)

[3]The official website of information-analytical center "Mineral". http://www.mineral.ru/

The high degree of competition in the industry determines the direction of company activities; strategic decisions are made in a context of close interdependence between market participants with implementation of company strategies affecting competition in the industry as a whole (Dmitrieva, 2015).

Despite the availability of common characteristics, the markets for different types of fertilizers differ from each other. So, for example, potash market is characterized by high concentration. At the same time, phosphate and nitrogen industries are not so much concentrated as the potash sector. The phosphate market, though concentrated, is still competitive. Comparative analysis of different segments of the mining and chemical industry in Russia is presented in Table 2.

Table 2. Comparative analysis of different segments of the mining and chemical industry

Characteristics	Potash segment	Phosphate segment	Nitrogen segment
Raw materials	Potash ores - potassium chloride	Phosphoric ores - phosphoric acid	Natural gas - ammonia
Geographical availability of raw materials	Limited	Limited	Available in many countries
Potential market volume	60 million tons	40 million tons	102,9 million tons
Barriers to market entry	Very high	High	High
Costs of new capacities	About 2,8 billion USD for 2 million tons (KCl)	About 1,5 billion USD for 1 million tons (P2O5)	About 1 billion USD for 1 million tons (NH3)
Development of new capacities	More than 7 years	About 3-5 years	About 3 years
Leading producing countries	1. Russia 2. Canada 3. Belarus 4. China	1. USA 2. Russia 3. China 4. Morocco	1. China 2. India 3. USA 4. Russia
Market participants	Units of major players	Several large players (dozens)	A significant number of players (dozens or hundreds)
Dynamics of prices in the long run	High	Average	Low
Profitability	High	Low / Average	Low / Average

Source: compiled by the authors using data from websites of companies Uralkali, PotashCorp, Phosagro.

Results

As the result, it can be concluded that the mineral base serves as the main source of sustainable competitive advantages for mining and chemical companies. In addition, it should be mentioned that the raw material independence of large companies in potash and phosphate segments also increases their competitiveness.

Another source of sustainable competitive advantages of mining and chemical companies could be the fact that, due to the geographic attachment of production capacities to mineral deposits, production, processing and consumption points can be located at a considerable distance from each other. In this regard, logistics costs take the largest part of costs. Therefore, the formation of an effective distribution system with own assets is one of the key activities of large companies for getting sustainable competitive advantage.

Depreciation of national currency is one of the sources of non-sustainable competitive advantages for the Russian mining and chemical companies in the global market. International trade in mineral fertilizers suggests calculations in US dollars. As a result of the depreciation of the ruble to the dollar, the cost of production has significantly decreased only at the expense of change in the exchange rate. This situation allows companies either to reduce the price for foreign consumers, or to get additional profit. Therefore, Russian producers of mineral fertilizers retain their competitiveness on the world market due to the weakening of the ruble exchange rate.

Due to the seasonality of demand for mineral fertilizers, as well as the unevenness of their consumption by regions, another area of competitive advantages formation for mining and chemical companies is the formation of supply flexibility. Diversification of products and markets would allow companies to respond flexibly to any changes in the market situation.

As the result of the research, possible competitive advantages of mining and chemical companies in high environmental turbulence were identified and presented in Table 3. These results addressing creation of effective corporate strategy for enterprises operating in fertilizers industry. The study presents new results relevant to Russian fertilizers companies operating in high turbulent markets. The obtained results could be used for strategy building and its implementation in fertilizers companies for gaining competitive advantages. It is related to the current situation in Russian fertilizers industry. They are useful not only for particular companies but also important for the whole mineral-based sector.

Table 3. Sustainable and non-sustainable competitive advantages of mining and chemical companies in high environmental turbulence

Competitive advantages of mining and chemical companies		
Sustainable	**Sustainable now but in high environmental turbulence could become non-sustainable**	**Non-sustainable**
Favorable geological and climatic conditions	High level of production processes automation	Poor productivity in the territories of consumers
Developed infrastructure of the regions of presence	Availability of access to the high technologies. Sufficient resources for R & D financing	The low costs in relation to the world market because of fluctuations of currency rates
The high content of commercial component in the product	Vertically-integrated business model	Availability of highly-qualified personnel
Rational use of natural resources	Availability of an effective logistics infrastructure (with transport assets), own distribution network	Diversification of activities through the providing services for rural areas
A flexible business model that allows fast changing the structure of products	Availability of a sufficient number of funds to finance new projects (processing capacities, etc.)	Formation of special centers in agro-industrial regions for servicing consumers and closer interaction with the final customers
A wide range of products including all types of mineral fertilizers and complex ones	Low costs compared to competitors (due to more favorable geological conditions or economy of scale)	The existence of a long-term strategy for the company

Source: own elaboration.

Conclusions

The fertilizer industry is characterized by sector-specific market and industry features and high level of turbulence of its external environment. In such conditions, it is extremely important for companies to gain competitive advantages that will lead to success. In addition, mining and chemical companies should focus precisely on the formation of sustainable competitive advantages that ensure the maintenance of competitiveness in the long term period and that influence on the company development.

It was revealed that the traditional competitive advantages gradually lose their competitive potential and companies need to find directions for expanding the areas of formation of competitive advantages. Russian mining and chemical companies in the phosphate and potash segment have a sustainable competitive advantage over foreign companies in the form of rich and high-grade ores.

Some mining and chemical companies are developing new niches for themselves. One of such directions can be, for example, the formation of service centers for final customers. It is also possible to develop informational products for increasing the level of mineral fertilizer application processes automation, providing their rational use, increasing the skill level of farmers, etc.

Nevertheless, despite the general characteristics, each segment of the mining and chemical industry has specific features that determine individual approach to the formation of competitive advantages - this is the object of further research.

Acknowledgement

The paper is based on research carried out with the financial support of the grant of the Russian Science Foundation (Project No. 14-38-00009, The program-targeted management of the Russian Arctic zone development). Peter the Great St. Petersburg Polytechnic University.

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Anna TSVETKOVA
Saint-Petersburg Mining University, Russian Federation
e-mail: 89215500042@mail.ru

World experience of strategic reserves mineral

Abstract

In the world practice has considerable experience of the strategic reserves of mineral raw materials. Composition of strategic minerals is not unique in different countries and not only determined by their scarcity, but also the level of their technical, industrial and innovative development, including ensuring provision for the future defense needs. The priority criteria are, first of all, their significance for the national economy and security of the country and then their accessibility-inaccessibility and sufficiency-failure of provision of the interior national needs for sustainable development of industrial production and also for export. The purpose of this article is to determine what types of reserves of oil and gas in Russia can be implemented in the future. The study uses economic and statistical methods and methods of system analysis. In the Russian Federation is possible to implement several types of reserves of oil and gas, but not all of them can and should be implemented now. It is necessary, first of all, to consolidate the legal base for their establishment and to identify priority objects for their formation.

JEL: D29, D45, E21

Keywords: *strategic types of minerals, types of reserves of oil and gas*

Introduction

In the world practice, considerable experience in organization of strategic reserves of mineral raw materials has been accumulated. The list of strategic types of mineral resources is not identical in different countries and determined not only by their scarcity, but also by the level of their technical, industrial and innovative development, including provision for the future of defense needs. At the same time, priority criteria are their importance for the national economy and security of the country and their accessibility-inaccessibility and sufficiency-insufficiency in providing domestic national needs for progressive development of industrial production, as well as for exports.

Literature studies

In the United States, there are about 40 types of mineral raw materials listed in strategic types of mineral resources. This list is not shorter in other developed countries, such as Great Britain, France, Japan, etc. But being the main source of energy for development of the economy, heat and power supply, oil and gas are used as strategic types of raw materials almost everywhere (Berezina, 2014).

The Federal Law "On Subsoil" (1992) stipulates expediency of forming a federal reserve of stocks of strategic types of mineral resources (STMR). The same provision was repeated in the last edition of the Federal Law "On Subsoil" (Article 19) of 03.07.2016, as well as in a number of other resolutions and orders of the Government of the Russian Federation.

Russia possesses extensive resources of many types of mineral raw materials in the subsoil, including strategic ones, but in previous years, against the background of the economic depression of the 1990s, sufficiency of many of them with an acceptable prime cost of development did not stimulate creation of state reserves of mineral resources. Now the situation in Russia is changing. First of all, the structure of the raw material base of STMR has changed: it is being depleted in developed regions, while requiring significant capital investments in undeveloped ones. Moreover, the developing economy requires reliable provision with raw materials.

For this purpose, almost all developed countries of the world have reserves of mineral resources (in their storages or subsoil) that are of strategic or economic importance for them in the present and (or) in the future for provision of vitally important nation-wide defense, industrial or civil needs (Cherepovitsyn, 2016; Cherepovitsyn, 2017). The systems of organization of hydrocarbon reserves have become most highly developed in the world.

Most countries having other reserves (apart from mobilization ones) are net importers of oil, and such reserves can be defined as strategic import-substituting reserves of the oil produced (Fedoseev, 2016). Taken together, they can be a stabilizing mechanism for the entire global economy. At the same time, not all reserves can be attributed to strategic ones which are created as a continuous system of protection against dependence on oil. A number of activities are tactical reservation: for example, due to the high likelihood of a military operation of the United States against Iraq, Saudi Arabia, Kuwait and other countries in the region have declared the need to create fuel reserves – and on the territory of other countries or on specially leased oil tankers positioned near potential consumers.

Methodology

The principal issue in creating reserves is the question of what exactly to reserve: oil or oil products. The choice depends on many economic and geopolitical factors:

- Crude oil: its main advantage is lower storage costs and greater flexibility in managing the situation (in terms of the possibility of its conversion into the desired product). For example, storage of exclusively or mainly crude oil is advisable in the United States where there is a well-developed transport system, a large number of oil refinery plants, as well as natural and technological opportunities to preserve oil without losing its quality;
- Oil products: a system of distributed warehouses of finished oil products that can be delivered immediately to the consumer may be more preferable for some countries. For example, France and Germany began to create reserves of oil products as early as at the beginning of the last century. But storages for oil products are more expensive both in construction and maintenance. Moreover, a constant rotation of the stocks themselves is required. Therefore, recently there has been a tendency to increase the share of crude oil in strategic reserves of countries.

The world practice of creating reserve funds of hydrocarbon raw materials shows two different strategic goals for their creation by different countries:

- Oil exporting countries – production of raw materials,
- Importing countries – tank farms for oil storage.

The United States and Saudi Arabia have the largest national reserve funds.

The main principles of organization of oil reserves in several countries and groups of countries are further analyzed.

Norway. Norway became a major oil producing country after discovery of the offshore Ekofisk oil field in late 1969. Prior to its discovery, the taxation of oil companies conducting offshore exploration activities had been the same as on land; the state had not taken part in development of the industry.

Along with the growth of importance of the industry in the national economy, the attitude towards it also changed, and the oil legislation began to form. In the beginning, in place of the earlier acting law, the new Mining Law of Norway (1972) was adopted, repeating the main provisions of the Mining Rights of the Anglo-

American system: the mining claim – the mining patent – the license (prospector) permit.

The Law "On Petroleum Activities" was published in 1985; later it was revised and amended in 1996. Now it is close to the Law "On Subsoil" adopted in 1995 in Russia.

State management of all types of work in the oil industry is provided to the Norwegian Petroleum Directorate, whose main functions are technical control and supervision in the field of oil and gas exploration and production, control over safety of all types of work, including compliance with employment and labor laws and the environmental consequences of offshore development. The Directorate is a body of consolidated powers which represents state interests before producing enterprises. At the same time, the Directorate has legal authority to extend, suspend or terminate business activities. It also owns accounting of hydrocarbon resources and making recommendations on their efficient use, in particular, for business enterprises. The Directorate has authority to select the areas of geological exploration in the country for providing oil production with the resource potential, as well as to issue regulatory legal acts and to control implementation of tax liabilities that are set and levied in Norway on the basis of the Law "On Petroleum Activities".

In Norway, the amount of tax is determined by the Petroleum Tax Council on the basis of a standard price corresponding to the value of capital involved in the business and return on sales by third party agents in the free market. This excludes any possibility for entrepreneurs to reduce the tax base for resource payments by selling raw materials to affiliated companies at bargain prices. Standard prices are established by the Government of Norway through their approvals with the subsoil users for a specific period.

Japan. In Japan, state and private (industrial) emergency oil reserves are combined.

Those reserves that are managed by the state-owned Japan National Oil Corporation (JNOC) contain only crude oil. The state reserve has been operating since 1978 and is distributed over 10 storages. Its volume is about 320 million barrels, which provides for 84 days of consumption.

According to the "Law on Petroleum Reserves" of 1975, companies are required to maintain a reserve with a volume sufficient for 70 days of consumption, including both oil and oil products. Accordingly, aggregated state and private reserves of Japan will provide for five months of consumption.

The state strategic reserve within the JNOC is financed by a number of special energy taxes. Because of these taxes energy prices in Japan are among the highest in the world. Thus, maintenance of the state reserve is passed on to the consumers.

Since January 2002, an important amendment has been introduced to the "Law on Petroleum Reserves", giving to the authorities the right to use the accumulated reserves to counteract rapid price appreciation, whereas previously the Law had only allowed for closing the physical deficit which threatened to stop production and spread the deficit along the food chain.

European countries. The EU's general requirement is the presence in the Union member state of reserves of oil and oil products that are able to provide for 90 days of domestic consumption. The EU does not regulate the forms of organization of oil reserves, and European countries solve this problem in different ways.

France introduced required oil reservation for importing companies back in 1928. Currently, France has approximately 125 million barrels of strategic reserves, and about 100 million of them are required reserves of crude oil and oil products of enterprises.

In 1988, the SAGESS Agency (Societe Anonyme de Gestion des Stocks Strategiques) was created in France to store and manage strategic reserves. It managed half of the reserves accumulated by companies until 1993, when the Professional Committee for Management of Strategic Reserves (CPSSP, Comite Professionnel des Stocks Strategiques Petroliers) was established.

Initially, enterprises were required to keep half of their required reserves in their own storages, but this share had been reduced to 20% by 1996. The remaining 80% of reserves are paid off by companies with cash contributions to the CPSSP which purchases and stores crude oil and oil products for this money in an amount equivalent to 90 days of imports. The SAGESS Agency also remains a major holder of reserves (16 days of domestic consumption).

Enterprises in France monthly provide the state bodies with reports on their reserves in oil and all categories of oil products.

Germany combines all three possible forms of reservation: state, agency and required reserves of enterprises. The government manages the Federal Reserve of crude oil (55 million barrels), as well as extensive reserves of oil products. For several years, the share of crude oil has gradually increased from 40 to 60%.

The task of the special Agency for Reserve Management (EBV, Erdolbevorratungsver-band) is uniform distribution of the burden of reservation between oil refinery plants and importers of oil products, as well as ensuring of access to reserves during the crisis. All oil refineries and oil traders are required to be members of the Agency and to pay fees.

In **Italy**, strategic oil and oil product reserves are managed by the state-owned Eni Company (about 7-8 million barrels). Private companies are required to maintain their own reserves at a rate of at least 90 days of consumption. All reserves are distributed between the state reserve, market operators which supplied oil and products for domestic consumption in the previous year, power plant stocks and commercial storages in the amount of 10% of their capacity.

International reserves. In recent decades, different countries have joined forces to create strategic oil reserves – in addition to more effective coordination this is beneficial due to lower costs of creating and maintaining reserves.

The largest systems of energy security with the use of the reservation mechanism have been developed within the European Union and the International Energy Agency (IEA), created by the member countries of the Organization for Economic Cooperation and Development (OECD) in 1975 as opposed to OPEC.

Membership in the IEA imposes legal obligations to have emergency reserves of at least 90 days of net imports from the level of the previous year. Net oil exporters, such as Canada, Denmark, Norway and the United Kingdom, are exempted from this obligation (although the latter two countries still have created such reserves).

Many member countries of the European Union are both members of the IEA and are subject to these and other requirements. The difference in requirements is negligible. Under the EU rules, countries should maintain stocks at the level of 90 days of domestic consumption in three categories of products: gasoline and related products, distillates, and oils. The IEA, in its turn, requires to maintain a 90-day stock calculated on the basis of net imports in the previous year, plus a 10% allowance to compensate for the technologically unrecoverable reserve.

As of today, the aggregate reserves of all leading consumer countries are generally sufficient to pay off supply disruptions, but the share of these countries in the global oil consumption is steadily declining. At the same time, the share of consumption of the rapidly growing economies of Asia is increasing, while they usually do not have any oil reserves at all, and the aggregate reserves of individual countries in the region are not enough. In terms of vulnerability of the entire global economy, the critical moment is the absence of national oil reserves in such countries as China and India.

OPEC countries. Excessive production capacities in oil exporting countries, as well as strategic reserves of net importers, act as a global stabilizer which is able to cover the deficit.

As of today, almost 100% of all free production capacities in the world are concentrated in the OPEC countries, and 90% of them are in the Gulf countries. According to different estimates, Saudi Arabia accounts for 2.5 to 3.5 million barrels per day of reserve capacity, and this figure is much higher than in any other country in the world.

USA. The United States possesses substantial oil reserves of its own, but is a net importer due to the huge volume of its own consumption. Apparently, the most complicated combined structure of the US reserves is also caused by this fact.

The United States began to create its oil reserve as a fund of deposits, and today it remains almost the only country where the reservation of deposits is formalized by the legislation.

The first strategic oil reserve in the United States was created in 1912 through consolidation of six abandoned oil deposits in state ownership. In 1923, by the Decision of President Harding, the National Petroleum Reserve in Alaska with an area of 7.7 million hectares was created to be used only in case of urgent nation-wide necessity.

However, in fact, the creation of strategic oil reserves was caused by an embargo on the oil supply to OPEC countries in 1973 - 1974. Cessation of oil flows from many Arab countries into the United States shocked its economy. As a result of the consequences of the oil crisis, the United States established strategic petroleum reserves (SPRs). Originally, SPRs which were created in 1975 had to contain at least 750 million barrels of crude oil as an insurance against future import restrictions (the maximum size was further reduced to 700 million barrels, when geologically unstable storage sites were decommissioned).

Creation of crude oil reserves in SPRs reduces vulnerability of the nation to disruptions in oil supplies and the consequences of maintaining economic and national security as well as conducting of foreign policy (Bridge G.,2017).

In the USA, there is no single federal agency that would manage state reserves of hydrocarbon raw materials. The structure of the US state reserve system includes the following levels:

- Federal;
- Federal subject – state;
- Administrative district of the federal subject – city, county.

At the federal level, the management of state material reserves is carried out by the President of the United States and by the heads of the sectoral ministries (they are delegated with limited authority to use part of the subordinated material reserves by the Decrees of the President of the United States) through their constituent agencies:

The procedures for creation and use of the Defense National Stockpile of the United States – stocks of strategic raw materials and supplies – is currently determined by the Strategic and Critical Materials Stockpiling Act of 1946, by the Strategic and Critical Minerals Stockpiling Act of June 30, 1979, and by Decree of the President of the United States No 12919 of June 3, 1994 "On the National Defense Industrial Resources Preparedness".

The President of the United States shall notify the Congress in writing of all planned changes in the nomenclature of material values and in the volumes of their storage, with a justification of the reasons and an assessment of the possible consequences of these changes. Changes can be implemented not earlier than in 45 days after the notification submission to the Congress. In exceptional cases (war or crisis), the President of the United States has the right to make an independent decision on the issue of available stocks of strategic and critical materials, with the subsequent immediate notification of the Congress.

Research results

In Russia, there are no analogues of Strategic Petroleum Reserves possessed by the United States and some other countries (the FRG, France, and Japan) (Ponomarenko, 2016). Based on the purposeful assignment of reserves of strategic types of mineral resources, on foreign experience and on domestic regulations, the following types of oil and gas reserves can be implemented in Russia in the future:

- Subsoil sites of federal significance;
- State fund of promising lands (mineral resources of future generations);
- Potential reserve fund of stocks on deposits developed or prepared for development (reserves of production capacities);
- State reserve of warehouse stocks (warehouse reserves).

Conclusions

All types of reserves proposed for implementation are very significant. But under the current legislative system of the subsoil use and under the current state of the raw materials base of STMR, not all of them should and can be implemented at the present time. First of all, it is necessary to consolidate the regulatory and legal framework for their creation and to identify high priority objects for their formation.

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Sergey Yur'evich AVKSENTIEV, Sergey Leonidovich SERZHAN
Saint-Petersburg Mining University, Russian Federation
e-mail: avksentiev@mail.ru; e-mail: sergei.serzhan@inbox.ru

The implementation of the EPCM project by a strategic development of supplier companies of technology solutions in the mining complex of the Russian Federation

Abstract

The article provides a brief description of the current situation of JSC «Uchalinsky GOK» and EPCM project implemented on the company. The problems existing now when transporting and laying concentration tailings of copper-zinc ore are revealed that causes need of modernization of system of hydrotransport and warehousing.

The multiple-purpose project which includes transportation of concentration tailings to the thickening equipment, the thickening and warehousing, on the place of the fulfilled open pit is in details considered. The thickening equipment which according to the agreement is delivered by the Outotec Company is considered. The standard scheme of implementation of the investment and construction project is presented. It is revealed that the basis of an economic evaluation of efficiency of implementation of the EPCM -project was the technology solutions accepted in process to development of the project documentation. The structure of capital expenditure for implementation of this pilot project is provided.

Calculation based on methodical recommendations about an efficiency evaluation of investment projects is given. Besides, in article summary technical and economic features in case of a thickening of concentration tailings and hydraulic filling of open pit are provided. On the basis of the provided project, authors considered and economically proved ways of a strategic development of supplier companies of complex technology solutions for upgrade of the entities in mining and ore mining and smelting industries. The main stages of implementation of possible strategy of the company taking into account influence of risk are allocated.

JEL: L70, L72, L95

Keywords: *hydraulic transportation; concentration tailings copper-zinc ore of Uchalinsky GOK; thickening; hydraulic filling; modernization of system of hydrotransport*

Introduction

Uchalinsky GOK which is a part of the Ural Mining and Metallurgical Company (UMMC) is the manufacture of a zinc concentrate, largest in Russia, and the third – on volumes of release of a copper concentrate.

Uchalinsky GOK is one of the main extracting assets of UMMC also has good investment opportunities for development and modernization in prospect of modernization of a technological complex of the enterprise by authors the EPCM project is considered (Kimelfeld, 2014; Titov & Titarenko, 2014).

At the present time taking into account increase in productivity of factory up to performance measure of 6 million tons per year on ore there is a need for modernization of the main technology solutions, including, in the solution of problems of storage operation of concentration tailings (Falagan et al., 2017). Traditionally concentration tailings are warehoused in the tailing dump (Gusev, 2004; Uy & Adajar, 2017).

However reduction of cubic contents of the existing tailing dump of Uchalinsky GOK has caused the beginning of works on research of new places of warehousing of concentration tailings (Ahmedyanov et al., 2014). Need of the forthcoming recultivation of the Uchalinsky pit has pushed to studying of a possibility of use for this purpose of a pit (Rao et al., (2016), mined-out space having large volume (Fig.1). (Lebre et al., 2017).

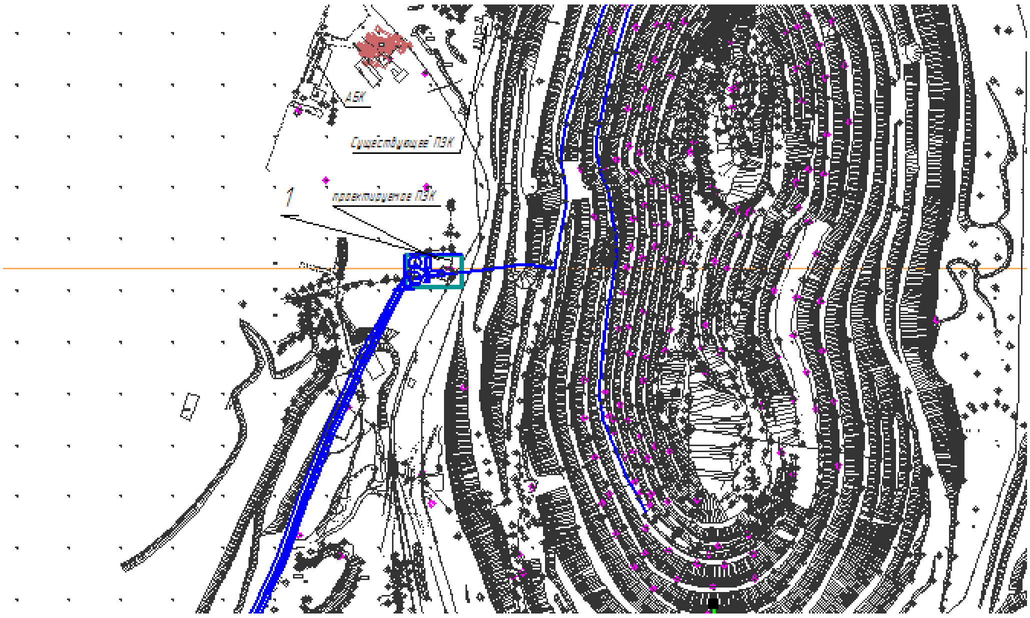

Figure 1. Location of unit of tailings thickening for their warehousing in a pot of the Uchalinsky pit
Source: (Avksentiev & Serzhan, 2017)

Materials and methods

The realized multiple-purpose project consists of several individual projects. Within the project a problem of transportation of concentration tailings (Chen et al., 2016) from factories to unit of tailings thickening (Blyuss et al., 2009) and problem of a concentration tailings thickening by concentrating mill (Yagudin et al., 2004) and complex problem of warehousing of the concentration tailings in a pit will be solved. Design of a hydroseparator of the high degree of a densification applied within the EPCM-project it is provided in Fig. 2.

For the purpose of the solution of a complex task, and including a problem of a tailings thickening to necessary concentration, CJSC Outotek Sankt-Peterburg realizes the EPCM project, carrying out design engineering development, detail engineering, buying of construction materials, constructions, processing equipment and accessories, and also performance of "turnkey" construction works. Thus, the main functions of the contractor are designated (in more detail - see Fig. 3) (Adiansyah et al., 2016).

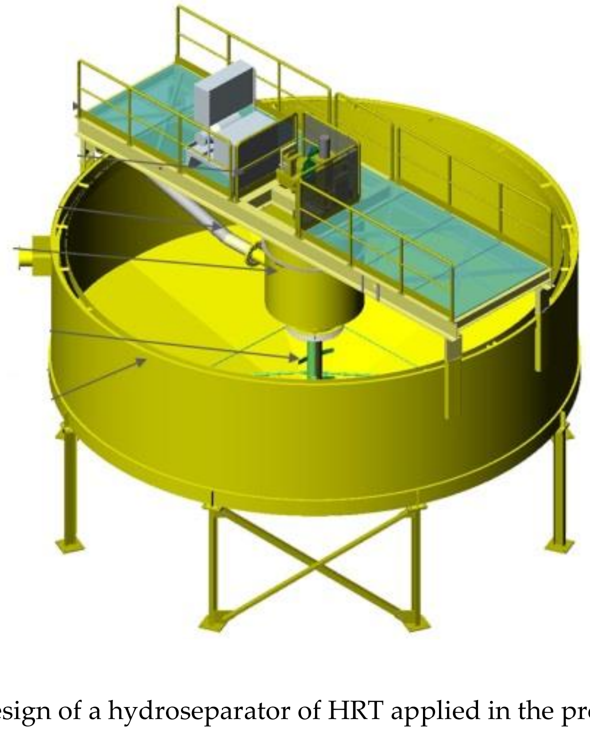

Figure 2. Design of a hydroseparator of HRT applied in the project (Outotec)
Source: (Avksentiev & Serzhan, 2017)

Stages of implementation of the project include a design stage, a procurement cycle of the equipment and a stage of construction. All risks for stages are born by the supplier of technology solutions.

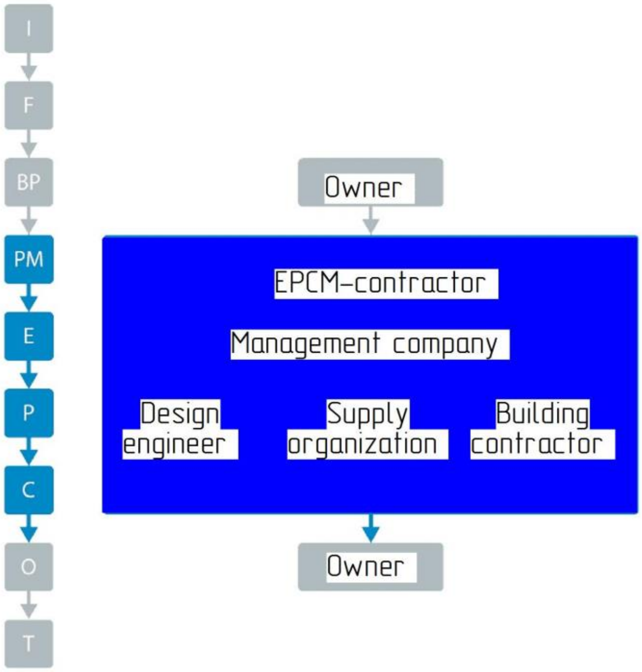

Figure 3. Standard scheme of implementation of the investment and construction project
Source: (Avksentiev & Serzhan, 2017)

It should be noted that this is pilot project for Outotec concern. From the point of view of strategic company management, implementation of this project gives significant advantages for the market in comparison with competitors:

1. The Outotec concern carries out not only supplies of equipment, and provides the complex technology solutions applicable for modernization of the enterprise in mining and ore mining and smelting industry
2. The concern considerably diversifies the business, providing implementation of the EPCM-project in regions of the Russian Federation.

Result of the choice of strategy of concern, in particular, for CJSC Outotek Sankt-Peterburg is that fact, that implementation of the similar pilot project opens considerable prospects when developing project and working documentation on construction of similar objects.

System approach to the solution of a complex task for JSC Uchalinsky GOK has economic advantages and also advantages from the point of view of a risk management as on the basis of the fixed price when pricing all financial risks are paid by the contractor.

The technology solutions accepted in process to development of the project documentation are the basis for an economic assessment of efficiency of implementation of the EPCM-project (Sukharev, 2007; Holt & Barnes, 2009; Tsarev, 2004).

Results

Authors have analyzed structure of capital investments with hydraulic filling of the developed pit space. The analysis has shown that the greatest expenses fall on a construction of a complex of a hydroseparator of concentration tailings - 84% of the cost of the general technological complex (Fig.4). The share of costs of a construction of all technological complex – makes 75% of the total amount of expenses. Thus, the EPCM project, realized by Outotec concern for JSC Uchalinsky GOK, are key from the investment point of view.

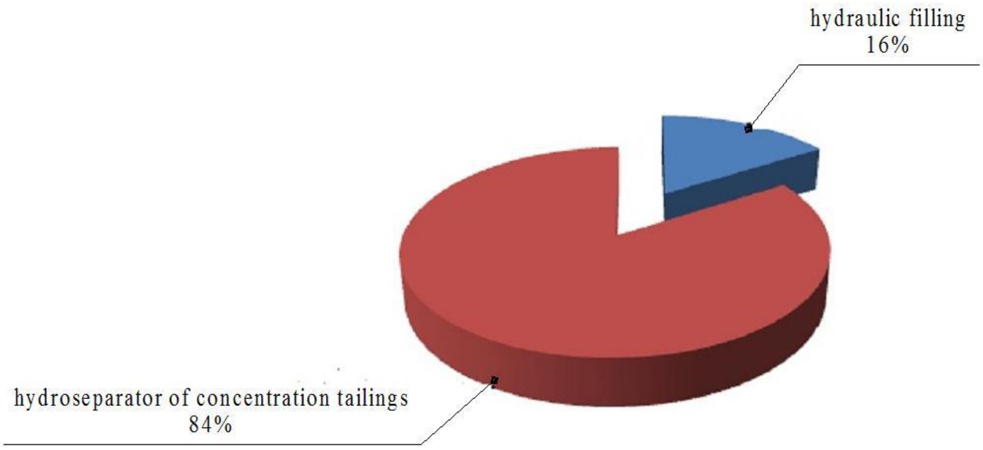

Figure 4. Structure of capital expenditure
Source: own elaboration.

In general the analysis of capital expenditure has shown that they are comparable to costs of construction of the tailing dump (80 mil.$), but at the same time is 33% less when filling of the developed pit space with hydraulic filling. For implementation of the above-stated EPCM-project capital investments will make approximately 1933 million rub.

During economic calculations on the basis of methodical recommendations about an assessment of efficiency of investment projects the following criteria have been calculated:

- net present value;
- internal rate of return;
- payback period;
- profitability index.

The discount rate is calculated by a formula (1) and has made 8%:

$$d = d_i + {}^{p}/_{100}, \qquad 1 + d_i = {}^{1 + {}^{r}/_{100}} \Big/ {}_{1 + {}^{i}/_{100}} \tag{1}$$

where:

p=7 – the amendment on risk for investments at intensification of production on the basis of the mastered equipment,

r - refinancing rate of the Central Bank of the Russian Federation on date of calculations (7,5%),

i =10 – the average rate of exchange inflation announced by the Government of the Russian Federation the current year (2013).

Basic data for calculation of efficiency criterion of investment projects it is presented in table 1.

Table 1. Basic data

No.	Basic data
1	Annual output on concentration tailings – 6 million t.
2	Investments – 1933 million rubles.
3	The period of construction of a stowing complex – 3 years;
4	Specific economy on warehousing and ecological payments – 56,2 rub/t.
5	Amortization is accepted at the level of 5% of the fixed assets value
6	Specific operating cost – 38,9 rubles/t
7	Wealth tax (2,2% of the fixed assets value)

Source: own elaboration.

The summary table of efficiency criterion by options is submitted in table 2.

Table 2. Summary technical and economic indexes at a thickening of concentration tailings and hydraulic filling of pit area

No.	Index	Unit measure	Indicator values
1	The annual volume of the thickening of concentration tailings and further stacking in the developed pit space	mil.t.	6
2	Net present value	mil.rub.	301
3	Payback time	year	15
4	Internal rate of return	%	1
5	Investments	mil.rub.	1933
6	Cost value of a thickening of concentration tailings and filling of the developed pit space	rub./t	48,9
7	Electric energy consumption	kWh /t	2,3
8	Consumption of auxiliary materials	rub./t	9,1

Source: own elaboration.

Conclusions

Outotec concern, being a strategic partner of the large metallurgical companies, realizes the pilot EPCM-project. The project includes the complex technology solution of modernization of system of hydraulic transportation, a thickening and hydraulic filling of concentration tailings of Uchalinsky GOK. Also provides system concept to construction design, delivery of processing equipment and "turnkey" construction of the facility for the chosen development strategy of the company.

The analysis of structure of capital investments with hydraulic filling of the developed pit space has shown that the greatest expenses fall on a construction of a complex of a hydroseparator of concentration tailings - 84% of the cost of the general technological complex.

In general the analysis of capital expenditure has shown that they are comparable to costs of construction of the tailing dump (80 mil.$), but at the same time is 33% less when filling of the developed pit space with hydraulic filling.

Technical and economic indexes of project: the annual volume of the thickening of concentration tailings and further stacking in the developed pit space – 6 mil.t; net present value – 301 mil. rub; payback time – 15 years; internal rate of return – 1%; investments – 1933 mil. rub; cost value of a thickening of concentration tailings and filling of the developed pit space - 48,9 rub/t.

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Olga Olegovna EVSEEVA, Alexey Evgenevich CHEREPOVITSYN
Saint-Petersburg Mining University, Russian Federation
e-mail: olgaevs@yandex.ru, alekseicherepov@inbox.ru

Comparative effectiveness analysis of Russian and foreign liquefied natural gas projects

Abstract

The theoretical and methodological basis of the research is the works of foreign and Russian experts on the analysis of the world gas market situation, as well as on the problems and development prospects of the liquefied natural gas global industry. The analytical and statistical materials of main research institutes, information from the official websites of the operator companies of existing and being constructed LNG projects, as well as scientific papers and specialized literature were used for writing the article. The purpose of this research is to conduct a comparative analysis of Russian and foreign LNG projects and to assess prospects of the large-scale LNG projects realization in Russia. The study applied the methods of comparative and value analysis, financial management methods and investment assessment. The main points of the research supplement the existing theoretical ideas in the economy of fuel and energy sector. The results obtained during the research can be used as a theoretical base for further research on the global LNG market development. The liquefied natural gas industry is dynamic, due to the constant changes of market indices. This research is related to the current period; analysis of industry figures was conducted in agreement with values relevant as of March 2017. The study assessed the current state of the global LNG market, analyzed the current state of LNG production in Russia and proved the expediency of new Russian LNG projects realization.

JEL: F15, F6

Keywords: *LNG, liquefied natural gas, Russian LNG projects, LNG market*

Introduction

Liquefied gas transportation and storage technology is becoming one of the key factors in the world energy market development. Although the history of liquefied natural gas (LNG) active use in the process of energy consumption diversification of countries in the world counts about half a century, development pace of the industry is high. As of 2015, 30 percent of global gas trade is LNG, according to present projections by 2035 it will amount to 50% of the gas market (CDUTEC, 2016).

Russia is a world leader in the world reserves of natural gas and is the largest exporter of this energy resource. However, currently the main market for Russian gas is Europe, due to the presence of the appropriate system of export pipelines. Pipeline-oriented realization of the Russian gas significantly limits the diversification possibilities of export deliveries as well as entails a number of market and transit risks, particularly in the conditions of unstable demand for natural gas in Europe.

In addition to the weak gas export diversification, there is another problem of the Russian gas business – the remoteness of planned deposits development, which influence the costs, associated with transporting finished product to consumers.

Active development of the LNG industry can become the solution to the identified problems. That will allow Russia not only to expand the geography of gas sales and increase the room for maneuver in the gas exports, but also to strengthen its position in the hydrocarbons market.

Literature studies

LNG technology provides an effective way of natural gas realization by transforming it into a liquid state by cooling to -161°C (Ulvestad & Overland, 2012). In the liquefaction process, the gas volume reduced 600 times, which leads to increased mobility of its transportation and storage. The LNG is regasified for using in the economic purposes, and then it is sent either to power stations for electricity generation, or directly to the consumer through a system of internal pipelines. LNG is also used as motor fuel without preliminary regasification.

The LNG industry is developing quickly for several reasons:

1. The world structure of primary energy carriers consumption. Leaders in the LNG consumption are the countries of the Asian region (more than 70% of the global market) (CDUTEC, 2016). Natural gas demand in these countries is growing annually, but there is no infrastructure for direct pipeline supply from major production centers.

2. Environmental problems and environmental protection policy. Currently, environmental responsibility is becoming a main priority in the development of many countries (Dzhiganshina, 2016). Particularly, it is reflected in the active replacement of fuels with high carbon content (coal) by fuels with a lower content of this component (natural gas) (Zietsman et al., 2012). For example, CO2 emissions from using the LNG is 45% less than from using coal (Morgan, 2012).
3. The geography of natural gas production. Application of LNG technology increases the development efficiency of hard-to-reach deposits, located on the continental shelf or in coastal areas. In addition, for suppliers isolated from the main consumption centers, gas realization is possible only in case of its transportation in a liquefied state.
4. Economic efficiency. The realization of liquefied gas becomes more efficient than pipeline transportation at a distance of 2500 km and volumes more than 6-7 billion m3 (Meshcherin, 2011).
5. Innovative potential of the industry. In attracting investments, innovations in maritime transportation, construction of floating LNG plants (FLNG), floating LNG storage and regasification terminals (FSRU) are of great interest. Thus, the increase of LNG carriers single deadweight allows to reduce the cost of LNG transporting, and, accordingly, to expand the geography of deliveries. Construction of the floating infrastructure is the least capital-intensive in comparison with stationary objects, and requires less time spent on the construction(Hewitt & Ryan, 2010).

The dynamic growth of the global LNG market is explained by the need of sources and forms of energy supply diversification of the economies of many countries in order to ensure national energy security. The LNG market shows a massive expansion of the number of suppliers and consumers of liquefied natural gas, an increase of its share in covering the energy needs of countries, constant development and introduction of new innovative technologies, expansion of liquefaction, regasification and transportation facilities. As the market grows and more and more players enter the market, it becomes more flexible and mobile. In recent years, there is a trend to the increase in LNG deliveries under short-term agreements, which allows the LNG sellers, if it is necessary, to reorientate export flows quickly in agreement with the changing demand, and allows the importers to regulate the amount of LNG deliveries in accordance with seasonal needs.

The volume of LNG world trade in 2015 amounted to 245.2 million tons, having increased almost fourtimes over the last 20 years (GIIGNL, 2016). To date, there are 34 countries importing LNG. The leaders are Japan (34% of global demand), South Korea (13,6%) and China (8,2%). LNG consumption structure is in constant dynamics (Mulcahy, 2015).19 countries are exporting this type of energy source. The leader among these countries is Qatar (32% of global supply) (Bridge & Bradshaw, 2017). Australia took the second place in LNG export volume in 2015 (12%) ahead of Malaysia (10.2 percent). Russia's position as an exporter of LNG in the global gas market is currently weak. In 2015, Russia's share accounted for only 4.3% of the world's LNG exports (GIIGNL, 2016). By the Energy strategy of Russia up to 2030, it is planned to increase the share in the global market to 15%, but today Russia has only one LNG plant – Sakhalin-2 (Henderson & Moe, 2016). Two production lines of the plant liquefy 14.9 billion m3 of natural gas per year, producing 10.9 million tons of LNG, which is exported to Asian Pacific countries (Sakhalin Energy, 2015).

The operator of the project Sakhalin-2 Sakhalin Energy is planning to build the third production line and thereby increase the designed capacity up to 16.2 million tons per year. In addition to the plant in Sakhalin, six more LNG projects are planned for implementation: Yamal LNG, Vladivostok LNG, Far Eastern LNG, Pechora LNG, Baltic LNG and Arctic LNG-2, whose key features are stated in table 1.

The beginning of the majority of Russian LNG projects operational stage is expected in 2017-2020 years; however, there is only one project – Yamal LNG – is under active construction. A number of factors currently affects the Russian LNG industry. Firstly, it is worth noting the introduction of the US and the EU economic sanctions, which limited the possibility of attracting foreign investments in projects that include "Rosneft" and "NOVATEK" (National Energy Security Fund, 2015). The second problem is the dependence of Russian projects from foreign technologies. For example, powerful turbo equipment and large heat exchangers, which form the basis of any large-capacity LNG production, are not produce in Russia, and in the conditions of technological sanctions, their purchase from foreign manufacturers has become almost impossible (Dmitrieva, 2015). The unfavorable economic situation caused by the fall of energy prices can be considered as the third problem. It threatens the profitability and payback of new projects.

Table 1. Characteristics of the Russian LNG projects

Project name	Location	Resource base	Project participants	Commissioning date	Capacity (mtpa)	CAPEX (billion $)
Sakhalin – 2 (extension)	South of Sakhalin	The Kirinskoye and Yuzhno-Kirinskoye fields	Sakhalin Energy	2019	5,4	7,4
Vladivostok LNG	Primorsky Krai	FieldsofSakhalin, Yakutia and Irkutsk gas production centers	Gazprom	2020	15	12
Yamal LNG	YNAO	The South-Tambeyskoye field	Novatek, Total, CNPC	2017	16,5	27
Pechora LNG	NAO	Kumzhinskoe and Korovinskoe fields	Rosneft, Alltech	2018	2,6-5,2	5,3-6,6
Baltic LNG	Leningrad region	Deliveries from UGSS	Gazprom,Shell	2020	10-15	10-11
Far East LNG	Sakhalin island	Fields of project Sakhalin-1	Rosneft,, Exxon Mobil	После 2023	5	30
Arctic LNG 2	YNAO	Salmanovskoye and Geofizicheskoe fields	Novatek	2024	16,5	10

Source: data from operating companies.

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Methodology

Despite the challenging geopolitical and economic environment, work on a number of large Russian LNG projects is underway. That is why the forecast for LNG capacity increase in Russia appears to be realistic. However, the effectiveness of capital-intensive LNG projects realization is largely dependent on two main parameters –competition of LNG suppliers to foreign markets and the level of energy prices. We suggest assessing the potential competitiveness of Russian LNG production in the global market.

To solve this problem, first of all it is necessary to analyze the correlation of LNG demand and supply on the world market. As shown on the figure 1, the dynamic of gas market development in the next few years will change its character: by 2020, the LNG industry is expected to leap forward, which will increase the total capacity of the existing industries by almost half. The difference between production capacity and expected demand will increase, that will lead to an increase in surplus and, as a consequence, to tightening the competition among exporters.

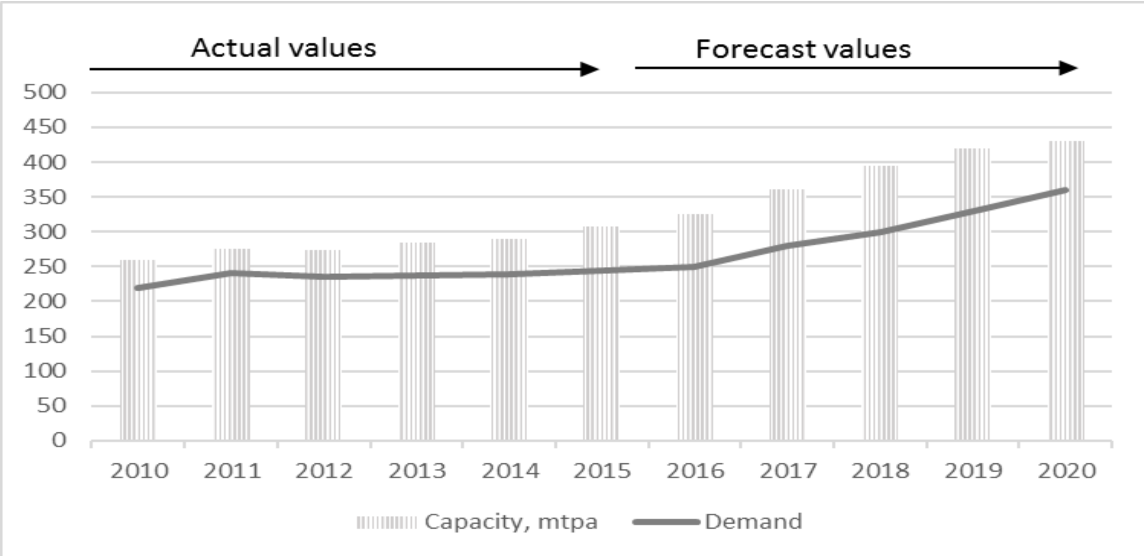

Figure 1. The correlation between world demand and production capacity [mln.t/year]
Source: Giignl, Nexant.

Further analysis of the Russian LNG projects competitiveness will be carried out on two characteristics: project costs of the LNG plants construction and the profitability of production sold on the external market.

Research results

By the end of 2015 LNG productions of total capacity amounting to 141.5 million tons with commissioning period before 2020 are being under construction. 82% of these projects account for 11 projects the USA and Australia (Fig. 2) (IGU, 2016). We think it is appropriate to conduct a comparative analysis of Russian, Australian and American LNG projects similar in technical characteristics and terms.

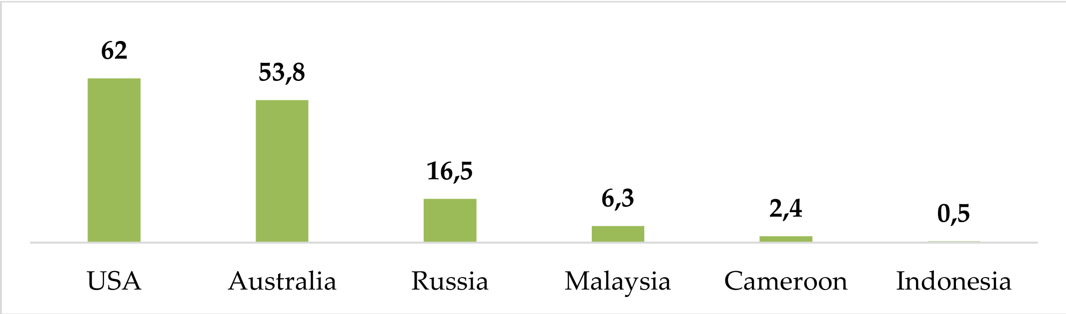

Figure 2. LNG projects under construction with commissioning period up to 2020 [million tons]
Source: IGU

Figure 3 shows the cost analysis, the objects of which are three American (Cove Point, Cameron, and Freeport), three Australian (Prelude, Ichthys, Gorgon) and three Russian projects Yamal LNG, Pechora LNG and Baltic LNG.

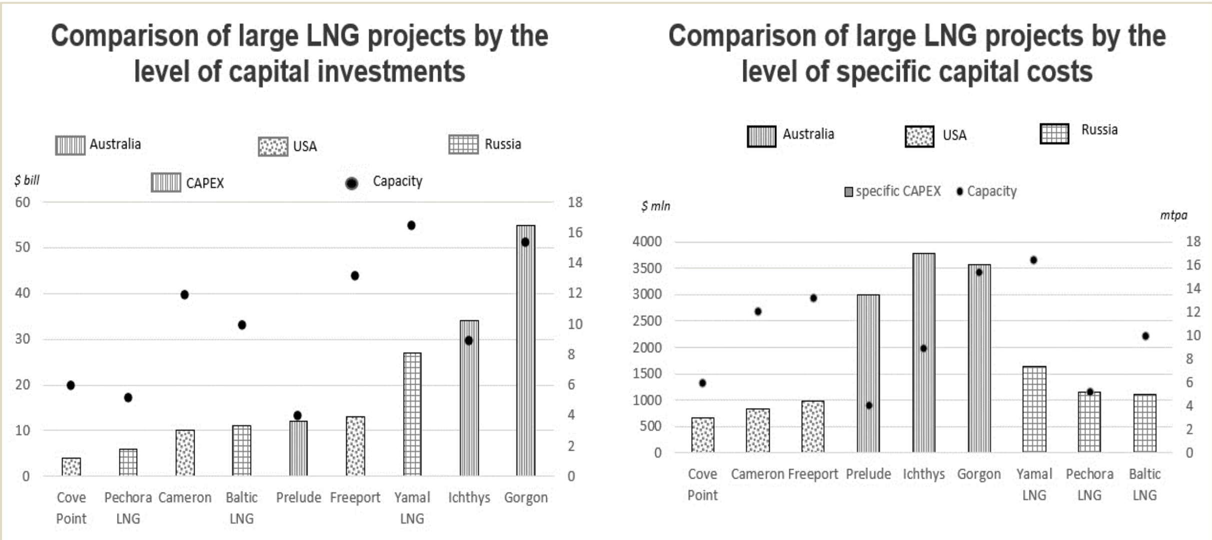

Figure 3. Comparison of major LNG production projects in terms of cost
Source: Nexant, IEA, ERI RAS

The regional specificity of these projects, affecting the level of their costs, can be note. Thus, the least capital-intensive are American projects that are constructed based on existing regasification terminals with their prepared infrastructure and do not include Upstream segment in the cost structure.Russian projects occupy an average price niche in the cost indicators. It should be noted that the cost of Russian projects as well as the cost of Australian projects, include expenses for the development of own resource base and the construction of the transport network from the extraction point to the liquefaction plant (Melnikova &Troshina, 2016).

The profitability of Russian LNG when entering the global market is a comparative analysis of the cost price of LNG production and prices on this energy carrier in a specific regional market. The following price-determining expense items are taken into account: the cost of the feedstock, liquefaction and transportation to the market and regasification.

To date, the main consumers of LNG are the countries of Europe and Asia. Their share of world trade in 2015 amounted to 16% and 70% respectively (BP, 2016). However, according to BCG, the needs of these regions in the supply of LNG will increase, so European and Asian LNG markets will remain attractive for exporters in the long term (Fig. 4) (BCG, 2016).

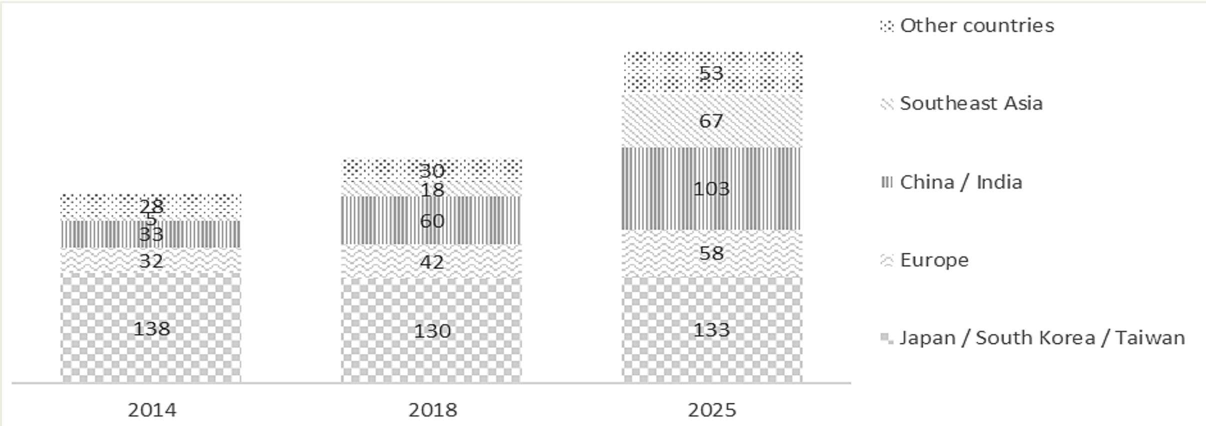

Figure 4. Forecast of demand on LNG in Asian and European market
Source: according to BCG

Figure 5 shows an evaluation of the profitability of Russian LNG when entering the main markets of Europe and Asia compared with supplies from competitor countries. Yamal LNG project, which will be launched this year, was chosen as the object of analysis for objective assessment of current average prices. The statement of "NOVATEK" president of the board Mark Jetway about gas production price amounting to 0.38 USD /MMBTu and the total cost of finished product amounting to 3 USD/MMBTuwas taken as the basis for cost calculation (B2BGLOBAL, 2016).In order to assess the consequences of price changes in the LNG market over the past three years, calculations of the LNG deliveries profitability will be provided not only in the market situation as of February 2017, but in price terms in 2014, when the Russian project moved to the construction phase.

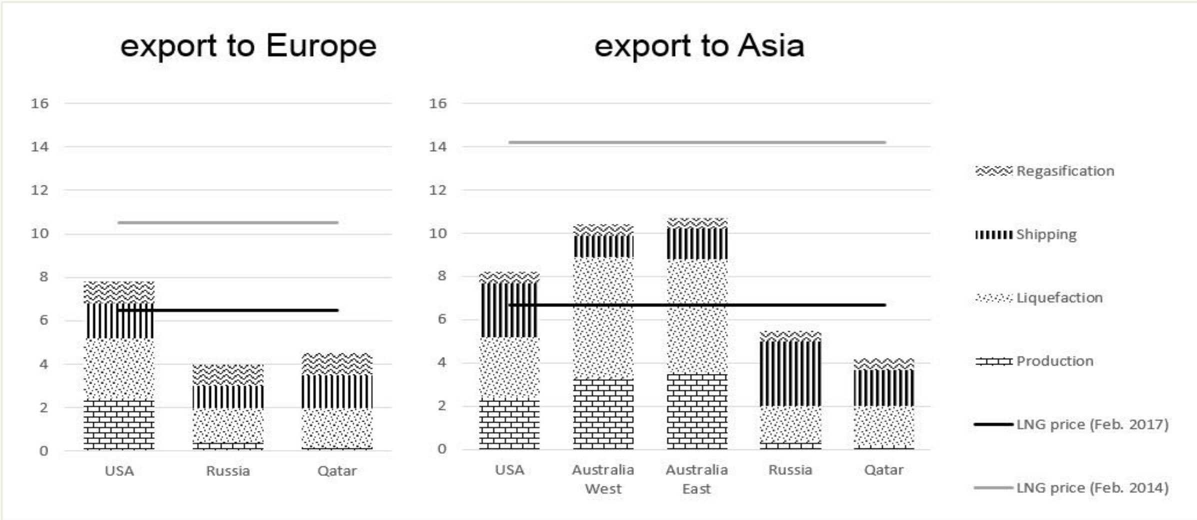

Figure 5. The cost of LNG deliveries to European and Asian market, in the market situation in 2014 and 2017 [USD /MMBtu]

Source: Nexant, ERI RAS, Argus, FERC

The LNG export to Europe and Asia in 2014 was profitable for all market participants. Nevertheless, over the last couple of years, trends in the global energy market has changed: the decline in hydrocarbon prices led to a change in price conjuncture on the LNG market. Large Asian market with its consistently high prices relative to other regions in current conditions became unfavorable for the Australian and US LNG realization. The deliveries of US LNG to Europe, launched in 2016 remain unprofitable. In the conditions of high uncertainty, which is typical for the energy market, it is rather difficult to predict energy prices, however, according to many analysts, there will not be a substantial growth in the near future. In today`s economic situation, the competitiveness of Russian LNG is quite high, maintaining prices for energy carriers at current levels will ensure effective realization not only of the analyzed Yamal LNG, but also of the Baltic LNG, which is also focused on export and planned to be realized in the near future.

We can note the following competitive advantages of Russian LNG:

1. Savings on cleaning stage due to the low content of impurities in natural gas in comparison with shale gas and coalmine methane;
2. Savings of power inputs for account of lower average annual temperatures;
3. Savings on transportation for account of favourable geographical location in relation to the main markets;
4. Production of conventional (natural) gas is cheaper than the production of shale gas and coalmine methane.

Conclusions

The liquefied natural gas global market is in a state of transformation. A large number of new productions, which will be commissioned in the next few years, according to forecasts, will lead to a market glut. This trend, combined with low energy prices, is likely to have a significant impact on the industry not only in the short term, but also in the long term.

LNG industry is a promising direction of the Russian energy potential development. Liquefied natural gas is becoming an integral part of the modern gas market; technology of natural gas transportation and storage in a liquefied state increases the efficiency of remote deposits development, and opens up new export directions. The prospects for increasing the LNG production potential in Russia are realistic. The planned construction of capacities for natural gas liquefaction and its transportation are competitive even in conditions of unstable hydrocarbon market situation, their realization will accelerate the development of domestic fuel and energy sector, as well as strengthen Russia's position in the global energy market.

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Victor ALEKSANDROV, Pavel MAKHARATKIN
Saint-Petersburg Mining University, Russian Federation
e-mail: Pavelnik@spmi.ru

Estimation of efficiency of hydrotransport pipelines polyurethane coating application in comparison with steel pipelines

Abstract

The paper presents analytical calculations of specific pressure loss in hydraulic transport of the Kachkanarsky GOK iron ore processing tailing slurry. The calculations are based on the results of the experimental studies on specific pressure loss dependence upon hydraulic roughness of pipelines internal surface, lined with polyurethane coating. The experiments proved that hydraulic roughness of polyurethane coating is by the factor of four smaller, than that of steel pipelines, resulting in decrease of hydraulic resistance coefficients entered into calculating formula of specific pressure loss - the Darcy-Weisbach formula. Relative and equivalent roughness coefficients are calculated for pipelines with polyurethane coating and without it. Comparative calculations show that hydrotransport pipelines polyurethane coating application is conductive to specific energy consumption decrease in hydraulic transport of the Kachkanarsky GOC iron ore processing tailings slurry by the factor of 1.5. The experiments were performed on a laboratory hydraulic test rig with a view to estimate character and rate of physical roughness change in pipe samples with polyurethane coating. The experiments showed that following 484 hours of operation, roughness changed in all pipe samples inappreciably. As a result of processing of the experimental data by the mathematical statistics methods, an empirical formula was obtained for calculation of operating roughness of polyurethane coating surface, depending on pipeline operating duration with iron ore processing tailings slurry.

JEL: C89, L70, L95

Keywords: *Darcy- Weisbach; hydrotransport; polyurethane; tubing; roughness*

Introduction

Specific pressure loss is one of the main parameters of hydraulic transport raw minerals processing, as actually determine operating costs for electrical energy in the process hydrotransport system. Modern trends in productivity growth as a result of the mining enterprise engaging in the processing of large volumes of all ores are responsible for increasing the load on the hydraulic transport system and tail slurries, respectively, on the tailings concentrator. Efficiency hydrotransport operating system can be estimated by the value of specific energy transport process (Aleksandrov, 2015). Decreasing the pressure loss reduces specific energy hydrotransport system, i.e. to reduce the electricity consumption for the pumps drive.

Literature studies

It is known that the major loss of energy in the pipeline transportation of liquids consumed to overcome the force of liquid flow friction against the internal surface of the pipeline in, and depend on the value of the coefficient of hydraulic resistance included in the formula for the Darcy-Weisbach (Darcy, 1857). Hydraulic drag coefficient is a function of the relative pipe wall roughness and Reynolds numbers (Heywood & Richardson, 1978) and determining the fluid flow regime, i.e. On Kachkanar GOK industrial testing of pipelines made of high density polyethylene were performed. Tests have not shown substantial increase in the service life slurry pipeline, since the outlet is made of polyethylene pipes installed at the distribution slurry pipeline through the work week had the through-hole from wear by solid particles.

At the same plant used angular rotations technical liquids, lined the inner walls of a polyurethane coating. Operation with a polyurethane coating turns shows that in this case, the service life of more than 10 times longer than the angular rotations of steel without a polyurethane coating. In laminar fluid flow regime ($\mathrm{Re} \leq 2300$) coefficient of hydraulic resistance does not depend on the roughness of the walls, but is determined only by the value of the Reynolds number for the Stokes formula (Heywood & Richardson, 1978). In the friction zone characteristic hydraulically smooth tubes (height roughness coated liquid film), the coefficient of hydraulic resistance does not depend on the roughness of the walls. Such a flow regime occurs at Reynolds numbers in a range $2300 < \mathrm{Re} \leq 100000$. This ratio is calculated by the formula Blasius. In practice all hydrotransport pipelines operating mode in the transition to turbulent and turbulent regimes, determining when the magnitude value of the hydraulic resistance value has a pipe wall roughness (Kumar et al., 2015; Schmitt, 2004).

Methodology

Let's calculate the value of the Reynolds number for the conditions of Kachkanar MPC by formula:

$$\mathrm{Re} = \frac{vD\rho_h}{\mu} \tag{1}$$

Let us assume for the calculation of the following values of the basic parameters: D = 1000 mm; v = 4,8 m/s; $\rho_h = c_v(\rho_s - 1) + 1 = 0{,}033(3{,}3-1)+1 = 1092$ kg/m^3; μ = 1,017·10^{-3} Па·с. In the calculation it is assumed that the mass concentration is equal to the tailings slurry $c_p = 10\%$, which corresponds to $c_v \cong 3\%$ by the formula:

$$c_v = c_p \frac{\rho_h}{\rho_s} = 0{,}1\frac{1092}{3300} = 0{,}033 \tag{2}$$

For pipe 1000 mm, the Reynolds number:

$$\mathrm{Re} = \frac{4{,}8 \cdot 1{,}0 \cdot 1092}{1{,}017 \cdot 10^{-3}} = 5{,}154 \cdot 106 \tag{3}$$

For pipeline 900 mm and average velocity of pulp v = 4.0 m/s and similar parameters, the Reynolds number is equal to:

$$\mathrm{Re} = \frac{4{,}0 \cdot 0{,}9 \cdot 1092}{1{,}017 \cdot 10^{-3}} = 3{,}865 \cdot 106 \tag{4}$$

In fact, we find that the pulp flow regime in pipes is developed turbulent.

When developed turbulent regime (square area of friction) coefficient is independent of the Reynolds number, as determined by the relative roughness coefficient in accordance with the formula Shifrison:

$$\lambda = 0{,}11\varepsilon^{0,25} \tag{5}$$

In the laboratory of the department of mining transport machinery of the St. Petersburg Mining University were carried out experimental studies of surface roughness of pipelines covered with polyurethane coating. The coating material is polyurethane having a hardness Shore surface - 83A, 85A and 90A (ISO 868—85). Experienced coated pipe samples are shown in Figure 1.

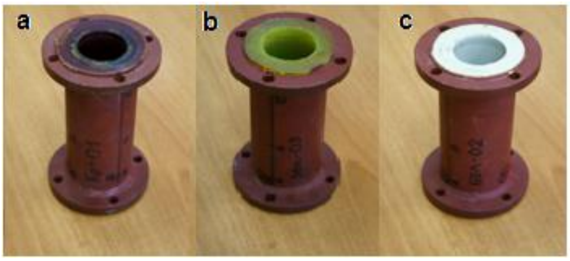


Figure 1. General view of the prototypes pipes with polyurethane coating: a - red color, hardness Shore 83A; b - the color yellow, hardness of 85A; c - gray color, hardness 90A
Source: own elaboration.

The roughness of the surface of the coating is measured using a special device, SJ-210. Contact profilometer (surface roughness meter) is an inductive sensor (detector in the form of a probe) with a diamond needle and based on the measured area (www.mitutoyo.com). The needle (probe) moves perpendicular to the inspected surface. The sensor generates pulses that pass through an electronic amplifier. Emerging with mechanical oscillation probe converted into a digital signal. Statistical analysis of several of these signals allows us to calculate the average value of the parameter - quantitative characteristic plot irregularities based on a certain length.

The test installation was assembled to carry out the measurements, the general form of which is shown in Figure 2.

Figure 2. General view of the measurement setup: 1 - profilometer, 2 – PC, 3 - lodgment, 4 - prototypes with a polyurethane coating, 5 – element of the steel pipe (new pipe), 6 - element of a steel pipe with a run-roughness (trumpet, the former in operation)
Source: own elaboration.

Measurements of the surface roughness of prototype tubes made according to the three coating forming on the inner length of 120 mm, a next bend in the samples 120 ° and three line samples on steel pipes. The total number of measurements at each measurement sample was equal to 27. The measured values were averaged. The arithmetic mean value is taken as the absolute surface roughness Δ.

Definition of roughness, coefficients hydraulic resistance and the losses of pressure

Adopted in hydraulics method of determining the roughness it takes into account that the natural (geometric $R_a = \Delta$) always heterogeneous - peaks and troughs have different shapes, sizes and location. Surface microrelief internal pipe wall depends on many factors including the material, method of manufacturing pipes and physicochemical properties of the fluid and lifetime. Since the natural roughness has multiple irregular shape (Figure 3a), set by any geometrically methods the averaged value of the height of hillocks, determining the effect of roughness on the pressure loss, it is impossible to. Therefore, the parameter of roughness is considered as a conditional value determined by a special scale of artificial homogeneous roughness (Figure 3b).

a) b)

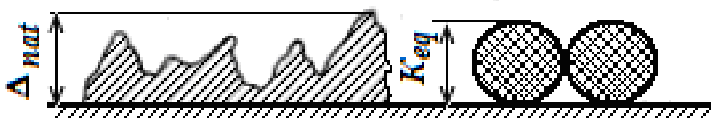


Figure 3. Natural (a) and equivalent roughness (b)

Such a scale is constructed with the help of calibrated grains of sand, glued to the smooth surface of the pipe. A set of such pipes with different grain diameters gives a number of values of relative roughness, in the function of which values are obtained (Nikuradse, 1933; Yagi et al., 1972) formula:

$$\lambda = \frac{1}{\left(2\lg\frac{\Delta}{D} + 1{,}14\right)^2} \tag{6}$$

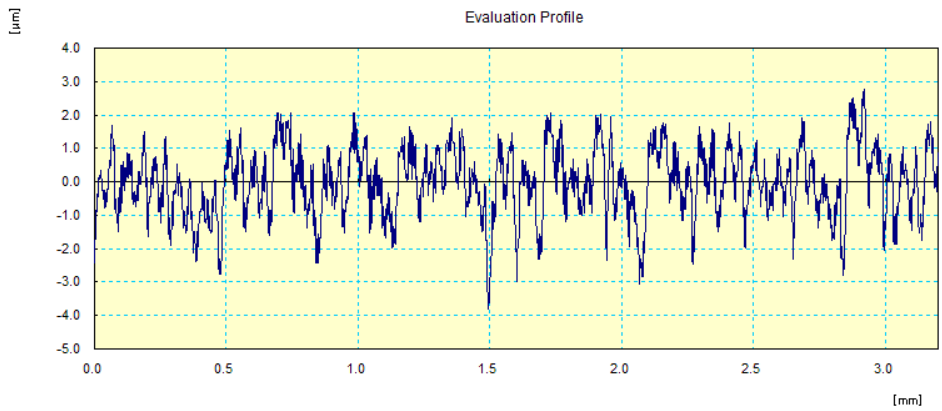
By means of such a scale, the absolute roughness is taken to be its equivalent value, that is, the size of the grains of artificial roughness sand, which in the quadratic region of friction with respect to the hydraulic resistance is equivalent to this inhomogeneous surface.

Research results

The results of each measurement to be displayed on the computer screen in the form of a spectrogram and characteristic table values. Example №1 display measurements shown in Figure 4. The average of the absolute roughness prototypes pipelines according spectrograms and tabulated values are given in Table 1. Similar measurements were performed for roughness elements wall steel pipe - new and used, see Table 2.

27- Jul -2016

CERTIFICATE OF INSPECTION



Work Name	Sample	Operator	Mitutoyo
Measuring Tool	SurfTest	Comment	Ver2.00

Standard	ISO 1997	N	4
Profile	R	Cut-Off	0.8mm
λs	2.5µm	Filter	GAUSS

Ra	0.799 µm	Rmr(c)2	2.609 %
Rq	1.007 µm	Rdc	0.581 µm
Rz	5.335 µm	Rt	6.557 µm
Rp	2.236 µm	Rz1max	5.868 µm
Rv	3.099 µm	Rk	2.536 µm
Rsk	-0.362	Rpk	0.771 µm
Rkµ	3.108	Rvk	1.249 µm
Rc	2.713 µm	Mr1	9.078 %
RSm	65.9 µm	Mr2	88.797 %
RDq	0.234	A1	3.50
Rmr	0.109 %	A2	7.00
Rmr(c)1	0.797 %		

Figure 4. Display roughness measurement results surface
Source: own elaboration.

To assess the nature and intensity changes with a polyurethane coating roughness prototypes pipes experiments on an operating time of roughness were performed on a laboratory hydraulic installation, Figure 5.

On linear part of the pipeline installed three prototypes of pipes with a polyurethane coating. In supply tank of installation capacity of 100 liters poured slurry tailings Kachkanarsky GOK with a weight solids content of 10%. The slurry was pumped through a pipeline with an internal diameter of 50 mm with using the centrifugal pump CP30/18. Pump flow was controlled by a frequency converter. Pump capacity is at maximum motor speed was 45 m^3/ h. From the pipeline slurry gets into the measuring tank, which is used to determine the flow rate, and then poured into the supply tank.

Figure 5. General view of the installation of the pipeline with experienced sample tubes coated with polyurethane inner surface
Source: own elaboration.

Table 1. Results of measurement of surface roughness prototypes tubes coated with polyurethane

The measuring point	hardness 83A			hardness 85A			hardness 90A		
	Line 1	Line 2	Line 3	Line 1	Line 2	Line 3	Line 1	Line 2	Line 3
	The measured values of roughness (Ra) , μm								
A	1.343	0.379	0.54	1.266	0.642	0.564	0.780	0.798	0.636
B	0.73	0.996	0.696	1.389	1.248	0.877	0.799	0.730	0.726
C	0.893	0.57	0.457	0.876	1.039	1.135	0.91	0.554	0.412
R_a	0.988	0.648	0.564	1.177	0.976	0.859	0.830	0.694	0.591
R_a = Δ	**0.734**			**1.004**			**0.705**		

Source: own elaboration.

From Hydrotransport practice it is known that the steady value of the surface roughness of steel pipe occurs approximately after one month of continuous operation of the pipeline, which corresponds to 720 hours. The average flow rate in the current pipeline (1000 mm) from the pumping station №1 of Kachkanarsky MCC (according to the company) is 4.8 m/s.

Table 2. Measured values of the inner surface of steel pipe roughness

The measuring point	New pipe			Pipe with run-roughness (used pipe)		
	Line 1	Line 2	Line 3	Line 1	Line 2	Line 3
	The measured values of roughness (Ra) , μm					
A	2.749	2.809	2.821	5.147	4.199	3.883
B	4.742	4.883	4.913	4.2	3.964	4.088
C	4.903	4.358	4.306	4.618	5.199	5.199
R_a	4.131	4.016	4.306	4.618	4.454	4.39
R_a= Δ	**4.053**			**4.499**		

Source: own elaboration.

From Hydrotransport practice it is known that the steady value of the surface roughness of steel pipe occurs approximately after one month of continuous operation of the pipeline, which corresponds to 720 hours. The average flow rate in the current pipeline (1000 mm) from the pumping station №1 of Kachkanarsky MCC (according to the company) is 4.8 m/s. These data were used to determine the total flow time of the slurry tailings through line pipes and prototypes until a steady operating time the inner surface roughness. Estimated time was 484 hours. To determine the nature and dynamics of the roughness of polyurethane coatings prototypes pipes total run time of the pump unit was divided into several time intervals: 4, 24, 24, 96, 96, 240 (hours). The pump was turned off, experienced pipe dismantled and measured the accumulated roughness of pipe samples after each time interval. The results of experiments on a pilot hydraulic stand are given in Table 3.

Table 3. Values accumulated roughness of experienced pipe samples

Sample pipe with a Shore hardness	The average surface roughness ($Ra \times 10^3$ $\mu м$) for the operating time, h						
	0	4	28	52	148	242	484
83A	0,734	0,815	0,908	0,876	0,764	0,95	0,828
85A	1,004	1,031	0,975	1,063	0,782	0,788	0,822
90A	0,705	0,783	0,872	0,962	0,983	0,854	0,935
The average value	**0,814**	**0,815**	**0,918**	**0,967**	**0,843**	**0,864**	**0,862**

Source: own elaboration.

It follows from the data that the roughness after 484 hours operating time for all samples experienced pipeline varies slightly. The roughness values are in the range from 0.814 to 0.862 μm. As a result of experimental data processing methods of mathematical statistics was obtained empirical formula for calculating the roughness, depending on the time of operation of the pipeline:

$$Ra = 0{,}814 + 9{,}92 \cdot 10^{-5} T_{op} \quad (7)$$

where:

Ra - the average roughness of the pipe wall, μm;

T_{op} - time of operation of the pipeline, h.

According to equation (4) can be predicted in time accumulated the roughness. For example, at time $T_{op} = 2000$ h (3 months) of continuous operation of hydrotransport system, the average roughness of the inner surface is equal to $Ra = 1{,}012$ μm; for $T_{op} = 4000$ h (5 months) $\rightarrow Ra = 1{,}211$ μm; $T_{op} = 8000$ h (approximately 1 year) $\rightarrow Ra = 1{,}608$ μm.

The results of studies (Dobromyslov, 2004) of the relationship between the coefficient of equivalent and natural roughness on 13 samples of low-pressure and high-pressure polyethylene pipes with diameters from 25 to 400 mm, as well as the results of studies carried out by G.A. Trukhin (two reinforced concrete collectors with diameters of 1.6 and 1.94 m) VNII VODGEO (eight water pipes from various materials with diameters from 0.7 to 1.2 m) made it possible to establish a mathematical dependence for determining this connection:

$$K_{eq} = 2 \cdot \Delta^{1{,}33} \quad (8)$$

where:

$\Delta = R_a$ - the natural roughness, μm.

Based on these assumptions, we calculate the value of the equivalent roughness coefficient by the formula (5), given by the operating time of the hydrotransport pipeline $T_{op} = 1000$ hours. We'll have:

$$K_{eq} = 2 \cdot \left(0{,}814 + 9{,}92 \cdot 10^{-5} \cdot 1000\right)^{1{,}33} = 1{,}772 \mu m \quad (9)$$

Thus, the expected value of the equivalent roughness for a pipeline with a polyurethane coating on the inner surface of the pipe with hardness in the range 83A-95A, after the operating $T_{op} = 1000$ hours, when pumping the slurry of the Kachkanarsky GOK processing tailings with a mass concentration of solid about 10%, is equal to $K_{eq} = 1{,}772$ μm.

We assume the obtained value of the equivalent roughness to calculate the coefficient of hydraulic resistance λ and the specific head loss I.

We determine the coefficient of equivalent roughness for a steel pipe that was in operation. In accordance with GOST 8.586 1-2005 (ISO 5167-2003), the equivalent roughness for steel pipelines is calculated by the formula:

$$K_{eq} = \pi R_a \tag{10}$$

For calculation K_{eq}, we use the value of the natural roughness of the hydrotransport pipeline element ($R_a = 4{,}49$ μm), Table 2.

$$K_{eq} = \pi \cdot 4{,}49 = 14{,}1 \ \mu\text{m} \tag{11}$$

Parameter t can be seen that the equivalent roughness values for a steel pipeline are significantly higher than the values for a coated pipeline (almost eight times). Accordingly, the coefficients of hydraulic resistance and the specific head loss will be significantly different. The coefficient of hydraulic resistance, which is a function of the relative roughness in the quadratic area of friction (resistance), for a pipe of 1000 mm with an inner polyurethane coating (λ_{coat}), according to Shifison's formula, will be equal to:

$$\lambda_{coat} = 0{,}11 \cdot \varepsilon^{0,25} = 0{,}11\left(\frac{K_{eq}}{D}\right)^{0.25} = 0{,}11 \cdot \left(\frac{1.772 \cdot 10^{-3}}{1000}\right)^{0.25} = 0{,}004 \tag{12}$$

The coefficient of hydraulic resistance for a steel spent pipeline (λ_{st}), will be equal to:

$$\lambda_{st} = 0{,}11\left(\frac{14{,}1 \cdot 10^{-3}}{1000}\right)^{0,25} = 0{,}007 \tag{13}$$

Specific head losses are calculated for the conditions of the Kachkanarsky GOK, taking into account the new values of the coefficients of hydraulic resistance λ_{coat} and λ_{st}. We will have for head losses in the pipeline lined with a layer of polyurethane with a hardness of Shore from 83A to 90A:

$$I = I_в + \Delta I_в = \lambda_{фут} \frac{v^2}{2gD} + k_\rho \delta \sqrt[4]{j} \cdot \sqrt[3]{c_{об}^2} \tag{14}$$

$$I = 0{,}004 \frac{4{,}8^2}{2 \cdot 9.81 \cdot 1{,}0} + 3.3 \cdot 0{,}056 \cdot \sqrt[4]{0{,}2} \cdot \sqrt[3]{0{,}04^2} = 0{,}0155 \tag{15}$$

In a steel pipeline, uncoated:

$$I = I_0 + \Delta I_0 = \lambda_{st} \frac{v^2}{2gD} + \Delta I_0 \tag{16}$$

$$I = 0{,}007 \frac{4{,}8^2}{2 \cdot 9.81 \cdot 1{,}0} + 3.3 \cdot 0{,}056 \cdot \sqrt[4]{0{,}2} \cdot \sqrt[3]{0{,}04^2} = 0{,}0232 \tag{17}$$

The results of calculations of the roughness coefficients, hydraulic resistances and specific head losses are given in Table 4.

Table 4. Calculated values of coefficients of roughness, hydraulic resistances and specific head losses (pipeline D=1000mm)

Pipeline	Parameters			
	Natural roughness (Δ), μm	**Equivalent roughness (K_{eq}), μm**	**Coefficient of hydraulic resistance (λ)**	**Specific head loss (I), m w.c./m**
Polyurethane coating	0,913	1,772	0,004	0,0155
Steel	4,49	14,1	0,007	0,0232

Source: own elaboration.

Conclusions

1. The established values of the surface roughness of polyurethane coatings, the values of the relative roughness coefficients and the calculated values of specific head losses confirm the efficiency of using pipelines with a polyurethane coating of the pipeline inner surface in hydrotransport system of tail pulp.
2. The hardness of the surface of polyurethane coatings in the Shore scale from 83A to 90A (experimental coatings) does not have a practical effect on the intensity of the change in the roughness of the coating surface.
3. Hydraulic resistance in pipeline during the transportation of tail pulp with a mass concentration of solid phase c_p= 10% is proportional to the ratio of equivalent roughness (K_{eq}) to the diameter of the pipeline by the formula $\lambda = 0{,}11\left(\frac{K_{eq}}{D}\right)^{0,25}$.
4. For the working diameter of the pipeline D= 1000 mm, when working in the zone of quadratic friction (developed turbulent flow regime of the slurry), the hydraulic resistance coefficient on average for 1000 hours of continuous operation will not exceed λ = 0.004.
5. The calculated values of the specific head losses in the pipeline with polyurethane coating for hydraulic transport of the slurry of the concentration tailings with a solid concentration of 10% is I_{coat}= 15.5 m w.c./km, which is almost 1.5 times less than in the uncoated steel pipeline (I = 23.2 m w.c./km).

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Paul SHCHERBAN
Immanuel Kant Baltic Federal University, Russian Federation
S. RAZUMOVICH
Kaliningrad State Technical University, Russian Federation
A. ELISEEV
Supervising Department Marketing Specialist for LLC "K-Potash Service"
e-mail: ursa-maior@yandex.ru

Sinking of vertical mine openings in unstable, water-bearing strata using mobile hydraulic complex

Abstract

The article reviews different aspects of vertical shafts construction and analyses peculiarities of blasting and mechanic type of shaft sinking. The study evaluates applicability of different approaches of shaft sinking especially in unstable and water-bearing layers. It shows features of shaft construction in terms of potassium-magnesium deposit Nivenskoe-1, located in the Kaliningrad region of the Russian Federation. The article also contains basic information about structure of tunneling complexes operating in such conditions. The main natural, technical and technological factors affecting the process of shaft sinking during excavation are considered. The overview presents an optimal approach to managing and reducing these risks (during mining operations).

JEL: L00, L11, L25

Key words: *Shaft sinking, mouth of the barrel, frozen rock drilling and blasting method, combine harvester, shaft floor*

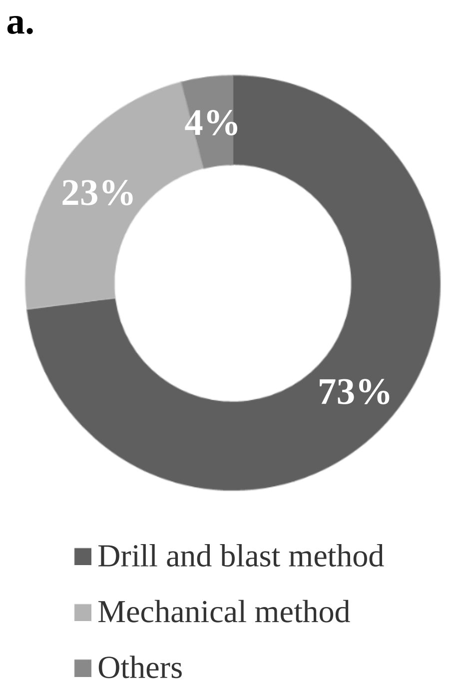
Introduction

A large deposit of potassium and magnesium salts is being currently carried out in the Kaliningrad region. The Nivenskoe-1 deposit is located in the southwest of the region and has significant reserves of salts that allow mining, processing and further development of the ore into different products (potassium sulfate, magnesium sulfate, bischofite, table salt) within the next 70 years. Development of Nivenskoye-1 potash-magnesium deposit assumes that the deposit will be opened with the use of vertical shafts. Such a way of mining is determined due to great depth of productive seams, presence of water-bearing layers, existence of surface facilities (railroad, inhabited settlements, ETL, water intake areas, etc.).

Mining of deposits covered by unstable water-bearing rocks

The project provides for construction of two mineshafts: a cage shaft and a service shaft. The service shaft serves for hoisting of personnel, equipment and materials together with conducting outflow air from the mine. The skip shaft serves for hoisting of potash-magnesium ore, emergency exit for personnel and fresh air intake to the mine.

Presence of water-bearing layers complicates opening of the mine and extracting of mineral resources. Moreover, prevention of water-conducting connections between water-bearing areas (incl. underground water-bearing systems) and mine openings is the crucial point of successful exploitation of the deposit. This provision is guaranteed by accordance between the shaft sinking method (a human-factor aspect) and geological/ hydrogeological characteristics of the deposit (area) (Shcherban & Nordin, 2016).



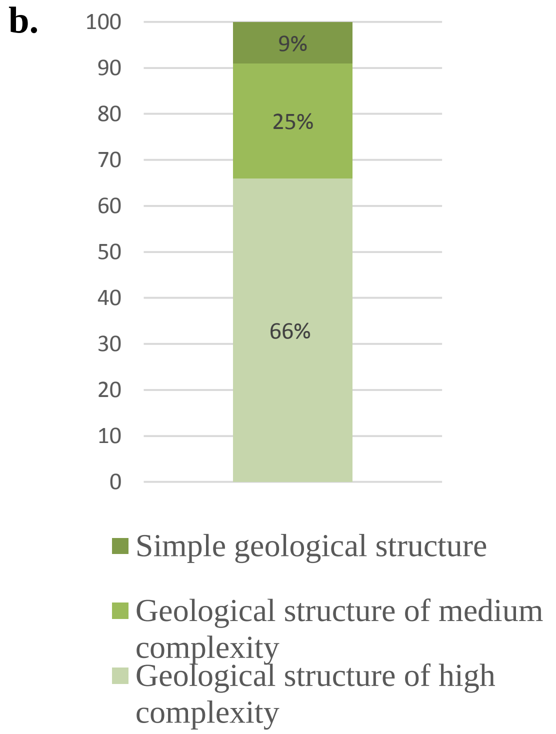


Figure 1. a - Ratio of vertical shaft sinking methods; b - Structure type of new mining deposits
Source: own work.

Particularity of shaft sinking in water-bearing strata containing several water-bearing layers is defined by rock-mechanical composition, presence of gravel-sand sediments, sandstones, their different mineralization grade. Sinking of vertical mine openings in the unstable strata is performed by using two basic methods, when the preliminary water sealing of the working area is made: tamponage and freezing of the rocks (Korchak, 2010). In case of Nivenskoye, which has large number of water-bearing layers (some of which are pressure horizons), the most efficient and safe method is freezing. The freezing technology is applied by drilling of wells along the contour of future vertical mine shaft, circulation of freezing fluid and further formation of the ice wall (Nordin & Shcherban, 2015).

Two basic methods of shaft sinking are: a drill and blast method and a mechanical method. As it is shown at the figure 1, the biggest part of the shafts is made in a drill and blast way.

Drill and blast include, in general, drilling of up to 4-meter-long blast-holes inside the face of the mine, installation of explosives, blasting, following ventilation, crushed material extraction, shaft walls shoring and, such wise, sequential repeat of the mentioned cycle until the projected depth is reached.

Mechanical method of shaft sinking uses a special sinking machine that is able to perform extraction of rocks with different strength by mechanical crushing followed by its hoisting to the surface and simultaneous shoring of the walls throughout the projected depth of the mine.

A comparative analysis of different shaft sinking methods in terms of the Nivenskoe-1 deposit

Choosing of the best suitable way of shaft sinking is based on several various indexes, such as rock-geological, hydrogeological, technical, technological and economical aspects, which are unique for each deposit under exploration.

Generally, if a drill and blast method is adopted, there is a risk of damage to the freezing columns, then the ice wall integrity is broken, and so is the water seal of the working area (Whyatt, 2008).

This is largely caused by embedded structure of soils, their non-uniformity, different water-bearing capacity and by differences in freezing temperature. In case of a gap in the ice wall (because of destruction of one or several freezing columns), a risk of water inflow and flooding of the mine shaft arises (Whyatt, 2008).

Concerning this, the optimal way that provides high sinking rate and best quality is the mechanical method.

Depth of the productive seam (mine level) at the Nivenskoye-1 potassium-magnesium salts deposit, determined as a result of geological exploration, is 1,100–1,150 m. This, in turn, stipulates temperature characteristics of the rocks at different depths. Recorded temperature values have significant influence on development of the rock-freezing technique (Millecento, 2010).

Figure 2. Location of potassium-magnesium salt deposit Nivenskoye-1 in Kaliningrad region

Source: own work.

At the same time, a freezing process is influenced by composition of the rocks, rheological and hydrogeological properties (intensity of water inflow, salinity, presence of clear direction of underground water flow) etc. Thereby, within the mining area of Nivenskoye-1 we can highlight areas with fresh, briny, salt water and brines (Millecento, 2010).

The hydrogeological cross-section considers three «floors», according to formation of ground waters and a way of water exchange: Meso-Cenozoic, Low-Upper Paleozoic and lower Paleozoic. The hydrogeological floors are separated by thick regional impermeable horizons.

A series of exploratory and hydrogeological investigations has helped to determine thickness of each water-bearing layer, its lithological composition, types of headers, conditions of feeding, correlation with other water-bearing layers and surface waters, levels of ground waters and other parameters, essential for calculation of possible water inflows into mine openings and engineering of dewatering and drainage measures (Millecento, 2010).

It is necessary to admit that the top of the productive seam is formed by Trias clays with up to 300 m thickness, which is a regional impermeable horizon. This layer appears to be waterproof and protect the salt layers from water inflows.

During sinking of the cage and skip shafts most issues can arise, when going through Jurassic and Trias aquifer systems, which have relatively high filtration rates and high pressure that exceeds similar criteria on the surface (Brovka & Romanenko, 2009).

Described hydrogeological characteristics of the deposit combined with rheological and temperature parameters constitute a significant difficulty of freezing of the shaft sinking area. According to this, there are additional regulations for the ice wall, and so for the complete freezing circuit with related equipment. Application of a similar freezing complex in described conditions has been simulated during several investigations.

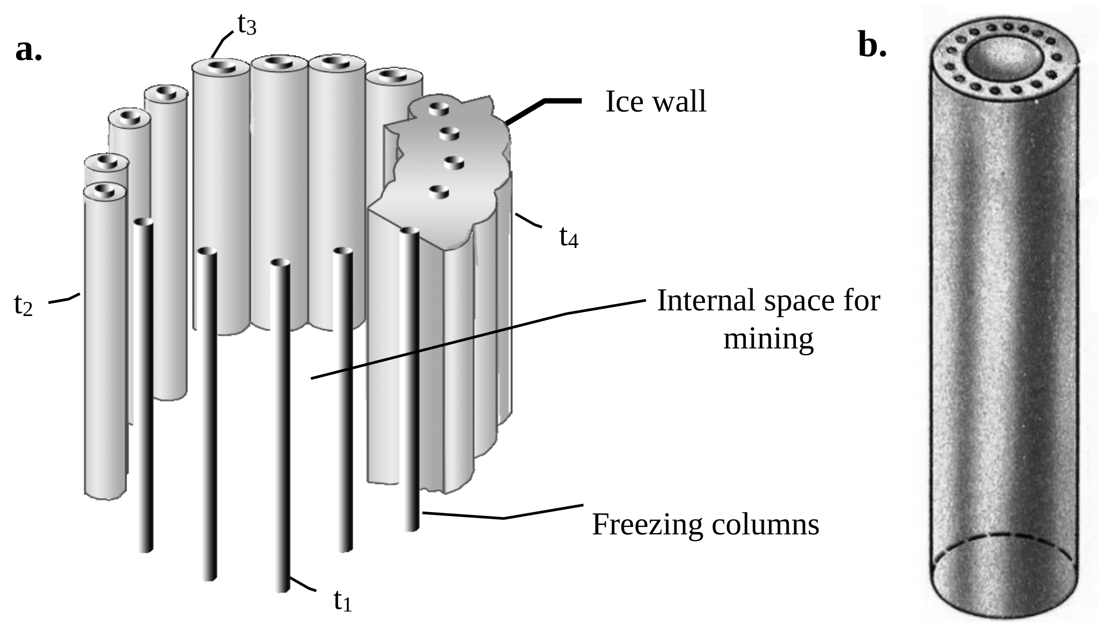


Figure 3. Creation of ice wall for further shaft sinking

Scheme of ice wall spreading b. Final shape of frozen shaft space

t_1 – Injection of liquor and start of freezing; t_2, t_3 – Freezing period and spreading of ice sphere; t_4 – Completed ice wall

Source: own work.

Application of the ice wall for shaft sinking, its possibility and reasonability was proved during these tests. In addition, the method requires a full scope of measures to protect and guarantee the ice wall integrity. Freezing includes the following:

drilling of the wells; freezing of columns and saline net installation; ice wall creation. Application of the drill and blast method poses a risk of deformation and destruction of freezing columns. Moreover, appearance of cracks and bursts in the ice wall becomes more likely (Brovka & Romanenko, 2009). This is mostly explained by a bedded structure of the rocks, their inhomogeneity, different rates of water saturation and difference in freezing temperatures. In case of appearance, such a crack in the ice wall or such destruction of one or more freezing columns entails a risk of water inflow into the shaft and its flooding.

The mechanical method includes fewer market regulations, due to the fact that the shaft sinking complex is initially engineered for such conditions of operation.

The process of shaft sinking and complete construction of the shafts takes place not only under geological and hydrogeological conditions, but also under the influence of a lining technology. The mechanical method allows controlling deformation of the shaft walls and performing construction of lining in points without deformation. This improves lining quality and lifetime (Zubov & Smychnik, 2013).

Considering the abovementioned, the Management has decided to draw up, manufacture and use the hydraulic-mechanical complex for shaft sinking at the Nivenskoye-1 potash-magnesium deposit, which allows performance of the whole scope of work, along with sinking. Initial rock convergence (deformation before temporary lining is installed) occurs during the operations within the wall face (Zubov & Smychnik, 2013).

Features of hydro-mechanized complex application during mining in severe natural conditions

The use of mechanical complex helps to solve this problem through installation of a flexible cover as a temporary lining in points of max. convergence. Design of the complex provides a possibility of defining the convergence directly during shaft sinking with high accuracy (±1 mm). Presence of such an option makes it possible to check current geological conditions and react to their variation accordingly. In case of extreme deformations, it is possible to increase the shaft diameter (for providing the projected dimensions of the lining and increasing its carrying capacity through thickening) (Brandy & Brown, 1985).

The complex allows installation of the temporary concrete lining 10-12 meters from the wall face, in zones with residual convergence, less intensive than the initial one. Taking into account the possibility of measuring deformation of the rock walls (initial convergence rate), it is possible to calculate the residual convergence and time needed for strengthening the lining, which allows installation of temporary lining with optimal parameters for further qualitative installation of the permanent lining in order to maintain long-lasting work of the mine (Patent No. 2600807 C1).

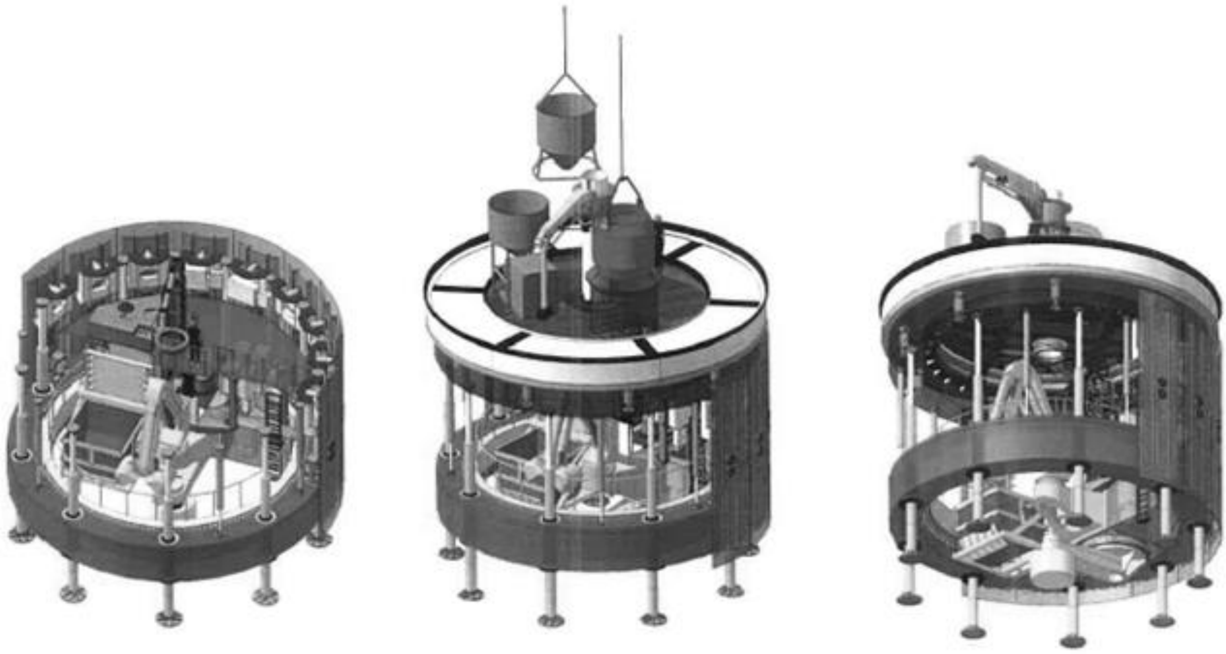


Figure 4. Mobile hydraulic complex SPKV -7,0

A hydraulic complex includes a number of sinking platforms of different functions and mechanic destruction unit. This part is used for crushing rock, its further loading and hoisting to the surface; the platforms serve for placing the equipment and mechanisms. A lower part of the sinking platform has a hold-down cover essential for safe work in the face. Three-sectioned extension-type falsework for erection of advance lining during sinking operations is placed further on. The necessity of a three-sectioned falsework results from a continuous process of concrete lining construction and simultaneous need for concrete strength development to the required hardness.

The use of the complex provides simultaneous performance of:

- ore breaking;
- ore bunker loading;
- ore winding;
- shoring of the shaft walls with extension-type fenders (for operational safety and support of the walls);
- advance support construction directly in the mine face, if required;

- the complex guarantees personnel safety and high speed of sinking operations (up to 90 meters per month);
- remote control of the complex;
- the complex doesn't need extra winches for relocation;
- the complex ensures an integral system of technological process management with contemporary control after support quality and rock pressure;
- verticality is controlled by the complex;
- changeable cutting parts of the complex allow sinking through rocks with different strength;
- the complex allows advance drilling in order to control the condition of underlying frozen seams;
- the complex provides support setting for the face of the shaft;
- the complex involves minimum of personnel (2-4 persons);
- there is a possibility of using a polymer cover, preventing the air from contact with frozen rocks;
- comparing with the drill and blast method, the complex allows saving up to 25% of concrete due to more qualitative treatment of shaft walls.

Engineering of the shaft sinking complex includes a developed system of bucket hoisting management. The project also includes a cyclogram of a sinking process, during which the following is calculated: speed and time needed for ore breaking, bunker loading, bucket loading, winding of ore inside the bucket, ore hoisting, concrete conveying to the place of advance lining installation, conveying of concrete to the areas behind the shaft support. Critical point in the calculated cyclogram is the ore hoisting procedure (Patent No. 2600807 C1).

For permanent lining installation, a special platform is provided for. This platform allows erection of tubing and stand-alone concrete lining with simultaneous operations of sealing. In severe conditions, lining can be installed right inside the shaft.

During mechanical sinking operations, the uncovered area is protected by a hydraulic shield which serves as a temporary support and provides operational safety for the personnel. The complex itself has three-staged falsework that supports the possibility to erect the advance lining during sinking operations. Moreover, a special tool ensures loading of the bunker with the ore, and the bunker is calculated in such a manner that during ore crushing and bunkering, the ore is simultaneously hoisted to the surface with buckets. After the bucket has arrived at the mine face, the ore is rehandled from the bunker.

During a sinking period, the complex is in constant operation. The use of the three-staged falsework, irrespective of the sinking speed, allows providing necessary hardness of concrete and safe operations (Patent No. 2600807 C1).

The complex can move itself with the help of jacks, without winches from the surface. Along with that, for estimation of mine face behaviour in relation to its freezing, a special hanging tool for advance drilling is installed. Removable drilling and fixing tools are also installed. They are also capable of mine face lining, drilling of spurs for certain operations concerning fixation. When the complex operates in rocks with higher strength, the cutting tool is replaced. The complex also includes a hydraulic hammer, which crushes occurring float stones and maintains sinking operations. The complex is also equipped with a special device for concreting, which might be necessary for maintaining the shaft walls in the mine.

The main advantage of mechanical sinking is alignment of ore crushing process, shaft walls lining and rock hoisting plus no significant stops and pauses during operation (except for those made for technological reasons). The technology of mechanical sinking allows hiring fewer members of personnel than in case of the drill and blast method, and it reduces the risk of an emergency and injuries, providing high sinking rates (Kicki et al., 2015).

Speaking about ecological comparison between drill and blast and mechanical extraction, one should point out that d&b requires additional measures against dusting and noise pollution and another approval from the regulatory authorities.

Conclusions

Development of mineral deposits, especially those with significant number of overlying aquifers, imposes additional security requirements on mining technologies.

The results of scientific research, a comparative analysis of various methods of shaft sinking, design and construction approaches presented in the article show that in case of shaft sinking operations in salt deposits, the use of tunneling complexes is better and safer. Taking into account negative experience gained in the Bereznyaki, Kalush, Garlyk, Gremyachinsk deposits and other old salt producing regions, development of new salt deposits in the world should be carried out using the most advanced engineering solutions and technologies. Integral elements ensuring safety of mining operations are mechanical shaft sinking, selective excavation of ores, backfilling of by-products, maintenance of waterproof layers integrity, control after mining system in common and rock pressure control in particular. In this list, the mechanical sinking of vertical shafts takes one of the leading places, since it is the point from which construction of shafts and development of deposit begins.

It is necessary to emphasize that in terms of proximity of recreational zones, national parks and large urban agglomerations, mining should be carried out in compliance with increased security requirements. Recent experience from construction of new mining enterprises, especially in America and Europe, shows that the use of shaft sinking complexes is one of key points in providing technical and environmental safety in mining industry.

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Pavel SHISHKIN, Inna TRUFANOVA

Saint-Petersburg Mining University, Russian Federation

e-mail: trinna@spmi.ru

The efficiency increase of hydro mechanized mining

Abstract

Many land deposits are beginning to tail off, the rapid growth of the world's population, with the demand for the manufacture of means of production and consumer goods, makes it necessary to seek new sources of mineral raw materials. Therefore, the extraction of minerals in the shelf zones appears inevitable and economically profitable in the foreseeable future. Increase the efficiency of the hydro mechanized mining method is possible due to the maximum densification and desludging of the slurry in the near-bottom zone, which allows reducing the energy and material consumption of hydrotransport of minerals. To achieve this goal, it is proposed to use a perforated section adjacent to the power unit, with a transverse cross section that reduces in its length in the direction of flow, in the pressure pulp pipeline system. The purpose of this article is to determine parameters of the perforated branch through the development of a mathematical model of a desludging unit of slurry, which allows increasing efficiency of hydro mechanized mining. The study uses complex research method, including theoretical and experimental parts and approved methods of hydrotransport. The application of the developed perforated branch of a pipe can be implemented, for example, in the underwater mining development of iron-manganese nodules in the shelf zone of the Barents Sea.

JEL: O13, O31, O33

Keywords: *hydrotransport, underwater mining, slurry, perforated branch*

Introduction

In a number of cases underwater mineral deposits development by the hydro mechanized method of nodule mining can be much more effective than mining using mechanical capture means, since it is more productive and allows for more complete processing of the underwater deposit. (Serpukhov, 1978).

However, significant disadvantages of this method are high energy consumption due to the considerable dilution of slurrybecause of an unavoidable suction of water into the receiving device of the power unit; significant cumbersomeness and metal consumption of the pipeline system with a large diameter of the flexible slurry pipeline (Smoldyrev, 1980); complex and costly pipeline management system (Tapsiev, 2009); the need to return to the bottom a large amount of liquefied sludge obtained as a result of primary nodules enrichment and dehydration through a special pipeline on the base vessel board (Parent, 2013).

Literature studies

In connection with this, problems arise in controlling the parameters of the slurry generated in the zone of nodule capture by the bottom unit (Fig. 1).

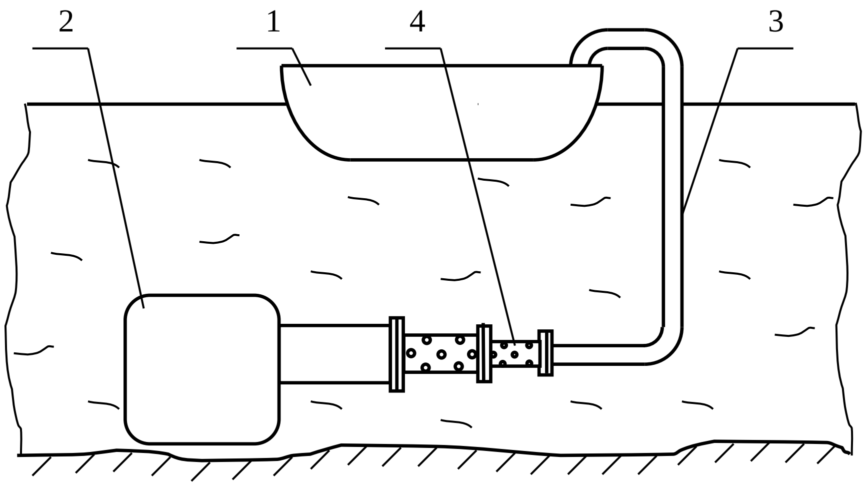

Figure 1. The device for the extraction of nodules from the seabed: 1 – base vessel, 2 – power unit, 3 – the main part of a pipeline, 4 – device for the slurry desludging and desliming
Source: Tarasov, 2003.

The solution of these problems (Blyuss, 2009) will significantly improve the technical and economic parameters of the hydro mechanized method of nodules mining due to the maximum possible slurry desludging and desliming (Vaezi, 2014) directly in the bottom zone, and also to optimize these parameters depending on mining conditions and nodules processing technology (Rao, 2016)on the base vessel. Therefore, the method of hydro mechanized mining may prove to be quite competitive to an alternative method based on mechanical capture of nodules from the bottom zone of their occurrence(Albion, 2009).

To do this, the part of the pressure pipeline adjacent to the power unit is proposed to be perforated with a gradual reduction in the diameter of the pipeline along the length of this section. In connection with the complexity of manufacturing a conical pipe of sufficient length, it is proposed to use a branch pipe, the diameter of which decreases away from the mining unit stepwise (Fig. 2).

The densification unit is a device which task (Fig. 2) is to ensure simultaneous dehydration and desliming of the slurry directly in the near-bottom zone at a given volume concentration.The diameter D of the perforated section of the slurry pipeline decreases away from the production unit stepwise (Fig. 2a), taking the values of D_1, D_2, D_3, etc.

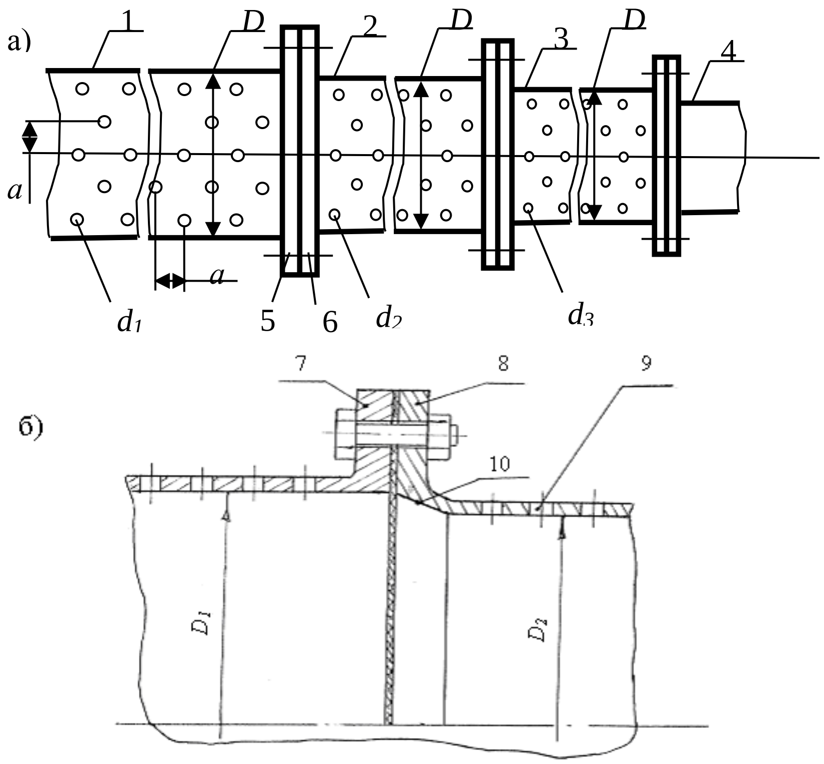

Figure 2. The device for the slurry densification and desludging.
Source: Tarasov, 2004.

The minimum diameter of the last section, for example D_3, and the total length of all sections determine the degree of densification and desludging of the slurry coming from the mining unit. The sections of the branch pipe 1, 2, 3 (etc.) of different diameters are connected together by flanges 7 and 8 (Fig. 2b). And the flange 8 of each area of smaller diameter is made on the inner perimeter with a conical bevel 10 in the direction of a smaller diameter.

All areas of the branch pipe 1, 2, 3, etc. are perforated with holes 9. In this case, the dimensions of the holes on the surface of the branch pipe can be taken to be the same or different (d_1, d_2, d_3, etc.) for sections of different diameters with a gradual decrease in the size of the holes 9 when changing over to a branch pipe of a smaller diameter. The maximum size of the holes should not exceed the minimum particle size of the conditioned fraction of mined nodules.

Depending on the value of the ratio of the maximum and minimum diameters of the branch pipe (D_1/D_2) and the total length of the sections, virtually any given concentration of slurry is provided in the main portion of the pressure slurry pipeline, and excess water and slurry remain in the bottom zone.

When dredging pump of a power plant is operating, the slurry, which is largely watered and contaminated with clayey and muddy bottom sediments, comes to the perforated section of the slurry pipeline under pressure slightly higher than the pressure necessary to transport the slurry to the base vessel. When the slurry is moving through the perforated part of a pipeline, excess water along with the mud component and small off grade fractions are removed through the holes in this section of the slurry pipeline due to overflow pressure. Slurry with a specified (optimal) volume concentration of the solid component is transported (Gillies, 2000) along the main section of the slurry pipeline of smaller diameter compared to the initial diameter. At the same time, the slurry is significantly enriched by separating the bulk of the sludge and off grade fractions from it, which simplifies and reduces the cost of the further slurry processing on the base ship and improves the ecological situation in the nodule mining area (Sanders, 2016).

Methodology

Underwater mining plants can be profitable through the use of high-performance hydraulic (Hanus, 2014; Kempinski, 2014) and hydromechanical development methods. The creation of fundamentally new technical means will significantly increase the efficiency of mining on the shelf. In connection with this, the current task is to improve the technical and economic parameters of the hydro mechanized mining method due to the maximum condensation and desludging of the slurry directly in the near-bottom zone. To solve the problems, a complex research method was used, including the theoretical and experimental parts with the construction of physical and mathematical models of the densification and desludging unit of slurry and approved methods of the theory of hydrotransport.

The main parameters of the device made in the form of a perforated section of a slurry pipeline of variable diameter for the slurry densification and desludging are determined in the following order.

1. The mass productivity M_s(t/h) is set by the nodule.
2. The volumetric productivity (m³/h) for nodules is calculated.

$$Q_S = \frac{M_S}{\rho_S}, \tag{1}$$

where:

ρ_s– density of nodules, kg/m³.

3. The volume concentration (S) of the slurry is determined in the main section of the slurry line, along which the calculated density of the slurry is determined (kg/m³).

$$\rho = (\rho_S - \rho_0)S + \rho_0, \tag{2}$$

where:

ρ_0 – density of working fluid (water), kg/m³.

4. The water flow rate (m³/h) in the main section of the slurry pipeline is determined.

$$Q_0 = Q_S \frac{\rho_S - \rho}{\rho - \rho_0} \tag{3}$$

5. The total flow rate of the slurry (m³/h) in the main section of the slurry pipeline is determined.

$$Q_2 = Q_S + Q_0 = Q_S \frac{1}{S} \tag{4}$$

6. Based on empirical (industrial) or experimental data obtained in laboratory studies, the values of the volumetric concentration ($S_0^{/}$) captured by a ground pump from an underwater face are taken.
7. The estimated pumping capacity (Q_1, m³/h) (flow rate) of the slurry, captured by the dredging pump, is determined.

$$Q_1^{/} = Q_S(1 + \frac{1 - S_0^{/}}{S_0^{/}}) = Q_S \frac{1}{S_0^{/}} \tag{5}$$

8. According to the calculated Q_1, the type and model of the dredging pump is selected in compliance with the specific conditions for the nodules extraction (sea depth, required head). In accordance with the performance of the selected dredging pump, its pumping capacity Q_1 and volume concentration S_0 is specified.
9. The initial D_1 and the final D_2 diameters (m) of the slurry line perforated section are determined as a function of the calculated velocity v (m/s) of the slurry motion (according to the usual method) and the ratio of slurry flow

rates at the beginning (V_1) and end (V_2) of the perforated section of the slurry pipeline under the assumption that the speed of the slurry is constant along the length of the slurry line.

$$D_1 = 2\sqrt{\frac{Q_1}{\pi V}}\ ; \quad D_2^{/} = 2\sqrt{\frac{Q_2}{\pi V}} = D_1\sqrt{\frac{Q_2}{Q_1}} = D_1\sqrt{\xi}\ , \tag{6}$$

where:

ξ – slurry density index, $\xi = \frac{Q_2}{Q_1}$.

10. The velocity (m/s) of the slurry through the pipeline can be determined from the following relationships:

$$V \geq (1{,}1 \div 1{,}2)V_{кр}; V \geq (2 \div 4)V_{Г}, \tag{7}$$

where:

$V_{кр}, V_{Г}$ – critical speed and hydraulic size, respectively.

Herewith:

$$V_{кр} = K_{П}\sqrt{вgD_2 fS}; \qquad V_{Г} = \sqrt{\frac{\pi}{6} вgd_{ср}\frac{1}{\psi}} \tag{8}$$

where:

$в$ – relative density of the slurry particles;

D_2 – the diameter of the pipeline, m;

f –generalized coefficient of particles friction on the pipeline walls;

$K_{п}$ – coefficient that takes into account the degree of the slurry mixing;

g –acceleration of gravity, m/s^2;

$d_{ср}$ – weighted average particle size, m; ψ – coefficient of resistance of particles to the flow by a stream of water, depending on the shape of the particles.

Values of the specified parameters:

$$K_{П} = 8{,}5 \div 9{,}5; \ \ f = 0{,}1 \div 0{,}75; \ \ \psi = 0{,}2 \div 1; \ \ в = \frac{\rho_S}{\rho_0} - 1; \ \ d_{ср} = \frac{1}{100}\sum(d_i\beta_i),$$

where d_i – the average particle size of a narrow class within the given granulometric composition of the slurry, m; β_i – the content of this class in the total mass (M_s) of solid, %.

The minimum diameter (D_2) of the slurry line is checked for the maximum size d_{max} of the nodules.

$$D_2^{//} \geq 3d_{\max} \tag{9}$$

11. The maximum of the two values obtained $D_2^{/}$ and $D_2^{//}$ is chosen, it should correspond to the standard diameter of pipes produced by enterprises.

12. The flow of water with sludge discharged on the perforated section of the slurry pipeline is determined: $Q = Q_1 - Q_2$.
13. On the basis of the grain-size composition of mined nodules, the minimum (commercial) fineness (d_{min}, m) of nodules is selected, according to which the slurry distribution should occur in the near-bottom zone.
14. The diameter (d, m) of the holes in the perforated section of the slurry pipeline and their spacing (a, m) in the axial direction and along the perimeter of the slurry pipeline are assigned.
15. The velocity of water flow (C, m/s) with slime particles (with particles less than d) through the holes in the perforated part of the slurry pipeline is determined.

$$C = \mu\sqrt{2gH_H}\,, \tag{10}$$

where:

H_H – pump head, m;

$\mu = \varphi\varepsilon$ – coefficient of slurry flow;

$\varepsilon = (d_c/d_o)^2$ – coefficient of jet compression;

d_c, d_o – the diameters of the jet and the hole;

$\varphi = 1/\sqrt{\alpha + \varsigma}$ – jet velocity coefficient; α – Coriolis coefficient; ς – coefficient of the hole resistance.

16. The length (l, m) of the perforated section of the slurry pipeline is determined by the following considerations.

Total square area (m²) of holes along the perimeter of the perforated section of the slurry pipeline at its removal x (m) from the head section (see Fig. 2):

$$F(x) = \frac{\pi d^2}{4} \cdot \frac{\pi D}{a} = \frac{\pi^2 d^2}{4a}\left[D_2 + \frac{D_1 - D_2}{l}(l - x)\right], \tag{11}$$

where:

D is the diameter (internal) of the perforated section of the slurry pipeline at a distance x from the head section, m.

If the number of rows of holes along the length of the perforated section $m = l / a$, then according to the formula (11) the total area of the holes at the elementary length dx of the perforated section of the slurry pipeline:

$$dF(x) = \frac{mF(x)}{l}dx = \frac{\pi^2 d^2}{4a^2}\left[D_2 + \frac{D_1 - D_2}{l}(l - x)\right] \tag{12}$$

Taking into account the foregoing, the flow of water with slurries (m³/s), which is discharged on the perforated section of the pulp pipeline, is found by integrating the equation (12) over the entire length of the density module:

$$Q = C\frac{\pi^2 d^2}{4a^2}\int_0^l \left[D_2 + \frac{D_1 - D_2}{l}(l-x) \right] dx = C\frac{\pi^2 d^2}{8a^2}(D_1 + D_2)l \tag{13}$$

The length of the perforated section of the slurry pipeline (m) can be expressed from the previous equation:

$$l = \frac{8Q_S(S-S_0)k^2}{\pi^2 SS_0(D_1+D_2)C}, \tag{14}$$

where:

$k = a / d$.

Research results

It is obvious that the change in the parameters of the slurry has a strong effect on the loading of the nodules hydrotransport system. A wide range of values of the average intensity of water-sludge separation at given values is explained by the fact that it is possible to thicken the slurry in the bottom zone to any concentration.

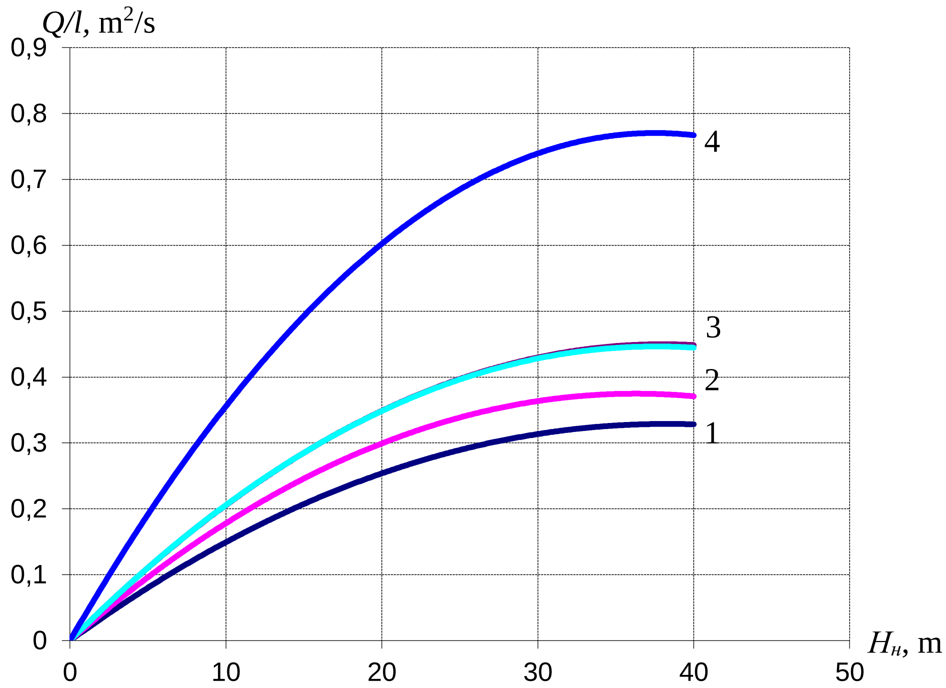

Figure 3. Dependence of average intensity of water-slime separation from the head created by the pump with Q: 1 – 240 m3/h; 2 – 444 m3/h; 3 – 792 m3/h; 4 – 1400 m3/h.

Source: own elaboration

The given graphs (Figs. 3-6) illustrate various functional dependences of the device parameters that allow evaluating and selecting the most appropriate technical solutions for the given conditions.

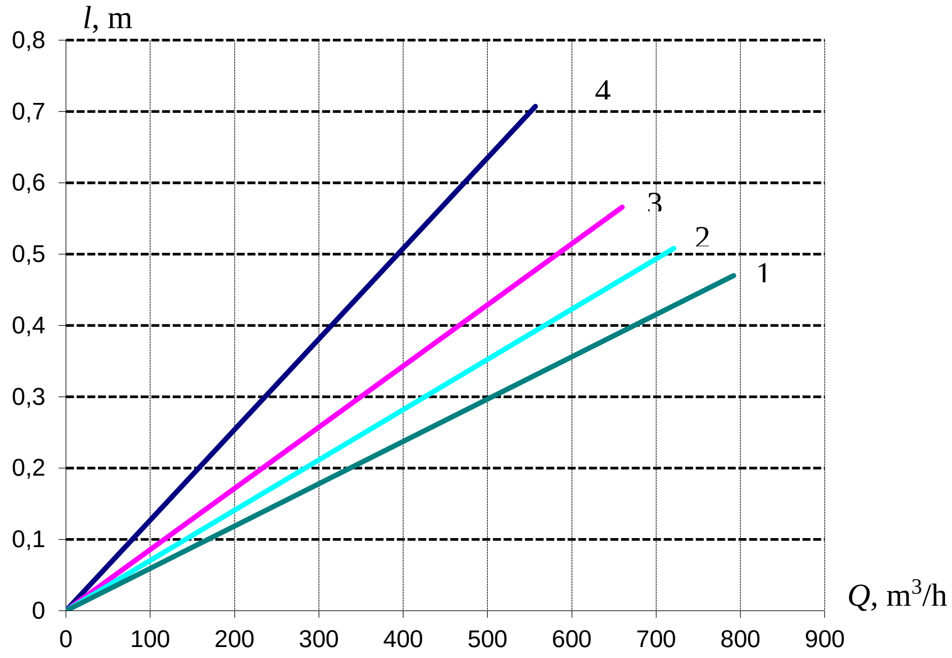

Figure 4. Dependence of the length of the perforated section of the slurry pipeline on the amount of water and sludge discharged in the bottom zone, with a/d = 3 and different pump heads: 1 – 40 m; 2 – 30 m; 3 – 20 m; 4 – 10 m

Source: own elaboration

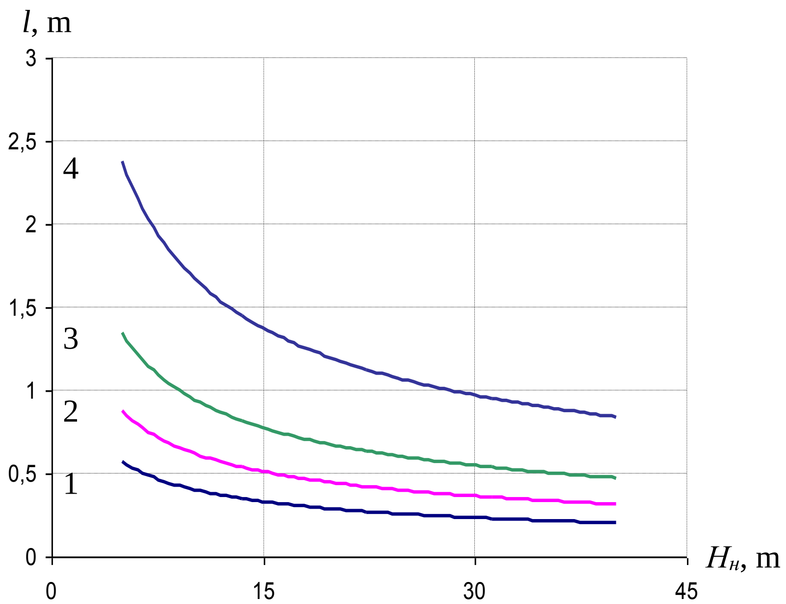

Figure 5. Dependence of the length of the perforated section on the head created by the pump at Q: 1 – 240 m³/h; 2 – 444 m³/h; 3 – 792 m³/h;

4 – 2700 m³/h

Source: own elaboration

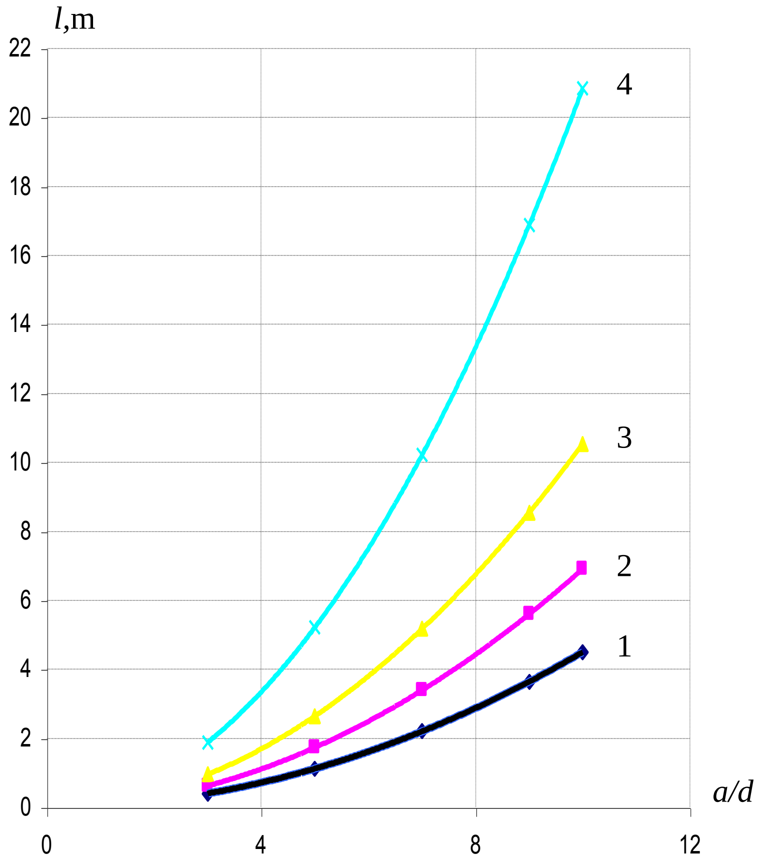

Figure 6. Dependence of the length of the perforated section of the slurry pipeline on the ratio *k=a/d* at constant head H_H = 10 m and different values of Q : 1 – 240 m³/h; 2 – 444 m³/h;3 – 792 m³/h; 4 – 2700 m³/h

Source: own elaboration

Conclusions

Analysis of functional relationships between the parameters of the device and the results of the performed calculations make it possible to draw the following conclusions:

1. The volume of excess water and sludges removed from the slurry with a uniform distribution of holes on the conic surface of the perforated section of the slurry line is directly proportional to the square root of the head (Fig. 3).
2. The length of the perforated section of the slurry pipeline at a predetermined value of the pressure head is directly proportional to the volume of excess water and sludges removed from the slurry (Fig. 4).
3. The required length of the slurry pipeline perforated section at a given value of the water-sludge separation with an increase in the pressure head of the dredging pump decreases sharply along the curve inversed saturation curve (Fig. 5).

4. The required length of the perforated section of the slurry pipeline with the given values of water-sludge separation and the dredging pump head gradually rises with the increase of ratio of the holes spacing and their diameter on the conical surface (Fig. 6).
5. The use of a device for concentration and desludging the slurry directly in the near-bottom zone while maintaining the same mass productivity with nodules makes it possible to ensure:

- a twofold decrease in the volume of the pumped slurry;
- a 30% decrease in the metal consumption of the pressure slurry pipeline main part;
- reduction of 40-50% of the sludge content of the slurry delivered on board of the base vessel.

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SUMMARY

Mining enterprises belong to traditional sectors, and in some world regions they are considered to be in the decline stage. Due to a strong decarbonization trends and promoting renewable energy sources in the European Union, coal mining is considered an uncompetitive industry that should be shut down. The above-mentioned circumstances result in limited attention paid to coal mining enterprises in management and production engineering literature. Meanwhile, mining industry – as a still operating sector that guarantees energy security in Poland – requires a professional approach, expertise and the exchange of experiences.

The papers included in this publication and the research results presented show that traditional industries can also be a source of managerial and technical creativity and innovativeness to be utilized. The mining production processes can be improved to obtain higher efficiency, market attractiveness and labor productivity. This industry can successfully recognize and counteract environmental and social risks related to its operation. Therefore, it can regularly implement sustainable development approach to mining production.

Here I would like to thank all authors and participants of the MEET 2017 conference for submitting papers and taking part in discussion on the challenges coal mining industry in Poland and worldwide is currently facing.

Izabela Jonek-Kowalska

The editor of this publication including the Scientific and Organizational Committee would like to cordially thank the co-organizers of the 3rd International Scientific Conference MEET 2017 from the Saint-Petersburg Mining University (Russian Federation), invited guests, reviewers and all those who were willing to devote their time and support this project.