

Creation of a competitive production on the basis of electrothermal and plasma technologies of combined coal and carbonate mineral raw materials processing with obtaining fuel and non-fuel products

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Abstract. Physicotechnical and organizational-technological models of technologies and technical means were developed, an integrated feasibility study of the organization of production of competitive products was performed, and the main technical and economic parameters of the newly created production were calculated for obtaining fuel and non-fuel products. When implementing the organizational and technological model of innovative production at the first stage, the following combined directions for processing mineral raw materials and new products are planned: 1) processing of carbonic acid mineral raw materials: calcium carbide, carbon dioxide (in gaseous, liquid or solid state); 2) acetylene, plant growth regulators (REGROST), plant protection products (TAKAR). Fuel products in the second stage: 1) synthetic ethyl alcohol (ethanol), antifreeze, ethylene glycol, dichloroethane, synthetic drying oils, acetone, etc.; 2) Carbamide (urea), ammonia, nitrogen in gaseous and liquid state, methanol, gasoline, etc. The previously developed economic-mathematical model (EMM) of production organization has a high degree of universality. It is advisable to implement the EMM differentially for alternative options at coal-mining, energy, gas producing and fuel-energy enterprises.

1. Introduction

In the Strategy for the Development of Fuel and Energy Resources in the Far Eastern Economic Region until 2020” the following tasks were set: “... to explore ways of overcoming the crisis situation by developing Far Eastern oil and gas fields on the basis of progressive methods of extraction and chemical processing of primary raw materials, and also by introduction of a policy of economy...”.

In this connection, it was necessary: 1) to develop a physico-technical and economic-technological model of technologies and technical means for deep chemical stage-by-stage processing of carbon-carbonate mineral raw materials; 2) to apply electrothermal and to develop plasma ecologically safe resource and energy saving technologies for processing carbonate and coal mineral raw materials using several modules (subsystems) to produce competitive fuel and non-fuel products [1, 7-9].

The developed and patented technologies provide for a complex waste-free processing of carbon-carbonate mineral raw material using several modules that at the first stage ensure the production of calcium carbide, calcium oxide, carbon dioxide, at the second stage – processing products of calcium carbide: synthetic and gaseous liquid fuel and non-fuel products.

In the new production complex for the production of calcium carbide (CaC_2), preliminary calcination of limestone (CaCO_3) is carried out to obtain calcium oxide (CaO) and carbon dioxide (CO_2); batch from calcium oxide (CaO) and coal (C) are used to produce calcium carbide (CaC_2).

Carbon dioxide (CO_2) formed during calcination of limestone is captured and carbon dioxide (H_2SO_3) is produced from it by means of equipment for trapping off-gases (figure 1).



During the production of acetylene hydrated lime – $\text{Ca}(\text{OH})_2$ is formed from calcium carbide, which is used in construction industry, in agriculture for the production of superphosphate – $\text{Ca}(\text{H}_2\text{PO}_4)_2$, in the water purification systems, etc.

Synthesis of (carbamide) urea – $\text{CO}(\text{NH}_2)_2$ is possible with the participation of carbon dioxide (CO_2) by addition of ammonia (NH_3) or carbamide can also be produced from calcium carbide using nitrogen (N_2). In this case, to obtain nitrogen (N_2) the separation of the air mixture is used – the rectification of the liquid air or by the oxidation of ammonia: $4\text{NH}_3 + 3\text{O}_2 = 2\text{N}_2 + 6\text{H}_2\text{O}$.

Carbamide (urea) is used to increase the efficiency of plant growth regulators (REGROST).

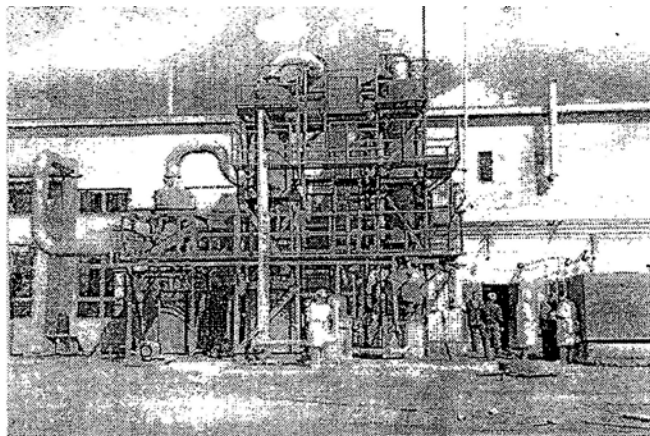


Figure 1. Installation for the capture of gases and the production of carbon dioxide (“dry ice”).

In Primorsky Territory the demand for calcium carbide is about 1000-1500 tonnes/year, carbon dioxide: 2000-2500 and more tonnes per year. At present, these products are imported from Eastern Siberia and partly from China, Temir-Tau (Kazakhstan).

The investment attractiveness of this project is very high, since its implementation allows local, abundant, inexpensive sources of raw materials to be used and valuable products to be produced on its basis with high added value and with sufficiently high demand stability for different sectors of the economy and a wide range of applications, which provides increased economic stability of

the enterprise during changes in market conditions and its different segments.

The main profit comes from the sale of agricultural products (REGROST and TAKAR), the price for which is set at 1.5-2 times lower than for imported analogues. Given the novelty of the products, preliminary measures on informing consumers about the advantages of REGROST and TAKAR in comparison with the known analogues [3-5] are planned in parallel with the construction of the plant.

2. Methods of research

Calcite carbide, calcium oxide, acetylene, methanol, carbamide, fertilizers REGROST and TAKAR are produced as the main products after processing of coal and carbonate mineral raw material; as well carbon dioxide, drinking or calcined water, calcium hydrate are produced as additional products.

Whereas, processing of acetylene makes it possible to obtain: synthetic ethylene and ethyl alcohol, naphthalene, hydrogen: synthetic drying oils (oil varnish), chloroprene rubber. In accordance with the polymerization reaction, the following products are also created: ethylene, polyethylene (polymer), propylene, polypropylene in the following directions of acetylene (C_2H_2) processing:

- 1) Acetic aldehyde (CH_3CHO) \rightarrow synthetic ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$);
- 2) Benzene (C_6H_6) \rightarrow naphthalene (C_{10}H_8) \rightarrow hydrogen (H_2);
- 3) Vinyl-acetylene ($\text{CH}_2 : \text{CH} \cdot \text{C} : \text{CH}$) \rightarrow divinyl-acetylene ($\text{CH}_2 : \text{CH} \cdot \text{C} : \text{C} \cdot \text{CH} : \text{CH}_2$) \rightarrow synthetic drying oils (oil varnish);
- 4) Vinyl-acetylene ($\text{CH}_2 : \text{CH} \cdot \text{C} : \text{CH}$) \rightarrow Chloroprene ($\text{CH}_2 : \text{CH} \cdot \text{C} \text{Cl} : \text{CH}_2$) \rightarrow chloroprene rubber;
- 5) In accordance with the polymerization reaction, the following products are created:
- 6) T, R, cat
- 7) ethylene ($n\text{CH}_2 = \text{CH}_2$) \rightarrow $(-\text{CH}_2 - \text{CH}_2 -)_n$ – polyethylene (polymer);
- 8)
- 9) T, R, Cat

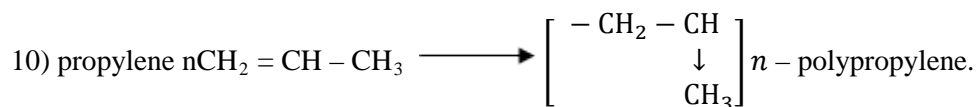


Figure 2 shows an example of a physical-technological model of an installation for the processing of coal and carbonate mineral raw materials. Similar physical and technological models are developed and protected by inventions for most of the products discussed above and published author's certificates [7,8,9].

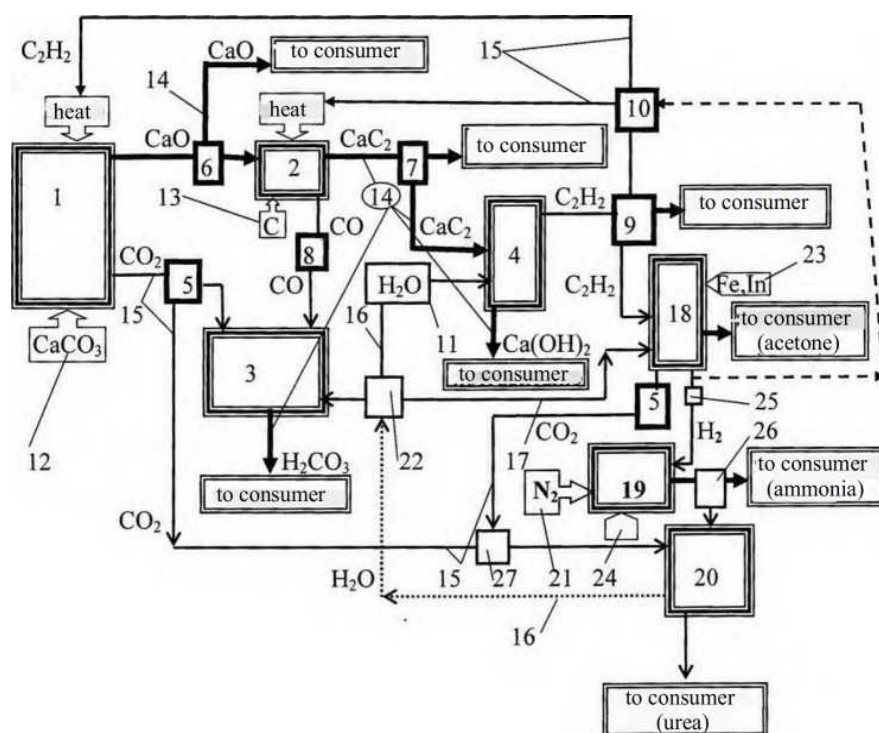


Figure 2. Physical and technological model of the unit for the processing coal and carbonate mineral raw materials: reactor of electrothermal furnace RKZ-2.5 (1), unit for calcining limestone and obtaining calcium carbide (2), unit for gas capture and production of carbon dioxide (3), unit for the production of acetylene (4), unit for capturing carbon dioxide (5), unit for producing calcium oxide (6), a calcium carbide storage bunker (7), acetylene station (9), electrothermal unit for melting mineral charge (10), a calcium hydrate storage (11), acetone production unit (18), unit for the production of ammonia (19), a device for the production of carbamide (20).

The invention can be used to produce calcium carbide, acetylene, quicklime and hydrated lime and carbon dioxide. The plant for processing carbonate mineral raw materials comprises a lime kiln 1, a furnace for calcium carbonate production 2, a carbon dioxide synthesis reactor 3, a gas generator 4, the first 5 and the second 8 gas sampling units, dispensers 6, 7, an acetone synthesis reactor 18, an ammonia synthesis reactor 19, a carbamide synthesis reactor 22. The first gas distribution unit 9 is connected to the first inlet of the acetone synthesis reactor 18, the second inlet of which is connected to the vapor source 22.

The invention makes it possible to expand the spectrum of the obtained commercial products of deep acetylene processing while ensuring a high level of diversification of production and exclusion of

the generation of man-made wastes [7,8]. Similarly, the following products can be obtained from calcium carbide: acetylene – synthetic ethanol, ethylene glycol, dichloroethane, antifreeze, acetone, synthetic drying oils, etc. [9].

3. Results and discussion

The developed economic-mathematical model (EMM) of the organization of innovative high-tech production, built for coal-mining, power and industrial enterprises engaged in both coal, gas, oil production and the production of natural and synthetic gaseous and liquid fuels, is possible during the reconstruction and diversification of this production. Such an economic and mathematical model of the organization of production has a high degree of universality and it is expedient to implement the EMM differentially for alternative options for coal-mining, energy and gas producing enterprises.

Economic-mathematical and organizational-technological models are planned to be applied for development of territorial investment programs of construction and diversification of enterprises in fuel and energy industries that use and process coal and carbonate mineral raw materials into traditional and alternative energy carriers and non-fuel products.

In the integrated feasibility study of the organization of high-tech production, the calculation of the main technical and economic parameters of the newly created production for obtaining fuel and non-fuel products was performed. The paper discusses a new ecologically clean patented method of combined processing of coal and carbonate mineral raw materials, which is the scientific, methodological and organizational development of the construction of the first-due mining and chemical complex in Primorsky Territory.

The relevance of the topic of this project is conditioned by the fact that thermochemical processing of coal and carbonates in newly created or reconstructed industrial enterprises provides the most valuable materials and products for the production sector, construction industry, energy engineering in this pilot project: calcium oxide, calcium carbide, carbon dioxides in gaseous, liquid and solid state (“dry ice”), acetylene, growth regulators and plant protection products (GRPPP).

Table 1 presents complex data of technical and economic indicators of investment projects, where column 4 indicates the performance of JSC “Spasskcement” in production of cement of various grades in 2012. The main initial indicator for comparison is the volume of mineral raw material used throughout the year: in line 3.1 it is shown that in the compared options for calculations – 990990 tonnes of limestone is accepted as ~ 1 million tonnes. For the second component – coal for the production of calcium carbide it will be required by approximately 100 thousand tonnes more, but this is completely compensated by the exception in this production of other mineral resources: clay, gypsum components, etc. [6, 10, 11].

Table 1. Integrated table of technical and economic indicators of investment projects (before the ruble devaluation in 2014).

No.	Name of the TEP	Units	Type of product						
			Cement	RKZ – 2.5			Plasma reactor		
				Calcium carbide	Carbon dioxide	Total	Calcium carbide	Carbon dioxide	Total
1	The volume of output	T	1415700	2500	3500	—	1200	1650/ 1319	—
2	The volume of mineral raw materials:								
2.1	Limestone	T	990990	5500	—	5500	2640	—	2640
2.2	Coal	T	218018	1750	—	1750	840	—	840
3	Cost of production	rub./t	1826	18220	4998	—	13990 (14419)	4172	—
4	Sale price	rub./t	3286	30000 – 36000	15000 – 25000	—	30000 – 36000	15000 – 25000	—
5	Number of IPP	person	1785	30	15	45	9	4	13

6	Product profitability	%	21.42	29.36 – 37.80	51.67 – 63.00	38.55 – 50.22	41.65 – 48.05 (40.22 – 46.85)	56.64 – 65.98	46.97 – 55.81 (46.04 – 55.13)
7	Revenues	million rub.	4652	75 – 90	52.5 – 87.5	127.5 – 177.5	36.00 – 43.20	19.79 – 32.98	55.79 – 76.18
8	Profit	million rub.	996.26	22.02 – 34.02	27.13 – 55.13	49.15 – 89.15	15.00 – 20.76 (14.48 – 20.23)	11.21 – 21.76	26.20 – 42.51 (25.68 – 42.00)
9	Revenue per person per year	million rub.	2.61	2.50 – 3.00	3.50 – 5.83	2.83 – 3.94	4.00 – 4.80	4.95 – 8.25	4.29 – 5.86
10	Volume of limestone per 1 tonne	th/t	0.70	2.20	—	2.20	2.20	—	2.20
11	Volume of coal per tonne	th/t	0.15	0.70	—	0.70	0.70	—	0.70
12	Energy costs per 1 ton of products	kWh	182.30	4000	1000	5000	2700	1000	3700
13	Pay-off period	year	—	3.17 – 2.06	1.48 – 0.73	2.24 – 1.24	1.13 – 0.82 (1.52 – 1.09)	0.89 – 0.46	1.03 – 0.64 (1.24 – 0.76)

The above data on the project for the processing of carbonate and coal mineral raw materials with the use of resource and energy-saving technologies only on the first subsystem (production of calcium carbide and carbon dioxide) shows their high efficiency and, equally importantly, environmental safety.

Technical and economic calculations of the application of a newly created plant for the processing of carbonate and coal mineral raw materials using an experimental industrial plasma reactor with a power of 500 kW throughout the above technological chain of products: calcium carbide, carbon dioxide, acetylene. REGROST and TAKAR with the same annual volumes of consumed mineral raw materials – **990990** tonnes of limestone and **315315** tonnes of coal show the following integrated production parameters:

- 1) volume of investments, mln. rub. – **21375**;
- 2) volume of output, t:
- 3) calcium carbide – **450450/656250**;
- 4) carbonic acid – **492244/616360**;
- 5) acetylene – **54000**; REGROST – **90000**; TAKAR – **144000**;
- 6) number of production personnel, person – **10425**;
- 7) profitability of the products sold, % - **68.9-69.3**;
- 8) revenue, million rubles – **87043- 95359**;
- 9) profit, million rubles – **60912 -65053**;
- 10) revenue per 1 person per year, million rubles – 8.87.

Thus, the proposed investment project, which ensures the rational combination of innovative (combined) technologies in a single technological complex, allows the extremely cost-effective and integrated use of local mineral raw materials and energy to be performed on the basis of highly profitable production with high profit margins and added value with a minimal for production projects payback period [10].

4. Conclusions

1) The parameters of physical-technological and economic-mathematical modeling of processes makes it possible to consider the configuration and parameters of the systems of restructuring and diversification of coal-mining and energy enterprises in more detail, to agree and determine the operating modes of control subsystems and production organization, to forecast technological and economic indicators of newly created and diversified production complexes

2) When processing coal and carbonates, it is planned to develop a physico-technical and economic-technological model for newly created technologies; the selection and justification of the scheme for the production of synthetic gaseous and liquid fuels is considered based on the specific conditions, the cost and quality of coal, energy supply, market conditions and other factors.

3) In the territorial investment programs it is advisable to envisage the application of electrothermal technologies and to continue the development of plasma ecologically safe resource and energy-saving complexes using the principles of modular design of a new production.

References

- [1] Sorokin A P, Avdeyko G P, Alekseev A V, Baklanov P Ya, Zhukov A V and Podolyan V I et al 2001 *Dal'nauka* **1** 12
- [2] Zhukov A V, Zhukova Yu A, Zvonarev M I and Umarov M S 2017 *Proc. of Int. Sci. Conf. on Science-intensive Technologies of Development and Use of Mineral Resources* (Novokuznetsk) **3** pp 21–26
- [3] Zhukov A V and Zhukova Yu A 2014 *Basic Research* **9** 13–7
- [4] Zhukov A V 2014 *FGBNU NII RINKTSE Innovation and Expertise* **2(13)** 235–42
- [5] Zhukov A V, Zhukova Yu A, Umarov M S and Mikhalkov A V 2015 *Development of Geo-resources in the Asia-Pacific Region. Mining Information and Analytical Bulletin* **4** 51–9
- [6] Zhukov A V, Kusraeva D E, Zhukova Yu A, Shmelev A A and Umarov M S 2016 *Advances in Modern Natural Science* **12(1)** 154–61
- [7] Zhukov A V, Zvonarev M I and Zhukova Yu A 2008 Patent 74912 Bul 20
- [8] Zhukov A V, Zvonarev M I and Zhukova Yu A 2009 Patent RU 2362735 C1 Bul 21
- [9] Zhukov A V, Zvonarev M I and Zhukova Yu A 2009 Patent RU 2373178 C2 Bul 32
- [10] Kutasov M L 2012 *GTh of Training Specialists in the direction 080502.65 – Economics and Management at the Enterprise*. Supervisor of the GTh – Doctor of Tech. Sci., Prof. Zhukov A V (Branch of Far Eastern State Technical University Spassk-Dalnyi of Primorsky Territory) 102
- [11] Zhukov A V, Zhukova Yu A and Umarov M S 2017 *Proc. of Sci.-Prac. Conf. on Geosystems of Northeast Asia: Territorial Organization and Dynamics* (Vladivostok, Pacific Institute of Geography, FEB RAS) pp 431–435