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IMPACT OF «ALUMINUM PRODUCTION» ON THE ENVIRONMENT AND WAYS TO SOLVE IT

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A comprehensive analysis was carried out on the main harmful components generated throughout the full technological cycle of aluminum production, which is a unique industry in Kazakhstan. The study included an assessment of pollutant emissions into the environment at various stages of the production process. In addition, a detailed review of modern methods and innovative technologies aimed at minimizing hazardous emissions and reducing the overall environmental impact of aluminum production was conducted.

The results of the study indicate that there is significant potential for reducing air pollutant emissions. For example, dust emissions can be reduced from 9010 mg/Nm³ to 50 mg/m³, while sulfur dioxide emissions can be lowered from 3378 mg/Nm³ to a range of 150–200 mg/m³. Similar reductions can also be achieved for other harmful components. These findings highlight the importance of implementing advanced environmental protection strategies that not only improve air quality but also promote the sustainable development of the aluminum industry by aligning production processes with modern environmental standards.

Keywords: aluminium, bauxite, alumina, electrolysis, electrolyte, alkali, aluminium electrolysis, best available techniques, hybrid bag filter.

«АЛЮМИНИЙ ӨНДІРІСІНІҢ» ҚОРШАҒАН ОРТАҒА ӘСЕРІ ЖӘНЕ ОНЫ ШЕШУ ЖОЛДАРЫ

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Бұл жұмыста Қазақстанның бірегей өнеркәсіп саласы болып табылатын алюминий өндірісінің толық технологиялық циклінде түзілетін негізгі зиянды компоненттерге кешенді талдау ұсынылған. Өндіріс процесінің әртүрлі кезеңдерінде қоршаған ортаға шығарылатын ластаушы заттардың көлемі бағаланды. Алюминий өндірісінің қоршаған ортаға әсерін азайтуға бағытталған заманауи әдістер мен инновациялық технологияларға ерекше назар аударылды.

Зерттеу нәтижелері атмосфераға шығарылатын ластаушы заттардың көлемін айтарлықтай азайту мүмкіндігін көрсетеді. Атап айтқанда, шаң шығарындысын 9010 мг/Нм³-тен 50 мг/м³-ке дейін, ал күкірт диоксидінің шығарындысын 3378 мг/Нм³-тен 150–200 мг/м³ диапазонына дейін төмендетуге болады. Басқа зиянды компоненттер үшін де осындай нәтижелерге қол жеткізуге болады. Алынған деректер заманауи экологиялық стандарттарға сай өндірістік процестерді қамтамасыз ете отырып, атмосфералық ауаның сапасын арттыруға және алюминий өнеркәсібінің тұрақты дамуын қамтамасыз етуге бағытталған алдыңғы қатарлы экологиялық технологияларды енгізудің маңыздылығын айқындайды.

Түйін сөздер: алюминий, боксит, глинозем, электролиз, электролит, сілті, алюминий электролизі, ең үздік қолжетімді технологиялар, гибридті қап сүзгісі.

ВЛИЯНИЕ «АЛЮМИНИЕВОГО ПРОИЗВОДСТВА» НА ОКРУЖАЮЩУЮ СРЕДУ И ПУТИ ЕГО РЕШЕНИЯ

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В данной работе представлен комплексный анализ основных вредных компонентов, образующихся на всех этапах технологического цикла производства алюминия — уникальной отрасли промышленности Казахстана. Проведена оценка выбросов загрязняющих веществ в окружающую среду на различных стадиях производственного процесса. Особое внимание уделено современным методам и инновационным технологиям, направленным на снижение объемов опасных выбросов и минимизацию экологического воздействия алюминиевого производства.

Результаты исследования свидетельствуют о значительном потенциале снижения выбросов загрязняющих веществ в атмосферу. В частности, выбросы пыли могут быть снижены с 9010 мг/Нм³ до 50 мг/м³, а выбросы диоксида серы - с 3378 мг/Нм³ до диапазона 150–200 мг/м³. Схожие результаты могут быть достигнуты и в отношении других вредных компонентов. Полученные данные подчеркивают необходимость внедрения передовых экологических технологий, направленных на повышение качества атмосферного воздуха и обеспечение устойчивого развития алюминиевой промышленности в соответствии с современными экологическими стандартами.

Ключевые слова: алюминий, боксит, глинозем, электролиз, электролит, щёлочь, электролиз алюминия, наилучшие доступные технологии, гибридный рукавный фильтр.

Introduction. Aluminum is the second most widely used material in the world [1]. This is due to its properties such as good electrical conductivity, ductility, and light weight. In addition, this metal retains its qualities even after multiple processing cycles. Because of its physical and chemical characteristics, aluminum is widely used in various sectors of the economy [2]. However, despite the many advantages and benefits of this metal, aluminum production has a negative impact on the environment [3] The main environmental impact of aluminum production is the release of harmful gases and the generation of solid waste. These emissions and waste are produced at various stages of the manufacturing process [4]. The formation of solid waste is mainly due to the extraction of alumina from bauxite. Emissions of harmful gases occur mainly during the electrolysis of alumina [5].

Globally, aluminium production is responsible for about 1% of annual greenhouse gas emissions. Reducing emissions has long been a key issue for the sustainability of the aluminium industry [6].

At present, aluminium production in our country operates on a full system cycle, i.e. the bauxite raw material required for the production of aluminium oxide (Al_2O_3) is first extracted from the earth' s crust by mining and then by the interaction of bauxite with caustic alkali the aluminium oxide required for the production of pure aluminium is produced. Finally, pure metallic aluminium is produced by electrolysis of aluminium oxide during electrolysis.

Currently, the number of harmful substances emitted into the environment (air, water system and soil) in each system chain of this production is enormous. The main environmental aspects of bauxite mining and processing operations are air emissions, mine water generation, waste and land use. The main harmful substances entering the environment during exploration are: dust, harmful gases, wastewater, waste, noise and vibration.

Aluminium electrolysis production also belongs to the category of industries with a high risk to public health and the environment. The main pollutants of the production are gaseous fluorides, low soluble fluorides, benzo(a)pyrene,

inorganic dust, hydrogen fluoride, aluminium oxide, carbon monoxide, resinous substances, sulphurous anhydride [7].

The aim of the study is a systematic assessment of the environmental impact of aluminum production at different stages of the technological cycle. The objectives of the study are to analyze the technological stages of aluminum production in terms of their impact on the environment, identify and classify the main pollutants and waste, assess the industry' s contribution to greenhouse gas emissions, and identify possible approaches to minimize negative environmental consequences.

Materials and methods. The data on pollutant emissions from aluminium production were obtained from official statistical sources, maximum permissible emissions reports and production control documents [8, 9]. Quantitative data on air emissions were structured by different process stages: bauxite mining, alumina production and primary aluminium electrolysis. The obtained values were analysed using standard statistical methods, including averaging minimum and maximum concentrations, comparing them with standard values and classifying by pollutant type [10].

The current levels and amounts of pollutants released into the environment from general aluminum production are shown in Table 1 [8]. These data provide a comprehensive analysis of pollutant emissions at different stages of the production process, highlighting the main environmental problems associated with the industry.

Table 1 - Dust emissions into the atmosphere

Name of object	Gross emissions of pollutants, tonnes	
	max	Min
1	2	3
B1	1.6	1.4

Table 1 provides quantitative data on the total emissions of pollutants resulting from open-pit mining operations during the removal of topsoil. The reported emissions range from 1.4 to 1.6 tonnes. These values are within the permissible environmental limits and do not exceed the established maximum limit values, indicating that pollutant levels are effectively controlled at this early stage of field development.

Based on this, Table 2 provides detailed information on the process of topsoil removal and associated dust emissions during mineral extraction. The data includes dust generation rates at different stages of deposit development, providing an understanding of the extent of environmental impact resulting from these operations.

Table - 2 Dust emissions from stripping operations

Name of object	Gross emissions of pollutants, tonnes	
	max	Min
1	2	3
B1	366.3	312.5

The main harmful emissions during drilling and blasting operations are gaseous substances (nitrogen oxides, carbon monoxide, sulfur dioxide) and inorganic dust, i.e. less than twenty percent of silicon oxide (SiO_2) emissions.

Table 3 - Dust emissions into the ambient air from alumina production

Name of object	Gross emissions of pollutants, tonnes		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Alumina production				
A2	60798.12837	48705.11001	9010	22.5

According to the data in Table 3, dust emissions from alumina production reach significant values: gross emissions vary from 48705.11 to 60798.13 tons, and concentrations from 22.5 to 9010 mg/nm³. Such a wide range indicates high variability of the technological process and the need for strict control of dust and gas cleaning systems.

Table 4 - NOx emissions to ambient air from alumina production

Name of object	Gross emissions of pollutants, tonnes		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Alumina production				
A2	785.6	130.97	4564.9	233.7

Based on the Table 4, the gross NOx emissions are in the range of 130.97–785.6 tons, with concentrations ranging from 233.7 to 4564.9 mg/nm³. The presence of high maximum concentrations indicates a significant potential for air pollution, especially under adverse meteorological conditions.

Table 5 - CO emissions to ambient air from alumina production

Name of object	Gross emissions of pollutants, tonnes		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Alumina production				
A2	498.8	18.4	23868	46.3

Table 5 shows data showing that gross CO emissions range from 18.4 to 498.8 tons, with concentrations fluctuating between 46.3 and 23.868 mg/nm³. Maximum carbon monoxide concentrations significantly exceed sanitary and hygienic standards, posing a threat to the health of workers and the population of adjacent areas.

According to Table 6, SO_2 emissions are in the range of 1013.9–1317.7 tons, with concentrations of 107–3378 mg/nm³. These figures also confirm the high level of pollution, especially when reaching the upper limits of the range.

Alumina production is characterized by high emissions of dust, nitrogen oxides, carbon

monoxide and sulfur dioxide, the concentrations of which in many cases significantly exceed the maximum permissible values. The greatest danger is posed by dust emissions and carbon monoxide, reaching extreme levels and posing a threat to public health and the environment. The data obtained indicate the need to modernize gas cleaning systems and strengthen air quality control.

Table 6 - SO_2 emissions to ambient air from alumina production

Name of object	Gross emissions of pollutants, tonnes		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Alumina production				
A2	1317.7	1013.9	3378	107

Table 7 - Substances making the largest contribution to emissions in primary aluminium production

Name of pollutant	Emission in 2020 tonnes according to inventory data	Share of total emissions, in %
1	2	3
Carbon oxide	42 344	80.75
Sulphur dioxide	8 114	15.47
Inorganic dust containing silicon dioxide in %: more than 70 (Dinas)	628	1.20
Aluminium oxide (Di Aluminium trioxide)	565	01.08
Inorganic dust containing silicon dioxide in %: less than 20 (dolomite, cement manufacturing dust - limestone, chalk, cinders, raw mix, rotary kiln dust, bauxite)	265	0.51
Inorganic, poorly soluble fluorides (aluminium fluoride, calcium fluoride, sodium hexafluoroaluminate)	226	0.43
Nitrogen oxides	94	0.18
Fluorinated gaseous compounds	74	0.14
Inorganic dust containing silicon dioxide in %: 70-20 (fire clay, cement, cement production dust - clay, clay shale, blast furnace slag, sand, clinker, ash, silica, ash from coal deposits in Kazakhstan)	40	0.08
Coal tar pitch with benz/a/pyrene content of 0.1 to 0.15%	13	0.02

The total number of atmospheric air pollution indicators (AAP) is 183 sources, 138 of which are organised, 45 are fugitive, according to the calculation of maximum permissible emission standards for pollutants in the atmospheric air from the aluminium industry (primary aluminium production). The total emissions of harmful substances amount to 52,439 tons per year.

The main pollutant emissions at the plant are produced during primary aluminium production by electrolysis and the use of fuel and energy resources. Carbon oxide and sulphur dioxide make up 96% of primary aluminium production emissions. The main pollutants are presented in Table 7 [8].

During the production of primary aluminium, various pollutants are emitted into the atmosphere, including fluoride and sulfur compounds, dust, carbon monoxide, and coal tar pitch sublimates. These emissions are primarily due to the specific technological processes involved in industrial aluminium production, which utilize raw materials such as fluoride salts, petroleum coke, and coal tar pitch [9]. Tables 8–12 present data on atmospheric pollutant emissions from primary aluminium production at the electrolysis section of facility A3 [8].

Table 8 - Dust (aluminium oxide) emissions into the ambient air from primary aluminium production

Name of object	Gross emissions of pollutants, tonnes/year		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Electrolysis aluminium production				
A3	14.0	10.45	2.96	2.42

Table 9 - SO_2 emissions to ambient air from primary aluminium production

Name of object	Gross emissions of pollutants, tonnes/year		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Electrolysis aluminium production				
A3	1130.5	1052	209.4	199.4

Table 10 - CO emissions from primary aluminium production

Name of object	Gross emissions of pollutants, tonnes/year		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Electrolysis aluminium production				
A3	8078.3	7297.6	1350.3	1257.2

Analysis of the presented data (Tables 8–12) shows that the largest contribution to air pollution in the production of primary aluminum comes from carbon monoxide emissions (Table 10). Their gross amount exceeds 8 thousand tons/year, and concentrations vary within the range of 1257.2-1350.3 mg/nm³, which significantly exceeds the indicators of other pollutants.

The second most significant pollutant is sulfur dioxide emissions (Table 9), reaching 1130.5 tons/year. SO_2 concentrations are 199.4–209.4 mg/nm³, which indicates a stable level of its

formation in the process of aluminum electrolysis.

Emissions of inorganic fluorides and fluorine-containing gaseous compounds (Tables 11, 12) are characterized by significantly lower values (3.3–6.86 t/year), but their environmental hazard is determined by high toxicity and the ability to accumulate in the environment.

Table 11 - Inorganic fluoride emissions into the ambient air from primary aluminium production

Name of object	Gross emissions of pollutants, tonnes/year		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Electrolysis aluminium production				
A3	6.86	6.06	0.95	0.90

Table 12 - Emissions of fluorinated gaseous compounds into the ambient air from primary aluminium production

Name of object	Gross emissions of pollutants, tonnes/year		Concentration, mg/nm^3	
	max	min	max	Min
1	2	3	4	5
Electrolysis aluminium production				
A3	3.7	3.3	0.60	0.56

As shown in Table 8, the emissions of dust (Al_2O_3) amount to 10.45–14.0 t/year, which is relatively small compared to other pollutants, yet they are significant due to their adverse impact on air quality in the sanitary protection zone.

According to the data in Tables 8–12, the main air pollutants in the production of primary aluminum are carbon monoxide and sulfur dioxide, which form the largest volumes of emissions. Despite the relatively smaller gross amounts of dust and fluorine-containing compounds, their environmental hazard is determined by their high toxicity and impact on public health. In general, the results of the analysis indicate the need for enhanced control over CO and SO_2 emissions, as well as the implementation of measures to reduce the concentration of fluorine compounds in the area of the enterprise' s impact.

Results and discussion. From the tables shown, it is possible to see thousands of tons of harmful substances entering the environment from each system chain of "Aluminum production". Currently, the principles of implementing the best available techniques for the purpose of environmental protection have been established at the world level, especially in the countries of the European Union. It is known that the countries of the European Union have reduced harmful substances such as dust and sulfur dioxide entering the environment by 90-94 percent in recent years by introducing the mentioned available techniques. In accordance with the new Environmental Code adopted in the Republic of Kazakhstan in 2021, handbooks are being developed by the Best Available Techniques Bureau of the "International Center for Green Technologies and Investment Projects" for the first category of fifty enterprises. References are being developed taking into account the best practices of the European Union, Russia and other countries.

Aluminum production in our country

(excluding aluminum electrolysis production) has been operating for about 60 years. Most environmental protection facilities are physically and technologically obsolete [11]. Therefore, in order to reduce the damage caused by this industry to the environment and human health, we offer the best of the world-class equipment and technology available, which are listed below: Environmental Management System, Energy Management System, Process Control System, Emission Control System, Wastewater Control System for all process systems of the aluminum industry.

Technological indicators of dust emissions in the processes of grinding, classification, transportation, storage, aluminum oxide production, aluminum electrolysis production, anode firing in aluminum production Hybrid bag filter (using electrostatic precipitator and bag filter), dry sorption gas cleaning ABART unit, regenerative thermal oxidizer, electrostatic It is quite possible to reduce the dust volume by 5-20 mg/Nm^3 using one or more of filter, bag filter, impulse filter, ceramic and metal fine filter techniques [12,13,14].

Table 13 - Parameters of hybrid bag filters [15]

Gas flow	156 000 Nm³/h
Exhaust gas temperature	425 °C until
Smoke hood	500 kW
Rarefaction	50 mbar
Surface of bag(length)	6м.
The composition of solid particles (dust) from the furnace, the volume of dust sent to the hybrid bag filter	2200 mg/m3
Composition of dust after cleaning (solid particles, estimated result of dust)	50 mg/m3
Actual result achieved	1,5 mg/m3

In order to reduce the emissions of sulfur dioxide (SO_2) from process gases, it is possible to reduce the amount of sulfur dioxide in the production of aluminum electrolysis to 150-200 mg/Nm3 by using the technology of using low-sulfur fuel and wet cleaning methods (wet scrubber).

Flue gas recirculation, selective non-catalytic reduction and selective catalytic reduction technologies can be used to reduce nitrogen oxide (NOx) emissions [16].

Carbon oxides in atmospheric air can be reduced by absorption purification using copper-ammonia solutions, catalytic purification technologies using steam reaction, regenerative thermal oxidizing, catalytic thermal oxidizing techniques [17].

Waste water from aluminum production is not discharged into natural water systems. After using the process water in the entire process chain, it undergoes mechanical cleaning as waste water and a decrease in water temperature in special facilities, and is then used again in process chains. This is a closed water circulation system used in production. This system does not harm the environment.

Conclusion. The analysis confirms that a significant reduction in pollutant emissions into the environment is achievable provided that targeted modernization of industrial aluminum production facilities is carried out. One of the key priorities in this process is the replacement of outdated and physically worn-out environmental infrastructure, which in the case of the aluminum industry has been in continuous operation for more than six decades. The technical and moral obsolescence of such equipment significantly limits the ability to meet modern environmental standards.

From an economic point of view, the aluminum

industry occupies a significant share in the industrial production and energy consumption of the country. According to available statistics, the industry consumes up to 4-5% of all electricity produced in the world [18, 19], while environmental protection costs remain below the industry average. At the same time, as international practice shows, the introduction of best available technologies (BAT) in aluminum production allows for a reduction in pollutant emissions by 20-35% while simultaneously reducing energy costs by up to 21% [20], which in turn ensures a reduction in operating costs and increased competitiveness in global markets.

The introduction of these best technologies into existing aluminum production will allow minimizing emissions of harmful substances into the atmosphere, reducing the consumption of natural resources and increasing the overall energy and operational efficiency of enterprises.

The obtained research results can serve as a starting point for research on reducing the negative impact on the environment and people' s health by replacing old facilities with new, the best available equipment in all large industrial facilities in the country.

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