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# АСПЕКТЫ ЭКОЛОГИЧЕСКОЙ МОДЕРНИЗАЦИИ ТЕХНОЛОГИЧЕСКОГО ОБОРУДОВАНИЯ ДЛЯ СНИЖЕНИЯ УРОВНЯ ЗАПЫЛЕННОСТИ ОТ ГОРНО-ОБОГАТИТЕЛЬНОГО ПРОИЗВОДСТВА

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***Аннотация:*** Представлен анализ способов экологической модернизации технологических агрегатов, аппаратов и машин горно-обогатительной отрасли, а также других отраслей. В частности, рассмотрены основные источники загрязнения воздушного бассейна населенных пунктов, механизм пылеобразования и образования потока дисперсного аэрозоля, приведена классификация различного рода пылеулавливающих устройств. Освещены проблемы создания малоотходных технологий и безотходных технологических комплексов. Представлены и проанализированы сравнительные параметры видов промышленного загрязнения окружающей среды. Сопоставлены данные о выбросах в атмосферный воздух вредных веществ от стационарных источников в ряде городов стран Содружества Независимых Государств (СНГ). По результатам анализа было установлено, что в настоящий момент не существует единой международной методологии экологической модернизации (усовершенствования) технологической единицы (аппарата, машины или их комбинации), в разработке которой на современном этапе существует острая необходимость для защиты окружающей среды от функционирования промышленных отраслей и производств.

***Ключевые слова:*** экологическая модернизация, технологические агрегаты, машины и аппараты горно-обогатительной и других отраслей промышленности, техногенное воздействие, защита окружающей среды, техносферная безопасность.

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## Aspects of ecological modernization of technological equipment to reduce the level of dust from mining and processing production

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***Abstract:*** This article presents an analysis of the ways of ecological modernization of technological units, apparatuses and machines of the mining and processing industry, as well as other various industries. In particular, the main sources of pollution of the air basin of settlements, the mechanism of dust formation and the flow of dispersed aerosol, the classification of various kinds of dust-collecting devices, the problems of creating low-waste technologies and waste-free technological complexes are considered. Comparative parameters of classification of types of industrial environmental pollution by machines and apparatuses of various industries and industries are presented and analyzed. Comparative data on emissions of harmful substances into the atmospheric air from stationary sources in a number of cities of the Commonwealth of Independent States (CIS) countries are presented. According to the results of the analysis, it was found that at the moment there is no single international methodology for environmental modernization (improvement) of a technological unit (apparatus, machine or in combination), in the development of which at the present stage there is an urgent need to protect the environment from the functioning of industrial sectors and industries.

***Key words:*** ecological modernization, technological units, machines and apparatuses of mining and processing and other industries, technogenic impact, environmental protection, technosphere safety.

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## Introduction

In October 1997 the President of Kazakhstan formulated in detail the Strategy of Kazakhstan until 2030, which outlined the long-term path of development of the country with the ultimate goal of turning it into a safe, stable and environmentally sustainable state. The Strategic Development Plan of Kazakhstan until 2030 is a key stage in the implementation of the Strategy «Kazakhstan–2030».

Speaking before the parade of troops dedicated to the Constitution of Kazakhstan, N.A. Nazarbayev expressed the need for «Technological modernization of the economy of Kazakhstan», This expression contributes to the illumination of economic efficiency, competitive goods, first of all, the ecological perfection of technology and technological processes.

Today, according to the Environmental Code of the Republic of Kazakhstan of 2010, the environmental foundations of sustainable development of the Republic of Kazakhstan are the following priorities:

1. achievement of goals to ensure at the state level a favorable environment for the health and life of the population;
2. environmental protection and biodiversity conservation;
3. the civil legal basis of legal relations for the development of natural and man-made resources and the protection of a number of interests in the field of nature management and environmental impact;
4. the possibility of meeting the needs for natural resources of future generations;
5. development of sustainable models of environmental management and greening of industry.

The waste and emissions that currently exist as a result of technological cycles of industries pose a significant danger to the population of large industrial regions, especially where various mining enterprises operate.

At this stage of innovative and industrial development of Kazakhstan, low-waste technology is more realistic, which differs from non-waste technology in that it provides a finished product with partially recyclable waste released during the production process and characterized by certain physical and chemical properties. Production waste suitable for processing into marketable products belongs to secondary material resources.

Due to the depletion of raw materials reserves around the world and in Kazakhstan, the time comes when the mass of finished products will be less than 1—1.5% of the extracted raw materials. This situation is taking place now in the mining industry.

Therefore, the main direction of innovative and industrial development in Kazakhstan should be the improvement of the technology of extraction, enrichment and transportation of ore and its processing, which makes it possible to increase the efficiency of extracting a useful product from raw materials. According to this indicator, the perfection of the entire complex of measures should be evaluated. The most difficult problem to solve here is to increase the environmental and economic efficiency of technological equipment, because In Kazakhstan, machine-building enterprises have not yet been established in the branches of production activity that meet modern requirements.

Consequently, at the current stage of scientific and technological development of the country, the main task is the ecological and economic modernization of existing units, apparatuses and machines. Thus, the purpose of this literary and patent research-review is to conduct and study the analysis of the current state of the environmental problem created by the activities of industrial enterprises for the modernization of existing units, apparatuses and machines.

## Results and discussion

*Problems of creating low-waste technologies and waste-free complexes*

At the same time, the amount of damage caused to the environment increases in such a way that it is no longer possible, as before, to overcome it in a natural way, without using a well-thought-out set of legislative and technological measures that affect all areas of human production activity.

Table 1 shows that the specific amount of toxic substances is almost equal to the daily human food intake. This indicator is equal for Kazakhstanis to almost 50 kg per day or an average of one kg of waste per kg of live weight, which is not allowed.

Table 1

***Amount of toxic waste***
***Количество токсичных отходов***

| Country | Amount of toxic waste, million tons / year | Specific amount, kg / year / person | Country area, thousand $km^2$ | Specific quantity, t year / $km^2$ |
|---|---|---|---|---|
| France | 10 | 160 | 357.0 | 28 |
| Finland | 0.4 | 100 | 338.1 | 1.2 |
| France | 17 | 140 | 544.0 | 31.3 |
| Netherlands | 2 | 100 | 41.5 | 48.2 |
| Great Britain | 7 | 120 | 244.1 | 28.7 |
| USA | 57 | 300 | 9363.4 | 6.1 |
| Kazakhstan | 281.8 | 18 000 | 2724.9 | 103.4 |

The conversion to the area of the territory of Kazakhstan is also acritical value that is many times higher than the same data for the United States and European countries. Therefore, it is necessary to bury solid waste. For example, concrete burial grounds are currently being built for sulfur, which is industrial waste. At the same time, this analysis clearly indicates the raw material orientation of the economy of our Republic.

The data presented in table 1 are incommensurable with the consequences of natural disasters. For example, the volcanic eruption in Iceland and the forest fires in Russia, Spain and Kazakhstan in the summer of 2010. So, it is estimated that the daily release of fire products in Russia amounted to 700 thousand tons.

In modern conditions, social reproduction requires the involvement of large volumes of raw materials and energy in economic turnover. In the Kazakh SSR until 1990, according to approximate calculations, approximately 1 t of natural substance (water, mineral raw materials, fuel, biomass, atmospheric oxygen) was consumed for each ruble of national income generated. At the same time, the mass of finished products was 1—1.5% of the mass of raw materials entering for processing.

Table 1 shows that a large amount of waste in Kazakhstan is associated not only with the industry's focus on the extraction of raw materials, but also indicates a low level of technologies and technological equipment used.

At this stage of innovative and industrial development of Kazakhstan, a low-waste technology is more realistic, which differs from a waste-free one in that it provides a finished product with incompletely recycled waste released during the production of basic types of products and characterized by certain physical and chemical properties. Industrial waste suitable for processing into marketable products is classified as secondary material resources.

Environmental pollution can be called a change in the quality of the environment that can cause negative consequences. The same agents are considered to have the same negative effects regardless of their origin, so dust originating from a natural phenomenon (for example, dust storms) should be considered the same polluting substance as dust emitted by an industrial enterprise, although the latter may be more toxic due to its complex composition (Table 2).

The presented classification is conditional. For example, dust generated as a result of industrial mechanical processes (crushing, grinding, transportation, pouring, etc.) can have both chemical, physical, and radiation effects on the environment.

Table 2

***Classification of types of industrial environmental pollution***
***Классификация видов производственных загрязнений окружающей среды***

| Pollution | Impact |
|---|---|
| 1. Mechanical | Contamination of the environment by agents that have only a mechanical effect without chemical and physical consequences (for example, garbage) |
| 2. Chemical | Changes in the chemical properties of the environment that have a negative impact on ecosystems and technological devices |
| 3. Physical | Changes in the physical parameters of the environment due to temperature, noise, electromagnetic, radiation and other influences. |
| 4. Biological | Penetration into ecosystems and technological devices of microbial species that are alien to these communities and devices due to changing conditions.<br>For example, the so-called «legionnaires' disease». |

*Main sources of air pollution in populated areas*

The Earth's atmosphere annually receives 150 million tons of various aerosols; 220 million tons of sulfur dioxide; 450 million tons of carbon monoxide; 75 million tons of nitrogen oxides. For every inhabitant of the Earth, almost one kg of air emissions is released every day.

Industrial production and other types of economic activity of people are accompanied by the release of various substances that pollute the air because of industrial enterprises, heat generating installations, transport.

Emissions from energy facilities account for about 58 – 61%, transport for 18 – 26%, and industry for 15 – 20%. This data is averaged. They do not reflect the actual situation.

Thus, according to [1 – 3], the share of mobile sources of air pollution in the Almaty city basin is 85% in winter, stationary sources (enterprises, thermal power plants and houses with coal heating) — 15%. In summer, they are 95% and 5%, respectively. This shows that there are errors in calculating the emissions of pollutants (EP) into the atmosphere. They consist in the fact that the methodology for estimating vehicle emissions (EVE) is not yet perfect. In addition, emissions from houses with individual heating are almost not taken into account.

The number of the most common types of harmful substances released into the atmosphere from stationary sources (industrial enterprises and thermal power plants) in a number of CIS cities is given in Table 3.

Table 3

***Emissions of harmful substances into atmospheric air from stationary sources in a number of CIS cities, thousand tons / year***

***Выбросы вредных веществ в атмосферный воздух от стационарных источников в ряде городов СНГ, тыс. т/год***

| City | Harmful substances | | | | | |
|---|---|---|---|---|---|---|
| | total | solid | gaseous and liquid | of these, | | |
| | | | | oxides sulphur content | including sulfur oxides nitrogen | oxides carbon monoxide |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Almaty | 113.3 | 1.5 | 9.8 | 3.4 | 3.2 | 1.8 |
| Irkutsk | 94 | 29 | 65 | 29 | 8 | 26 |
| Kemerovo | 122 | 37 | 85 | 26 | 28 | 21 |
| Krasnoyarsk | 259 | 78 | 181 | 39 | 13 | 115 |
| Magnitogorsk | 849 | 170 | 679 | 84 | 34 | 548 |
| Moscow | 312 | 30 | 282 | 70 | 99 | 28 |
| Novokuznetsk | 833 | 136 | 697 | 90 | 34 | 562 |
| Saint-Petersburg | 236 | 46 | 190 | 74 | 47 | 41 |
| Ust-Kamenogorsk | 65.5 | 4.4 | 61.1 | 39.1 | 5.9 | 13.6 |
| Ufa | 304 | 9 | 295 | 72 | 25 | 36 |
| Chelyabinsk | 427 | 94 | 333 | 60 | 29 | 210 |
| Shymkent | 52.3 | 28.2 | 24.1 | 2.8 | 2 | 2.2 |

Due to the significant increase in the automobile fleet, its role in air pollution is constantly increasing. A passenger car emits upto 3 $m^3$/h of carbon monoxide CO, while a truck emits upto 6 $m^3$/h (3 — 6 kg/h). High concentrations of carbon monoxide were detected at high altitudes, as well as in working and residential areas of high-rise buildings, and on streets with heavy automobile traffic.

Air pollution has a number of adverse effects.

• Sanitary and hygienic consequences. Since air is an environment in which a person is located throughout his life and on which his health, well-being and performance depend, the presence in the air environment of sometimes even small concentrations of harmful substances can adversely affect the physical condition, intellectual and labor activity of a person.

• Environmental consequences. The daily decrease in the level of air quality due to the presence of various amounts of pollutants in its composition contributes to the destruction of forests, agricultural products, flora and fauna, pollution of surface waters, and also has a negative impact, in particular, the destruction of cultural monuments, various building structures, structures, etc.

• Economic consequences. Dust and gas content in the air, both in quarries and especially in industrial premises, contributes to a decrease in the quality of labor productivity and, accordingly, the loss of time intended for work due to an increased level of morbidity. In a number of industries, the presence of dust in the air contributes to the deterioration of the quality of products and accelerated wear of equipment. During the production, mining and transportation of various types of materials, in particular raw materials and products, some of these substances are able to pass into a finely dispersed phase and subsequently be lost (for example, ore, coal, cement, fertilizers, etc.), while exerting effect of pollution about the environment. Thus, in a number of industries, production losses occur, which can reach 3.0 — 5.2%. Which in turn contributes to the occurrence of significant damage due to environmental pollution.

The latter, according to various experts, can reach from 9.5 to 26.7% of the total emissions into the atmosphere.

One of the significant causes of various emissions into the atmosphere are: or weak localization of sources of dust and gas emissions; weak tightness, structural inaccuracies, shortcomings of industrial equipment, technical and technological malfunction; unskilled maintenance of technological processes and equipment. The most important thing is the environmental imperfection of technological units or installations.

*Mechanism of dust formation and dispersed aerosol flow*

As a result of repeated collisions of particles with each other or with the walls of apparatuses and devices in the technological paths of raw material preparation, particles are destroyed with the formation of substandard fractions, and the granulometric composition of raw materials changes significantly. The data presented in the literature on the grinding of raw materials in technological paths of preparation can be conditionally divided into four groups [3].

In the works belonging to the first, most representative group, the facts of spontaneous grinding and changes in the granulometric composition of raw materials during technological operations are stated, usually with an indication of the amount of fines formed during re-filling.

For example, in [4] it is shown that when anthracite is loaded into wagons, the amount of fines increases to 15.6%. The following figures are also given: as a result of the charge transportation at the enterprises of the phosphorous industry, the amount of formed fines of 0 – 10 mm is 30% [3]. The author of [5] provides information that when magnetite ore of the initial fraction (10 – 25) mm falls from a height of 15 m, the amount of substandard fines formed (fraction 10 – 25 mm) is 17.6%. There are still a number of works devoted to the problem of grinding charge materials during technological transfer [6 – 8].

In the studies assigned to the second group, it is shown that grinding during technological transfers is a negative phenomenon that causes the formation of a large amount of substandard fines and leads to production costs, in particular, to an increase in the cost of coal dressing [9]. The authors of [9, 10] studied the destructibility of coals by dropping them from certain heights and proposed a correlation between the anthracite grinding index, the strength coefficient according to M. Protodyakonov, and the content of fines in the initial fraction (class 0 – 6 mm). The results of similar experimental studies are given in [11]. The experimental method consisted in studying the patterns of coal grinding when dropped from different heights on different surfaces (for example, coal, metal, etc.) and determining the amount of fines (0 – 6 mm). The author found that at a drop height of 6.5 m, the yield of fines is from 0.3 to 10% and depends on the type of impacted surface.

In almost all industries, technology requirements impose strict restrictions on the content of small fractions of raw materials [12]. It is particularly important to accurately dose the fractions of the charge components for thermal processes, since gas-dynamic processes occurring in the layers of granular material must pass at certain speeds. It was shown in [13] that the agglomerate for blast furnace production should contain a minimum amount of fraction 0 – 10 mm, since the hydraulic resistance of the fraction is (5 – 10) mm by 2 – 2. 5 times; (3 – 5) mm by 4.5 – 5 times; (1 – 3) mm is 9 – 13 times higher than the resistance of the fraction (12 – 25) mm. Based on the process of gas permeability of the layer, loading of raw materials of a fraction (0 – 5) mm into the furnace is unacceptable.

The third group includes works that provide constructive recommendations for reducing the grinding of raw materials in the technological paths of raw material preparation. V. Pokrovskaya's monograph covers the domestic and foreign experience of creating coal transshipment points [14]. All these technical solutions are designed to prevent crushing of materials and dust formation, reduce the loss of raw materials, and protect the cargo-carrying body (for example, the belt of conveyor belts) from damage. It should be noted that they are mainly based on industrial practice and engineering intuition.

In recent years, Kazakh scientists have conducted research that reveals the regularities of the processes of destruction of charge particles and describes methods for predicting the granulometric composition of the charge as a result of technological backfills [15, 16].

It follows from the above that the technological preparation of raw materials requires a sufficiently large number of transporting equipment. Moreover, the transfer of material from one equipment to another in most cases is carried out in technological paths. As a result of the acquisition of a certain speed by the material and the subsequent impact on the rigid or damped surface of the structural elements of the equipment, some of the pieces of materials are destroyed, forming an undesirable byproduct over-ground [17, 18].

A similar situation occurs when filling bunkers, silos, and other process tanks. The large number of overflow paths leads to a significant increase in the proportion of substandard over-ground material. For example, in drum drying units, the heat carrier-flue gas-comes into contact with the dispersed solid phase that is being dried from the rotating nozzle blades [19, 20].

A number of technological processes are aimed at obtaining various fine-dispersed materials consisting of small particles, for example, gypsum, flour, coal dust, cement, etc. The fine fraction of these materials is capable of being transported by air masses, forming an aerosol-like flow, a significant parameter of which is the dispersion of dust (particle size), its density, on which depends the efficiency of its capture and deposition in atmospheric and gravitational conditions. The higher it is, the greater the probability of clogging of individual elements of the technological unit, environmental equipment and sticking to the flues. The finer the dust, the higher its stickiness, which increases significantly when it is moistened [21—22].

The wettability of particles by liquid (water) affects the operation of wet dust collectors, and the electric charge of particles affects their behavior in dust collectors and flues.

In our opinion, the process of dedusting air includes the following main stages:

1. Prevention of dust generation (PP) in technological units, installations and apparatuses;

2. Capture of dust (PO) from the aerosol;

3. The dispersion of the dust aerosol persists after a number of previous stages, which consist in increased propagation of dust-like particles in the air and aeration of the dispersed dust medium in the atmosphere of the surface layer.

Thus, based on the consideration of a number of scientific papers, it has been established that the technology of dedusting the air mass of the atmosphere consists of three main components: prevention of dust formation (PP), dust cleaning (PO) and dust dispersion (RP). Each component of the system is capable of being implemented by a variety of different methods and methods, which have the ability to determine the nature of directed various external influences on the dust-like aerosol. Any method and method can be implemented by various technological solutions and technical means.

*Classification of dust collecting devices*

At the present stage, the classification of technological solutions for dedusting is based on the use of a wide range of methods [23]. According to State Standard 12.2.043-89 «Dust collecting equipment. Classification» [24]: all technological equipment designed for dust cleaning is divided into five classes depending on the efficiency and size of the particles captured (Table 4).

Table 4

***Classification of dust collectors***
***Классификация пылеуловителей***

| Class of the device | Dimensions of effectively captured particles, microns | Efficiency by mass of dust, with dust dispersion group | | | | |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | V |
| I | more than 0,3—0,5 | — | — | — | 99,9—80 | <80 |
| II | more than 2 | — | — | 99,9—92 | 92—45 | — |
| III | more than 4—99 | — | 99,9—99 | 99—80 | — | — |
| IV | more than 8 | >99.9 | 99—95 | | — | — |
| V | more than 20 | >99 | — | | — | — |
| Note. The efficiency limits correspond to the boundaries of the dust group classification zones. | | | | | | |

Table 5

***Dry dust collection devices***
***Аппараты для сухого улавливания пыли***

| Group of equipment | Type of apparatuses | Scope of application | |
|---|---|---|---|
| | | of air filters | of dust collectors |
| Gravity | Hollow | – | + |
| | Shelf | – | + |
| Inertial | Chamber | – | + |
| | Louver | – | + |
| | Cyclone | – | + |
| | Rotary | – | + |
| Filtration | Fabric | – | + |
| | Fibrous | + | – |
| | Granular | – | + |
| | Mesh | + | – |
| | Sponge | + | – |
| Electric | Single-zone | – | + |
| | Two-zone | ++ | + |

Table 6

***Wet dust collection devices***
***Аппараты для улавливания пыли мокрым способом***

| Group of equipment | Type of apparatus | Scope of application | |
|---|---|---|---|
| | | of air filters | dust collectors |
| Inertial | Cyclone | – | + |
| | Rotary | – | + |
| | Scrubber | – | + |
| | Impact | – | + |
| Filtration | Mesh | + | – |
| | Foam | – | + |
| Electric | Single-zone | – | + |
| | Two-zone | ++ | + |
| Biological | Biofilter | – | + |
| Note. The «+»sign means recommended; the « – » sign means not recommended. | | | |

For sanitary cleaning of air and gas flows from various suspended particles can be divided into two categories: for «dry» and «wet» cleaning. «Dry» (Table 5) and «wet» (Table 6) methods of dedusting are divided into groups by design.

The concept of modern separators for capturing suspended particles in the air [25 – 27] is based on various technological dust collectors divided into classes by particle size capable of efficiently capturing (Table 7). This classification contributes significantly to the selection of means for capturing and depositing dust.

Table 8 shows data on the hydraulic resistance of dust collectors, which is an energy parameter that greatly facilitates the selection of suitable equipment for sys-

Table 7

***Classification of dust collectors by the size of effectively captured particles***
***Классификация пылеуловителей по размеру эффективно улавливаемых частиц***

| Separator class | I | | II | | III | | IV | | V |
|---|---|---|---|---|---|---|---|---|---|
| Minimum size of effectively trapped particles, microns | 0.3 | | 2 | | 4 | | 8 | | 20 |
| Dust group by dispersion | V | IV | IV | III | III | II | II | I | I |
| Median particle diameter, microns* | less1 | 1...10 | 1...10 | 10...40 | 10...40 | 40...120 | 40...120 | more than 120 | more than 120 |
| Maximum cleaning degree, % | 80 | 80...99 | 45...92 | 92...99 | 80...99 | 99...99.9 | 95...99.9 | more than 99.9 | more than 99 |
| * Note: The dust group and the corresponding particle size that can be captured with the maximum degree of purification in this separator class. | | | | | | | | | |

Table 8

***Energy parameter of dust collectors***

***Энергетический параметр пылеуловителей***

| Indicators | Dust collectors | | | | | Filters | |
|---|---|---|---|---|---|---|---|
| | gravity | centrifugal | | wet | | fabric | electric |
| | | low-pressure | medium | pressure | low-pressure high-pressure | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Hydraulic resistance, Pa | up to 100 | 100 – 300 | 750 – 1250 | 750 – 1500 | 5000 – 12 500 | 750 – 1500 | 100 – 400 |

tems for cleaning air and gas emissions from suspended particles.

Simple methods of handling the emissions of modern production processes are also not likely to provide an adequate degree of cleaning to prevent significant environmental damage.

For example, in an electrofilter, an important role is assigned to hydraulic resistance, as it contributes to determining the required fan pressure and, consequently, power consumption.

In turn, the power consumption depends more on the hydraulic resistance of the process equipment. Electricity in the electrofilter is mainly consumed when an electrostatic field occurs. At the same time, the power consumed during single-stage cleaning varies within the following limits (0.035 – 1.0 kWh per 1000 $m^3$ of air).

Recently, to determine the efficiency of cleaning and trapping devices, the specific energy consumption of the process has been used as one of the important indicators of the process, the costs of which are spent on a certain process by a number of methods for dedusting and deposition. Thus, the energy balance indicator, by analogy with the efficiency coefficient, is used in the so-called energy efficiency:

$$n = \frac{E_n}{E}, \quad (1)$$

where $E_n$ is the useful energy used. $E$ is all the energy used in the dedusting process.

This approach does not take into account thermodynamic losses associated, for example, with the non-opacity of the actual thermal process accompanying the dedusting process. Therefore, the assessment of dedusting systems by energy efficiency cannot always be considered justified.

The most reliable method for estimating energy consumption for achieving the required dust collection efficiency is the energy parameter:

$$E_n = \frac{DR}{n_{fr}}, \quad (2)$$

where $DR$ is the hydraulic resistance of the dedusting process (dust collector); $n_{fr}$ – fractional efficiency of dust capture from the air.

Thus, the main economic component of air purification from dust is its cost, which may differ significantly depending on the technological equipment. And the more efficient the dust cleaning is, the higher the economic costs for it will be. For example, if we compare the economic indicators of the cost of dust cleaning a certain amount of air in a relatively simple device, for example in a high-performance cyclone, and take it as a coefficient of 1.0. Then the similar cost of dust cleaning of a similar volume of air in a battery–type cyclone will have a coefficient of 1.2. In a cyclone using a water film – 1.3. In a cyclone of a type B scrubber type VTI – 1.4. In an electrofilter it will be 2.2. When using bag filters (depending on the type of fabric) in the range of 2.6 – 2.8. In the conditions when using a two-stage cleaning in the cyclone battery-type system, the cost coefficient will be 3.3.

## Conclusions

From the analysis of the current state of the environmental problem created by man-made activities of industrial enterprises that have a negative impact on the environment and public health, it follows that:

- The creation of low-waste technologies at each stage of production (extraction, processing, transportation and main production) depends on the ecological and economic perfection of the equipment;
- The lack of a modern machine-building base for production branches dictates the need for environmental modernization of the currently used equipment (unit, apparatus, machine or technological line);
- In world practice, there is no methodology for environmental modernization (improvement) of a technological unit (apparatus, machine or in combination);
- Based on the fact that environmental modernization is a new direction in the field of environmental engineering, accordingly, there is a need to develop the most optimal global integrated approach to research.

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