Environmental and Economic Advantages of Disposal of Phosphoric Industry Waste

Maxat SHANBAYEV1, Khalima TURGUMBAYEVA2, Dagnija BLUMBERGA3, Aziza AIPENOVA4, Tuleuzhan BEISEKOVA5

1,2Satbayev University, 22 Satpayev Str., Almaty, Republic of Kazakhstan
3Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV-1048, Latvia
4Suleyman Demirel University, 1/1 Abylai khan Str., Almaty region, Kaskelen city, Republic of Kazakhstan
5Almaty University of Power Engineering and Telecommunications, Baitursynuly street 126/1, Almaty, Republic of Kazakhstan

Abstract - The article presents the types and classification of waste from the phosphorus industry of the Zhambyl region of the Republic of Kazakhstan. Waste is classified by its use as recyclable materials for construction materials. The results of a comparative assessment of the physical, chemical and structural properties of the phosphorus industry waste are presented. The article shows that all studied types of waste have astringent properties and can be used as building materials. In this work, a study of the properties of large-tonnage wastes of the phosphorus industry was carried out: 1) electrothermophosphoric granular slag (granulated slag); 2) phosphogypsum; 3) overburden. A technology has been developed for producing non-fired binders from waste of the phosphorus industry and a methodology for designing the composition of raw mixtures of multicomponent building composites has been proposed.

Pilot tests and calculation of technical and economic indicators have been carried out, which have shown the economic feasibility of producing a non-firing binder for the construction industry from phosphorus production waste.

Keywords – Binders; construction composites; phosphogypsum; recycling; technogenic waste

1. INTRODUCTION

World experience shows that construction is one of the most material-intensive industries that require an expansion of the range of binders and building mixtures used, the main components of which can be a variety of industrial waste products. To solve the above problems, it is preferable to use local man-made materials - waste of phosphorus production, such as phosphoric slag, phosphogypsum, as well as overburden from phosphorite mining [1]–[8].

In the development of industrial production, one of the leading places is occupied by the problem of environmental protection and rational use of raw materials. These problems are especially acute at phosphorus production enterprises [9].

The Republic of Kazakhstan has huge reserves of phosphorite ores, concentrated mainly in the bowels of the Karatau basin, located in Zhambyl and partly in South Kazakhstan regions. Here, up to 50 phosphorite deposits have been identified with recorded balance reserves in the amount
of 5 billion tonnes of ore and about 1.2 billion tonnes of phosphorus pentoxide ($P_2O_5$). Therefore, in recent years, the phosphorus industry has been one of the most promising and financially stable sectors of the chemical complex of the Republic of Kazakhstan. But this development of the industry has negative features in the form of the generated large-tonnage waste of the phosphorus industry.

Currently, more than 40 million tonnes of this waste have been accumulated in the Zhambyl region, which occupy vast areas and have a negative impact on environmental components and affect the ecological and economic state of society. The volumes of technogenic waste in the dumps are: phosphogypsum (stale, dumps of the plant LLP ‘Kazphosphate’ Mineral fertilizers – MU) ~8.5 million tonnes; granulated phosphoric slag (Zhambyl branch of Kazphosphate LLP, Novodzhambul phosphoric plant – NDFZ) ~10–12 million tonnes; overburden (deposits of phosphorite ores of Karatau) ~20 million tonnes.

To solve the problems associated with the disposal of accumulated and newly formed wastes of the phosphorus industry, a preliminary analysis was carried out for the main types of target products of the phosphorus industry (phosphorus-containing fertilizers, phosphoric acid, yellow phosphorus) associated with the formation of waste. The results of systematization of industrial waste in the Zhambyl region in terms of accumulation volumes made it possible to identify the emerging waste market and the possible volumes of their involvement in economic circulation as raw materials in the production of construction materials.

The importance of using industrial waste is determined by the following factors: solving the problem of environmental protection; release of land plots occupied by dumps; improvement of the ecological situation and public health.

The use of industrial waste in the construction industry will reduce the needs of this industry for natural raw materials and provide production with a source of cheap and already prepared raw materials.

The possibility of using man-made waste in the production of building materials is considered on the basis of a comprehensive study of their composition, physicochemical, mineralogical and toxicological properties [10].

The purpose of this study is to implement scientific and technical solutions for the disposal of industrial solid waste in the production of building materials.

2. METHODS AND METHODOLOGY

A comprehensive study of their composition, physicochemical, mineralogical and toxicological properties is considered for the development of a technology for the complex processing and use of industrial waste in the production of building materials.

The chemical composition of waste is determined using standard methods of physicochemical and chemical quantitative analysis in accordance with state standard 20851.2-75; state standard 20851.3-93; state standard 20851.4-75 [11], [13].

During the analysis, the content of the following compounds is determined in the waste: $SO_3$, $SiO_2$, $CaO$, $MgO$, $Fe_2O_3$, $P_2O_5$, $Al_2O_3$, $F$, $Na_2O$.

For research, we use measuring instruments (SI) that have passed the verification: Photoelectric concentration colorimeter KFK-2; Laboratory ionomer EV-74; Flame photometer FLAPHO-4; Laboratory scales ‘VLR-200’; Atomic absorption spectrophotometer AAS-3 [14].

X-ray phase analysis of phosphogypsum is carried out on an automated DRON-4 diffractometer based on the diffractograms of powder samples using the method of equal portions and artificial mixtures. Interpretation of diffraction patterns is carried out using data from the
ASTM Powder diffraction file and diffraction patterns of minerals clean from impurities (gypsum, quartz, calcium phosphates) [15].

The study of the specific effective activity of natural radionuclides in samples of industrial waste is carried out according to the method of measuring the activity of radionuclides using a Progress BG scintillation gamma spectrometer. The measurement results are compared with the level of effective specific activity established by the Sanitary Rules.

3. RESULTS AND DISCUSSION

3.1. Investigation of the physicochemical, mineralogical and toxicological properties of the phosphorus industry waste in the Zhambyl region

Waste from the production of phosphorus and phosphoric acid (phosphoric slags and phosphogypsum) is a large-tonnage waste of the chemical industrial complex.

When mining phosphorus ores, huge masses of overburden are also formed, which are limestones, dolomites, sands, clays, shales with admixtures of sulphur and phosphorus, which enter the overburden dumps and are currently practically not used.

The project investigated the properties of large-tonnage waste of the phosphorus industry: 1) electrothermophosphoric granular slag (granulated slag); 2) phosphogypsum; 3) overburden.

Based on the analysis of the experimental results, it was shown that the main wastes of phosphorus production (granulated slag and phosphogypsum) have an almost constant composition regardless of the place and time of sampling at the dumps.

In all the wastes selected for the study, the main components are calcium and silicon oxides, in some wastes there are aluminium and iron oxides, which play an important role in the technology of producing building mixtures (Portland cement, alumina cement, glass, fine ceramics, etc.).

The results of X-ray phase analysis showed that these wastes are mainly represented by minerals containing calcium and magnesium oxides, which will make it possible to use the waste of the phosphorus industry in the production of building materials and mixtures.

When choosing wastes from the phosphorus industry as a raw material for the production of building materials, their compliance with the standards for the content of radionuclides was investigated [16]. The sanitary-epidemiological conclusion confirmed the possibility of using this waste as a mineral raw material for all types of building materials without restrictions, since the total specific activity of radionuclides for each type of waste did not exceed 370 Bq/kg, which meets the requirements of the Sanitary Rules and Regulations.

3.2. Development of a design methodology for the composition of raw mixes of building materials

The work carried out research on the mathematical modelling of the compositions of new building composites containing such raw materials as phosphogypsum dihydrate, granular phosphorus slag, limestone, phosphate-clay shale, and phosphate-siliceous shale [17], [18]. The presence of oxides CaO, SiO₂, Al₂O₃ in a certain ratio determines the hydration properties of raw materials that can be used as binding mixtures.

To determine the optimal composition of the basic oxides that make up the binders, it was proposed to use the diagram of the CaO – SiO₂ – Al₂O₃ system (Rankin diagram) as a technical model. The CaO – SiO₂ – Al₂O₃ system plays an important role in the technology for the production of Portland cement, alumina cement, fireclay and high-alumina refractories, glass, fine ceramics, since the diagram gives an idea of the quantitative composition of CaO, SiO₂,
Al₂O₃ oxides, which have a major effect on the hydration and hardening processes in building binders.

The design methodology is that the initial composition of the main four oxides CaO, SiO₂, Al₂O₃, Fe₂O₃, which are part of the components of the designed composites, must be reduced to the composition of the oxides CaO, SiO₂, Al₂O₃, Fe₂O₃ of Portland cement, as a binder with high physical and mechanical characteristics. The basis also includes iron oxide Fe₂O₃, which forms calcium hydroferrites in the process of hydration, increasing the density and strength of the resulting binders. Other oxides besides the mentioned four oxides are not considered, since they have the least effect on the physical and mechanical characteristics of the resulting binder and hydration processes [19].

Table 1 presents the results of designing compositions of three new building composites: composite 1: phosphate-clay shale – phosphogypsum – limestone.

As an activator, Portland cement was introduced into the composite in an amount of 5 % of the total mass of the mixture, which today of all binder materials has the best physical, mechanical and technical characteristics. The results of the calculation showed that for this composite, the quantitative composition of the oxides of the raw components (wt. %) is closest to the quantitative composition of the oxides of Portland cement.

Table 1. Results of calculation of the charge composition of new building composites

| Waste from the phosphorus industry of the Zhambyl region of the Republic of Kazakhstan | Standard Estimated values of the oxides of the raw mixture of the designed binder, reduced to the values of the standard |
|-----------------------------------------------|---------------------------------------------------|
| Oxides                  | Phosphate-clay shale | Phosphogypsum | Limestone | Portland cement | |
| CaO                    | 5.18                 | 64.56         | 91.62     | 67.52           | 67.52       |
| Al₂O₃                  | 4.28                 | 1.10          | 0.21      | 5.6             | 4.9         |
| SiO₂                   | 86.87                | 32.4          | 2.02      | 23.3            | 23.3        |
| Fe₂O₃                  | 3.67                 | 1.94          | 6.15      | 3.56            | 3.56        |
| Share values of composites in binder          | 7.11                 | 50.49         | 37.71     | 4.67            | 95.3 ~ 100  |

Analysis of Table 1 showed that the chemical composition of the composite mixture from the waste of the phosphorus industry of the Zhambyl region is as close as possible to the chemical composition of the standard: Portland cement in the CaO, SiO₂, Al₂O₃, Fe₂O₃ system. Moreover, the program selected such a composition of the components of the projected binder, in which the content of oxides CaO, SiO₂, Fe₂O₃ is 100 % identical to the standard. In general, the composition of the chemical oxides of the raw mixture is close by 95.3 % to the chemical composition of the main oxides of Portland cement.

Based on the decision of the program (table 1), the composition of raw materials for the projected binder was determined in the following proportions: phosphate-clay shale – 7.11 %; phosphogypsum – 50.49 %; limestone – 37.71 %.

3.3. Experimental-industrial tests for obtaining building mixtures and study of their physical and mechanical properties

The process of obtaining non-firing mineral binders was carried out according to the developed technology. During the tests, a building composite was obtained in the form of a moulding plaster test, which was poured into special moulds 40x40x160 mm in size to obtain beam samples (Fig. 1).
Fig. 1. Obtained beam samples from waste.

After the beams hardened (after 28 days), studies were carried out on the physical and mechanical characteristics of non-fired binders obtained from the waste of phosphorus production.

With the obtained non-fired binders, which are crushed samples of beams, a number of tests were carried out according to the methods of state standard 23789-79 ‘Gypsum binders’ [20] and the grade of gypsum binder was determined according to state standard 125-79 [21].

The ‘water-gypsum ratio’ indicator was determined according to state standard 23789-79 p. 4.1-3.

The value of the ratio of gypsum: water (G:W) = 1:0.065.

The preparation of the gypsum dough of standard consistency at the above values of the ratio G:W and the determination of the setting time was carried out in accordance with state standard 23789-79 ‘Plaster binders’ clause 4.4-6.

On the Vika device, experiments were carried out to determine the time of the beginning and end of the setting of a plaster dough of standard consistency.

The obtained values of the time of the beginning and the end of the setting of the gypsum dough obtained from non-fired binders (composites 1) were compared with the requirements of state standard 125-79 (Table 2).

TABLE 2. VALUES OF BINDING TIME

| Name of the gypsum binder | Index of hardening terms | Setting times, min |  |
|--------------------------|--------------------------|--------------------|---|
| Fast hardening (state standard 125-79) | A | Not earlier than 2 | Not later than 15 |
| Normally hardening (state standard 125-79) | B | Not earlier than 6 | Not later than 30 |
| Slowly hardening (state standard 125-79) | C | Not earlier than 20 | Not standardized |
| Composite 1 | C | 30.0 | 135.0 |

Tests of binder samples to determine the compressive and flexural strength were carried out on standard samples of beams 40×40×160 mm in accordance with state standard 23789-79 ‘Gypsum binders’ (Table 3).
TABLE 3. RESULTS OF STRENGTH TESTS OF BEAMS MADE FROM PHOSPHOGYPSUM BINDER

| Indicators                              | Composite 1 | Required state standard for brand G-4 |
|-----------------------------------------|-------------|---------------------------------------|
| Tensile strength bending, MPa           | 2.2         | Not less than 2.0                     |
| Tensile strength in compression, MPa    | 4.0         | Not less than 4.0                     |

Thus, a sample of a non-firing binder obtained from phosphorus production waste should be classified as a slowly hardening gypsum binder, and the strength of standard beams in bending and compression corresponds to the G-4 gypsum binder [22].

4. ECONOMIC EFFICIENCY

4.1. Technical and economic efficiency of obtaining non-fired binders from waste of phosphorus production.

This section presents the comparative performance indicators of two sites for the production of binders from various raw materials: site No. 1 from natural gypsum raw materials and site No. 2 from phosphorus industry waste.

The main performance indicators of conditionally operating industries (No. 1 and No. 2) and operating costs are presented in Table 4 and Table 5.

TABLE 4. MAIN INDICATORS OF WORKING CONDITIONALLY WORKING PRODUCTION

| Name                                         | Unit measurement          | Sales of binder                 |
|----------------------------------------------|----------------------------|---------------------------------|
| Average production per day                   | tonnes per hour           | 5                               |
| Average production per day                   | tonnes                     | 38                              |
| Average sales volume per day                 | tonnes                     | 28                              |
| Average profit (commercial cost)             | thousand tenge/ton         | (14.0–2.353) = 11.647           |
| Average selling price of non-fired binder    | thousand tenge/ton         | 2.353                           |
| USD exchange rate                            | tenge/USD                  | 417                             |
| Number of days in the estimated month        | days                       | 26                              |

When calculating the items of expenses related to the wages of the main personnel of the working people, we accept the work of section No. 2 – one-shift; recommended staffing table is presented in Table 6.

Calculation of the production cost of 1 tonne of non-fired binder produced at site No. 2 from the waste of phosphorus production:

The production cost is calculated as the sum of the unit costs in monetary terms for the purchase and transportation of raw materials, the cost of energy resources when processing raw materials, as well as salary costs.

When summing up the above listed costs, we get the average profit – the commercial cost \( C_{\text{com}} \) of the product (non-fired binder from phosphorus production waste) equal to 14000–2352.9 = 11 647 tenge/tonne. For comparison, the market value of natural gypsum is 14 000 tenge/tonne.
### Table 5. Operating Costs of Conditionally Working Area

| Name                        | Unit measurements | Total     |
|-----------------------------|-------------------|-----------|
| **Productive capacity:**    |                   |           |
| Working hours               | hour              | 8         |
| Work days                   | day               | 26        |
| Reduction factor            |                   | 0.7       |
| **Fare**                    |                   |           |
| Transportation cost per 1 ton | tenge / ton     | 300       |
| Transportation cost per year | thousand tenge / year | 2489.76 |
| **Electricity**             |                   |           |
| Average power consumption   | kW                | 4         |
| Working hours               | hour              | 8         |
| Work days                   | day               | 26        |
| Cost of 1 kWh               | tenge             | 22.00     |
| Total cost of electricity   | thousand tenge / year | 329.472  |

### Table 6. Staff List of Key Personnel

| Position                                  | Number of employees | Salary per month, thousand tenge | Amount of wages/year, thousand tenge/year |
|-------------------------------------------|---------------------|----------------------------------|------------------------------------------|
| Foreman (foreman) shift                   | 1                   | 150.0                            | 1800.0                                   |
| Operators of receiving and preparing raw materials | 1                   | 100.0                            | 1200.0                                   |
| Shift duty locksmith, electrician         | 1                   | 100.0                            | 1200.0                                   |
| Technician-technologist                   | 1                   | 140.0                            | 1680.0                                   |
| **Total:**                                | **4**               |                                  | **5880.0**                               |

The production cost and the forecast of income and expenses for the year are presented in Table 7 and Table 8.

Due to systematic fluctuations in prices and rates for services, the calculations presented in this section cannot be considered final. However, they can serve as a basis for the development of an algorithm for calculating the production cost of a non-fired binder from the waste of the phosphorus industry.

### Table 7. Production Cost for the Year

| Name                                                   | Unit measurement      | Total     |
|--------------------------------------------------------|-----------------------|-----------|
| Average purchase price of waste (phosphogypsum, overburden, granulated slag) | tenge / tonne         | 1000      |
| Average sales volume per year                          | tonnes                | (28·26·12) = 8736.0 |
| Average annual consumption                             | tonnes                | (38·26·12) = 11 856.0 |
| Average cost of consumed non-fired binder              | thousand tenge / year | (988·1000·12) = 11 856.0 |
| Average cost of transportation of products per year    | thousand tenge / year | 2489.76   |
| Total direct costs per year (prime cost)               | thousand tenge / year | 20 555.28 |
| Total direct costs per 1 ton:                          | tenge / tonne         | 20555.28/8736.0 = 2352.9 |
TABLE 8. PREDICTION OF THE COST OF PRODUCTION OF ANNOUNCED BINDER FROM WASTE OF PHOSPHORIC PRODUCTION

| Name                                                      | Amount per year, thousand tenge / year |
|-----------------------------------------------------------|----------------------------------------|
| Income from sales of products at site No. 1               | (8736.0 ∙ 14.00) = 122 304.0           |
| Cost of sales (non-fired binder) at site No. 2             | 20 555.28                              |
| Gross profit                                              | 122 304.0 − 20 555.28 = 101 748.72      |

**Expenses**

**Administrative expenses:**

| Item                                | Amount          |
|-------------------------------------|-----------------|
| Wages                               | 5880            |
| Electricity                         | 329.47          |
| Rent                                | 1200.00         |
| Security                            | 720.00          |
| Fuels and lubricants for own needs  | 240.00          |

**Total expenses**

8369.472

**Net profit**

101 748.72 – 8 369.472 = 93 379.248

**Net profit, thousand USD per year**

38 939.146

As the results of the calculation show (Table 9), the expected profit from the work of section No. 2 will be 93 379.248 thousand tenge per year, or 38 939.146 thousand US dollars per year.

Thus, the performed technical and economic calculations have shown the economic feasibility of producing a non-fired binder for the construction industry from the waste of phosphorus production.

4.2. Environmental and economic assessment of environmental protection measures for the disposal of phosphorus production waste

The assessment of the economic efficiency of environmental protection measures is determined by comparing environmental costs with the amount of prevented environmental damage.

The work calculates the costs of environmental protection measures associated with the use of waste from the phosphorus industry as raw materials for the production of building materials.

The introduction of this measure will significantly reduce the volume of waste disposed of on dumps and having a negative impact on environmental components due to dusting and blowing off pollutants from the surface of the dumps. Phosphogypsum, which is a finely dispersed material, is especially dangerous in this regard.

Dusting from the dump increases under unfavourable weather conditions, especially when the wind speed increases to 10–15 m/s, which is typical for almost the entire territory of South Kazakhstan.

To calculate the effectiveness of environmental protection measures, the following main economic indicators are determined: one-time costs associated with the implementation of a technical measure (capital investments), changes in current operating costs.

Calculation of prevented environmental damage:

For calculations, we take the dusting of phosphogypsum from the dump of the mineral fertilizers plant Kazphosphate LLP (Table 9).

The calculation of the amount of harmful substances emitted during dusting is determined by Eq. (1):

\[ M_\theta = k \cdot q_{\text{spec}}^{n} \cdot A \left( 1 - \eta' \right), \]  

(1)
where

\( K \) a dimensionless coefficient that considers the gravitational settling of harmful substances (for solid particles it is taken equal to 0.16; for gases – 1.0);

\( q_{\text{spec}}^n \) specific blowing off of dust from the surface of open dumps (mg/m²s) at wind speed (m/s);

\( A \) the amount of pollutants escaping from the emission source, t/year;

\( \eta' \) coefficient of efficiency of the means of dust and gas suppression, dol. units, which was taken equal to 0.6.

To calculate the prevented damage according to Table 9, we select open dumps with a dusty surface at an average wind speed of 6–8 m/s, then the specific dust blowing will be equal to 25 mg/m²s.

**TABLE 9. INDICATORS OF DUST BLOWING OUT FROM DUSTY SURFACES**

| Place of dusting | Specific dust blowing, mg/m²s, at wind speed, m/s | up to 4 | 6–8 | 10 |
|------------------|-----------------------------------------------|--------|-----|----|
| Surface open dumps | Moderately dusty | 0.4 | 18 | 100 |
| | Dusty | 0.6 | 25 | 200 |
| | Extremely dusty | 1.0 | 50 | 350 |
| Surface of waste dumps | Freshly filled | 1.0 | 9 | 15 |
| | 3 months after filling | 0.6 | 5 | 8 |
| Surface of tailing ponds | Tailings moisture content 4 % | 2.8 | 1300 | 400 |
| | Tails with moisture content 4–6 % | 1.8 | 35 | 60 |

According to Table 10, we determine the amount of pollutants A escaping from the source of emission – we select inorganic dust (111.7605 t/year – the permitted regulatory emission).

**TABLE 10. LIST OF POLLUTANTS RELEASED INTO THE ATMOSPHERE FROM THE SURFACE OF THE PHOSPHOGYPSUM DUMP**

| Contaminant code | Substance A | Substance Name | Pollutant Emission, g/s | Pollutant Emission, t/year |
|------------------|-------------|----------------|-------------------------|--------------------------|
| 2914 phosphogypsum dump | Inorganic dust | 7.4040 | 111.7605 |

The amount of inorganic dust blown off from the surface of the phosphogypsum dump is calculated according to Eq. (2):

\[
M_{\text{dust}} = 0.16 \cdot 25 \cdot 111.7605 \cdot (1 - 0.6) = 178.81 \text{ t/year.}
\]

Payment for emissions into the environment carried out by users of natural resources within the limits of the standards specified in the environmental permit is charged according to the list of pollutants and waste types approved by the Government of the Republic of Kazakhstan.

The amount of prevented damage from the emission of pollutants into the atmosphere is determined by Eq. (3):

\[
\Delta Y = P \cdot K_1 \cdot K_2 \cdot M_{\text{ave}} \text{ (thousand tenge/year),}
\]

where
$P$ — rate of payment for emissions of pollutants into the atmosphere, MCI/tonne;

K1 multiplicity factor equal to 10;

K2 multiplicity factor, taking into account the environmental hazard of pollution;

$M_{\text{ave}}$ is the averted mass of the emission of the $i$-th pollutant as a result of the implementation of an environmental measure, equal to the difference in the mass of emissions before and after the implementation of the environmental measure.

The results of calculating the prevented damage are presented in Table 11.

| Contamination code | Substance | $M_i$ before, t/year | $M_i$ after, t/year | Payment rate, MCI/tonnes | Prevent. damage, thousand tenge/year |
|--------------------|-----------|----------------------|----------------------|--------------------------|------------------------------------|
| 2914 dump          | Inorganic dust | 178.81               | 85.52                | 5·2269                   | 10 583.75                          |

* Note - when calculating K1, it was taken equal to 10; K2 = 1; Monthly calculation index, MCI = 2269 tenge

Calculation of the indicator of the absolute economic efficiency of environmental solutions.

Considering the magnitude of the prevented economic damage, it is possible to determine the absolute efficiency of capital investments in the implementation of environmental protection measures – utilization of waste from the phosphorus industry.

The absolute efficiency of capital investments in environmental protection measures is determined by Eq. (4):

$$E_p = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} (\mathcal{E}_{ij} - C)}{K},$$  (4)

where

- $E_p$ indicator of the overall economic efficiency of capital investments in environmental protection measures;
- $\mathcal{E}_{ij}$ result (effect) of nature protection measures of the $i$-th type at the $j$-th object. When solving a single-purpose task to prevent or reduce the negative impact of the object on the natural sphere, $E_{ij}$ is equal to the value of the annual prevented damage to the environment ($\Delta V_{ij}$), which amounted to 10 583.75 thousand tenge/year, considering the impact of only one of the wastes of the phosphorus industry – phosphogypsum;
- $C$ annual operating costs for maintenance of fixed assets of environmental protection, i.e. the cost of production of building materials from phosphorus waste at site No. 2 is 20 555.28 thousand tenge/year;
- $K$ capital expenditures for environmental protection measures were taken on the basis of the construction of similar production sites and were estimated at 600 000 thousand tenge.

When solving a multipurpose task in the process of implementing environmental measures based on the use of waste as a secondary raw material in the production of building materials, an increase in income $E_{ij}$ can be obtained, which will be equal to the sum of $\Delta V_{ij}$ and $\Delta D$.

Table 8 calculated the expected profit ($\Delta D$) from the operation of site No. 2 for the production of building materials from phosphorus production waste, which amounted to 93 379.248 thousand tenge per year. Thus, the expected effect of environmental protection measures – $E_{ij}$ will be: $\mathcal{E}_{ij} = \Delta V_{ij} + \Delta D = 10 583.75 + 93 379.248 = 103 962.99$ thousand tenge/year.

To assess the feasibility of introducing measures, it is proposed to compare $E_p$ with the standard coefficient of the efficiency of capital investments – $E_n$, which for environmental protection measures is taken equal to 0.12. If $E_p$ is greater than or equal to $E_n$, the environmental measure is recognized as cost-effective: $E_p = (103 962.99 – 20 555.28) / 600 000.0 = 0.14$
Since $E_p$ is greater than 0.12, therefore, the use of phosphorus production waste as a raw material for the production of building materials is cost-effective (Table 12).

**TABLE 12. RESULTS OF TECHNICAL AND ECONOMIC CALCULATIONS**

| Indicators               | Measurement units | Indicator values |
|-------------------------|-------------------|------------------|
| Capital investments, $K$ | thousand tenge    | 600 000.00       |
| Operating costs, $C$     | thousand tenge    | 20 555.28        |
| Prevented damage, $\Delta V_j$ | thousand tenge | 10583.75         |
| Absolute economic efficiency ratio, $E_p$ |              | 0.14             |

Thus, the introduction of environmental protection measures will significantly improve the environmental situation in the dumping area at the enterprises of Kazphosphate LLP, in particular, by reducing the area of dusty surfaces [10].

5. **CONCLUSIONS**

Summary of the results:
- Carried out systematization of wastes from the phosphorus industry in the Zhambyl region of the Republic of Kazakhstan in terms of possible areas of their use, as well as a comprehensive study of their composition, physicochemical, mineralogical and toxicological properties, which made it possible to establish the expediency of using these wastes in the production of building materials.
- A systematic approach to designing the composition of a multicomponent mineral binder made it possible to obtain composite materials of complex structure (composites 1), consisting of mineral materials (waste) with different properties and acquiring a complex of new properties as a result of their combination.
- Investigation of the physical, mechanical and strength characteristics of the phosphogypsum binder obtained from the waste of phosphorus production, showed that the samples of the non-fired binder can be classified as slowly hardening gypsum binder. The results of strength tests (for compression and bending) of standard beams made of binder showed their compliance with the requirements of state standard for gypsum binder grade G-4.
- Calculation of technical and economic indicators for obtaining non-fired binders from phosphorus production wastes has been carried out. The calculation results showed that the production of a non-fired binder for the construction industry from the waste of phosphorus production is economically feasible.
- An ecological and economic assessment of environmental protection measures for the disposal of phosphorus production wastes was carried out by comparing environmental costs with the amount of prevented damage to the environment. It is shown that the introduction of environmental protection measures is cost-effective, since it will significantly improve the environmental situation in the area of dumps at the enterprises of Kazphosphate LLP, in particular, by reducing the area of dusty dump surfaces.

**ACKNOWLEDGMENT**

The main sections of the work were carried out within the framework of a scientific project ‘Disposal of waste from the phosphorus industry to obtain multipurpose products for the construction industry’ (state registration number: 0115RK01932) approved by the State Institution ‘Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan’.
REFERENCES

[1] Mirsaev R. N., Akhmadulina I. I., Babkov V. V., Nedoseko I. V., Gaitova A. R., Kuzmin V. V. Gipsoshlakovyye kompozitsii izotkhodov promyshlennosti v stroitel'nykh tehnologiyakh. (Gypsum slag compositions of industrial wastes in building technologies). Construction Materials 2010:7:4–6. (In Russian).

[2] Bishimbaev V. K., Zhekeev M. K., Dmitrievsky B. A., Zhekeev R. M. Ekologicheskiye aspekti elektrotermicheskoy pererabotki fosfata. (Environmental aspects of electrotermal processing of phosphates). Chemical technology 2011:5:307–313. (In Russian).

[3] Dvorkin L. I., Dvorkin O. L., Mironenko A. V., Kundos M. G. Sul'fatno-shlakovyye vyazhushcheye povysshennykh prichnosti i dolgovechnosti. (Sulfate-slag binders with increased strength and durability). Dry construction mixtures 2011:3:36–38. (In Russian).

[4] Karpovich E. A., Vakal S. V., Zolotarev A. E. Otrabotka promyshlennogo varianta tekhnologii pererabotki fosfogipsa na gipsovoye vyazhushcheye. (Development of an industrial version of the technology for processing phosphogypsum into a gypsum binder). Mater. XVI international scientific Conference ‘Ecology and human health. Protection of air and water basins. Recycling’. Kharkiv: UKSTC Elektrostal 2008:2:234–238. (In Russian).

[5] Huang Y., Lin Z. A binder of phosphogypsum-ground granulated blast furnace slag-ordinary portland cement. J. Wuhan Univ. Technol. Mater. Sci. Ed. 2011:3(26):548–551. https://doi.org/10.1007/s11595-011-0265-6

[6] Martinez-Aguilar O. A., Castro-Borges P., Escalante-Garcia J. I. Hydraulic binders of Fluorgypsum Portland cement and blast furnace slag. Stability and mechanical properties. Construction and Building Materials 2010:24(5):631–639. https://doi.org/10.1016/j.conbuildmat.2009.11.006

[7] Huang Y., Lin Z. Investigation on phosphogypsum steel slag granulated blast-furnace slag limestone cement. Construction and Building Materials 2010:24(7):1296–1301. https://doi.org/10.1016/j.conbuildmat.2009.12.006

[8] Chernysheva N. V., Sverguzova S. V., Tarasova G. I. Polucheniye gipsovogo vyazhushchego iz fosfogipsa Tunisa. (Obtaining a gypsum binder from phosphogypsum of Tunisia). Building Materials 2010:7:28–30. (In Russian).

[9] Tleuov A. S., Kulakhmet A. M., Tleuova S. T., Altybaev J. M., Shanbayev M. Zh. Utilizatsiya otkhodov fosfornoy promyshlennosti s polucheniyem mnogotselevyye produktov dlya stroitel'noy industrii. (Disposal of waste from the phosphorus industry to obtain multipurpose products for the construction industry). 2015–2017. (In Russian).

[10] Dvorkin L. I. Stoitel'noe materialy iz otkhodov fosfornykh promyshlennostey. Construction materials from industrial waste. Rostov: Phoenix 2007. (In Russian).

[11] Tleuov A. S., Kulakhmet A. M., Tleuova S. T., Altybaev J. M., Shanbayev M. Zh. Utilizatsiya teknogennykh otkhodov fosfornykh promyshlennostey. (Utilization of industrial waste produced by the phosphoric industry). Int. J. Chem. Sci 2016:14(4):2891–2910. (In Russian).

[12] Kaptysheva A. G., Bondarenko G. V. Proyektirovaniye sostava kompozitsionnogo bezobzhiogovogo vyazhushchego na baze tekhnogennykh otkhodov Cherepovetskogo promyshlennogo uzla i issledovaniye yego tekhnicheskikh karakteristik. (Designing the composition of a composite non-fired binder based on industrial waste from the Cherepovets industrial hub and a study of its technical characteristics). Chemical Industry Today 2011:11:37–41. (In Russian).

[13] Kurbatov I. M. Sovremennyye metody khimicheskogo analiza. State standard 20851.4-75 Mineral fertilizers. Methods for determination of water. State standard 20851.3-93 Mineral fertilizers. Methods for determination of pottassium content. State standard 20851.2-75 Mineral fertilizers. Methods for the determination of phosphates. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications. State standard 23789-79 Gypsum binders. Test methods. State standard 125-79 Gypsum binders. Specifications.