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Development of HSE Management CALS-System for Waste Utilisation of Phosphoric Industry of Russian Federation and Kazakhstan

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The problem of phosphoric industry waste utilisation is one of the important aspects of the environmental protection in Russia and Kazakhstan as well as in some other countries world-wide. Effective solution of this problem requires using of the system analysis methods and the most modern information technologies. Therefore, the main purposes of our work are: the system analysis of the influence of innovative activity for environmental characteristics of the phosphoric industry of Russia, and also the development of the information technology for the rational phosphoric industry waste utilization of Kazakhstan.
As a part of EC co-funded project ECOPHOS No. INCO-CT-2005-013359 had been developed of information technology tool for the HSE management of phosphoric industry of Russia and Kazakhstan based on CALS-concept (Continuous Acquisition and Life cycle Support). CALS-technologies (ISO 10303 standard) offer standardised software tool system for presentation of ecological information.

1. HSE management at the leading enterprises of the phosphoric industry of Russia

The phosphoric industry has been always in centre of the attention because of severe environmental concerns (Seferlis et al., 2006; Klemeš, 2010). Innovative activities of 165 enterprises of chemical industry were analysed for the period of 1995-2010 based on contracts for the Ministry of Industry of Russia (Bessarabov et al., 2009). Researches dealing with factorial analysis of innovative development influence on ecological policy (Bessarabov et al., 2010a) were included to the HSE management for 18 leading enterprises of Russian phosphoric industry (Ministry of Education and Science of Russian Federation; Contract no. 11.519.11.5005).
At the first stage, during the factorial analysis there were defined the values of correlation coefficients among several basic results of innovative activity. Also the most significant directions of activity of the enterprises of the phosphoric industry, influencing decrease of environmental pollution, were taken into account.
As the input parameters were chosen the results of innovative activity, which got the highest point marks according to the statistical data analysed by the authors team for 1995-2010: “Output quality improvement” (2.32 points), “Capacity growth” (1.99), “Compliance with modern technical regulations, rules and standards” (2.09), “Rising of production flexibility” (1.74).

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The output ecological parameters (Values of objective functions) were chosen. They included several environment-oriented innovative results as “Reduction of environmental pollution” (2.14 points), and also “Reduction of power expenses” (1.79) and “Reduction of material costs” (2.19) which are straight connected with it.
At the second stage factorial analysis for influence of material and energy resources economy for “Decrease of environmental pollution” was carried out.
As a result of calculation for parameter “Decrease of environmental pollution” following values of correlation coefficients (R_{ij}) were received: for “Output quality improvement” (R_{11} = 0.76), “Capacity growth” (R_{21} = 0.67), “Compliance with modern technical regulations, rules and standards” (R_{31} = 0.75) and “Rising of production flexibility” (R_{41} = 0.61).
On the basis of the conducted factorial analysis it is shown that with results of innovative activity of an environmental orientation most closely correlate the actions concerning quality of innovative production. Introduction of innovations for improvement of quality of production, and also application of the materials certificated under the international environmental standards, will allow to lower total amount of a waste. Carrying out of actions on HSE management of waste (Diwekar and Shastri, 2011) at leading enterprises of the phosphoric industry of Russia will allow reaching the least negative influence on environment.

2. CALS-system of HSE management for waste utilization for the phosphoric industry of Kazakhstan

Within the research of the phosphoric industry of Kazakhstan (Bessarabov et al., 2010b) directions of utilisation of the main phosphorus-containing waste for three leading enterprises were analysed: “Shymkentphosphor” (Chimkent), "Kazfosfat" (Dzhambul) and “Novodzhambulskiy Phosphoric Factory” (Taraz). Phosphoric slags and phosphogypsum with volume more than 10 Mt are stored in dumps of these phosphoric factories.
Under the influence of difference of temperatures, atmospheric influence, a moisture and a wind phosphoric slags and phosphogypsum, obtained during the production of inorganic and organic phosphate fertilizers (Rodrigues et al., 2011), are subject to gradual destruction with formation of dispersed dust and evaporation of toxic gases in the form of HF (Hydrogen Fluoride) and PH_3 (Phosphine). Propensity to water dissolution of fluorides and phosphines, containing in a waste, promotes infection for underground and surface water. According to investigation in underground waters of Taraz town the fluorine content is 8.2 – 8.4 mg/L, that is eight times exceed maximum concentration limit. The dust containing compounds of fluorine and phosphorus, also causes diseases of eyes, respiratory ways, promotes development of cardiovascular insufficiency, infection of kidneys, liver and stomach (Sims and Sharpley, 2005).
Removal of toxic substances from structure of initial raw materials is impossible or very difficult, and stocks of natural raw materials are rather limited. Therefore, obtaining of ecologically safe constructional materials from industrial wastes is a perspective direction for expansion of a raw-material base of the industry of constructional materials, development of manufacture, reduction of costs for production for building purposes, prevention of formation of new dumps and reduction of requirements for the equipment of new refuse dumps.
A prospective way of dealing with this waste is a production of road-constructional materials (asphaltic concrete). However due to the fact, that phosphoric slags and phosphogypsum represent the danger for human and environment, it is necessary to examine their contents (Table 1) and determine the degree of their radioactivity.

Table 1. Content of chemical and radioactive substances in phosphoric slag and phosphogypsum.

No.	Name of waste	Content, mg/kg					Effective specific activity, A_{eff}, Bk/kg
		Sr	Cd	As	Mn	Ti	
1	Phosphoric slag	812	412	212	2580	1286	174÷231
2	Phosphogypsum	823	515	254	2620	1395	34.4÷105

The research showed that phosphorus-containing waste includes such harmful elements as Sr, Cd, As, Mn, Ti and that they have some radioactive background. The complex estimation of ecological impurity of phosphoric slag and phosphogypsum is necessary for recommending their use. An indicator of ecological impurity defined according to the formula:

$$I_{ei} = \sum_{i=1}^{m} (m_i \bullet K_{pi}) + K \bullet \sum (m_g \bullet K_{xg}) \quad (1)$$

where m_i and m_g – mass proportions of radioactive and chemical polluting substances, accordingly, in one ton of raw materials; K_{pi} – coefficient of relative danger of natural radionuclides defined as: $K_{pi} = A_{eff}/370$; K – coefficient considering joint actions of various chemical pollutants; K_{xg} – coefficient of relative ecological and economical danger of the polluting substances. They have been defined according to the Technique of the State Committee of the Russian Federation on preservation of the environment.

Values of found indicators of environmental impurity, which consider mass portion of radioactive and chemical polluting substances in 1 t of raw materials, are in Table 2.

Table 2. Indicators of environmental impurity of phosphoric slag and phosphogypsum.

No.	Type of waste	$I_{ei\ min}$, %	$I_{ei\ max}$, %	$I_{ei\ avg}$, %
1	Phosphoric slag	1.02	1.4	1.21
2	Phosphogypsum	1.3	1.78	1.54

Results of analytical investigation for rare heavy metals, radioactive elements, etc. which are the components of waste, were included to the CALS-system (Figure 1), made according to the CALS concept (Saaksvuori and Immonen, 2010). There were developed the information category that included researches both about content of chemical and radioactive substances in phosphoric slag and phosphogypsum and also values of Indicators of environmental impurity.

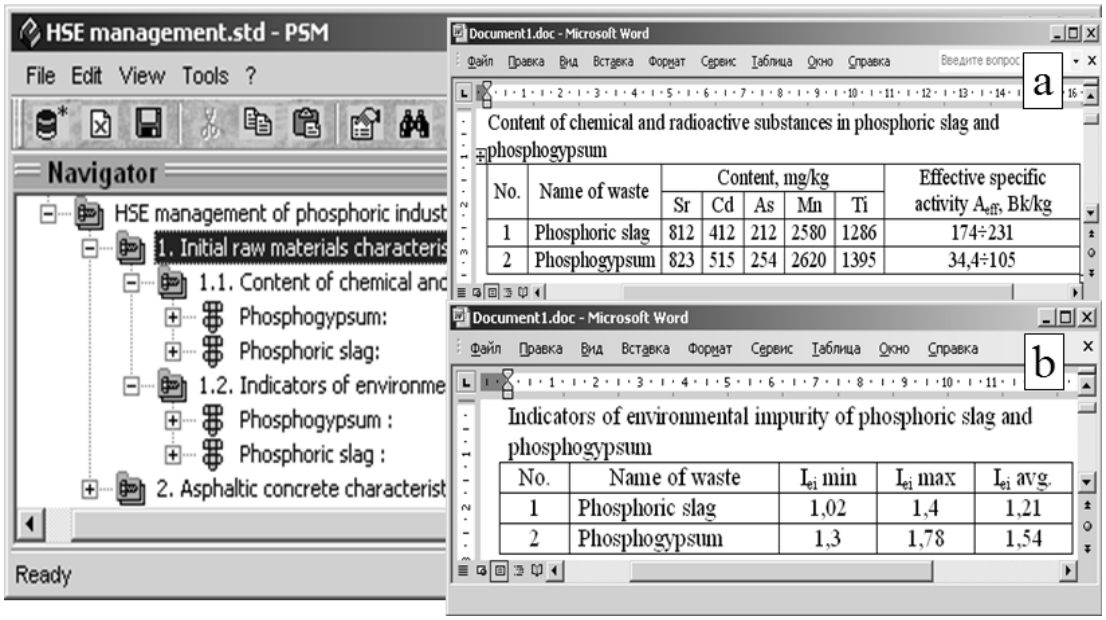


Figure 1: CALS-project "Characteristics of initial raw materials": a – Content of chemical and radioactive substances; b – Indicators of environmental impurity.

2.1 CALS-project of radiation danger for phosphorus-containing waste

Production of road surface materials based on phosphoric slags and phosphogypsum requires thorough chemical and analytical evaluation for the initial phosphorus-containing raw materials. There were carried out an analysis with application of atom-adsorption method allowing to define rare heavy metals, radioactive elements etc. together with rock-forming elements. Phosphoric slags are complex polycomponental substances which base on system CaO - SiO_2 - P_2O_5 (Sims and Sharpley, 2005).

The quantity of impurities of Al_2O_3, MgO, Fe_2O_3, Na_2O depends on structure of initial raw materials and technological process of sublimation of phosphorus. On a chemical composition phosphoric slags are similar with blast-furnace ones, but differ from them with low content of Al_2O_3, MgO, Fe_2O_3, Na_2O and in addition contain phosphorus and PO_x.

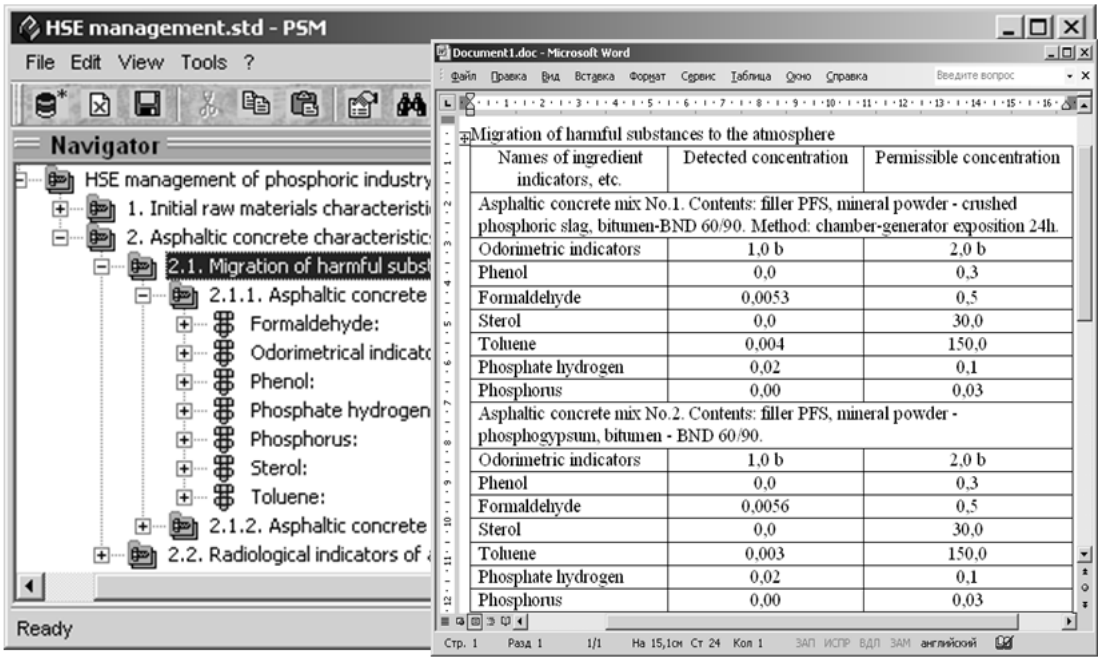
The given waste of the chemical industry meets EC requirements "Norms of radiating safety" and can be used in building of roads without restrictions under the radiating factor. The data of the chemical analysis uploaded to the CALS-system (Figure 1) show that in phosphoric slag and phosphogypsum contain harmful elements as Sr, As, Cd, Ti and Mn.

Indicators of Environmental Impurity (I_{ei}), considering a mass fraction of radioactive and chemical polluting substances in 1 t of raw materials, coefficient of relative danger of natural radionuclides, coefficient considering joint actions of various chemical pollutants, coefficient of relative environmental and economic danger of polluting substances of industrial wastes were also brought in the CALS-project (Figure 1). The analysis of the data of CALS-system shows that phosphine (PH_3), fluoric hydrogen and heavy metals are one of the basic pollutants in phosphoric slag and phosphogypsum.

Obtaining of road-building materials (asphaltic concrete) is one of the rational ways of phosphoric industry waste utilisation. As a result of complex theoretical and experimental works the structure of a hot asphaltic concrete made of phosphoric slag of various fractions and phosphogypsum as a filler was developed.

2.2 CALS-project of sanitary-hygienic analysis of impurities in asphaltic concrete

Sanitary, hygienic and radiological examination of obtained asphaltic concrete with use of phosphoric slag and phosphogypsum were defined for the formulation of recommendations about introduction to the industrial production. There were carried out a research concerning determination of degree of exhalation of harmful substances to the air. Results of this research were uploaded to the CALS-system and presented on the Figure 2.



Names of ingredient indicators, etc.	Detected concentration	Permissible concentration
Asphaltic concrete mix No.1. Contents: filler PFS, mineral powder - crushed phosphoric slag, bitumen-BND 60/90. Method: chamber-generator exposition 24h.		
Odorimetric indicators	1,0 b	2,0 b
Phenol	0,0	0,3
Formaldehyde	0,0053	0,5
Sterol	0,0	30,0
Toluene	0,004	150,0
Phosphate hydrogen	0,02	0,1
Phosphorus	0,00	0,03
Asphaltic concrete mix No.2. Contents: filler PFS, mineral powder - phosphogypsum, bitumen - BND 60/90.		
Odorimetric indicators	1,0 b	2,0 b
Phenol	0,0	0,3
Formaldehyde	0,0056	0,5
Sterol	0,0	30,0
Toluene	0,003	150,0
Phosphate hydrogen	0,02	0,1
Phosphorus	0,00	0,03

Figure 2: CALS-project "Characteristics of asphaltic concrete": Exhalation of harmful substances to air.

The results of the analysis for the data of CALS-system shown that the found out concentration of toxic impurity in asphaltic concrete mixes on the basis of phosphoric slag and phosphogypsum was considerable below maximum permissible.

2.3 CALS-project of analysis for radiological activity of asphaltic concrete

Besides this the radiological activity of asphaltic concrete mix on the basis of phosphoric slag was defined. Five samples (asphaltic concrete mixes 1-5) were analysed and the results of are in Table 3. Analyses were conducted by means of gamma spectrometer method.

Table 3. Radiological indicators of asphaltic concrete.

Name of sample	Effective specific activity, A_{eff}, Bk/kg			
	Ra-226	Th-232	K-40	A_{eff}
Asphaltic concrete mix 1	35+15	54+10	617+83	125-196
Asphaltic concrete mix 2	37+16	58+9	622+81	124-192
Asphaltic concrete mix 3	36+12	59+8	615+85	125-191
Asphaltic concrete mix 4	35+11	63+11	619+72	123-189
Asphaltic concrete mix 5	36+12	56+8	616+68	127-193
Average	36.4+13.2	58+9.2	617.8+77.8	124.8+192.2

Gamma spectrometer method showed that all of asphaltic concrete mixes contain radioactive isotopes as Ra-226, Th-232 and K-40. Results of the analysis were uploaded to the CALS-system (Fig. 3).

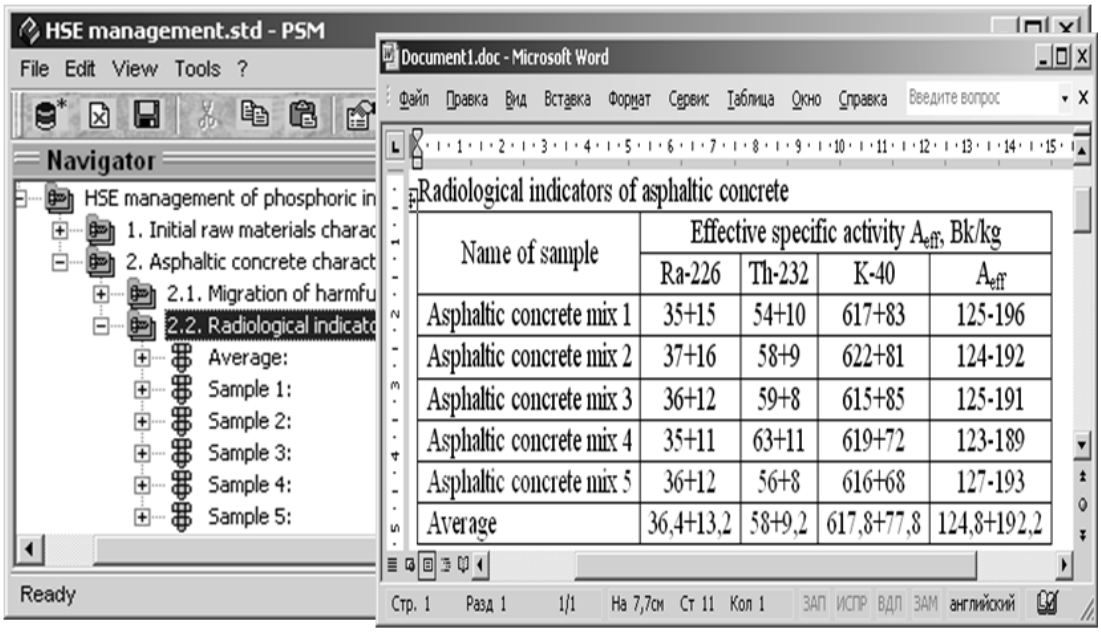


Figure 3: CALS-project "Asphaltic concrete characteristics": Radiological indicators of the asphaltic concrete.

Results confirmed that the application of developed CALS-system provided the justification which permits to use of phosphoric slag and phosphogypsum without restriction in building of the roads. Results of our research showed that using of phosphoric slag and phosphogypsum in structure of asphaltic concrete meet Kazakhstan and EC radiological and sanitary-hygienic requirements and it don't consistent the danger for human population and is not polluting the environment above legal limits.

In the results of the research it was shown, that the perspective way of Kazakhstan phosphoric industry waste treatment is a production of road-constructional materials (asphaltic concrete). Analytical

researches about content of radioactive and chemical polluting substances in phosphoric slag and phosphogypsum, and also asphaltic concrete characteristics based on phosphorus-containing waste were brought to the information CALS-system. It was shown, that using of phosphoric industry waste in production of the asphaltic concrete doesn't pollute the environment.
This should allow higher volumes of phosphoric industry waste utilisation. The future studies should also include the Life Cycle Assessment (Klemeš and Huisingh, 2008) and The Environmental Performance Strategy Map (De Benedetto and Klemeš, 2009)

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