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Strategy of Construction and Demolition Waste Management after Chemical Industry Facilities Removal

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Abstract. Mixed waste products are generated in the process of irrelevant industrial projects’ removal if conventional techniques of their demolition and dismantling are applied. In Russia the number of unused chemical industry facilities including structures with high rate of wear is growing. In removing industrial buildings and production shops it is used conventional techniques of demolition and dismantling in the process of which mixed waste products are generated. The presence of hazardous chemicals in these wastes makes difficulties for their use and leads to the increasing volume of unutilized residues. In the process of chemical industry facilities’ removal this fact takes on special significance as a high level of hazardous chemicals in the waste composition demands for the realization of unprofitable measures aimed at ensuring environmental and industrial safety. The proposed strategy of managing waste originated from the demolition and dismantling of chemical industry facilities is based on the methodology of industrial metabolism which allows identifying separate material flows of recycled, harmful and ballast components, performing separate collection of components during removal and taking necessary preventive measures. This strategy has been tested on the aniline synthesis plant being in the process of removal. As a result, a flow of 10 wt. %, subjected to decontamination, was isolated from the total volume of construction and demolition waste (C&D waste). The considered approach allowed using the resource potential of more than 80 wt. % of waste and minimizing the disposed waste volume.

1. Introduction
At present the acceleration of unused chemical industry facilities’ removal including structures characterized by high rate of wear is observed in Russia. Conventional techniques of structures removing involve demolition works and mechanical failure resulted in generation of mixed waste containing recyclable, ballast and environmentally hazardous components [1]. Also it takes place considerable polluting powder-gas emission which is accumulated in the working space. In this case all the waste products are considered to be non-utilized and their distribution in the environment becomes economically inexpedient and environmentally dangerous as there is a strong probability of the secondary pollution of neighbouring areas and toxic components migration into the environment [2–4].

Enterprises of chemical industry founded in the 1930s – 1950s are characterized by a heavy deterioration of structures and facilities, availability of obsolete equipment and strongly contaminated sites of solid waste and liquid effluents accumulation. More than 10 thousand potentially hazardous chemical facilities belonging to different branches of industry continue to operate in Russia.
Moreover, 70% of them are located in the cities the population of which is more than 100 thousand people [5].

Conducted research shows that removal of industrial buildings directly involved in production processes leads to considerable generation of hazardous waste. This fact defines the necessity of applying the strategies [6, 7] which includes: the separation of waste into the recyclable, hazardous and ballast flows; determination of preventive measures aimed at minimizing the volume of hazardous waste flows; identification of hazardous waste [1, 8, 9] and its preliminary removal from the waste flow; evaluation of suitable for recycling waste’s resource potential, the choice of their recycling technologies [10, 11], the ways of their recycling and evaluation of competitiveness of secondary materials obtained on their basis; the choice of environmentally-friendly, economically affordable and technologically feasible method of demolishing or dismantling.

The algorithm of realizing the waste management strategy after demolition and dismantling of chemical industry facilities is given in Figure 1.

At the first stage a reconnaissance inspection of buildings and facilities is carried out. Then the construction and archival documents denoting the operating conditions of the building are analyzed. These conditions include: the period of the building use; the main parameters of engineering process; conditions of hostile industrial environment; information about emergency situations; production control data and monitoring of fruits and intermediates of production in the air of working area.

At the second stage expert-analytical evaluation of the object of removal is carried out: identification of resource potential and competiveness of materials which can be derived from waste after removal; analysis of the factors of the waste’s resource potential change; selection of economically affordable, environmentally-friendly and technologically feasible ways of removal; assessment of waste’s environmental safety.

According to the results of the made analysis recyclable, ballast and hazardous waste streams are separated; the amount of unutilized fractions’ landfill is determined; the choice of hazardous waste neutralization techniques and methods of utilized waste flows’ processing is made [12]. After that the projects of buildings’ demolishing and dismantling as well as the project of further recovery of contaminated areas are developed.

The third stage consists of demolishing, dismantling or reshaping of buildings and of the territory’s recovery. Refined territory is assigned for the secondary use. After completing these kinds of works, the territory is provided for the secondary use. To increase the resource potential of demolishing and dismantling waste it is necessary to neutralize the dangerous flow, to landfill the ballast flow and to recycle the utilized waste flow aimed at its further reuse.

Strategy of waste management after industrial buildings removal has been tested at one of typical industrial facilities of aniline production. In the course of work material flow of waste has been identified, their hazard has been estimated and the techniques of recycling and the waste resource potential use aimed at minimizing the volume of unutilized residue intended for safe distribution in the environment have been proposed.

The following tasks have been solved beforehand:
- The rate of wear of building structures have been analyzed on the base of information about the change of physical-mechanical properties of materials;
- The modeling of C&D waste material flows has been made for several variants of the test subject removal.
- The volume, the composition and the risk of C&D waste generated after removal have been defined;
- The guidelines for C&D waste resource potential use and reduction of waste level in the environment have been developed.
Figure 1. Algorithm of C&D waste strategy realization after removing chemical facilities
2. Materials and methods

Analysis of the rate of wear of building structure in chemical production

Under the influence of industrial aggressive factors the intensity of surface damage and corrosion of building structures is increased. Thus, toxic products are accumulated in building materials.

Floor and wall ceramic tile, plaster, cores of wall constructions’ concrete and other materials have been sampled. It is known that the greatest amount of pollutants is accumulated in the finishing materials.

Therefore, studies of changes in the physical and mechanical characteristics of finishing agents [13] based on the ranking of the building according to the degree of contamination have been carried out (Table 1).

Table 1. Modification of physical and mechanical characteristics of finishing agents

<table>
<thead>
<tr>
<th>Characteristic, measure</th>
<th>Starting value (standard)</th>
<th>Area of high level of contamination</th>
<th>Area of average level of contamination</th>
<th>Area of low level of contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual bending strength, %</td>
<td>100.0</td>
<td>63.7–87.0</td>
<td>67.0–97.8</td>
<td>75.0–94.6</td>
</tr>
<tr>
<td>Water absorbing rate, % of weight</td>
<td>1.80–2.00</td>
<td>4.50–7.47</td>
<td>2.57–3.20</td>
<td>1.84–2.41</td>
</tr>
</tbody>
</table>

C&D waste hazard assessment

High level of contamination of finishing agents remaining in the area of direct contact with the basic reactant has been identified during the examination of industrial workshops. Accumulation of aniline as the main pollutant has been found at a depth of 30–35 mm. The aniline content in the samples of building materials varies from 4.8 to 832.3 mg/kg of dry substance of the sample. Moreover, the amount of aniline migrating in the aqueous medium has been estimated in the amount of 17.8 wt. % upon the average. High level of aniline migration in aqueous medium proves the potential environmental hazard of C&D waste during their allocation in the environment and reuse without preliminary decontamination.

The obtained data and identified dependences of the major pollutant migration made possible to justify the requirements for necessary degree of wall constructions’ neutralization.

We have obtained the following approximated dependencies which characterize the migration of a pollutant deep into constructions of two buildings situated in the closed industrial complex (Δc – the concentration of water-soluble aniline in wall construction material, h – depth of sampling):

\[ f_1(\Delta c) = 709.1824 e^{-0.601243 h}, \quad (1) \]

\[ f_2(\Delta c) = 669.25 e^{-0.074 h}, \quad (2) \]

(1) – building 1, (2) – building 2.

The obtained data and identified dependences (1) and (2) allow justifying the requirement for decontamination of wall construction and the importance of making surface pre-cleaning from finishing agents which performed a barrier function in the aggressive environment of production shops.

To prevent secondary pollution of the environment during dismantling and demolition it should be neutralized chemical contamination of the finishing agents’ surfaces. According to the assessment of substance migration in the construction the treatment is to be made at the depth from 5 to 30 mm.

The proposed approach aimed at preventing secondary pollution of environment can be used in the development of model schemes designed for the C&D waste treatment.
Analysis of the component and quantitative composition of C&D waste
There are two ways of C&D waste volume determination:
- According to the passport of the object (estimation and project construction documentation);
- According to the technical inspection of the object. Such inspection includes measuring of its parameters and calculation based on the average density of each building material defined by regulations.

In order to calculate the total volume of C&D waste it was used the first way. The analysis of the project documentation of the removed production revealed the total waste volume amounted to 25 000 tones. The calculated component composition of C&D waste is presented in Table 2. The silicate brick, concrete and ferroconcrete building structures, metal and other materials predominate in the waste composition. The amount of contaminated C&D waste which is subject to decontamination and landfill as well as nondifferentiable waste makes more than 10 wt. %.

Table 2. Component and quantitative composition of waste from main industrial buildings removing

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Amount of waste, tn.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Building 1</td>
</tr>
<tr>
<td>Concrete</td>
<td>3756.29</td>
</tr>
<tr>
<td>Ferroconcrete</td>
<td>2944.86</td>
</tr>
<tr>
<td>Calcium-silicate brick</td>
<td>2500.23</td>
</tr>
<tr>
<td>Metal</td>
<td>714.57</td>
</tr>
<tr>
<td>Soft roofing</td>
<td>0.02</td>
</tr>
<tr>
<td>Felt roofing</td>
<td>0.00</td>
</tr>
<tr>
<td>Sandstone tile</td>
<td>53.03</td>
</tr>
<tr>
<td>Glass</td>
<td>6.07</td>
</tr>
</tbody>
</table>

Total mass of C&D waste, tn.: 24715.84

Analysis of C&D waste material flows in different ways of removal
Finding the alternative for the method of object’s removal three approaches has been considered. To compare the main approaches we have carried out the modelling of different materials and waste streams [14].

The first approach is a combined method of removal. For constructions being of high hazard and rate of wear it has been proposed the method of undermining. Mechanical demolition has become the optimal technique for constructions having low risk level and rate of wear. Materials obtained in the process of mechanical demolition should be directed to recycling while blasting waste should be directed to disposal.

The second approach is based on the method of mechanical elementwise dismantling [15] with a preliminary decontamination of finishing agents and contaminated areas (Figure 2). Decontamination is implied as removing of the layers of construction materials from the walls, floor and ceiling at the depth of contaminant’s penetration.

Glass, wood and metal waste runs to processing. It has been proposed to allocate strongly hazardous waste after its neutralization in the environmentally-friendly place or to reuse it in case of competitive ability.

In the third approach material and waste streams have been estimated in the process of production complex restructuring for a different function. The process consisted in mechanical dismantling of constructions having a high rate of wear, decontamination of industrial surfaces and reconstruction of buildings. After removing the elements of structures being of high rate of wear and finishing agents which accumulated dangerous chemicals the building could be used again including further restructuring of the object.
3. Results and discussion

During the comparison of approaches to removal of chemical industry facilities the following estimated figures have been considered:

- Ways of the given industrial territory use
- Technical state of constructions
- The depth and the area of mechanical pre-treatment of contaminated industrial surfaces of the object aimed at reduction of harmful effects on the environment
- The amount of waste which is subject to processing and recycle
- The forecast of the potential harmful effects on the environment
- The environmental effectiveness of the method
- Technical and economic parameters (duration of work, logistics and tooling backup, etc.).

The main possible directions of this industrial area using are the following: residential construction, agricultural use, recreation area, industrial construction, industrial restructuring and realigning into administrative objects.

The realigning of buildings into administrative objects is impermissible without preliminary decontamination of premises and hydrophobization of walls owing to the considerable accumulation of contaminants in finishing agents.

According to the existing practice of managing the closing industrial sites in Russia all the approaches can be realized with the view of further industrial development or object’s realigning. Removed production is a part of a large industrial complex, and it is located near the boundaries of the enterprise. The liberated territory can be used for planting or reducing of the sanitary protection zone.

The technical state of industrial constructions characterized by the following features: minor damage, presence of cracks in some areas, partial damage of corrosion protection. The buildings can be restructured with preliminary extraction of material fractions contaminated with production chemical agents. It will be required maintenance work and local damage repair without reinforcing of constructions.
The first approach doesn’t involve preliminary decontamination of surfaces which allows saving of time. However, it should be noted that waste formed by undermining without preliminary extraction of contaminated fractions becomes more hazardous for the environment. It is characterized as Hazard Class 3 and its allocation at landfills is rather unprofitable.

The preliminary decontamination of walls’ surfaces is an advantage of Approach 2 and Approach 3. In both cases building structures are refined from finishing agents (tile, plaster, paint, etc.) and the layer of contaminated materials is removed.

Approach 2 is characterized by a maximal quantity of waste assigned for recycling. The first approach is recognized as the most ineffective one in terms of using resource potential of waste after production removal. Approach 3 has minimal quantity of waste directed for disposal (Table 3).

The third approach of removal simplifies the management of waste since its volume is reduced to minimum but it does not make possible to remove thoroughly C&D waste directed to disposal.

The types of removal damage effects on the environment are as follows: air pollution, a negative effect on soil-vegetable layer, pollution of hydrosphere, secondary pollution and indirect effect on the ecosystem.

### Table 3. Management of C&D waste in different approaches of plant removal

<table>
<thead>
<tr>
<th>Removal Approach</th>
<th>Amount of waste for disposal, tn.</th>
<th>Amount of waste for recycling, tn.</th>
<th>Percentage of waste for disposal, %</th>
<th>Percentage of waste for recycling, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>20838.68</td>
<td>3876.97</td>
<td>84.31</td>
<td>15.69</td>
</tr>
<tr>
<td>No.2</td>
<td>2549.15</td>
<td>22166.69</td>
<td>10.31</td>
<td>89.69</td>
</tr>
<tr>
<td>No.3</td>
<td>1376.82</td>
<td>5712.30</td>
<td>5.57</td>
<td>23.11</td>
</tr>
</tbody>
</table>

The first approach includes all the listed and most hazardous processes. So, it will be the maximal environmental stress at its application. Approach 2 and Approach 3 contain two processes which have a negative impact on the environment. However, taking into account little amounts of disposal waste and partial mechanical decomposition in Approach 3 application environmental stress will be minimal. In terms of ecological effect Approach 1 does not prevent negative effect on environment. Approaches 1 and 2 have maximum ecological effect. In addition, forecasting of environmental consequences has been carried out. The consequences include: secondary emission of pollutants into water and soil, suppression of ecosystems in the area of potential impact, agreements for temporary use of land, potential harmful effect on a man (direct contact, inspiration). All these consequences are probable for the first Approach. Approach 3 has a risk of air quality problem in the working area after realigning of buildings in case of their careless clearing from the previous emissions.

In the capacity of technical-and-economical performance of each approach there were considered the following: working efficiency, the number of additional expendable materials, engineering and tooling backup, mass of waste which is subject to transportation, mass of waste which is subject to disposal, mass of waste which is subject to processing.

The final choice of removal technique has been carried out by the method of expert evaluation. According to the final comparison of different approaches of removal the optimal one are as follows: elementwise mechanical method of dismantling with preliminary decontamination of surfaces (Approach 2) and the method of restructuring (Approach 3).

Results of the evaluation allowed making a conclusion that in terms of environmental safety of the last life cycle stage the Approach 3 is the most favourable. Approach 3 has such peculiarities as neutralization, reconstruction and repair of buildings with further restructuring. This Approach provides a minimal amount of waste destined for disposal being the urgent task of environmental safety. Large duration of work, i.e. time required for decontamination and for works aimed at renovation of industrial facility could be recognized as the main disadvantage of Approach 3.

The following: working efficiency, the number of additional expendable materials, engineering and tooling backup, mass of waste which is subject to transportation, mass of waste which is subject to disposal, mass of waste which is subject to processing.
Approach 2 makes possible to achieve environmental safety of the removal process and to minimize the mass of waste destined for disposal for the less period of time. Moreover, during its application is possible to process maximum amount of building materials.

4. Conclusion
It has been proposed the management strategy for construction and demolition waste of chemical industry as well as an algorithm of its realization which allows reducing the risk of generated waste to an acceptable level, minimizing the volumes of unutilized residues and making the most out of the waste resource potential use.

Proposed strategy has been tested at one of the typical objects of organic synthesis – the aniline production. On the base of the analysis of three approaches to the removal of aniline synthesis structures it has been selected the optimum alternative which includes the elementwise mechanical dismantling with preliminary mechanical removal of the most contaminated layers of materials. The use of the utilized waste stream resource potential and decontaminated dangerous stream enables to minimize the amount of landfills.

References
