ISSN 2226-3780

UDC 504.064.2.001.18
DOI: 10.15587/2312-8372.2018.124300

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BIOINDICATIVE STUDIES OF ROADSIDE ECOSYSTEMS

Проведено дослідження стану придорожніх екосистем вздовж автомагістралей України різних категорій. Досліджувалися ділянки на дорогах М02, М03, Н07, Н12 та Р44. Оцінка впливу на екосистеми здійснювалася біоіндикаційними методами, за допомогою лишайників та вищих рослин (овес). Показано, що рівень забруднення придорожніх екосистем тим більший, чим вища категорія дороги, а відповідно інтенсивність руху автотранспорту.

Ключові слова: *придорожні екосистеми, автомагістралі України, біоіндикаційні методи, індекс атмосферної чистоти.*

1. Introduction

Ecosystems adjoining the highway are an immediate vehicle pollution acceptor. These ecosystems can have different characteristics (forest, meadow, agro ecosystems), but what unites them all is that the prevailing impact on them is exerted by emissions from motor vehicles. The continuous growth of vehicle fleet and traffic flow intensity lead to load increment in the above-mentioned ecosystems. Therefore, to research them is an urgent task.

Plants give a well-defined response to abiotic changes, thus, performing an indicative role. The chemical composition of plants reflects exactly that elemental composition of the environment in which their development occurs. Plant bioindication of the environmental condition is believed to be one of the most accessible techniques for estimating anthropogenic load [1]. Besides, the undeniable advantage of bioindicative assessment is that we observe the «live» response of a particular biocenose to changes in the environment.

2. The object of research and its technological audit

Ecosystems directly adjoining interstate, state and regional highways (Fig. 1) were selected as an object of research. They are:

1. H12 (Sumy – Poltava) – close to the town of Okhtyrka.
2. H07 (Kyiv – Sumy – Yunakivka) – close to the town of Romny.
3. P44 (Hlukhiv – Sumy) – close to the town of Bilopillia.
4. M02 (Kipti – Hlukhiv – Bachivsk) – close to the town of Baturin.
5. M03 (Kyiv – Kharkiv – checkpoint Dovzhansky) – close to the town of Pyriatyn.

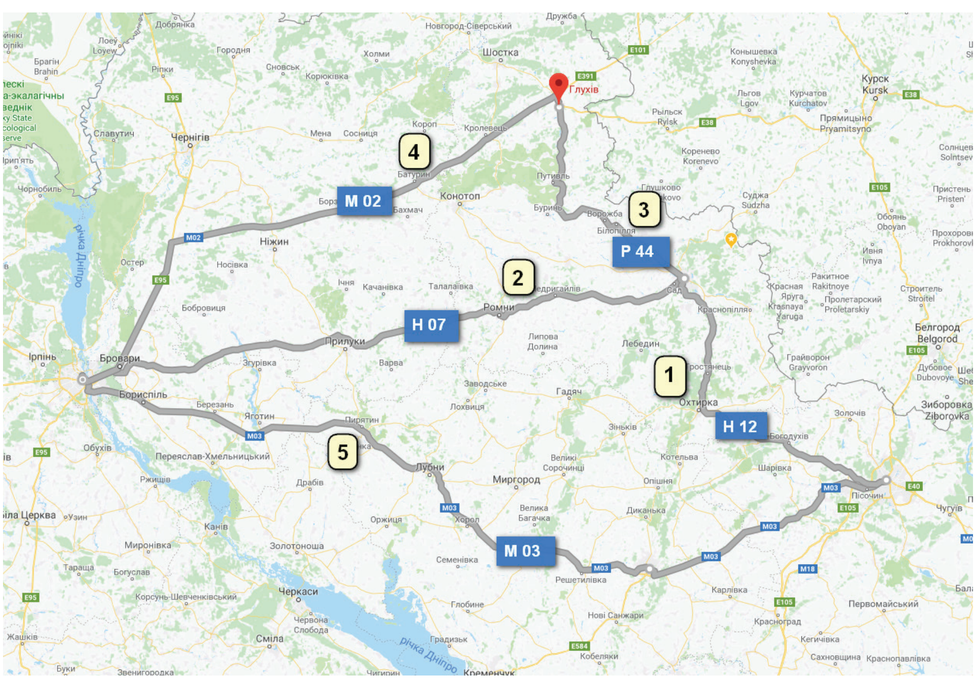

Fig. 1. Highway sections under investigation

Traffic flow intensity in the investigated areas was determined by means of calculation in accordance with the procedure provided in [2]. The results are shown in Fig. 2.

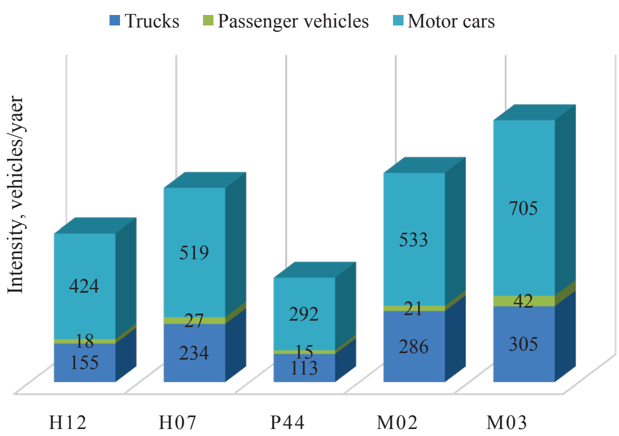

Fig. 2. Traffic intensity (vehicle density) in the investigated highway sections

One of the most urgent problems is the detection of trends of the impact of the vehicles movement characteristics on roadside ecosystems. After all, along with the increasing intensity of movement in the selected areas, other factors also have negative influence, the roadway condition in particular. In places with existing rocks, irregularities, the speed of the car goes down to the ranges in which the amount of pollutant emissions in the atmosphere is significantly increased. This gives grounds for expecting an increase in the load on the roadside ecosystem, which predetermines this research.

Assessment of roadside ecosystems is a perspective and difficult task. Roadside ecosystems are a direct acceptor of transport pollution and are subject to simultaneous exposure to both harmful atmospheric impurities and washing of contaminants from the highway.

3. The aim and tasks of the research

The aim of the research is a bioindicative assessment of the condition of roadside ecosystems with different bioindicators.

To achieve this aim, the following tasks are defined:

1. To estimate the level of air pollution along highways according to the state of roadside ecosystems.

2. To estimate the level of soil contamination along highways.

4. Research of existing solutions of the problem

The bioindicative assessment of the condition of roadside ecosystems should be based on an integrated approach. Plants are clearly responsive to environmental changes and can play an indicative role as noted in the work [3, 4]. At the same time in the works [5–7] is recommended to use not one but several phytoindication methods to make environmental assessments more reliable, in particular to supplement it with phytotesting of soils. Soils state can be considered as an integral indicator of the multi-year pollution process. After all, substances that enter into the atmosphere with the exhaust gases, deposited in the soil and accumulate there as the authors [8, 9] point out. Phytotesting is based on the sensitivity of plants to exogenous chemical aggression, which affects the growth and morphological characteristics [10]. This allows the test body to respond to the relevant reaction of the entire set of toxic agents. The laboratory methods of phytotesting are especially important in environmental control as the most rapid and economical [5]. Various types of plants are used for phytotesting (salad, mustard, cereals, etc.).

The most suitable atmospheric pollution bioindicators (especially SO_2) are lichens [11, 12]. The sensitivity of lichens to environmental pollution is conditioned by their physiology and symbiotic nature. The lasting action of low-concentrated pollutants causes such damages to lichens which do not disappear until the death of their thalli as notices in [13].

Of all the ecological groups of lichens, the most sensitive are lichen-epiphytes which are sensitive to changes in the air of some chemical elements and compounds included into motor vehicle emissions (sulfur dioxide, nitrogen oxides, heavy metals) [12]. The monitoring takes into account the frequency of finding lichens in the study area, as well as their projective cover that makes it possible to draw a conclusion about air quality [14]. In [15] is proposed to determine the degree of air pollution according to presence or absence of certain species of lichens.

Thus, in order to assess the condition of roadside ecosystems, methods of lichen indication and phytotesting have been selected.

5. Methods of research

The study of plant groups was carried out in the areas along the designated highways. It was taken into account that the plants suitable to be indicators had to meet the following requirements:

– wide ecological amplitude;
– wide distribution area;
– low spontaneous frequency of the accountable sign.

The selected experimental procedure is the universal non-specific indicator of the environmental condition, therefore, it does not require additional chemical and analytical work to confirm its aptitude.

The bioindicative studies were carried out by optical methods. Interpretation and experimental data processing were performed with the help of software products ABBY Finereader 9.0 and Adobe Photoshop 8.0.

In order to check the obtained observation data, index of atmospheric purity (I.A.P.) was calculated by D. DeSloover and F. LeBlanc's methodology [16]. The evaluation of a computation result is carried out in compliance with the following logic: the higher the result, the less ecologically favourable the area is. This coefficient is calculated in total for all the sections and reflects the average pollution level throughout the terrain. For this purpose, used the formula:

$$I.A.P. = \frac{1}{10\sum_{i=1}^{n} Q_i \cdot F_i}, \quad (1)$$

where n – the number of lichen species in the area under investigation; Q_i – an ecological indicator of the species i (an average number of species growing together with the species i in the investigated area); F_i – frequency of occurrence/species covering i in accordance with the given scale [15].

The product of Q_iF_i is divided by 10 to get a more graphic figure.

Phytotesting is employed as a method for soil quality assessment. Experimental technique provides for soil sampling from the investigated sections with the further growing test-object on them. Control is taken over seed germination energy, germinant root length and germinant height.

Depending on germination energy of seeds on the test substrates, they are assigned one of the four levels of pollution [17]:

1. No pollution. Seed germination reaches 90–100 %. Seedlings are unanimous, germinants are strong, regular.
2. Weak pollution. Germination is 60–90 %. Sprouts are of almost normal length, strong, regular.
3. Medium pollution. Germination is 20–60 %. Sprouts are much shorter and thinner. Some of them are malformed.
4. Severe pollution. Seed germination is poor (less than 20 %), germinants are small and malformed).

To assess soil toxicity, we determine a phytotoxic effect (inhibitory effect) which depends on the average root length in the experiment and the average root length in the control. It is calculated by the formula [17]:

$$FE = \frac{L_k - L_m}{L_k} \cdot 100\ \%, \qquad (2)$$

where L_m – average root length in the experiment, mm; L_k – average root length in the control, mm. Oats were selected as a test-crop according to MP 2.1.7.2297-07 technique [18]. Oats are an annual monocotyledonous (monocot) plant that has a heightened sensitivity to soil contamination. This bioindicator is characterized by rapid seed germination and almost 100 % germinating ability which perceptibly declines in the presence of contaminants. In addition, stems and roots of this plant under the influence of pollutants undergo significant morphological changes (growth inhibition and curvature of plants, decrease in root length, as well as in number and mass of seeds). Oats withstand high soil acidity [17]. The roots of oats have a large number of root hairs whose surface makes more than 90 % of the entire root system. Such hairs are of increased activity, so the oats root system is remarkable for its high absorption capacity, which to a great extent causes indicative capabilities of oaths. Oats, as a bioindicator, are also convenient because the action of stressors can be studied simultaneously with a large number of plants having a small workplace area.

6. Research results

6.1. The results of lichenological studies. Lichenological observations were carried out in the period from 2012 to 2017. The observations revealed that the substrates for lichen settlement in the study areas were roadside stones, as well as trees (willow, black poplar, drooping birch, etc.). To assess the motorway air pollution, trees were examined on both sides of the road. In the course of observations, taking photos of the available lichens was carried out for the purpose of their further identification.

To analyze air pollution with sulfur dioxide, the following parameters were determined:

– the total number of lichen species;
– the coverage of each tree with lichen thalli;
– frequency of occurrence of each species;
– the quantity of each species.

60 species of trees were examined in the study areas (15 trees in each study area on average), and 13 most common lichen species were identified. When determining the species of lichens, there were used photos obtained in places of growth and electronic determinants [19]. In compliance with the scale [10] lichens which were found in the study areas, were classified according to the classes of toxic tolerance (Table 1).

Table 1

Distribution of lichen species by sensitivity in the investigated areas

Sensitivity	Lichen
Class S – Sensitive	*Caloplaca discolor.* *Caloplaca marina*
Class I – Intermediate	*Anaptychia ciliaris.* *Physcia adscendens.* *Ramalina pollinaria.* *Xanthoria parietina.* Xanthoria polycarpa
Class T – Tolerant	*Hypotrachyna revoluta.* *Parmelia acetabulum.* *Parmelia caperata.* *Parmelia vagans.* *Caloplaca pyracea.* *Physconia grisea*

Percentage ratio of the classes of toxic tolerance to SO_2 in lichen species found in all the study areas is shown in Fig. 3.

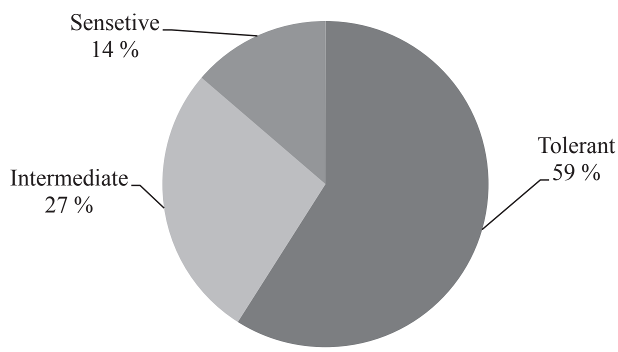

Fig. 3. Percentage ratio of toxic tolerance classes to SO_2 of the identified lichen species in all the investigated areas

The highest percentage belongs to lichens of T (Tolerance) class – 60 % that indicates an increased content of sulfur oxides in the atmospheric air of the study areas.

Fig. 4 graphically demonstrates the average projective cover of lichens in the study areas, where the numerical value characterizes the level of contamination: the higher the value, the lower the pollution level is.

Having analyzed the data obtained in the study, we can draw the following conclusions. The lowest number of lichens is found in the section along M-03 highway. These lichens refer to the class of Tolerant. Sensitive and Intermediate species are not available. The score on the Brown- Blanche scale is 2.

In the sections along M-02 highway, the projective cover level is 42 % higher, and in the sections along H-07 and H-12, it 200 % and 267 %, respectively, exceeds the

M-03 indicators. That makes it possible for these sectors to be reported as less polluted and to score them as high as 4 on the Brown-Blanche scale.

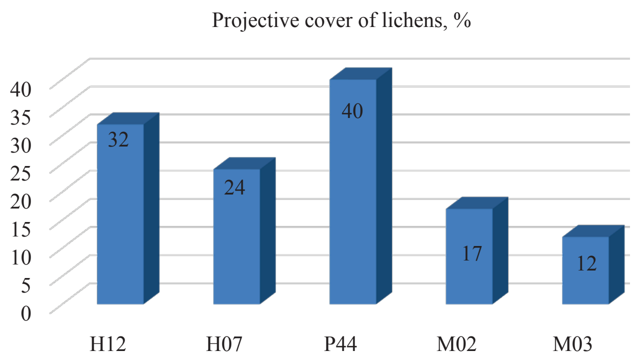

Fig. 4. The average projective cover of lichens in the study areas, %

In the section along P-44 highway there occur 8 lichen species, most of them refer to sensitive and medium-sensitive. The average projective cover makes 40 %. The score on the Brown-Blanche scale is 4. So, the road segment is not significantly affected by sulfur dioxide.

It can be assumed that the maximum concentration of SO_2 is available in M02 and M03 motorway sections where the traffic of vehicles is the most intensive, including trucks. Only persistent lichen species are found here with the projective cover of 10–25 %. The minimum concentration of SO_2 is registered along the P44 highway section, where three classes of lichens are found, the projective cover makes 50–75 %. Our observations confirm the following regularity: the higher the traffic intensity is, the more pronounced is the influence on the projective lichen cover of the area.

The results of lichenological studies and the acquired estimated values are shown in Table 2.

Table 2

The results of lichenological studies

Section	Polluted area (On Brown-Blanche scale)	Average projective cover, %	Assessment of pollution	Index of atmospheric purity *I.A.P.*	Approximate concentration of SO_2 in the polluted area, mg/m^3
M02	3 available crustose lichens	17	Medium	0.6	0.05–0.2
M03	2 on the north side, the greenish algae deposit	12	Severe enough	0.4	0.3
H07	3 available crustose lichens	24	Medium	1.8	0.05–0.2
H12	3 available crustose lichens	32	Medium	1.2	0.05–0.2
P44	4 available foliose lichens	40	Not great	3.2	<0.05

Note. Maximum permissible concentration of SO_2 is 0.05 mg/m^3

6.2. The results of soil phytotoxicity acquired by germinant method. Soil samples from five study areas were selected (Fig. 1). Soil specimens were taken at a 5 m distance from the road. All the samples were selected under the same weather conditions. Soil sampling was carried out according to DSTU ISO 10381: 2004 [20]. Selected samples were numbered and registered. The soil type was defined according to [21] as grey forest. The average height of seedlings during the experiment is shown in Fig. 5.

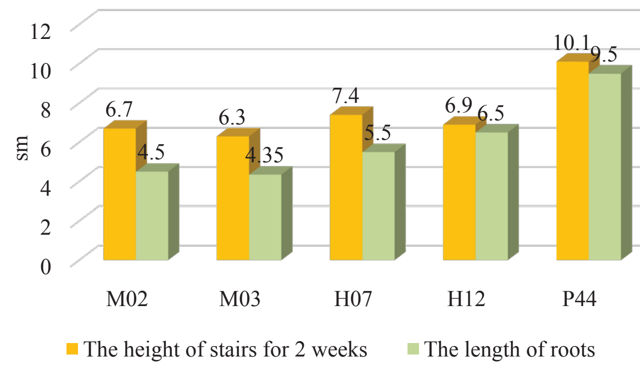

Fig. 5. Graphic interpretation of research results

Throughout the vegetation period, phenological observations were being carried out. Photographs of plants were taken at different stages of growth. Phenological observations are necessary and very important in this experiment. Their purpose consists in differentiation in the growth and development of plants during the period of vegetation in different soil samples, determination of the occurrence time of plant development phases. Phenological observations help to explain positive and negative changes in the development of the crop under investigation. Measurement results are shown in Fig. 5.

The results of phytotoxicity effect calculation are respectively (2) presented in Fig. 6 in the form of diagrams.

The phytotoxic performance is considered to be proven if the phytotoxic effect (FE) makes 20 % or more. In our experiment, the phytotoxic effect in all the samples except one (from P44 road segment) is higher than 20 %. But the highest reading of 58 % and 52 % corresponds to the sections along the M03 and M02 highways, therefore, phytotoxicity in these samples is proven.

It is obvious that the phytotoxic effect is directly proportional to the traffic intensity (vehicle density), and accordingly to the road category. But there arises a question why, with rather considerable differences in traffic intensity on roads of state and interstate significance (Fig. 1), the calculated phytotoxicity values have a smaller difference. In our opinion, another parameter that affects the pollution of roadside ecosystems by means of motor transport emissions is the condition of road surface, i. e. the presence of dents and pits.

Unsatisfactory condition of the road surface entails changes in vehicle running parameters. Drivers have to go at a low speed, often slowing down. Such changes increase emissions of hazardous substances containing exhaust gases [22].

ISSN 2226-3780

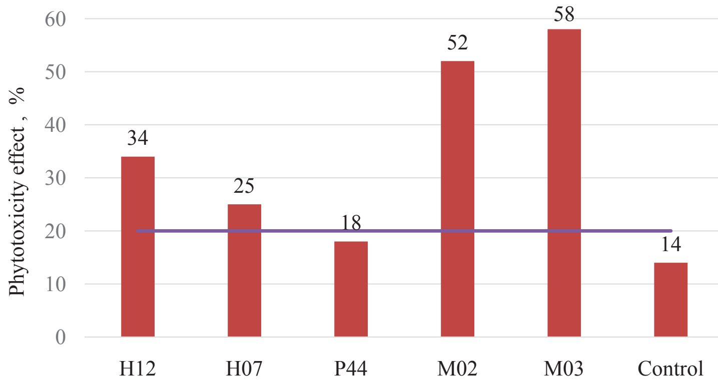

Fig. 6. Graphic interpretation of the results of phytotoxicity effect calculation

7. SWOT analysis of research results

Strengths. The state of roadside ecosystems can be estimated using bioindicative methods. This allows quickly and accurately determines the degree of contamination of the ecosystems' components by the direct reaction of living organisms to the environment. These methods do not require large material costs and additional equipment. They allow to carry out an express assessment of the roadside ecosystems state.

Weaknesses. The contamination degree is determined approximately depending on the reaction of the test object to the environmental factors. It is impossible to determine precisely the concentration of the pollutant, but only its range.

Opportunities. The research of roadside ecosystems allows to carry out an express assessment of the environment pollution level by vehicles emissions. After all, bioindicator plants clearly react to the presence of such pollutants as nitrogen oxides, sulfur, carbon, heavy metals, and the like. Such an assessment makes it possible to conduct long-term observations. On their basis, it is possible to develop recommendations for monitoring roadside ecosystems and degrading their condition.

Threats. The appropriate results of bioindicative studies may be negatively affected by incorrect selection of a bioindicator or test object and violation of the rules for selecting, storing and transporting soil samples as well as non-compliance with the procedure of the experiment.

8. Conclusions

1. It is shown that the level of atmospheric pollution by sulfur dioxide along highways of interstate importance is higher than the corresponding pollution level along motorways of other categories. Only along the highway P44 the concentration of sulfur dioxide is lower than the maximum permissible. Accordingly, at sites along the roads of M02, H07 and H12, the concentration of sulfur dioxide is from 0.05 to 0.2 mg/m^3, while the M03 reaches 0.3 mg/m^3. This can be explained by the intensive movement of vehicles, including trucks. After all, combustion of diesel fuel is a significant source of sulfur dioxide.

2. According to the calculation of phytotoxicity effect, the highest level of soil contamination along highways is observed along the ways M03 and M02 (58 % and 52 % respectively). And along the section of the road P44 does not exceed the rate of 20 % and it is 18 %. Along the roads of national importance H07 and H12 this figure was 25 % and 34 %.

The research has shown that the impact on roadside ecosystems depends on the category of a highway, as well as its technical condition. The impact level is higher on the roads with busy traffic and areas with poor technical condition.

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БИОИНДИКАЦИОННЫЕ ИССЛЕДОВАНИЯ СОСТОЯНИЯ ПРИДОРОЖНЫХ ЭКОСИСТЕМ

Проведено исследование состояния придорожных экосистем вдоль автомагистралей Украины различных категорий. Исследовались участки на дорогах М02, М03, Н07, Н12 и Р44. Оценка воздействия на экосистемы осуществлялась биоиндикационными методами, с помощью лишайников и высших растений (овес). Показано, что уровень загрязнения придорожных экосистем тем больше, чем выше категория дороги, а соответственно интенсивность движения автотранспорта.

Ключевые слова: придорожные экосистемы, автомагистрали Украины, биоиндикационные методы, индекс атмосферной чистоты.

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UDC 66.083.2:66-971:614.849
DOI: 10.15587/2312-8372.2018.124341

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ANALYSIS OF THE TECHNOGENIC LOAD ON THE ENVIRONMENT DURING FORCED VENTILATION OF TANKS

Досліджено вплив світлих нафтопродуктів (бензин, дизельне паливо, гас) на стан навколишнього середовища в зоні впливу резервуарів зберігання цих продуктів. Обгрунтовано, що застосування примусової вентиляції з традиційною подачею повітря є екологічно небезпечною операцією. Доведено, що альтернативою цьому рішенню є ежекторний-вихровий метод подачі повітря при дегазації резервуарів з подальшим уловлюванням парів нафтопродуктів за допомогою абсорбційної-конденсаційної установки.

Ключові слова: *примусова вентиляція, ежекторний спосіб подачі повітря, екологічна небезпека, резервуари зберігання нафтопродуктів, оцінка ризику.*

1. Introduction

Storage tanks for oil products are environmentally hazardous sources of anthropogenic impact on the environment, acting as objects of uncontrolled emissions of steam-air mixtures or vapor-gas-air mixtures and spills of oil products, followed by fires and explosions. The environmental relevance of storage is essentially dependent on its potential to pollute the environment and on the physical and chemical properties of the stored substances. Petroleum tanks are used on the farm to store gasoline and diesel fuel. Properly designed petroleum storages must prevent leaks and the potential contamination of soils, surface water or groundwater. The analysis of the sources of environmental impact during the operation of the reservoirs indicates that the vertical steel tanks, even during normal operation, are environmentally hazardous.

Preparation of tanks with residues of petroleum products for fire repair works is one of the most complex and environmentally hazardous technological operations in the process of exploitation of tanks. Fires and explosions on reservoirs from flammable substances and flammable liquids often occur during cleaning and preparation for repairs, and in the course of repair work directly [1]. The share