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DEVELOPMENT OF RECOMMENDATIONS FOR THE SELECTION OF MECHANIZATION MEANS FOR THE LIQUIDATION OF EMISSION FUNNEL GENERATED AS A RESULT OF THE EXPLOSION OF PROJECTLES AND ROCKETS

The object of research is the mechanization of the process of eliminating emission funnels on the earth's surface, formed as a result of explosions of shells and rockets.

The problem being solved in the work is related to the military operations on the territory of Ukraine, because of which thousands of hectares of land appeared, disturbed as a result of explosions of shells and missiles, excluding their further effective use without restoration. The first step in the restoration of such lands is backfilling by means of mechanization, however, due to the different sizes of the formed emission funnels, there is no universal equipment for achieving the set goals.

In the course of the work, the main types of disturbances of the earth's surface, formed as a result of the explosion of shells, represented by emission funnels in open areas, were determined. It has been established that the number of disturbed soil layers as a result of the formation of a funnel depends on its depth. Efficient methods of mechanization of backfilling of emission funnels in accordance with their parameters are proposed. Schemes of five main types of emission funnels are presented, taking into account the number of soil layers disturbed as a result of the explosion, which make it possible to determine the sequence of restoration of disturbed areas of the earth's surface.

It has been established that the dependence of the volume of emission funnels on their depth is a power law, while the angle of inclination of the slopes also has a significant effect on the value of the funnel volume. It has been determined that with an increase in the funnel depth from 1 to 10 m, its volume increases from 350 to 450 times depending on the funnel slope angle, and an increase in the funnel slope angle by 28 % from 35° to 45° leads to an increase in its volume by 95 %, and the area by 98 %.

The recommendations developed in the work on the choice of mechanization means for the elimination of emission funnels formed as a result of explosions of shells and rockets, depending on the depth of the funnel, can be used in practice. The established dependences of the required time for backfilling the emission funnels on their depth can be used for a preliminary assessment of the cost of restoration work, depending on the chosen means of mechanization and the volume of emission funnels.

Keywords: *land restoration, emission funnels, mechanization of backfilling of emission funnels, choice of means of mechanization.*

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1. Introduction

Since 2014, large areas of Ukrainian lands have been shelled with heavy weapons, which has led to the appearance of territories unsuitable for agricultural use [1]. As a result of explosions of shells and rockets, emission funnels are formed, the area of which can reach 300–500 m^2, which makes it impossible to eliminate them without the involvement of mechanization.

The size and shape of the emission funnels depend on the type of ammunition that exploded. Also, according to the standard sizes of funnels, it is possible to assess the damage caused to the soil cover and to establish the basic chemical composition of pollution.

In modern conditions, the analysis of disturbed territories by military aggression is carried out using satellite technologies, which make it possible to find funnels with a diameter of one meter on the surface of the earth.

After carrying out work to clean the soil from harmful chemicals, reclamation and reclamation work is carried out.

When solving the problem associated with planning the disturbed relief of the earth's surface, there is an urgent problem of choosing efficient mining, construction or agricultural equipment, depending on the specified parameters of emissions.

An analysis of the current state of research on the restoration of disturbed lands as a result of shell explosions should be considered in the context of mining and technical reclamation, since emission funnels in their parameters resemble mine workings used in the extraction of minerals, and in volume they can reach hundreds of cubic meters. Therefore, research work in the direction of restoring lands disturbed by open mining, including during the extraction of amber, deserves special attention, since the shape and size of the emission funnels are similar to the violation of the upper soil layers during the illegal development of this raw material.

The studies carried out in [2] confirm that the conflict in the east of Ukraine has led to serious environmental problems from groundwater pollution to the incapacitation of large areas of arable land. Pollution comes from both poisonous chemicals and metal fragments and the use of explosives. However, the paper does not address the issues of solving these problems. In [3], considerable attention is also paid to the emission funnels, which disfigured the earth and destroyed protected areas after the hostilities. The issues of violation of the functioning of the upper layers of soil as a result of the construction of ditches and fortifications are considered.

The authors of [4] give a general description of the territories disturbed as a result of illegal mining of amber in the Dubrovytskyi forestry. It has been determined that it is most expedient to carry out a complete reclamation of the disturbed area, since the nature and extent of the violation does not allow achieving the goal by partial reclamation. However, the paper does not consider the issue of choosing mechanization for reclamation work, depending on the parameters of disturbed workings. The author of the work [5] proposes, after carrying out restoration work on lands disturbed by the war, to conduct an environmental and economic assessment of the territories in order to determine the future direction of use. The main stages of carrying out restoration work are presented, taking into account the specifics of the problem.

The papers [6, 7] consider the issue of using satellite technologies for monitoring lands affected by mining operations. When using specially developed software, a search is made for disturbed objects on the earth's surface, after which the information is accumulated and transmitted to the relevant authorities for reclamation work. This technology can be used to capture the parameters of emission funnels.

The analysis of research works [8, 9] confirms that the issue of restoring the lands raised as a result of explosions of shells and rockets in the conditions of modern Ukraine is an extremely important task, the effective solution of which depends on the sustainable functioning of the agricultural complex in the areas affected by artillery shelling. The creation of economically attractive territories for development is the key to the experience of successful post-war renewal in many countries [10].

To solve the problem, there is no systematization of the parameters of emission funnels, taking into account their depth, width and volume, as well as the number of disturbed soil layers necessary to develop recommendations for choosing safe methods of backfill mechanization.

In the works presented earlier, the dependence of the volumes of emission funnels on their depth and slope angles was not established, which makes it difficult to select the necessary mining, construction or agricultural equipment for their elimination, since even a slight change in these parameters leads to a significant increase in volumes and terms of liquidation of soil violations.

Consequently, *the aim of research* is to develop recommendations for the selection of effective mechanization means for eliminating emission funnels formed as a result of explosions of shells and rockets. This aim can be achieved by solving the following tasks:

- to classify the emission funnels formed on the earth's surface as a result of explosions of shells and missiles;
- to establish the dependence of the volume of funnels on their depth at variable slope angles;
- to develop recommendations on the choice of mechanization means for the elimination of emission funnels, depending on their size.

2. Materials and Methods

The object of research is the mechanization of the process of elimination of emission funnels on the earth's surface, formed as a result of explosions of shells and missiles. Since this process requires a lot of effort and cannot be carried out without the involvement of powerful mechanized tools used in the mining or construction industry.

During the work let's use:

- analytical method of research in the analysis of parameters and classification of existing emission funnels formed on the earth's surface as a result of explosions;
- graphic-analytical research method for studying the dependence of the volume of emission funnels on their depth at different slope angles, as well as in developing recommendations for the choice of mechanization to eliminate emission funnels.

3. Results and Discussion

As a result of hostilities on the territory of Ukraine since 2014, thousands of hectares of land have been formed, mutilated by artillery shells and rockets [1]. In addition to funnel emissions, the ravaged lands are poisoned by a variety of chemicals and littered with metal debris. The solution to this problem must be comprehensive and take into account both the cleanup of chemicals and the planning of disturbed land surfaces to bring them to a safe state for further use in economic activity.

The complexity of the task lies in the fact that all emission funnels have different sizes, which primarily determine the volume of ground work and the choice of the type of equipment that can be safely used to eliminate them. In this regard, there is an urgent problem of developing methodological provisions for the choice of mechanization means for eliminating emission funnels, depending on their geometric dimensions.

To classify the emission funnels formed on the earth's surface as a result of the explosion of shells and rockets, it was established that their size depends on the power of the types of shells. When a projectile of 220 mm caliber breaks, a funnel with a diameter of about 7 m can form, at 152 mm up to 6 m, at 120 mm up to 3.5 m, at 82 mm about 1 m. Cruise missiles that form funnels with a diameter of 10 m or more up to 20 m. According to the information given, the types of emission funnels are classified according to the size and number of disturbed soil layers (Table 1).

Table 1

Types of emission funnels formed as a result of projectile explosions

Funnel type	Depth, m	Width, m	Funnel volume, m^3	Number of disturbed soil layers	Backfill mechanization method
Small	Up to 0.7	Up to 1.5	Up to 0.4	1	Scraper Bulldozer
Shallow	0.7–1	1.5–2.5	0.4–1.6	1	Bulldozer Loader
Medium	1–1.5	2.5–3.5	1.6–4.8	1 2	Bulldozer Loader
Deep	1.5–3.5	3.5–5.6	4.8–28.7	1 2 3	Loader
Super-deep	More than 3.5	More than 10.5	More than 28.7	1 2 from 3	Excavator Loader

Schematic representations of the emission funnels formed as a result of projectile explosions are presented by type in Fig. 1.

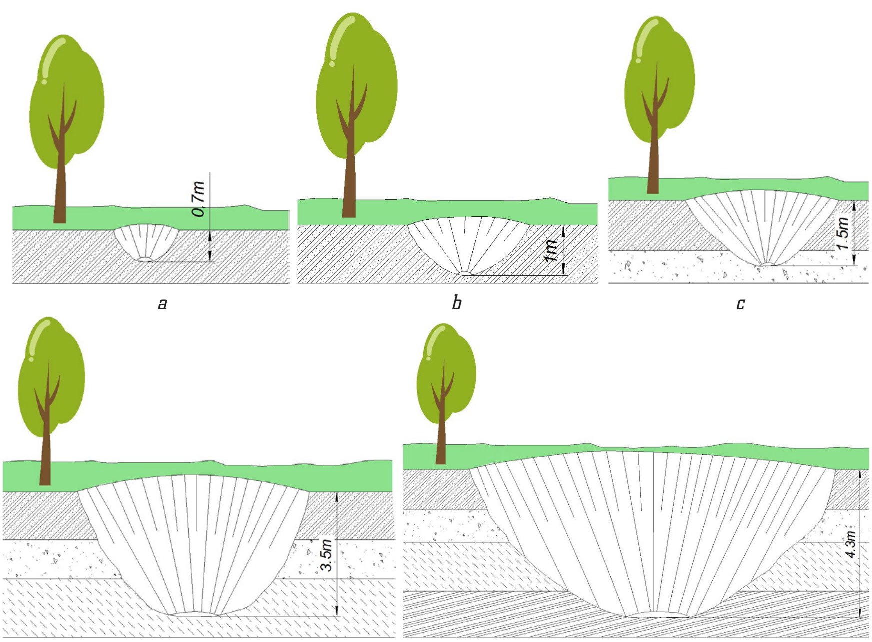

Fig. 1. Schematic representation of emission funnels: *a* – small; *b* – shallow; *c* – medium; *d* – deep; *e* – superdeep

In accordance with the increase in the depth of the emission funnel, its volume increases, this in turn has a significant impact on the choice of mining equipment for backfilling. To solve the problem of determining the timing of backfilling the formed emission funnels with mining equipment, it is necessary to establish the influence of the depth of the funnel on its volume, taking into account changes in the slope angles of the funnel.

Since a conventional emission funnel has the shape of a truncated cone, it is proposed to determine its volume by the following expression:

$$V=\frac{1}{2}\cdot\pi\cdot h\cdot\left(r_1^2+r_1+r_2^2+r_2\right),\ \text{m}^3; \quad (1)$$

where h – funnel depth, m; r_1 – funnel bottom radius, m; r_2 – top radius of the funnel.

According to expression (1), the main parameter that has a significant impact on the volume and further choice of backfill mechanization means is the depth of the funnel. It should be noted that the radius of the bottom of the funnel and its total radius are related to each other by the angle of inclination of its slope. With this in mind, the determination of the funnel volume can be performed even if there is no value of the funnel radius on the surface r_2 in accordance with the proposed expression:

$$V=\frac{1}{2}\cdot\pi\cdot h\cdot\left(r_1^2+r_1+\left(r_1+h\cdot\text{ctg}\alpha\right)^2+r_1+h\cdot\text{ctg}\alpha\right),\ \text{m}^3; \quad (2)$$

where α – funnel slope angle, deg.

To establish the dependence of the volume of the funnel on its depth, the following output parameters are set: the radius of the bottom of the funnel is 0.5 m; funnel depth from 1 to 10 m; funnel slope angle 35° and 45°. The results of the obtained calculations are given in Table 2.

The established parameters of the emission funnels (Table 2) make it possible to determine the dependence of volume on depth in the range from 1 to 10 m, taking into account the slope angles (Fig. 2).

Analysis of the research results (Fig. 2) confirms that the funnel volume has a power-law dependence on depth in a given range. In this case, the main influence on the value of the volume, in addition to the depth of the funnel, is exerted by the angle of inclination of the slopes. With an increase in the depth of the funnel by a factor of 10 from 1 to 10 m, its volume increases from 350 to 450 times, depending on the slope angle of the funnel. It should be noted that an increase in the funnel slope angle by 28 % from 35° to 45° leads to an increase in its volume by 95 %, while the area increases by 98 %.

The established dependencies confirm that even a slight increase in the depth of the emission funnel leads to a significant increase in its area and volume. This, in turn, has a significant impact on the type of mining equipment that should be used during their liquidation and the time of its operation.

When developing recommendations on the choice of mechanization means for eliminating emission funnels, depending on their size, the issue of cleaning the land from poisoned chemicals and metal fragments should first of all be considered. After bringing the state of the soil to a safe state, it is necessary to carry out a set of works that, to a certain extent, meet the requirements of mining and technical reclamation in the restoration of lands disturbed by mining. A list of works is carried out related to the planning of relief differences using mining, construction or agricultural equipment, depending on the specified amount of work.

Table 2

Influence of the depth of emission funnels on their volume

Funnel depth, m	Funnel diameter, m		Funnel area, m^2		Funnel volume, m^3	
	$\alpha=35°$	$\alpha=45°$	$\alpha=35°$	$\alpha=45°$	$\alpha=35°$	$\alpha=45°$
1.0	3.9	3.0	11.7	7.1	5.2	3.4
2.0	6.7	5.0	35.4	19.6	27.6	16.2
3.0	9.6	7.0	71.9	38.5	80.2	44.8
4.0	12.4	9.0	121.3	63.6	175.7	95.3
5.0	15.3	11.0	183.4	95.0	327.0	174.1
6.0	18.1	13.0	258.4	132.7	546.8	287.5
7.0	21.0	15.0	346.2	176.7	848.0	441.7
8.0	23.9	17.0	446.8	227.0	1243.4	643.0
9.0	26.7	19.0	560.2	283.5	1745.8	897.7
10.0	29.6	21.0	686.4	346.4	2368.1	1212.1

The established dependences (Fig. 2) made it possible to determine that the volume of a 10 m deep funnel can reach 2368 m^3, which requires a significant amount of time to eliminate it. The main difficulty in the use of mechanized backfill is the need to attract and transport over long distances powerful excavation and loading and auxiliary equipment. Therefore, in order to develop recommendations on the choice of rational means of mechanizing the backfilling of emission funnels, it is proposed to take their hourly productivity as a criterion, since their work is calculated on an hourly basis.

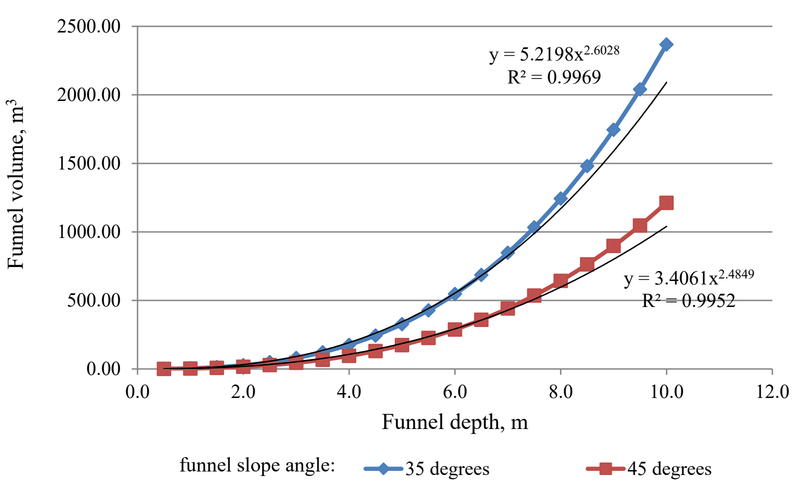

Fig. 2. Dependence of the volume of emission funnels on their depth at funnel slope angles of 35° and 45°

According to the Table 1 means of mechanization adopted the following performance indicators: bulldozer – from 150 to 200 m^3/h; wheel loader – from 250 to 300 m^3/h; excavator – from 350 to 400 m^3/h. Taking into account the specified performance indicators of excavation-loading and auxiliary equipment, as well as the volumes of emission funnels with a depth of 0 to 10 m, recommendations were developed for choosing the necessary mechanization means and the required number of machine hours for filling them was determined (Fig. 3).

According to the presented scheme (Fig. 3), funnels up to 1 m deep are proposed to be planned by a bulldozer without the involvement of additional equipment with soil rocks located around the funnel. The elimination of such a funnel under normal conditions will last up to one hour. A wheel loader is the most efficient way to deal with a 1–5 m deep funnel, as the maximum funnel volume is close to 320 m^3, which corresponds to the machine's hourly output.

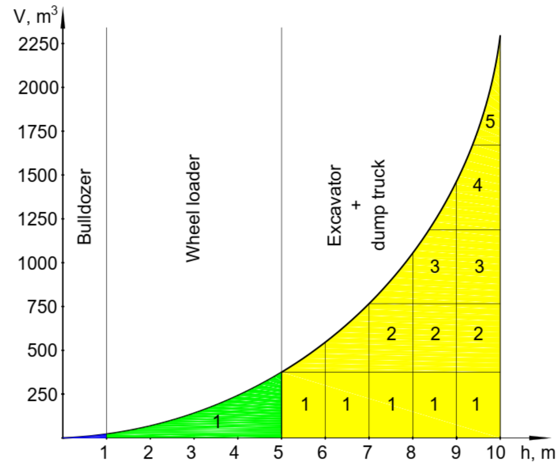

Fig. 3. Scheme for the selection of mechanization means for eliminating emission funnels and establishing the number of machine hours for filling them up

In addition, eliminating a funnel of this size requires the use of additional volumes of soil, which a wheel loader can bring under its own power without the involvement of dump trucks. Emission funnels with a depth of 5 to 10 m are recommended to be backfilled by excavators working in tandem with a dump truck, which will first deliver soil for backfilling from a specially designed place. Since funnels 10 m deep can reach more than 2000 m^3 in volume, their elimination can take up to 6 hours, and in some cases this time can even be increased due to the need to form a certain sequence of soil layers, as well as provide the necessary soil compaction.

The obtained research results can be useful for scientists and designers in the field of mining and construction. The developed recommendations will be useful to theoretical scientists and practicing researchers in the context of solving problems of determining the scope of work to restore lands that have been disturbed in the form of emission funnels as a result of shell and rocket explosions during hostilities.

4. Conclusions

The main types of disturbances of the earth's surface, represented by emission funnels formed as a result of the explosion of shells, are determined. According to the systematized parameters of emission funnels, a classification has been developed that takes into account their depth, width and volume, as well as the number of disturbed soil layers as a result of the formation of a funnel. Based on this, possible ways of backfill mechanization are proposed. Schemes of five main types of emission funnels are presented, taking into account disturbed soil layers

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as a result of explosions, which make it possible to determine the sequence of restoration of disturbed areas of the earth's surface.

It has been established that the dependence of the volume of emission funnels on their depth is a power law, while the angle of inclination of the slopes also has a significant effect on the volume of the funnel. It was determined that with an increase in the funnel depth by 10 times from 1 to 10 m, its volume increases from 350 to 450 times depending on the funnel slope angle, and an increase in the funnel slope angle by 28 % from 35° to 45° leads to an increase in its volume by 95 % and area by 98 %.

Recommendations have been developed on the choice of mechanization means for eliminating emission funnels, depending on their depth. It has been established that the required time for their backfilling can vary from one to five hours, depending on the chosen means of mechanization and the amount of planning work.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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