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Oleksandr Phorostianenko
Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. Master of Chemistry. (Ukraine)
forostenenkoshasha@gmail.com
ORCID : 0009-0008-8990-372X
Halyna Petruk
Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. PhD, Associate professor (Ukraine)
petrukgd60@gmail.com
ORCID 0000-0002-7148-9312

THERMAL TREATMENT AS A METHOD OF REMEDIATION OF SOIL CONTAMINATED WITH PESTICIDES

Thermal treatment of pesticide-contaminated soil is one of the effective methods of purifying soil from harmful pollution. Since pesticides have a harmful effect on humans and the environment, especially if they enter the body through food, there is a need to reduce their amount in the soil. Thermal treatment of soil contaminated with pesticides consists in raising the temperature of the soil to a certain level, which allows the destruction of pesticides and other harmful substances. The purpose of this work is to analyze the results of previously conducted studies using high-temperature processing and their conclusions regarding the effectiveness of the method.

The review of research was conducted on the basis of the criteria for the effectiveness of thermal treatment and its potential use for the remediation of pesticide-contaminated soils.

Recent research shows that thermal treatment of pesticide-contaminated soil can be a self-sufficient and simple method of soil purification. However, further research is needed in this area to improve methodology, techniques and environmental safety development regarding post-procedural soil behavior and waste disposal. All this can help in further work on solving the problems of soil pollution and help preserve the health of people and ecosystems.

It has been established that heat treatment is one of the most effective methods of remediation of soil contaminated with pesticides. It allows you to reduce the level of pollution by a significant amount after just one application of this method. However, before using the treatment, it is necessary to study in detail all possible factors affecting the effectiveness of the method, including temperature, duration of treatment, type of soil and others.

Various methods of heat treatment, their effectiveness and possibilities of use in real conditions were analyzed. The main factors affecting the effectiveness of the method, as well as various options for the application of heat treatment, depending on the type of soil and the level of contamination, were also investigated.

Keywords: soils, purification, pesticides, remediation, heat treatment.

Introduction. Pesticides are substances designed to control pests of plants, animals, and other organisms that damage crops. However, their improper use and accumulation in the soil can lead to serious consequences for the environment and human health. One of the most serious problems associated with the use of pesticides is their accumulation in the soil. In the case of long-term use of pesticides, they can accumulate in the soil and transfer to plants and animals that feed on contaminated areas. This can lead to serious food contamination and affect the health of the people who consume it. In addition, pesticides can have a harmful effect on the environment, as they can enter groundwater and rivers, which can affect the diversity of ecosystems and lead to the death of fish and other aquatic organisms [1].

Thus, soil contamination with pesticides is a serious problem that requires immediate measures to solve it. Thermal soil treatment is one of the effective methods of remediation of pesticide-contaminated soils and can be used to restore soil quality and ensure food safety. Another problematic aspect of soil contamination with pesticides is that these substances can be transferred to different ecosystems and thereby affect human and animal health. Many of the pesticides are very persistent and can remain in the soil for decades. This means that even if the use of pesticides is stopped, their residues can affect insects

for a long time. Therefore, many researchers are looking for new technologies to remediate pesticide-contaminated soil. One of these methods is heat treatment of the soil. It consists in treating the soil with high temperatures, which reduce the concentration of pesticides in the soil by destroying them.

Although heat treatment is a fairly effective method of remediation, it has its advantages and disadvantages. One of the biggest disadvantages is that high temperatures can kill the beneficial microorganisms that live in the soil and are necessary for its fertility and is a rather expensive method, as it requires a lot of energy and time.

Therefore, it is necessary to continue research and develop new methods of remediation of pesticide-contaminated soil that are more effective and less harmful to the environment and human health.

Analysis of research and publications. A review of soil remediation methods for pesticide contamination examines several effective methods, such as phytoproduction, phytosenization, phytoremediation, bioremediation, and phytoextraction. However, all of these methods have their own peculiarities. Phytoproduction and phytosenization are very effective methods because they use natural processes to clean the soil but they usually require a lot of time and resources. Bioremediation, which uses microorganisms to break down pesticides, is effective but requires temperature and humidity control [1]. Phytoremediation and phytoextraction are the newest methods of soil remediation. Phytoremediation is the use of plants to break down pesticides and clean the soil. This method can be more effective than phytoproduction and phytosenization, because plants can produce enzymes that break down pesticides faster than natural processes [0]. Phytoextraction is the use of plant extracts to remove pesticides from the soil. This method can also be effective, but requires a large amount of plants and water to produce the extract [7].

It is important to consider all possible methods of soil remediation in order to choose the optimal and effective approach to solving the problem of pesticide contamination. One of the soil remediation methods is thermal soil treatment. It involves heating contaminated soil to high temperatures to destroy pollutants and can be applied to a variety of pesticides. In addition, thermal treatment is a relatively fast and effective method that can be applied at the site of contamination without the need to transport the soil to special sites . However, this method also has its limitations and disadvantages, in particular, the high cost and the need for large energy costs for heating the soil .

After analyzing various methods of soil remediation , thermal treatment was found to be the optimal method for remediation of pesticide-contaminated soil. This method allows for the destruction of pesticides in the soil by raising the temperature to high levels and is an environmentally acceptable method as it does not use chemicals to destroy pesticides.

The purpose of research is to study the heat treatment as a potential method of remediation of soils contaminated with pesticides and the principle of action of heat treatment, its effectiveness and the possibility of application for practical purposes. Parameters affecting the reduction of the amount of pesticides in the soil are also analyzed.

Thermal treatment of soil is based on the use of high temperatures to break down pollutants into simpler components. As a result, pesticides break down into less toxic substances that can be safely removed from the soil or used as a source of nutrients for plants. One of the key elements of heat treatment is temperature, which is usually in the range of 300 - 700 ^{0}C [2]. This method can be used to remove various types of pesticides, including organic insecticides, herbicides and fungicides. In addition, thermal treatment can be applied to different types of soil, such as sands, clays, and soils with a high humus content [5].

During heat treatment, the soil is exposed to a high temperature, which leads to the decomposition of pollutants into simpler components. This process occurs in two stages: desorption and degradation. During desorption, pesticides are released from the soil and enter a gaseous state, after which their degradation occurs due to thermal decomposition. However, it is worth noting that heat treatment can have some disadvantages, in particular, it can affect the structure of the soil and its physical properties, such as water permeability and gas permeability. In addition, the process can be quite complex and require a lot of energy. It is also important to consider that thermal treatment may not be effective in removing pesticides that are in hard-to-reach places, for example, in soil pores or in aqueous solution.

Heat treatment parameters such as temperature, duration and intensity are important for process efficiency. The temperature should be sufficient to destroy pesticides, but at the same time should not lead to damage to beneficial microorganisms in the soil. The most effective soil treatment temperature depends on the type and concentration of contamination. The duration of treatment is also an important parameter, as it is necessary to ensure sufficient time for the destruction of pesticides, but at the same time should not allow damage to beneficial microorganisms. The intensity of heat treatment affects the

speed of the process and ensures even distribution of heat in the soil. To achieve optimal results of soil treatment, it is necessary to balance all parameters well, taking into account the content of pesticides in the soil and their chemical properties.

The results of the study have shown that the optimal temperature for remediation of soil contaminated with pesticides is 250-300 ^{0}C, while the duration of treatment should be at least 4 hours. It has been proven that when the temperature drops below 200 ^{0}C, the effectiveness of remediation is significantly reduced, since the complete decomposition of pesticides does not occur. At the same time, when the temperature rises above 350 ^{0}C, soil degradation and loss of nutrients can be observed, so it is necessary to choose the optimal temperature taking into account these factors [4].

Different methods can be used for thermal treatment of pesticide-contaminated soil, which differ in the type of thermal energy used for treatment. One such method is steam treatment, which can significantly reduce heat treatment time and increase process efficiency[5]. Another method is infrared heating, which uses infrared energy to heat the soil to high temperatures and break down pesticides and other pollutants in the soil. After that, the soil can be used again for crop production [6]. The method using water vapor is that the soil is first heated, after which it is moistened so that the water becomes saturated steam. The water then turns into steam, which penetrates the soil and helps remove pesticides. After that, heating is carried out again, which helps to evaporate water and reduce the level of moisture in the soil. There are also other thermal treatment methods, such as incineration and exothermic oxidation, but they are less efficient and may have a greater negative impact on the environment.

An overview analysis of the results of scientific research confirms that heat treatment can be an effective method of remediation of soil contaminated with pesticides. However, the success of this method depends on several interrelated factors, the most important of which are the treatment parameters and the properties of the contaminated soil.

It was established that different types of soil can affect the efficiency of heat treatment. It has been studied that heavy clay soils may be less amenable to heat treatment because their structure may prevent effective heating of the entire soil mass. Conversely, sandy soils may be more amenable to heat treatment due to greater heat permeability. In addition, the effect of temperature on pesticide decomposition may depend on its physical and chemical properties. For example, in acidic soils the decomposition of organic matter can be slow, while in alkaline soils it is fast. Also, the location of pesticides in the soil can affect the effectiveness of the treatment: the depth of their occurrence, their concentration, and the time they stay in the soil [7].

The mechanism of pesticide degradation during heat treatment also depends on the type of pesticide and the processing conditions. Usually, decomposition occurs through the processes of dehydration, disintegration, and oxidation [8].

Depending on the type of pesticide, the decomposition mechanism may differ. Pesticides containing fluorine, chlorine and bromine atoms can be decomposed at temperatures below 400 ^{o}C, while pesticides containing phosphorus and sulfur atoms can be more resistant to thermal treatment. Organophosphates , on the other hand, have high thermal stability, so their degradation occurs at high temperatures (more than 500 °C).

Studies show that heat treatment can lead to changes in soil structure, depending on the type and duration of treatment. In addition, a change in soil pH is possible due to a decrease in the content of organic matter and water, as well as an effect on the content of organic matter and other elements that are important for plant development and human health [4,8].

For example, studies have shown that thermal treatment can contribute to a decrease in soil pH and an increase in its solubility, as well as to a change in the structure and composition of organic soil, which in turn affects the absorption of pesticides by the soil, its properties and general condition [4].

It is especially important to preserve soil structure after heat treatment, as soil structure is one of the main properties that determines the ecosystem functions of soil, such as interaction with plants and biodiversity. Studies have shown that high temperatures can cause a decrease in soil structural stability, which can lead to soil coagulation and reduced ventilation, as well as reduced water permeability and water content. However, temperature can have a positive effect on the effectiveness of pesticide remediation, as high temperatures increase the decomposition of pesticides in the soil.

Investigating the effect of thermal treatment on the microbiological composition of soil is an important step in studying the effectiveness of this method for remediation of soil contaminated with pesticides. During thermal treatment, the temperature of the soil is maintained at the level of 70-100°C, which can affect the microbiological composition of the soil. Thermal treatment can affect the composition of the bacterial and fungal population of the soil, reducing their number. However, at the

same time, heat treatment can reduce the number of pathogenic microorganisms and other undesirable microorganisms, which can be a positive effect. Thus, the study of the effect of high temperature on the microbiological composition of the soil is an important stage of researching the effectiveness of this method and taking this effect into account when planning remedial measures [7].

It is known that heat treatment can have a certain effect on the vegetation and ecosystems of the surrounding environment. However, the level of this effect may depend on several factors, such as the intensity of treatment, the type and time of heat treatment, and the type of soil.

Also, it is worth noting that during heat treatment, harmful substances can be formed, which can negatively affect plants and animals. For example, dioxins and furans can be formed , which are potentially carcinogenic [8].

Comparison of advantages and disadvantages of thermal methods . The advantages of the thermal treatment method for the remediation of soil contaminated with pesticides include:

1. Effectiveness: Heat treatment is an effective method for destroying pesticides in soil because it can reach high temperatures that ensure the decomposition of pesticides into safe substances.
2. No need to use chemical reagents: the treatment does not require the use of chemical reagents, which makes it safer for the environment.
3. Shorter turnaround time: Heat treatment can be completed within hours, which is significantly faster than some other remediation methods.
4. Preservation of soil quality: Heat treatment can preserve soil quality because it does not use chemical reagents that can damage the soil.
5. No residual products: after processing, no residual products remain that can negatively affect the environment or human health.
6. Suitable for a wide range of pesticides: High-temperature treatment can be applied to neutralize different types of pesticides, making it more versatile than other remediation methods.
7. Cost-effectiveness: the heat treatment method can be beneficial from an economic point of view, since it is not necessary to spend significant funds on the purchase of chemical reagents and other equipment.[4,5,7]

The disadvantages and limitations of the thermal treatment method for remediation of pesticide-contaminated soil are important issues to consider before using this method. One of the most serious disadvantages is the high energy consumption and costs for ensuring the required temperature conditions. There are also certain limitations associated with soil types where the application of thermal treatment may be less effective or even impossible.

Heat treatment can have a negative effect on the biological activity of the soil, as it can reduce the content of organic matter and destroy beneficial microorganisms. Also, there may be some problems with uniform heating of the soil, especially large volumes, which can lead to uneven distribution of heat and uneven decomposition of pesticides.

In addition, there is a risk of evaporation of toxic substances during heat treatment, which can lead to environmental air pollution. The consequences of such pollution can have a harmful effect on the health of people and animals, as well as on the natural environment.

Also, heat treatment can cause changes in the structure and properties of the soil, which can negatively affect the ecosystem. For example, an increase in temperature can lead to a decrease in organic matter in the soil, which can reduce its nutrient and moisture-holding capacity. A change in the structure and morphology of the soil cover, in turn, can reduce the microbiological activity of the soil and reduce its fertility [8].

When choosing a remediation method soil and pesticide disposal, it is necessary to take into account all shortcomings and limitations by selecting the optimal parameters of high-temperature treatment of the fertile soil layer, the area and depth of the soil cover; also, the processing method involves preliminary studies of the content of pesticides, their chemical composition, soil toxicity[2,4,7].

Conclusions . As a result of the analysis of research carried out by Ukrainian and foreign scientists, it was established that heat treatment can be an effective method for removing pesticides from the soil. It makes it possible to achieve more than 90% reduction in the concentration of pesticides in the soil, provided the procedure is performed correctly.

The effectiveness of heat treatment depends on such basic factors as the type of pesticides and the type of soil. At the same time, high temperature during heat treatment can lead to a decrease in the physical and chemical properties of the soil, such as pH and organic matter content. At the same time, heat treatment can have a negative effect on the microbiological composition of the soil and plant cover.

One of the biggest economic drawbacks is that heat treatment can be quite an expensive and

complex process that requires special equipment and skilled personnel.

In general, thermal treatment of soil is recognized as an effective method of pesticide remediation , however, some disadvantages and limitations must be taken into account, including limitations on the depth of treatment and the impact on the microbiological composition of the soil and the environment.

It is necessary to carry out preliminary additional research on certain areas of the soil cover to determine effective methods, techniques and frequency of heat treatment.

Considering the advantages and disadvantages of thermal soil treatment, such methods can be an effective choice for remediation of pesticides in soil, provided the necessary safety measures are observed and its limitations are taken into account. These results can be useful for farmers, scientists and representatives of government bodies dealing with soil pollution problems, remediation of the fertile soil layer and disposal of toxic wastes present in soils and groundwater.

References

[1] Carsten A. Brühl, Johann G. Zaller., Biodiversity Decline as a Consequence of an Inappropriate Environmental Risk Assessment of Pesticides. *Sec. Toxicology, Pollution and the Environment*. 7.(2019). https://www.frontiersin.org/articles/10.3389/fenvs.2019.00177/full

[2] Da Ding, Xin Song, Changlong Wei., A review on the sustainability of thermal treatment for contaminated soils. *Environmental Pollution*. V. 253, (2019). 449-463 https://doi.org/10.1016/j.envpol.2019.06.118

[3] Divine N. Tarla, Larry E. Erickson, Ganga M. Hettiarachchi., Phytoremediation and Bioremediation of Pesticide-Contaminated Soil. *MDPI Journals. 10* (4). (2020). 1217. https://doi.org/10.3390/app10041217

[4] Kanghee Cho, Jinkyu Kang, Songbae Kim., Effect of inorganic carbonate and organic matter in thermal treatment of mercury-contaminated soil. *Environmental Science and Pollution Research*. 28. (2021) 48184–48193 https://link.springer.com/article/10.1007/s11356-021-14024-z

[5] M. Aresta, A. Dibenedetto, C. Fragale., Thermal desorption of polychlorobiphenyls from contaminated soils and their hydrodechlorination using Pd- and Rh-supported catalysts. *Chemosphere*. V.70, I.6. **(**2008**).** 1052-1058. https://doi.org/10.1016/j.chemosphere.2007.07.074

[6] Osvalda Senneca, Fabio Scherillo, Alfredo Nunziata. Thermal degradation of pesticides under oxidative conditions. *Journal of Analytical and Applied Pyrolysis*. V**.** 80, I**.** 1, **(**2007**).** 61-76. https://doi.org/10.1016/j.jaap.2007.01.002

[7] R. Petruk, T. Yakovyshina., Analysis of the environmentally friendly restoration methods of pesticide-polluted soils. *Ecological Safety and Balanced Use of Resources*. 2(20). (2019). https://doi.org/10.31471/2415-3184-2019-2(20)-102-111

[8] William L. Troxler,Steven K. Goh &Lynton W.R. Dicks., Treatment of Pesticide-Contaminated Soils with Thermal Desorption Technologies. *Air & Waste*. 43(12). 1993. 1610-1617. https://doi.org/10.1080/1073161X.1993.10467230

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