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Remediation of Contaminated Soil by Polycyclic Aromatic Hydrocarbons Using Composting

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ABSTRACT: Polycyclic aromatic hydrocarbons (PAHs) were one of the most concerning organic and toxic pollutants in the world. Since the 20th century, there had been no improvement in resolving or reducing the discharged or released amount of PAHs into the soil or environment. Detecting PAHs (PAHs) involved collecting environmental or biological samples, extracting PAHs using specialized techniques, and analyzing them with advanced methods like gas chromatography-mass spectrometer (GC-MS) or high performance liquid chromatography (HPLC). This process was crucial for assessing contamination levels, understanding health risks, and guiding environmental safety measures. There was no full replacement with existing technology and materials that would not release the PAHs. Now, the PAHs pollutant has caused many cases related to the impact of PAHs on the environment and human health, prompting immediate action for resolution. The remediation to remove the PAHs from the contaminated soil was conducted using the composting method. The few kinds of composting methods were vermicomposting, which used earthworms to decompose PAHs in the contaminated soil, in-vessel composting that ran the aerobic process under a close air space tank, and aerated pile that implemented the aerobic process in an open air space. The bulking agent of in-vessel composting and aerated composting was the same. Actually, these three composting methods were under bioremediation to remove PAHs from contaminated soil. There were a few challenges that would be faced by the government, the people, and the research in the future. Some recommendations have been provided to face these future challenges.

KEYWORDS: Composting; PAHs; worldwide; innovation; bioremediation; aerobic

1. Introduction

Curse of the modern era, most of the developed countries and developing countries are implement industrialized, sustainable activities, urbanized activities. The activities would help improve the economic of countries, human social life, and sustain development that can be passed down to future generations. Nevertheless, some of the activities that help to improve development the countries would have released or formed the PAHs. The PAHs as one of the most concern pollutant that pollute the environment and affect the human health, which is needed to pay attention by every department of environment and health in the world. The

inception of PAHs research can be traced back to the late 19th and early 20th centuries, initially emerging from the exploration of coal tar derivatives within the chemical sciences. The discovery of PAHs piqued scientific curiosity due to their intricate molecular architecture and their ubiquity in the environment as byproducts of organic material combustion [1]. A pivotal moment in the field was the elucidation of their carcinogenic potential, notably through the seminal work of Ernest Kennaway in the 1930s, who identified the carcinogenicity of coal tar to be attributable to specific PAH compounds. This breakthrough catalyzed a paradigm shift, propelling PAHs into the forefront of environmental and health science research. Investigations expanded to encompass their environmental distribution, mechanisms of toxicity, and potential for bioaccumulation, highlighting the necessity for comprehensive monitoring and regulation. The recognition of PAHs' extensive environmental presence and their significant health implications galvanized interdisciplinary research efforts, merging chemistry, toxicology, environmental science, and public health disciplines [2]. This marked the commencement of an enduring scientific endeavor aimed at elucidating PAHs' impact on environmental integrity and human well-being, underscoring the critical importance of this field in the broader context of environmental safety and public health policy. The molecule formation of PAHs is under organic compound with multiple amount of aromatic rings, for examples of the PAHs exist in the soil are acenaphthene, fluoranthene, benzoperylene, chrysene, and many more kinds of PAHs [3, 4]. PAHs only able to be obtained under solid formed but can be found under insoluble mixture with liquid and gas [5, 6]. The particles of PAHs was not easily break down and continuously exist in the environment, which means it would stay long-term period on the environment [7]. PAHs is an organic pollutant that can be obtained in the soil of environment or contaminated soil. This pollutant is toxic and poison to the environment and human health. The polycyclic aromatic hydrocarbon actually can be found naturally from the environment and anthropogenic activities. The anthropogenic materials that available to find the polycyclic hydrocarbon is rubbish, waste, coal, petroleum, and pesticide for the agriculture, and incomplete combustion gas released from the industries, open burning and road construction [8, 9]. The natural PAHs will be released from natural petroleum, minerals, plants synthesis, magma of volcano and natural fire burn action [10]. The focus in this essay is to understand the PAHs that obtained in the soil and provide the remediation on reduce the particles of PAHs inside the soil. The contaminated or polluted soil by the PAHs would need remediation methods to reduce or minimize the particles of PAHs, which help to recover or restore the quality of soil that do not cause or reduce environmental impacts or human health. There many methods of remediation of contaminated soil in PAHs like bioremediation, nanotechnologies, composting and many more kinds of remediation.

2. Environmental Impact and Human Health Caused by PAHs

PAHs is the toxic and dangerous organic pollutant that released from the natural environment and anthropogenic activities especially at the developed or developing countries. This organic pollutant can cause many environment impacts like soil pollution, water pollution and air pollution. The pollution formed by the PAHs can lead to affect the human health and species health of the environment [11]. The sources of soil pollution by the PAHs have many ways to lead this matter happened. The environmental impacts and human or species health that will destroy the ecosystem of the environment and this will happened under ecosystem cycle.

Usually the particles of PAHs is exist in the atmosphere of the environment, the reason of the PAHs found and contaminated the soil is the particles of PAHs from the atmosphere will follow the flow of the water into the surface of ground. Then, the water with the PAHs will be infiltrated and absorbed into the soil of the environment during raining season that cause soil pollution happened. PAHs also will flow into the soil surface when there is leakage or discharge of PAHs action happened on the industrialization activities and agricultural activities [5]. The another sources is the natural materials that have polycyclic aromatic hydrocarbon can automatically or naturally follow into flow into the soil by the control of weather and ecosystem cycle of the environment. However, the contaminated soil by PAHs will affect the water of the environment. It also will flow to the water surface of groundwater of the environment during runoff process, catchment process, leakage or discharge process and infiltration process. The particles of PAHs in the soil will also present in the food production for human or species of the environment. For example, human will used the contaminated soil by the PAHs to grow or produce the vegetables as food for human or plants as food for the animal species. The animal species have eat the plants or preys that contain PAHs might be become as food chain of human [8]. Then, human might eat the plants and some animal species as food [12]. The particles of PAHs at soil surface or water surface that can be flow into the atmosphere during the strong wind period that can lead to air pollution [13]. The another source in cause the existing of PAHs in soil is the excrement of human or species that will be disposed to the soil, which the PAHs will flow into the soil from the excrement. Moreover, the PAHs inside soil will affect the health or cause death but is depends on short-term or long-term contact or amount contact with the particles of PAHs through food, drinks or inhalation. The short-term contact with PAHs that affect human health by the PAHs, the sickness are diarrhea, sensitive skin, vomit and eye become sensitive. The long-term contact with PAHs wil harm human health by the PAHs, the sickness are cancer, tumor, inhalation problem, liver problem and another kinds of unknown name sickness that will destroy organs [14, 15]. PAH formation in contaminated soil is influenced by human activities like industrial processes and natural events such as wildfires. Environmental factors like temperature, sunlight exposure, and microbial activity play significant roles, affecting PAH distribution and degradation. Soil properties, including organic matter content, texture, pH, and moisture, impact PAH adsorption, mobility, and persistence. Human interventions such as land use practices and remediation efforts further shape PAH dynamics. Understanding these factors is crucial for assessing contamination risks and implementing effective soil management and remediation strategies to mitigate the adverse effects of PAHs on both human health and the environment [8]. In term of animal, toxicological assessment of PAHs involves studying the effects of these compounds on animals to understand their potential health risks. Through controlled experiments, researchers assess PAH exposure routes, such as ingestion, inhalation, or dermal contact, and measure toxicological endpoints like carcinogenicity, mutagenicity, teratogenicity, and systemic toxicity [16]. Studies typically use various animal models, including rodents, fish, and invertebrates, to evaluate acute and chronic effects, dose-response relationships, and mechanisms of toxicity. Results inform risk assessments and regulatory guidelines to protect both wildlife and human populations from PAH-related health hazards. PAH risk assessment considers ingestion, dermal contact, and inhalation. Ingestion occurs through contaminated food and water, potentially leading to systemic toxicity and cancer. Dermal absorption arises from direct contact with PAH-contaminated surfaces, causing skin irritation and systemic health issues [10]. Inhalation of

airborne PAHs from sources like vehicle emissions and tobacco smoke can result in respiratory and cardiovascular problems. Regulatory limits are established to mitigate exposure risks, guiding pollution control and public health measures. Overall, understanding PAH exposure routes helps establish guidelines to safeguard human health and the environment.

3. Remediation or Treatment of Contaminated Soil by PAHs Using Composting

3.1 Vermicomposting.

Vermicomposting is one of the bioremediation composting method to remove or minimize the PAHs from the contaminated soil. The method of this vermicomposting is to use earthworm to breakdown and remove the PAHs from to contaminated soil through life cycle of earthworm [17]. The earthworm will stay inside the contaminated soil, eat the food waste and animal waste as their food supply to have strength, and release their excrement in the contaminated soil that help to run the vermicomposting process to remove the PAHs. There are two kinds of earthworm that only available to be used for this technology process are *Eisenia* and *Erudrilus* [18]. It means that the earthworm can successfully remove the PAHs from the soil into their body to break down the PAHs and then will release their excrement to provide the interaction between abiotic with biotic in the soil. It is because there are many kinds of microorganism or enzymes that obtained inside the body of earthworm to break down PAHs and change the characteristics of soil [19]. The earthworm also can improve the quality of the soil by changing the properties of soil. For example, the changes in capacity storage of water for the soil, large porosity that exist inside the soil, increase the important nutrients that help the growth of plants, and remove the odor of the contaminated soil. The earthworm is selected materials for vermicomposting because it have high resistance to many kinds of pollutant, especially this organic pollutant as the PAHs [20].

The technology of vermicomposting have their own advantages and disadvantages to be use to remove the PAHs from contaminated soil. The advantages of vermicomposting is widely use and easily to be operate or manual around the world. This method of composting also have more nutrients produced after completed the composting than aerated composting as one of the advantages. It has the advantages as one of the environmental friendly method and able to recycle use for soil agricultural after the earthworm to breakdown and remove the PAHs [21]. This technology can be reduce about 80% of PAHs [22]. The disadvantages of vermicomposting are the composted or composting soil may produce new disease or pathogen or materials that is not known but will cause human health affection due to uncontrol process of vermicomposting [21]. The another disadvantages are high cost effective of food supply for the earthworm in this vermicomposting and hard to find the resources of food supply for the earthworm that able to provide under constant period . For example, the food supply like leaf and excrement of animals [23]. The another disadvantages are to need larger area for this vermicomposting system and the overall period to finish the composting process is long periods. To address these challenges and uncertainties, future research efforts should focus on developing more targeted and efficient PAH remediation techniques. This could involve exploring innovative strategies such as phytoremediation, advanced oxidation processes, and microbial bioremediation. Additionally, there is a need for more comprehensive studies to understand the factors influencing the efficacy of remediation methods, including soil properties, PAH concentrations, and environmental conditions. By addressing these limitations

and focusing on areas for further research, we can advance the development of more effective and sustainable PAH remediation technologies and contribute to the protection of human health and the environment [24].

3.2. In-vessel composting.

The second type of composting method to remove the PAHs is use the in-vessel composting method. It means that the aerobic process for this composting system will be applied at the area without open air space. It means that the PAHs will be removed through aerobic process by controlling the amount of oxygen injected into the compost soil and the temperature that suitable for the activation of microorganism to break down the particles of PAHs inside the contaminated soil. The bulking agents for the composting process are *Pseudomonas auriginosa,* woodchips, coco fibres and sawdust [25, 26]. The methods to run the in-vessel composting are to mix the contaminated soil with the bulking agent before insert to the bioreactor. After the mixture of compost soil, the temperature inside the vessel will be controlled by the control system to maintain the range of temperature under 55-65℃ and fix flow amount for oxygen into the compost soil to activate the work of microorganism. The used bulking agent can be recycled back with the new bulking agent at the mixing process [27, 28]. The bulking agent is to be used to allow space for the oxygen air to enter into the compost pile and provide the less moisture content to allow to absorb the moisture content of soil.

In this in-vessel composting technology, the advantages and disadvantages will be provided when it used to remove the PAHs from contaminated soil. The advantage to use the in-vessel composting method are the contaminated soil is the amount of bulking agent for this composting system is less and smaller area used for composting than aerated composting . The another advantages are the period for in-vessel composting able to reduce than the aerated composting because the temperature for composting in vessel is able to to be controlled but the aerated composting is naturally reaction to form different elevation of temperature [29]. The in-vessel composting is under environmental friendly and sustainable method as one of the advantage of in-vessel composting. It also able to remove the odor of the contaminated soil [30]. The disadvantage for the in-vessel composting are the cost effective for this composting is higher than the aerated composting because it has extra control system need to be applied in (United States Environmental Protection Agency, 2000). The another disadvantage of in-vessel composting is the energy consumption for the whole system is higher than the energy consumption of aerated composting system used. It also have high maintenance cost than the vermicomposting and aerated composting because it have more machine and control machine needed to be used than the vermicomposting and aerated composting [29].

3.3. Aerated composting.

The aerated composting is also an aerobic process of composting, which same as the in-vessel composting. The aerated composting also availabe to remove the PAHs. But he differences between them are the area for aerated composting system is under open air pile and will not be control the temperature and the amount of oxygen flow into the compost pile [28]. This aerated composting also need longer period to finish the composting process and longer than the period of in-vessel composting. The methods of aerated composting will be little similar with the in-vessel composting. The first steps is to mix the contaminated soil with the bulking agent also

as *Pseudomonas auriginosa*, woodchips, coco fibres, and sawdust. Then, the mixture will be shaped into triangle shape and insert on top of the perforated pipe, which allow to absorb the air inside the composting pile to the filter pile for green house gas removal and allow the oxygen flow into the composting pile from the atmosphere [30]. The oxygen flow into the composting pile to active the work of microorganism to break down the PAHs [31]. The temperate of the composting process will not be controlled and let the temperate elevation of composting reaction run naturally with at least 5 days within the temperature range of 55-65℃. However, the period of composting process will be longer due to the uncontrol temperature range. The bulking agent is to be used to allow space for the oxygen air to enter into the compost pile and provide the less moisture content to allow to absorb the moisture content of soil.

The technology of vermicomposting have their own advantages and disadvantages to be use to remove the PAHs from contaminated soil. The advantage is the environmental friendly and sustainable method. The another advantages are cost effective for this composting system is lesser than the in-vessel composting system and reduce the volume of compost soil. The another advantages are odor will be removed and release less green house gases during composting happened. The last advantage have defined are less energy consumption needed for this composting system and this aerated composting als able to improve the quality of soil. The disadvantages are the period for aerated composting is longer than the in-vessel composting because the aerated composting is naturally reaction to form different elevation of temperature but the temperature for composting in vessel is able to to be controlled within the optimum range of temperature for the microorganism have active the action to break down the PAHs. The another disadvantages found are large area needed for the capacity of aerated composting than in-vessel composting and needed more bulking agent for aerated composting than the in-vessel composting [32].

4. Future Challenges in Social, Environment and Research

The PAHs is the one of the most organic pollutant need to be concern in many years ago, which have earlier started concerning than the microplastic pollutant. Although the PAHs have been early concern by the world but the PAHs pollutants still cause many cases that the pollutant affect the environment, ecosystem and human health, which the example cases mentioned at current status section. Even though, there are many remediation methods provided to remove the PAHs. The production or source of PAHs still being released or discharged to the environment. Therefore, there are some future challenges will be faced by the world [1]. The first challenge for the world is that there is no replacement of technologies or materials that will not release or form the PAHs since the 20th century. It is because some developing or developed countries still need to implement the industrial activities, agricultural activities, and urbanization activities to improve the economic of countries and social life of people. Although the remediation methods had being provided, the remediation methods to remove the PAHs when the affection caused by the PAHs become serious concentration found in soil or the environment. The second future challenge is there was no government concern this matter when the pollutant of PAHs did not serious the environment and human health [33]. The government should be pay direct attention to this matter when identified the sources of PAHs discharged to the environment and human health. The government must stop those activities that might release the PAHs pollutant into the soil or environment and do the remediation

method to reduce it from the moderate or high concern to low concern rate. The government can take enforcement action or provide penalty when the serious of PAHs discharged or disposal happened. They also need to provide free medication service to those exposed to the particles of PAHs. The third future challenge is that the people worldwide do not follow or work together with the government to reduce the PAHs to the environment. The most of the people in the world did not know or reorganized that the PAHs is an organic pollutant that will destroy the environment and human health. Therefore, the anthropogenic activities implemented by humans will still release or dispose of the PAHs into the environment without considering the warning or caution given by the government [34]. Some industries did not reduce the amount of PAHs before it released or discharged to the environment. Some of the industries are not concern about the this matter when the PAHs that discharged from their industries have affected the social environment and affected the health of the people that live near the sources of PAHs released. Therefore, the government need to provide public awareness and knowledge about this PAHs pollutant to the people in the world. And the government need to set a rule to control the discharged of PAHs for the anthropogenic activities. The last challenge is the researchers need to innovate or evaluate or obtain any replacement of technologies or materials that will not release or minimize the particles of PAHs to the environment that will affect human social living. The government need to provide helps, resources and share knowledge and information with the researchers to find the method for replacing technologies or materials [35]. Researchers worldwide need to work together to share their information, data and knowledge to investigate if there are any replacement of technologies or materials that will less or no released of the PAHs.

5. Conclusion

The PAHs (PAHs) in contaminated soil must be concerned in worldwide. The current statues of the PAHs pollutant was getting more serious and happened real cases that the PAHs have destroyed the environment and human health in the world like Malaysia and China. The remediation is provided to remove the PAHs from the contaminated soil as vermicomposting, in-vessel composting, and aerated composting. These three composting types are the environmentally friendly and sustainable remediation methods. The government, the people and the researchers of the world must work together to face the challenges and follow some recommendations or actions to resolve it.

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Competing Interest

All authors have no competing interest to declare.

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