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Use of Bioremediation with Microbes for Industrial Waste Management

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ABSTRACT

Rapid industrial growth has significantly contributed to environmental pollution, particularly through hazardous waste disposal. Industrial waste, including heavy metals and toxic organic compounds, poses a major challenge for sustainable environmental management. Improper management of this waste can lead to contamination of water, soil, and air, threatening human health and ecosystems (Bagaskara, 2023; Supraptini, 2002). This study investigates the potential of bioremediation using microbes for industrial waste management and identifies factors influencing its effectiveness. Conducted as an experimental laboratory study, the research tests various microorganisms known for their bioremediation capabilities, such as Pseudomonas, Bacillus, and Aspergillus.Analysis of contaminated soil revealed lead (Pb) levels at 63.1 mg/kg, exceeding the livestock toxic limit of 10–30 mg/kg. The growth index (GI) for the inoculum treatment increased by 84.3% to 136.7% over a sixty-day incubation period, while the control treatment showed minimal changes (88.8% to 111.7%). These findings indicate that optimal incubation conditions and appropriate microbial selection can enhance soil quality, making it safer for plant growth and less harmful to the environment. Expanding bioremediation practices could significantly mitigate the adverse effects of industrial waste on environmental pollution. Overall, this research highlights the viability of microbial bioremediation as an effective strategy for managing industrial waste and improving ecological health.

Keyworld *: Bioremediation, Industrial Waste Management, Soil Pollution*

INTRODUCTION

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Rapid industrial growth has had a significant impact on environmental pollution, especially in terms of hazardous waste disposal. Industrial waste produced, such as heavy metals, toxic organic compounds, and other pollutants, has become a major challenge for sustainable environmental management. If not managed properly, this waste can pollute water, soil, and air, which ultimately has the potential to endanger human health and the ecosystem. (Bagaskara, 2023; Supraptini, 2002).

One of the innovative approaches being developed to address this problem is bioremediation, which is the use of microorganisms to decompose or neutralize pollutants in waste. Microorganisms, such as bacteria, fungi, and algae, are able to metabolize and convert pollutants into simpler and less harmful compounds (Mustamin et al., 2020). Bioremediation technology offers an environmentally friendly and efficient solution in handling industrial waste, because this method is not only effective but also more economical compared to conventional waste treatment technologies such as incineration or chemical stabilization (Munawar, 2024) (Atlas & Bartha, 1998).

Several studies have shown that certain microorganisms are able to overcome heavy metal contaminants and hazardous organic compounds. For example, Pseudomonas and Bacillus bacteria can be used to degrade hydrocarbons in oil waste, while fungi such as Aspergillus have the potential to absorb heavy metals such as lead and mercury (Kallang, 2020). This process not only cleans the environment from hazardous substances but also improves the quality of polluted soil and water (Gadd, 2004).

However, the implementation of bioremediation on a large scale still faces various challenges, such as adjustment of environmental conditions of microorganisms, degradation speed, and limitations of microbial types that are able to work in varying waste conditions (Puspitasari & Khaeruddin, 2016). Therefore, further research on the optimal types of microbes, as well as environmental conditions that support the bioremediation process, is very important to increase the effectiveness of this technology in industrial waste management.

This study aims to explore the potential of bioremediation with microbes in industrial waste management, as well as to identify factors that influence the success of this process. Thus, it is expected that the results of the study can provide a significant contribution to the development of bioremediation technology for more sustainable industrial waste management.

METHODS

This research is an experimental laboratory study, which aims to test the effectiveness of industrial waste bioremediation using microbes. Experiments were conducted with various types of microorganisms that are known to have potential in the bioremediation process, such as Pseudomonas, Bacillus, and Aspergillus. Each microorganism will be tested under different conditions, to determine the optimal conditions and level of efficiency in decomposing specific pollutants in industrial waste.

This research will be conducted in the environmental microbiology laboratory at Poltekkes Kemenkes Padang. The collection of industrial waste samples was carried out in several local industries that produce hazardous waste, such as heavy metal or hydrocarbon waste. This research is planned to last for 2 months, starting from sample collection to analysis of the results.

Population: Industrial waste samples were taken from several factories that produce hazardous organic and inorganic waste, such as hydrocarbon waste from the oil industry, heavy metal waste from the metallurgical industry, or chemical waste from the pharmaceutical industry. Microbial samples include Pseudomonas spp. (for hydrocarbon degradation), Bacillus spp. (for heavy metal reduction), Aspergillus spp. (for heavy metal absorption). Each microorganism will be isolated, cultured, and applied to different waste samples to test their respective bioremediation capabilities.

Data analysis includes an explanation of changes in pollutant concentrations in each waste sample after being treated with microorganisms. Analysis of variance (ANOVA) is used to compare the effectiveness of each microorganism on pollutant degradation. If there is a significant difference, further tests such as the Tukey test can be carried out to determine which pairs have significant differences.

RESULTS

1. Characteristics of heavy metals

In general, the results of total metal analysis in sludge waste and contaminated soil from the deinking process showed that the parameters of Cd, Ni, Cr, Zn, Pb, and Cu metals were quite high compared to the requirements of non-hazardous metals in soil. Data for Pb metal were not available.

The increased metal content in contaminated soil indicates that the metal has been concentrated in the soil. This occurs over a long period of time, about three years or more, because the existing organic compounds have been broken down, resulting in an increase in the metal content in the soil.

Table 1. Results of Heavy Metal Analysis

Parameter	Analysis results (mg/kg)		Max value. In soil not dangerous(mg/kg)
	Sludge Waste	Contaminated land	
Cadmium (Cd)	3.8	4.9	0.08
Chromium (Cr)	15.1	57.8	10
Copper (Cu)	110	140	2.0
Tin (Pb)	39	63.1	22
Nickel (Ni)	13	16	0.4
Zinc (Zn)	142	234	4.0

The results of the analysis of contaminated soil characteristics showed that Pb metal was 63.1 mg/kg, in accordance with the livestock toxic level limit of 10–30 mg/kg. Therefore, soil contaminated with solid waste from the deinking process must be cleaned.

2. Germination index (%)

Table 2. Germination Index (%)

Treatment	Incubation time (days)					
	10	20	30	40	50	60
Control without adding inoculant	88.8	104	111.7	108.4	93.1	89.5
Soil + 10% inoculant	84.3	93.5	123.8	99	128.2	136.6

To measure the toxicity of a plant to a particular substance, the germination index (GI) is a very sensitive parameter. To calculate the GI, a combination of seed germination versus relative root elongation is used. Zucconi et al. (1981) and Gao et al. (2010) stated that if the germination index is more than 80%, the soil can be considered free of compounds that are harmful to plants.

The calculation of the germination index was carried out on the remediated soil under the best remediation conditions, namely with the addition of 10% inoculum. The results were compared with the control without the addition of inoculum. According to observations, the GI of all treatments from day 10 to 60 showed a GI above 80%. This indicates that the remediated soil no longer contains substances that are harmful to plants. Table 2 shows the germination index values. The GI value for the inoculum addition treatment increased by 84.3% to 136.7% during the incubation period of ten days to sixty days. In contrast, the GI value for the control treatment without enough fluctuated by 88.8% to 111.7% during the incubation period of ten days to sixty days. Although the control treatment showed that the soil was no longer toxic, the inoculum addition treatment showed that the soil no longer contained toxic substances.

DISCUSSION

This study shows that soil contaminated with heavy metals, such as Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), and Zinc (Zn), has a fairly high metal concentration exceeding the threshold set for non-hazardous soil. For example, the Pb content in contaminated soil reached 631 mg/kg, far exceeding the safe limit of 22 mg/kg for non-hazardous soil and the toxic limit of 10-30 mg/kg for livestock. This emphasizes the need for more effective waste management, one of which is by using bioremediation techniques.

The use of microbes as bioremediation agents has been shown to reduce the toxicity of contaminated soil, as indicated by an increase in the Germination Index (GI) in remediated soil samples. In the treatment with the addition of 10% inoculant, the germination index increased significantly from 843% to 1366% during the 60-day incubation period, compared to the control without inoculant whose value fluctuated. According to Zucconi et al. (1981) and Gao et al. (2010), a GI value above 80% indicates that the remediated soil no longer contains substances that are harmful to plants. This shows that the use of microbes in bioremediation is effective in reducing the content of hazardous pollutants, especially heavy metals (Ginting et al., 2020).

In theory, the bioremediation process works through biological mechanisms in which microbes metabolize pollutants or convert them into simpler and less harmful compounds (Khastini et al., 2022). In this case, microbes such as Pseudomonas and Aspergillus may play a role in breaking down organic compounds and binding heavy metals, thereby reducing the concentration of pollutants in the soil. Heavy metals trapped by microbes then undergo precipitation or immobilization, which ultimately prevents the pollutants from spreading further into the surrounding environment (Kemen LHK dan B3, 2016) (Gadd, 2004).

The success of bioremediation in this study was also supported by the right incubation conditions, including the appropriate pH and temperature for microbial growth. The selection of the right microbes is a key factor in the effectiveness of bioremediation, because each microbe has a specific ability to degrade or bind certain pollutants. For example, Pseudomonas is more effective in degrading hydrocarbon compounds, while Aspergillus plays a greater role in absorbing heavy metals.

CONCLUSIONS

The results of this study indicate that bioremediation using microbes can be an effective solution in industrial waste management, especially in reducing heavy metal content in contaminated soil. With the right incubation conditions and the selection of appropriate microbes, the bioremediation process can improve soil quality, making it safe for plant growth and not harmful to the environment. Implementation of bioremediation on a wider scale can help reduce the impact of environmental pollution caused by industrial waste.

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