

Effect of Stirring Circulation on the Effectiveness of Microbial Consortium in Sludge Oil Bioremediation Process

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ABSTRACT: Sludge oil is a by-product of crude oil processing that poses significant environmental and efficiency challenges in the oil and gas industry. This study aims to evaluate the effectiveness of using microbial consortia to address sludge oil, with a focus on the impact of agitation on oil recovery enhancement. An experimental and laboratory analysis approach was employed to implement bioremediation for cleaning sludge oil from crude oil tanks. Factors such as agitation conditions, types of microorganisms, environmental conditions, and handling time were evaluated to understand their effects on oil recovery efficiency. The experiment compared two conditions: microbial consortia in agitated and non-agitated systems. The results showed that the use of microbial consortia in an agitated system was significantly more effective in reducing sludge oil and enhancing oil recovery compared to the non-agitated system. Agitation was found to improve microbial circulation and nutrient distribution, contributing to an increase in sludge oil degradation by up to 17.1%. However, the success of this method was also influenced by the composition of the sludge oil and environmental conditions. This research contributes to the development of more effective solutions for managing sludge oil and improving oil recovery in the oil and gas industry. The results of this experiment can serve as a foundation for further research on optimizing bioremediation for different operational conditions and supporting environmental sustainability.

KEYWORDS: Agitation, Bioremediation, Microbial consortium, Oil recovery, Sludge oil.

INTRODUCTION

The accumulation of sludge in crude oil storage tanks poses significant challenges, including reduced storage capacity, oil quality degradation, and potential damage to infrastructure (Kurniawan et al., 2024; Hassanzadeh et al., 2018). This sludge, a complex emulsion of hydrocarbons, water, and solid particles, contains toxic substances and heavy metals (Tudorache & Antonescu, 2024). Various methods have been developed to address this issue, such as modifying inlet pipes to distribute sludge more evenly (Kurniawan et al., 2024), using surfactants and solvents to reduce viscosity (Hassanzadeh et al., 2018), and employing robotic cleaning technologies (Tudorache & Antonescu, 2024). Additionally, several management options exist for recovering materials and energy from tank bottoms, including solvent extraction, centrifugation, pyrolysis, and anaerobic co-digestion (Hochberg et al., 2022). The choice of technology depends on sludge characteristics, treatment capacity, and operational costs, with some approaches integrating multiple methods for optimal recovery and reduced energy demand (Hochberg et al., 2022).

Bioremediation and biodegradation are promising approaches for addressing oil sludge contamination, utilizing microorganisms to break down complex hydrocarbons into simpler, less toxic compounds (Ubani et al., 2013; Wang et al., 2011). These methods are environmentally friendly and cost-effective compared to physical and chemical treatments (Wang et al., 2011). Successful bioremediation depends on factors such as nutrients, pH, moisture, aeration, and temperature (Ubani et al., 2013). Techniques include natural attenuation, biostimulation, and bioaugmentation (Shahsavari et al., 2015). Compost bioremediation is gaining popularity as a treatment option (Ubani et al., 2013). However, challenges remain, including the complex composition of oil sludge, environmental conditions, and microbial adaptation to extreme environments (Hu et al., 2013). Future research should focus on improving current technologies and combining oil recovery with sludge disposal to meet both resource reuse recommendations and environmental regulations (Hu et al., 2013).

This study aims to evaluate the effectiveness of the use of microbial consortium in sludge oil management, focusing on the effect of stirring on the success of bioremediation and increasing oil recovery. It is expected that this study can develop more efficient strategies for sludge oil management and increasing oil recovery, as well as contributing to the optimization of bioremediation and biodegradation in the oil and gas industry.

Sludge Oil or oil mud is a thick and viscous hydrocarbon mixture consisting of sediment, water, oil and high hydrocarbon concentrations, which is encountered during crude oil refining, cleaning of oil storage containers and refinery wastewater treatment (Ubani et al., 2013). Sludge oil in crude oil tanks is formed due to particle sedimentation. (Jiang et al., 2020). Crude oil settles in storage tanks and separates into heavier and lighter petroleum hydrocarbons. Heavier hydrocarbons settle with water and solid particles and the mixture remains at the bottom of the storage tank (Hu et al., 2013).

Sludge oil is a residue that is difficult to decompose and is a stable emulsion consisting of a mixture of water, solids, Petroleum Hydrocarbons (PHC) and metals. PHC and organic compounds in sludge oil are divided into four groups: saturated, aromatic, resin and asphaltene. Sludge oil can come from various sources in the refinery, such as separators, storage tank bottoms and floating sludge from industrial wastewater treatment facilities (Hu et al., 2013). In crude oil storage tanks, sludge oil usually consists of sulfides, phenols, heavy metals, aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) with rings 4, 5, 6 or more, and has a higher concentration, namely 10-20 times (Li et al., 1995). Paraffin, asphaltene and a mixture of aromatic hydrocarbons make up more than 90% of the Sludge oil material. Paraffin is a saturated hydrocarbon (alkane) with the general formula C_nH_{2n+2} , which can be straight or branched chain. Asphaltene is a group of polycyclic aromatic hydrocarbons that have various substituted alkyl side chains. Unsaturated ring compounds consisting of three or more complex polycyclic aromatic hydrocarbons are also known as aromatic hydrocarbons (Ubani et al., 2013).

Due to its flammable and toxic nature, Sludge oil is categorized as hazardous solid waste (B3). The dangers of Sludge oil are mainly caused by the content of polycyclic aromatic hydrocarbons, heavy metals, anthracene, pyrene, phenol and other toxic substances. If not treated for a long time and improper disposal of sludge oil due to inefficient processing methods can damage the environment, this sludge can pollute the soil, groundwater and air, and interfere with the growth of plants, animals and human health. (Chen et al., 2020; Thong et al., 2021). therefore, it is necessary to eliminate and reduce the dangers of sludge oil, as well as recovery from sludge oil. With methods such as Bioremediation.

METHODOLOGY

The research began by conducting a literature study to understand the relevant theories and previous research. After that, research preparation was carried out which included planning and compiling the methodology. The next stage was sampling from the crude oil tank. The samples taken were then given microbial treatment to observe their effectiveness in oil recovery and sludge oil management. Furthermore, observations and analysis were carried out on the results of microbial treatment on the samples. The results of this study were then summarized and analyzed to draw conclusions. Finally, the results of the study were compiled into a thesis before the research was declared complete.

Measurement of fluid density and specific gravity is carried out using a tool called a Density meter. In this study, phase behavior testing was carried out for 21 days to determine the acquisition of a stable emulsion against Crude Oil (Suparmanto et al., 2023).

A. SAMPLING

Sludge Oil samples were obtained from Crude Oil storage tanks. This Sludge Oil has the characteristics of being black and very hard like a rock. Some of the Sludge Oil has a soft texture like very thick and dense mud as in the picture below. (Figure. 1)



Figure 1. Sludge Oil Sample from Crude Oil Tank.



B. MICROORGANISMS

Microorganisms or microbes used in the sludge oil treatment in this study are bacteria. Bacteria have different properties and types. In this study, the microbes used were M & S microbes, which are paired microbes with a symbiotic relationship or also called consortium microbes.

This study was conducted by observing periodically every week, the jar container for the sample was closed to create stable anaerobic conditions. Every week, the samples in the container were given special treatment by opening the jar, which caused the samples to be exposed to oxygen so that they became aerobic conditions. Therefore, this study shows that the microorganisms used are semianaerobic.

C. NUTRITION

In this experiment, the nutrients used for microbial growth are a mixture of NPK fertilizer and granulated sugar. NPK fertilizer contains nitrogen (N), phosphorus (P), and potassium (K). Nitrogen can be in the form of ammonium (NH_4^+), nitrate (NO_3^-), or urea ($\text{CO}(\text{NH}_2)_2$), and plays a role in microbial metabolism and the production of enzymes needed to decompose sludge oil. Phosphorus, in the form of phosphate such as ammonium phosphate or superphosphate, provides the energy needed for biodegradation activities and the synthesis of genetic material. Potassium, in the form of potassium chloride (KCl) or potassium sulfate (K_2SO_4), helps maintain cellular stability and microbial enzymatic function. Granulated sugar is used as the main energy source for microbes. Under semianaerobic conditions, microbes metabolize sugar through fermentation or anaerobic respiration to produce ATP (adenosine triphosphate), which supports cellular activity. Sugar also stimulates the production of enzymes such as oxidases, peroxidases, and dehydrogenases that are needed to break down the complex hydrocarbons in sludge oil. With enough energy and carbon, microbes can be more efficient in sludge oil degradation.

D. BIOSOLVENTS & BIOSURFACTANTS

This study used additional biosolvents and biosurfactants. Where biosolvents dissolve and disperse sludge oil components so that they can increase the contact surface between microbes and the substrate (sludge oil that needs to be decomposed). This can make it easier for microbes to access and degrade hydrocarbons. Biosolvents ensure that microbes and nutrients are evenly distributed and have access to all parts of the sludge oil. While biosurfactants help in the mobilization of oil trapped in the sludge matrix, facilitating the recovery and decomposition of oil. Biosurfactants play a role in stabilizing the emulsion and preventing re-precipitation. By stabilizing the emulsion, biosurfactants also help maintain the stability of the decomposition process, so that microbes can continue to access and degrade oil.

E. TEMPERATURE

In this experiment, both samples were stored in a closed state and at room temperature ranging from 25-35°C.

RESULTS AND DISCUSSION

After treatment from day 0 to day 3, the development of microbes in degrading sludge oil will be observed and analyzed in samples 1 and 2. This observation and analysis were carried out on day 7, day 14 and day 21. This process aims to monitor the effectiveness of microbes in gradually degrading sludge oil and to identify changes that occur in the composition of sludge oil during the treatment period. These periodic observations will provide important data on the dynamics of the bioremediation process and help in evaluating the success of the applied treatment method.

In the sludge oil recovery experiment, the analysis focused exclusively on sample 1. The selection of sample 1 was based on a comparative evaluation that showed that this sample performed very well compared to sample 2. It was carried out using a 3-liter jar. In the jar, 500 grams of sludge oil and 300 ml of demineralized water were placed to reach a total volume of 800 ml. During the period from the first to the third day, 100 ml of M&S microbes, 50 ml of biosurfactant, 50 ml of biosolvent, 100 ml of light hydrocarbons and 50 ml of nutrients were added each day. This process was repeated three times so that the total volume added reached 1,050 ml. On the seventh, fourteenth, twenty-first and twenty-seventh days in sample I, the process was continued with the addition of 50 ml of M&S microbes, 25 ml of light hydrocarbons and 25 ml of nutrients. This amount was increased four times so that the total additional volume reached 400 ml. After the volume calculation was carried out, it was seen that the increase in the volume of crude oil in the jar reached 2,763 ml in 27 days.

After the processing was completed, the total volume of crude oil successfully produced was 2,250 ml. The processing results and volume increase reached 92.1% of the total capacity of the jar. The increase in recovery from sludge oil reached 17.1% with a 513 increase in the volume of crude oil produced from the sludge oil bioremediation process.

These results indicate that the processing method applied using consortium microbes and the circulation process in this experiment is effective in increasing the recovery of crude oil produced from sludge oil, with significant growth in the percentage of processing results.

It can be seen in Figure 2 the condition of sludge oil before and after bioremediation. Before the bioremediation process, sludge oil was still hard like a rock. However, after bioremediation was carried out on Sample 1 for one month, the initially hard sludge oil successfully melted into crude oil with an API gravity of 16.24, which shows that the results obtained within one month were heavy crude oil. These results demonstrate the effectiveness of bioremediation in converting solid sludge oil into a more manageable liquid form.



Figure 2. Sludge Before and After Treatment

CONCLUSION

The circulation process through stirring has been proven to be effective in increasing the bioremediation of sludge oil. Stirring increases the distribution of microbes and nutrients, accelerates hydrocarbon degradation, and reduces the viscosity of sludge oil to 16.24 degrees API which is categorized as heavy crude oil. As a result, oil recovery increased compared to the system without stirring which resulted in an oil recovery of 17.1%, indicating that circulation is a key strategy to optimize bioremediation in the oil and gas industry.

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