REKAYASA 19 (2) (2021): 46-61

REKAYASA

Jurnal Penerapan Teknologi dan Pembelajaran

http://journal.unnes.ac.id/nju/index.php/rekayasa

Recovery in Oil Contaminated Soil (A108D) by Using Subcritical Water

Mareta Ramadhona[1*], Sri Haryati[1], David Bahrin[1]

[1] Environmental Technology, Chemical Engineering Department, Universitas Sriwijaya,Palembang, Indonesia

Email: maretaramadhona2@gmail.com [1]

DOI: https://doi.org/10.15294/rekayasa.v19i2.34429
Submit: 10 January 2022; Revision: 30 May 2022; Accepted: 05 June 2022

Abstract

Production activities in the oil and gas industry can cause environmental pollution, one of which is soil pollution. Soil contamination is generally found in the refinery area caused by oil spills or pipe leaks, loading and unloading, and oil transportation. In this study, oil-contaminated soil is processed by extracting the oil contained in the ground using water. The treatment process was applied to oil-contaminated soil, sandy soil, and mud, with a processing time of 30 to 120 minutes and flow rates of 46, 90, 139, and 183 mL/minute. The temperature of the water used for processing is ±175°C with a pressure of 14.5 atm. The results showed that the average reduction in oil content in oil-contaminated samples, namely soil, sandy soil, and mud, was 37.7%, 5.8%, and 88.4%, respectively. This method is most suitable for waste soil contaminated with dirt. Based on the flow rate and processing time, the longer the processing time, the less oil content in the oil-contaminated soil waste, and the more oil is produced. This oil recovery system on waste soil contaminated with oil can save a budget of up to 1.1 million rupiahs per tonne.

Keywords: hazardous waste, oil-contaminated soil waste, oil recovery, subcritical water, soil washing

INTRODUCTION

The needs of human life and the activities on fuel oil as an energy source have made the oil and gas processing industry develop rapidly, one of which is marked by the construction of an oil refinery as a facility for processing petroleum into fuel oil products (Zulkifliani, 2017).

Petroleum exploration and exploitation activities tend to involve significant risks to the environment, so they have the potential to cause environmental pollution. Whether solid, liquid, or gas, the residual material produced in each process can contaminate the surrounding elements, such as soil, water, or air. Countermeasures for pollution from petroleum processing activities are experiencing rapid development using modern technology and a continuous monitoring system. However, the processing technology is still carried out physically, chemically, and biologically (Ossai et al., 2020)

In the oil and gas industry, soil pollution is generally found in oil refinery areas due to pipe leaks, tank cleaning spills, or loading-unloading and oil transportation processes. Some methods commonly used to recover oil-contaminated soil include physical, thermal, and biological treatment. Physical processing can be in the form of soil washing, soil flushing, or soil vapour extraction. Thermal processing, for example, is in the form of thermal desorption and incineration. Meanwhile, biological processing includes biodegradation, bioremediation, and phytoremediation (Zhao et al., 2019).

Several studies related to the remediation of contaminated soil have been carried out, including research (Zulkifliani, 2017) regarding the remediation of oil-contaminated soil and the processing of oily waste in the oil industry. In this study, the management was carried out using a soil washing technique on a demo plant scale, where oil-contaminated soil was washed using a bio solvent. The results showed a decrease in Total Petroleum Hydrocarbons level, initially 24.71%, down to 0.91% in oil-contaminated ground. Furthermore, removing heavy metals in contaminated soil using the Chelating Agent Ethylene Diamine Tetra Acetate (EDTA), where the Fe and Pb metals contained in the soil decreased in concentration after washing using EDTA (Aziz et al., 2015). Furthermore, soil washing to extract lead, copper, and zinc from contaminated soil using biodegradable chelators in Ethylenediamine Disuccinic Acid and Hydroxyiminodisuccinic Acid and Ethylenetriamine Tetra Acetic Acid, and Diethylenetriamine Penta Acetic Acid (DTPA) as persistent chelators (Hasegawa et al., 2019). Soil washing was carried out using varying temperatures and processing times. The results stated that EDTA and DPTA were more effective than the use of biodegradable chelators.

In this study, oil-contaminated soil waste was treated by recovering the oil contained in the soil waste using subcritical water through the soil washing method. Because it is more environmentally friendly than remediation using chemicals, the costs are lower. In addition, from several previous studies, water can reduce diesel oil levels in contaminated soil by up to 70% (Islam et al., 2015). Another study demonstrated that washing the ground using subcritical water can reduce the value of Total Petroleum Hydrocarbons and Aromatic Hydrocarbons byup to 91% (Islam et al., 2014). The optimum temperature for extracting oil-contaminated soil using subcritical water at 250°C for 120 minutes was able to reduce the levels of Polycyclic Aromatic Hydrocarbons by 87.3% (Taki et al., 2018). Therefore, in this study, water was chosen as a medium for treating soil contaminated with oil.

This study aims to determine and analyze the effectiveness of reducing oil content, the flow rate and processing time effect on oil-contaminated soil waste and recovered oil, the quality of the liquid waste from the processing, and the efficiency of the B3 waste management budget.

METHOD

The materials used in this study were waste soil contaminated with oil (in the form of soil, sandy soil, and sludge) and water (temperature ±175°C and pressure 14.5 atm). The tools used a modified drum as a reactor (the device's schematic is shown in Figure 1.), pressure gauge, distillation condenser, extractor, oven, desiccator, filter cloth, spatula, filter, container, and measuring cup. The research process is divided into three stages: treatment and product analysis. The process flow diagram is shown in Figure 2.

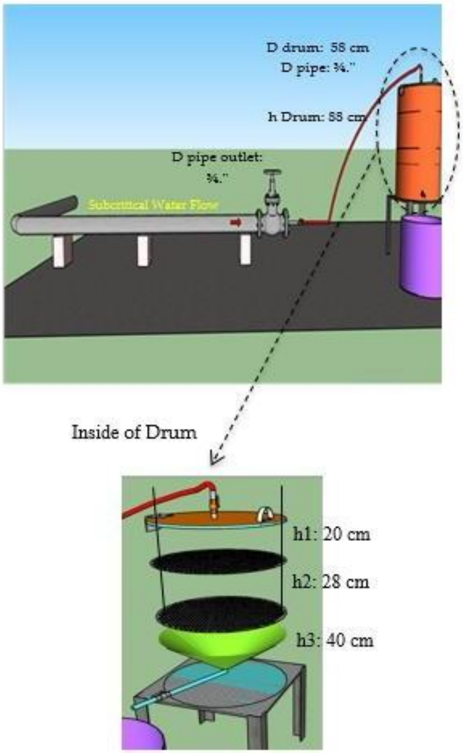

Figure 1. Equipment Scheme of Recovery in Oil Contaminated Soil (A108D) by Using Subcritical Water

Preparation

In this study, the raw material used was soil waste contaminated with crude oil, divided into three types: soil, sandy soil, and sludge. Each sample of raw materials was taken as much as 5 kg for initial analysis to determine how much Oil Content, Water Content, and Sediment were contained.

Recovery Proces

Furthermore, the raw materials were divided into 16 samples. A weight of 5kg each from the three types of raw materials was 48 samples. The treatment process was carried out by recovering the oil contained in each piece using the Batch System. The solvent used is subcritical water with a temperature of ±175°C at a pressure of 14.5 atm with various flow rates, processing times, and types of oil-contaminated soil waste. The recovery process uses a modified drum reactor. Two products were produced from this process: water mixed with oil and soil. Water and oil will come out simultaneously from the outlet pipe and then be accommodated in a holding container, while the ground will remain inside the drum.

The remaining soil was weighed and analyzed for Oil Content, Water Content, and Sediment, then compared with the initial analysis data before treatment. At the same time, the output water is then allowed to stand to separate the oil and water (settling process). After being separated, the weight of the oil will be measured and analyzed for its oil content, water content, and sediments contained in the oil. While the quality of the water will be analyzed for the quality of the liquid waste from the oil-contaminated soil treatment process followingthe Regulation of the Minister of the Environment concerning Wastewater Quality Standards and South Sumatra Governor Regulation, and also concerning Liquid Waste Quality Standards for Industrial, Hotel, Hospital, Domestic and Coal Mining Activities, as well as Palembang Mayor's Permit in 2020 concerning Permit for Disposal of Liquid Waste.

Product Analysis

The mass of the sample and the recovered oil produced were measured manually using a scale. Water Content is the amount of water contained in a sample, usually expressed in % weight Sediment is some deposit contained in a crude oil or sludge sample, usually expressed in % by weight, for analysis of sediment by extraction using the ASTM D473 method. Oil content is the amount of oil contained in the sample, usually expressed in % by volume or by weight. The value of Oil Content is needed to determine how much oil content is in the model. The percentage of oil content was influenced by the sample's water content and sediment.

Liquid waste analysis was carried out at the RU III Refinery Laboratory with the following parameters: pH, BOD, COD, Oil & Fat, NH_3, Phenol, Sulfide, and Temperature. Then compared with the applicable regulations, such as Regulation of the Minister of the Environment No. 5 of 2014 concerning Wastewater Quality Standards; South Sumatra Governor Regulation No. 8 of 2012 concerning Liquid Waste Quality Standards for Industrial Activities. Hotel. Hospital. Domestic and Coal Mining; and Palembang Mayor Permit 658.31/IPLC/0015/DPMPTSP-PPL/2020 concerning Permit for Disposal of Liquid Waste at RU III Plaju.

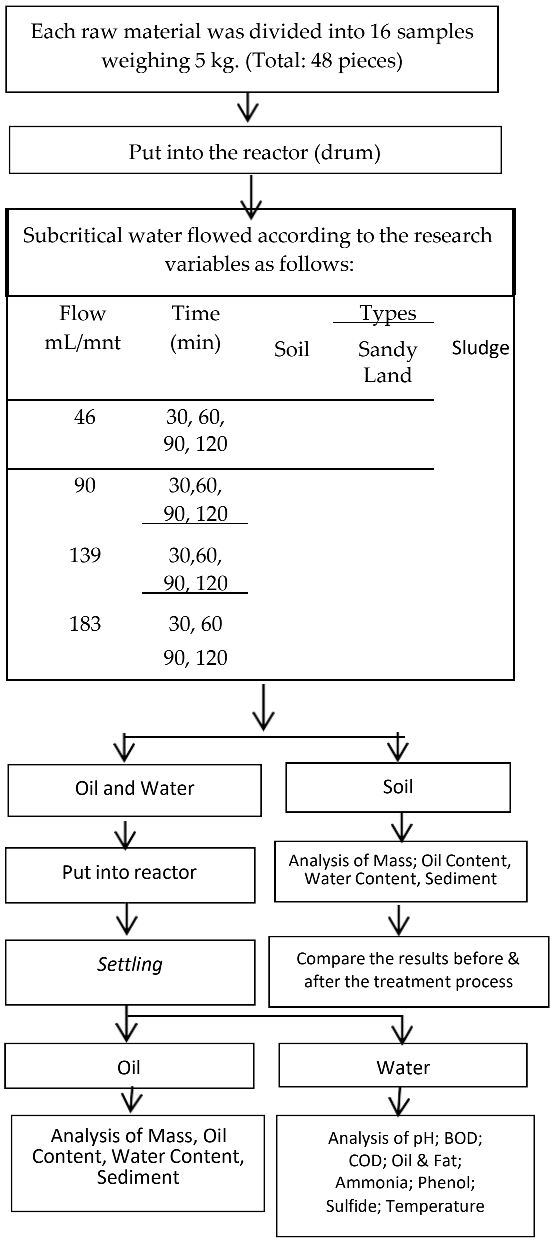

Figure 2. Flowchart of an experiment of Recovery in Oil Contaminated Soil by Using Subcritical Water

RESULT AND DISCUSSION

Oil Content Reduction Effectiveness.

The percentage of waste reduction after the oil recovery process is shown in Table 1. The decrease in the amount of waste in each sample was: 32.0%-44.8% for the oil-contaminated soil; -0.4%-12.0% for the oil-contaminated sandy soil; and 79.4%-95.4% for the sludge, with the averages respectively: 37.7%; 5.8%; and 88.4%. One sample of sandy soil contaminated with oil increased by 0.4% from the initial weight because of boiling water. In contrast, only a tiny amount of oil was recovered, resulting in an imbalance between the bound water and the released fat. However, for the rest, all samples decreased.

This decrease in waste occurred due to the oil recovery process. It happens during the processing by contacting solids in the form of waste soil samples contaminated with oil with a solution in the form of subcritical water. This fat becomes a pollutant and will melt, separating soluble substances (solutes) and inert solids (inert). In normal conditions, water is polar, but above the boiling point of 100°C, the water will turn non-polar. Oil is non-polar, so the suitable solvent for extraction is a non-polar organic solvent (Loyao, 2018).

It causes subcritical water to be used as a solvent because both are non-polar, so the oil in the sample will dissolve in subcritical water. The dissolved substance will be accommodated in the reservoir for further settling to separate water, sediment, and recovered oil. The separation process varies according to the amount of oil that has been successfully recovered.

It is in line, Taki. et al. (2018) research regarding extracting crude oil from oil-contaminated soil using subcritical water. Then another study, the recovery of diesel oil from contaminated soil using subcritical water (Islam et al., 2017). This study showed a decrease in diesel content after extraction with subcritical water. Several studies show that oil in contaminated soil can dissolve in subcritical water solvents so that the oil can be recovered, and the quantity of waste contaminated with oil is reduced.

Table 1. Percentage of Waste Mass Reduction After Oil Recovery Process

No	Description of Sample	Analysis Results (%)			
		Combined	Oil Contaminated Soil	Oil Contaminated Sandy Soil	*Sludge*
1	Lowest Value	-0.40	32.00 %	-0.40 %	79.40 %
2	Highest Value	95.40	44.80 %	12.00 %	95.40 %
3	Average	43.95	37.65 %	5.80 %	88.41 %

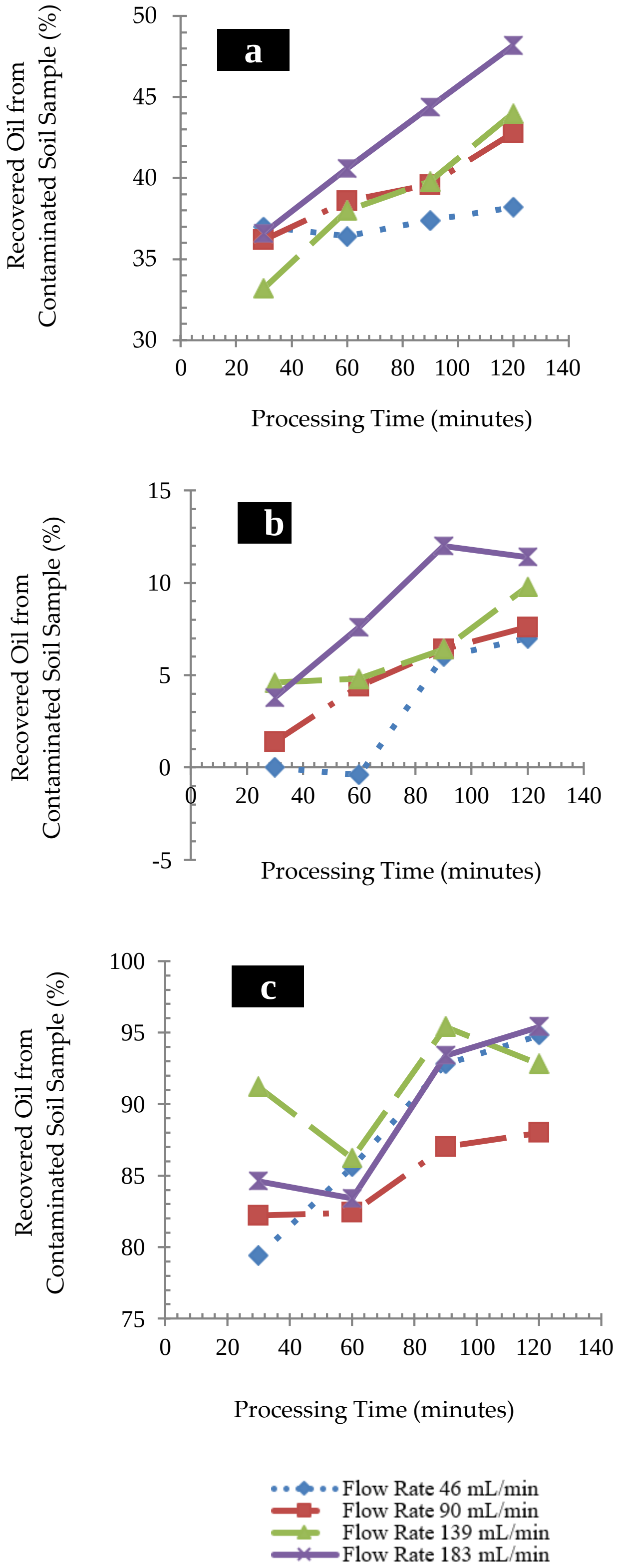

Figure 3. Graph of Effect of Flow Rate and Processing Time on Reduction of Waste Mass in Samples (a) Oil Contaminated Soil; (b) Oil Contaminated Sandy Soil, and (c) Sludge

The effect of flow rate and processing time on soil type is viewed from two sides: the effect on the soil sample and its effect on recovered oil or oil that has been successfully recovered.

A. Effect of Flow Rate and Processing Time on Soil Samples

Effect of Flow Rate and Processing Time on Soil Samples can be shown in Figure 3 on the percentage reduction in the amount of waste in each sample. At a flow rate of 46 mL/minute with processing times of 30, 60, 90, and 120 minutes, the decrease in the amount of waste in the soil type samples was 32.8% to 38%. Pieces of sandy soil types are in the range of -0.4% to 7.00%, As for sludge is 79.4% to 94.8%. Of the three types of samples, if processed at a flow rate of 46 mL/minute.

Then, the most significant waste reduction percentage is equally found at a processing time of 120 minutes. The lowest is if it is processed for 30 minutes for samples of the sludge type and 60 minutes for other models.

Then at a flow rate of 90 mL/minute with the same processing time, the decrease in the amount of waste in the soil, sandy soil, and sludge samples, respectively, was in the range of 35.0%-38.8%; 1.40%-7.60%; and 82.2%-88.0%. From the analysis results, the most significant percentage decrease in the amount of waste for a flow rate of 90 mL/minute was found at a processing time of 120 minutes, while the lowest was 30 minutes. At a flow rate of 139 mL/minute with processing times of 30, 60, 90, and 120 minutes, the decline range is 32.0%-42.2% for the soil type sample, 4.60%-9.8% for the soil type sample sand, and 86.2%-95.4% for the sludge type sample. For soil and sandy soil samples, the effectiveness was the processing time of 120 minutes. Meanwhile, the sludge sample was present at a processing time of 90 minutes.

Furthermore, at a flow rate of 183 mL/minute with the same processing time, the reduction in the amount of waste type of soil, sandy soil, and sludge is 35.0%-44.80%, respectively; 3.80%-12.0%; and 83.40%-95.40%. The processing time that has the most effect on reducing the amount of waste for soil and sludge types is 120 minutes, and the processing time is 90 minutes for sandy soil type waste. Overall, the most considerable percentage reduction in waste was found in the sludge type sample with a 183 mL/min of flow rate and processed for 120 minutes.

This research separates soluble substances from a mixture with inert solids using a liquid solvent, leaching, or solid-liquid extraction. The solid-liquid extraction process is influenced by several factors, including the type of solvent, solvent volume, temperature, particle size, and the extraction process time (Vazquez-Roig & Picó, 2015)

In this study, the solvent used was subcritical water with a temperature of 175°C. From the graphs of the study results above, the effect of flow rate on reducing waste is still quite varied. Flow rate is one factor that affects the leaching process because it will affect the volume of solvent used. The larger the solvent volume, the more solvent is in contact with the sample (Khaw et al., 2017). If based on the theory, then it should be higher than flow. Then the decrease in the mass of the waste will be higher because more solute is in contact with the solvent. However, the flow rate used to get the optimal result in other pieces gave less than optimal results, so the effect of flow rate on reducing the amount of waste is still quite varied.

This discrepancy can be influenced by several factors, including the different oil content in each initial sample and the particle size of the piece. The finer the particles, the easier to extract the oil (Worthington et al., 2018).

However, the effect of processing time is known that the longer the processing time, the higher the amount of oil recovered, and vice versa, the shorter the processing time, the lower the results. The longer the processing time, the more contact will be, and the volume of the solvent will also increase, so the amount of oil that has been recovered will increase. It is also related to the particle size of the sample, such as the sandy soil type sample has larger particles than other types of models. The initial analysis results show that the sandy soil type sample has a lower oil content than the soil and sludge type sample. The more extensive the particles, the longer it takes for the liquid to diffuse.

Conversely, the smaller the particles, the shorter the time it takes for the liquid to diffuse. It affects the sample of sandy soil types, the decrease in the amount of waste did not decrease significantly. One piece experienced an increase in mass from the mass before processing. The growth is influenced by the condition of the sample that can absorb water (Sinulingga.M. et al. 2012) so that the water that should be the solvent will be absorbed into the soil sample,while the amount of solute that easy be extractedis not as much as the amount of water absorbed. It causes an increase in mass in the sample.

On the other hand, the sludge type sample occurred. In this sample, the reduction in the number of samples is very significant.Because the oil content in the sample is relativelyhigh, the particles are also smaller than the othersamples. When the leaching process is carried out, there will be a lot of dissolved substances in the solvent. It causes the inert to be reduced.

Samples of soil type, sandy soil, and sludge, based on the effect of processing time, it is known that the longer the processing time, the higher the mass and percentage of mass waste reduction will be. It is in line with the theory, which states that processing time is one factor that affects the leaching process. The longer the processing time, the longer the contact between the solute and the solvent, so the extraction yield will also increase (Elboughdiri, 2018).

The results of this study are also in line with research conducted by Taki et al. (2018), which explains that the flow rate does not significantly impact the removal of crude oil on oil-contaminated soil. However, coarse oil removal increased with increasing processing time for the processing time varies. Therefore, crude oil extraction does not depend on the flow rate variable (Taki et al., 2018).

B. Effect of Flow Rate and Processing Time on Recovered Oil

Effect of flow rate and processing time on recovered oil mass. It can be found in Figure 4. At a flow rate of 46 mL/minute with processing times of 30, 60, 90, and 120 minutes, the amount of oil from the soil was 36.4% to 38.2%. For samples of soil, namely 1.2% to 8.00%. Meanwhile, the sludge sample ranges from 80.4% to 95.2%. Of the three types of instances, if processed at a flow rate of 46 mL/minute, the most significant percentage of the amount of oil was at a processing time of 120 minutes for samples of soils contaminated with oil and sludge, and 90 minutes for samples of contaminated sandy soils. In comparison, the lowest is if it is processed for 30 and 60 minutes for recovered oil from samples of soil and sandy soil contaminated with oil, and 60 minutes for recovered oil of other types of pieces.

At the same 90 mL/minute flow rate, the amount of oil from the soil, sandy soil, and sludge samples was 36.2%-42.8%, respectively; 3.40%-9.60%; and 84.0%-89.4%. The percentage of the amount of oil from each sample type was the largest at a processing time of 120 minutes. In contrast, the lowest is at a processing time of 30 minutes. At a flow rate of 139 mL/minute with processing times of 30, 60, 90, and 120 minutes, the range of recovered oil from oil-contaminated soil samples was 33.2%-44.0%. Recovered oil from sandy soil samples contaminated with oil is 4.80%-10.2%. The recovered oil from the sludge type sample is 86.4%-95.6% of soil type and sandy soil contaminated with oil—the processing time of 120 minutes and 90 minutes for recovered oil from the sludge sample. Meanwhile, the lowest processing time was 60 minutes for recovered oil from the sludge sample and 30 minutes for recovered oil from others.

Furthermore, at a flow rate of 183 mL/minute with processing times of 30, 60, 90, and 120 minutes, the amount of oil successfully recovered from the types of soil samples, sandy soil, and sludge, respectively, namely 36.6%-48.20%; 5.0% -12.6%; and 84.4%-97.2%. The processing time that most influences the amount of oil for oil and sludge contaminated soil types is 120 minutes, while oil-contaminated soil type waste is 90 minutes.

From the graph above, the effect of flow rate and processing time on sample mass, water content, sediment, and oil content on recovered oil from each sample type is still quite varied. The results obtained in the highest flow rate are more optimal than those using a lower flow rate, but in other samples, the flow rate used to get optimal results gives less than optimal results. So that the effect of flow rate on mass, water content, sediment, and oil content is not too significant. However, the impact of processing time on the mass of recovered oil is known that the longer the processing time, the higher the amount of oil recovered, and vice versa, the shorter the processing time, the lower the yield.

Like the flow rate and processing time

effect on soil samples, the development of flow rate on the amount of recovered oil did not significantly impact crude oil removal in oil-contaminated soil. However, for the processing time variable, it is explained that the removal of crude oil increases with increasing processing time (Taki et al., 2018), which means the amount of oil will also increase.

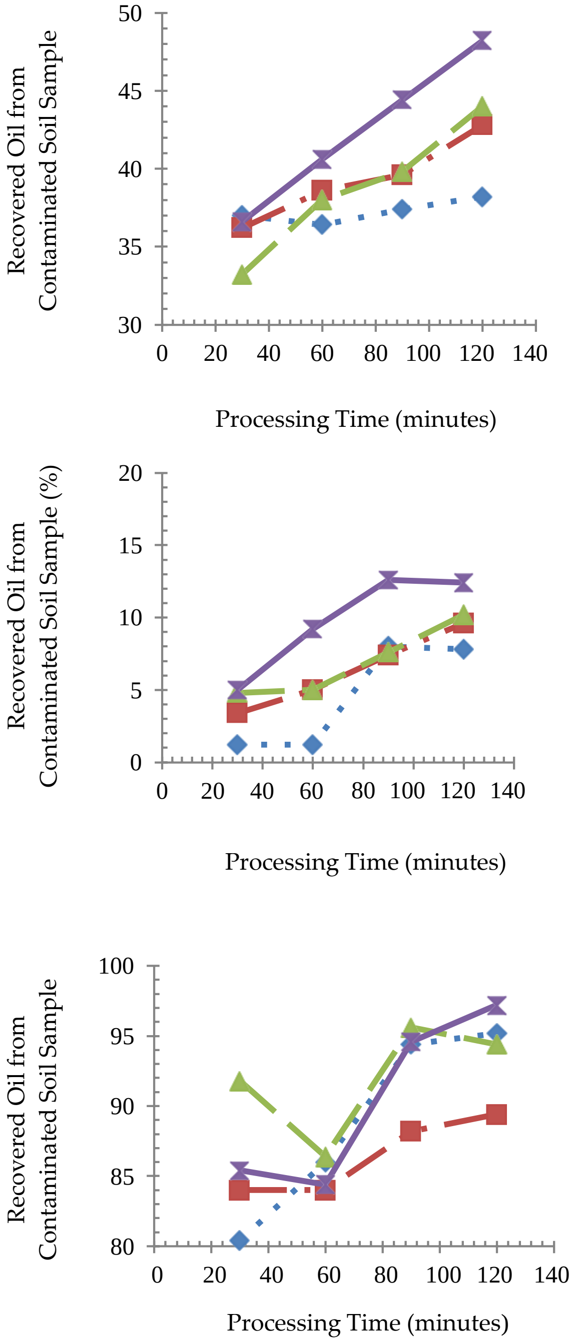

Figure 4. Effect of Flow Rate and Time on Mass on Recovered Oil (a) Recovered Oil from Soil Samples; (b) Recovered Oil from Sandy Soil Samples; (c) Recovered oil from Sludge Sample

Quality of Wastewater from Treatment Process

The graph for evaluating the trend of wastewater quality is shown in Figure 5. From the chart of the direction of wastewater quality above, the parameters of BOD, COD, Oil & Fat, and pH, are above the established Environmental Quality Standards, while the parameters of Ammonia, Phenol, and Sulfide are below the specified quality standards. COD, BOD, and Oil & Fat parameters are closely related to water quality (Tekaya et al., 2016). Oils and fats are one type of pollutant from wastewater. Oils and fats are organic compounds that come from nature and are insoluble in water but soluble in non-polar organic solvents because they have the same polarity. Oils & fats can be harmful if they exceed the specified quality standards. Oils & fats in the water will be in the surface layer because it has a lower density than water. The accumulated layer of oil and fat will block the entry of sunlight into the water, so aquatic plants cannot carry out photosynthesis. In addition, oils & fats can bind oxygen needed by marine biota for respiration (Eljaiek-Urzola, 2017). Oils & fats are the main components of carbon and hydrogen which are insoluble in water and slightly soluble in alcohol but will dissolve entirely in diethyl ether, benzene, chloroform, hexane, and halogen solvents (Fidia, 2017). Oil and grease in wastewater will cover the water's surface, thereby preventing the entry of oxygen. Lack of oxygen causes the balance of the water ecosystem to be disturbed, causing the death of various biota and affecting other parameters (Ganefati, 2011). It is also one of the factors driving the high content of COD and BOD in wastewater.

In addition to the high oil and fat content, the degree of acidity (pH) is also one factor that significantly affects the BOD and COD values due to the decomposition of various organic pollutants in wastewater. pH, BOD, and COD are parameters that state the oxygen levels needed to decompose organic pollutants in sewage (Uyun. 2012). With the high content of oil & fat and low acidity, the oxygen content in the water will be lower, causing the BOD and COD values to be higher. It is almost similar to the Micro-Emulsion treatment, which has little effect on the physical and chemical properties of the soil so that the recovered crude oil has a higher saturation fraction while the aromatic content, asphaltene, density and viscosity decrease (Wang et al., 2019).

Hazardous Waste Management Budget Efficiency

The amount of waste management of oil-contaminated soil through the oil recovery system is shown in Table 2. The graph shows that the oil recovery application will be more effective if applied to sludge type samples than in other models, where the recovered oil produced reaches 88.41%. This method is more efficient for dealing with moderate soil contamination if carried out at a low level. Phytoremediation is used by extracting soil steam to achieve crude oil derivative content in the soil of less than 0.5% (Zamani et al., 2014).

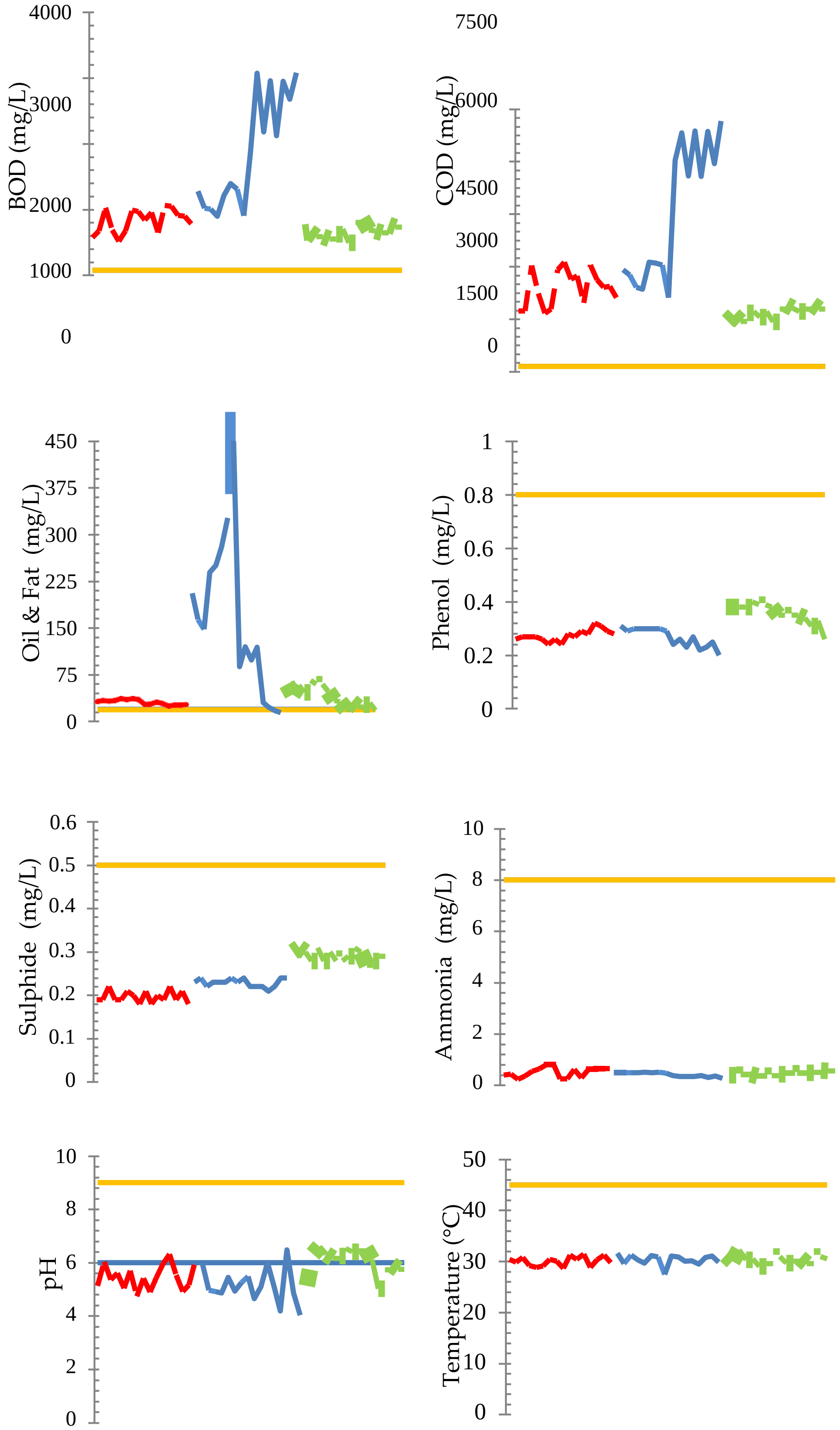

Figure 5. The trend of Wastewater Quality Parameters of (a) BOD, (b) COD, (c) oil & fat, (d) phenol, (f) Sulphide, (g) pH 9, (h) Temperature

Oil Contaminated Soil, oil-contaminated Sandy Soil and sludge

Waste management activities contaminated with oil using the recovery oil system could reduce waste by 43.95% (range 5.80%-88.41%). Based on this, it will impact the cost of B3 waste management, especially the type of soil contaminated with oil (Waste Code: A108d) which will be more efficient than before because the amount or volume of the waste is reduced.

Estimated budget savings are in Table 3. which shows that each type of contaminated soil waste has additional estimated cost savings, depending on the amount of waste handed over to a licensed third party. The amount of waste is reduced through oil recovery, so management costs are also reduced. After processing, the management budget becomes IDR 1,457,191.67 per ton. So if it is adjusted to the volume of the contract, the total budgeted cost is from 5.2 billion/2,000 tons to IDR 2,914,383,333.33/2000 tons (rounding up to Rp 2,914,384/2,000 tons). The cost is calculated based on the type of contaminated soil waste. However, the most significant cost savings are in the sludge type sample at each type because the oil recovered is an average of 88.41%, and the estimated budget savings is IDR 2,298,720/ton.

Meanwhile, in oil-contaminated sandy soil, the estimated savings are only IDR150,000/kg. The reduction in the volume of waste is only about 5.90% of the initial weight, so the budget savings will not be too significant. Based on this, the estimation of the enormous budget savings is in sludge type waste, then oil-contaminated soil, then oil-contaminated sandy soil. The more oil gets, the amount or volume of waste will decrease, so management costs.

If viewed from the cleaning cost estimation technique used, an assessment of the cost-effectiveness of the remediation method can be carried out without ignoring legal penalties for the recovered oil, which can result in cost savings. A significant concentration of responsibility for those in charge could improve recovery-focused technologies (Prendergast & Gschwend, 2014).

CONCLUSION

The reduction of waste in the soil reached 32.0% - 44.8% for the soil sample contaminated with oil, 0.4% - 12.0% for the type of sandy soil contaminated with oil, and 79.4% - 95.4% for the mud sample. The amount of waste has decreased to 95.4% from the initial amount of waste before being processed. Applying an oil recovery system to oil-contaminated soil waste is reasonably practical in solving fuel oil and gas problems, especially on soil contaminated with oil sludge. The use of flow rate variations in the processing does not have a significant effect. The treatment process produces an output in wastewater, some of which are above the Environmental Quality Standards, which are required to be effective enough to be implemented, with budget savings of up to IDR 1,142,808.33 per ton of waste.

Table 2. Waste Management of Oil Contaminated Soil in Each Soil Type

No.	Waste Management	Sample Types							
		Combined		Oil Contaminated Soil		Oil Contaminated Sandy Soil		Sludge	
		Qty	%	Qty	%	Qty	%	Qty	%
1.	Reused	105.490	43.95	1.883	38	0.290	6	4.421	88
2.	Handed over to the third party	134.510	56.05	3.118	62	4.710	94	0.579	12
3.	Stored in	0.000	0.00	0.000	0	0.000	0	0.000	0

Table 3. Estimated Budget Savings to recovery oil from variation Soil

Categories		Unit	Combined	Oil Contaminated Soil	Oil Contaminated Sandy Soil	*Sludge*
Without Processing	3rd party	Kg	5	5	5	5
	Price *)	IDR	5.2 B	5.2 B	5.2 B	5.2 B
	Contract Volume	Ton	2000	2000	2000	2000
	Unit price	Kg	2.600	2.600	2.600	2.600
	Unit Price	5 kg	13.000	13.000	13.000	13.000
	Unit Price	Ton	2.6 M	2.6 M	2.6 M	2.6 M
With Processing	3rd party	Kg	2.8023	3.1175	4.7100	0.5794
	Price *)	IDR	5.2 B	5.2 B	5.2 B	5.2 B
	Contract Volume	Ton	2000	2000	2000	2000
	Unit price	Kg	2.600	2.600	2.600	2.600
	Unit Price	5 kg	7.286	8.105	12.246	1.506
	Unit Price (10^3)	Ton	1,457.2	1,621.1	2,449	0,301
Estimated Budget Saving	Estimated Budget Saving /Ton	IDR (10^3)	1,142.8	978.9	150.8	2,298.7
	Estimated Budget Saving/ 2000 Tons	IDR (10^6)	2,285.6	1,957.8	301.6	4,597.4

REFERENCES

Aziz, T., Rizky, A., & Devah, V. (2015). Removal Logam Berat dari Tanah Terkontaminasi dengan Menggunakan Chelating Agent (EDTA). *Jurnal Teknik Kimia*, *21*(2), 41-49.

Elboughdiri, N. (2018). Effect of time, solvent-solid ratio, ethanol concentration and temperature on extraction yield of phenolic compounds from olive leaves. *Eng. Technol. Appl. Sci. Res*, *8*, 2805-2808.

Eljaiek-Urzola, M., Romero-Sierra, N., Segrera-Cabarcas, L., Valdelamar-Martínez, D., & Quiñones-Bolaños, É. (2019). Oil and grease as a water quality index parameter for the conservation of marine biota. *Water*, *11*(4), 856.

Hasegawa, H., Al Mamun, M. A., Tsukagoshi, Y., Ishii, K., Sawai, H., Begum, Z. A., Asami. A.A., Maki. T. & Rahman, I. M. (2019). Chelator-assisted washing for the extraction of lead, copper, and zinc from contaminated soils: a remediation approach. *Applied Geochemistry*, *109*, 104397.

Huang, D., Hu, C., Zeng, G., Cheng, M., Xu, P., Gong, X., Wang, R & Xue, W. (2017). Combination of Fenton processes and biotreatment for wastewater treatment and soil remediation. *Science of the Total Environment*, *574*, 1599-1610.

Islam, M. N., Jo, Y. T., & Park, J. H. (2014). Subcritical water remediation of petroleum and aromatic hydrocarbon-contaminated soil: a semi-pilot scale study. *Water, Air, & Soil Pollution*, *225*(7), 1-8.

Islam, M. N., Jung, S. K., Jung, H. Y., & Park, J. H. (2017). The feasibility of recovering oil from contaminated soil at petroleum oil spill site using a subcritical water extraction technology. *Process Safety and Environmental Protection*, *111*, 52-59.

Islam, M. N., Park, H. S., & Park, J. H. (2015). Extraction of diesel from contaminated soil using subcritical water. *Environmental earth sciences*, *74*(4), 3059-3066.

Islam. MN Taki. D. Jung. Y.J. Jung. SK and Park. JH (2018). Remediation of Gulf War Oil Spill Contaminated Soil by A Subcritical Water Extraction Process: Oil Removal. Recovery and Degradation. Soil and Sediment Contamination. An International Journal. ISSN: 1532-0383.

Khaw, K. Y., Parat, M. O., Shaw, P. N., & Falconer, J. R. (2017). Solvent supercritical fluid technologies to extract bioactive compounds from natural sources: A review. *Molecules*, *22*(7), 1186.

Loyao Jr, A. S., Villasica, S. L. G., Peña, P. L. L. D., & Go, A. W. (2018). Extraction of lipids from spent coffee grounds with non-polar renewable solvents as alternative. *Industrial Crops and Products*, *119*, 152-161

Ossai, I. C., Ahmed, A., Hassan, A., & Hamid, F. S. (2020). Remediation of soil and water contaminated with petroleum hydrocarbon: A review. *Environmental Technology & Innovation*, *17*, 100526.

Taki, G., Islam, M. N., Park, S. J., & Park, J. H. (2018). Optimization of operating parameters to remove and recover crude oil from contaminated soil using subcritical water extraction process. *Environmental Engineering Research*, *23*(2), 175-180.

Tekaya, M., Mechri, B., Dabbaghi, O., Mahjoub, Z., Laamari, S., Chihaoui, B., Boujnah, D., Hammami, M. & Chehab, H. (2016). Changes in key photosynthetic parameters of olive trees following soil tillage and wastewater irrigation, modified olive oil quality. *Agricultural Water Management*, *178*, 180-188.

Vazquez-Roig, P., & Picó, Y. (2015). Pressurized liquid extraction of organic contaminants in environmental and food samples. *TrAC Trends in Analytical Chemistry*, *71*, 55-64.

Worthington, M. J., Shearer, C. J., Esdaile, L. J., Campbell, J. A., Gibson, C. T., Legg, S. K.,

& Chalker, J. M. (2018). Sustainable polysulfides for oil spill remediation: repurposing industrial waste for environmental benefit. *Advanced Sustainable Systems*, *2*(6), 1800024.

Zamani, M. M., Fallahpour, M., Yousefi Harvani, G., Khodi Aghmiuni, S., Zamani, M., Minai Tehrani, D., & Savaghebi Firrozabadi, G. (2014). Recent proportionate treatment methods for crude oil contamination evaluation of the Tehran refinery site soil. *Thrita*, *3*(1).

Zhao, C., Dong, Y., Feng, Y., Li, Y., & Dong, Y. (2019). Thermal desorption for remediation of contaminated soil: A review. *Chemosphere*, *221*, 841-855.

Zulkifliani, Z. (2017). Remediasi Tanah Terkontaminasi Minyak Dan Proses Pengolahan Limbah Berminyak Di Lingkungan Industri Minyak (Remediation of Oil Contaminant Soil and Treatment Process of Oily Sludge in the Oil Industry). *Lembaran publikasi minyak dan gas bumi*, *51*(3), 159-164.

Prendergast, D. P., & Gschwend, P. M. (2014). Assessing the performance and cost of oil spill remediation technologies. *Journal of cleaner production*, *78*, 233-242.

Wang, L., Liu, H., Chen, S., Wang, M., Liu, Y., Yu, W., & Zhang, X. (2019). Crude Oil-Contaminated Soil Treatment and Oil Recovery through Micro-Emulsion Washing. *Energy & Fuels*, *33*(11), 11486-11493.