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Utilization of PDAM Sedimentation Sludge as a Multi Soil Layering (MSL) Substance in the Degradation of Liquid Waste Contaminants from the Tofu Industry

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ABSTRAK.
Disposing of production process wastewater into bodies of water without treatment has a negative environmental effect. MSL is an environmentally friendly liquid waste treatment process. In this investigation, sedimentation waste (PDAM) was employed to replace soil. The purpose of this study is to investigate the efficacy of the MSL method in degrading pollutants in liquid waste from the tofu industry under two conditions: changes in Hydraulic Loading Rate (HLR) and Hydraulic Retention Time. The research results showed HLR values of 11.48 L/m2/hour, 4.76 L/m2/hour, and 2.48 L/m2/hour, with the highest effectiveness level of 2.48 L/m2/hour. The pH and DO values changed to 7.4 and 19.5 mg/L respectively, while the TSS effectiveness value reached 76.32%, the TDS value decreased 75.21%, turbidity decreased 99.69%, and COD decreased 99%. .66%. At the HRT values of 4 hours, 6 hours, 8 hours, 10 hours, and 12 hours, the most favorable HRT variations occurred at 12 hours. Changes in pH and DO from 19.5 mg/L to 7.5, and success in reducing COD values of 98.95%, 51.11%, and 73.5%. The results obtained show that the MSL strategy which utilizes PDAM sedimentation waste material can minimize the level of pollution in the tofu making industry.

1. Introduction

Indonesia's tofu industry is one of the fastest expanding food industries. According to the Gabungan Koperasi Produsen Tempe Tahu Indonesia (Gakoptindo), tofu production in 2019 reached 1,4 million kilograms per day, with approximately 30,000 producing units involved. These manufacturers are dispersed throughout more than 200 regencies and localities in 27 provinces in Indonesia. According to Purba et al. (2020), the daily production of tofu in Banda Aceh is between 500 and 600 kilograms, or 45.360 boards. Several studies have revealed that the Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solid (TSS) values of tofu liquid refuse exceed the quality standards established by the Ministry of Environment in KepMen LH Regulation Number 5 of 2014 concerning Tofu Industry Activities. According to a study conducted by Armi (2019) at a tofu factory in Banda Aceh, processing 100 kg of soybeans can generate 150 – 430 liters of liquid waste per day with a Biochemical Oxygen Demand (BOD) value of 2.800 – 4.300 mg/L, Total Suspended Solid (TSS) value of 615 – 629 mg/L, pH 3.4 - 3.8 and Dissolved Oxygen (DO) value of 1.5 - 2.2 mg/L. Therefore, tofu liquid refuse must be treated prior to being discharged into the environment.

Multi Soil Layering (MSL), which employs soil as its primary processing material and is easy to apply and control, is one of the environmentally friendly and cost-effective liquid waste treatment techniques (Aba et al., 2021). Multi Soil Layering (MSL) is a procedure for treating liquid waste that employs soil as its primary medium. The MSL is composed of a layer of soil mixture (Soil Mixture Block) and a layer of limestone arranged in a brick pattern (Karima et al., 2022). The soil mixture is comprised of soil, charcoal as a carbon component, organic matter, and other materials such as iron ore. Depending on the type of rock available, the rock strata may consist of gravel, zeolite, perlite, or a combination of zeolite and pearlite (Haribowo et al., 2019).

In the MSL process, HLR is vital in estimating the volume of waste water that will flow to the MSL reactor and influencing the detention time. The hydraulic loading rate (HLR) is the rate at which waste water hydrolyzes on a surface over a given time period. The lower the HLR, the better the MSL's ability to remove pollutants. However, a larger HLR is necessary to remove amounts of BOD, COD, nitrogen, and phosphorus. Determining the appropriate HLR can help to prevent clogs in the MSL reactor while it is in operation (Masunaga et al., 2017). The HLR quantity usually employed in MSL reactor applications is mL/minute (Kasman et al., 2021). To determine HLR changes, calculations must be performed based on waste volume, detention duration, and reactor surface area.

The MSL approach has been used in multiple developed nations, such as China and Japan, across diverse sectors encompassing home and industrial waste. Empirical evidence has consistently demonstrated the method's efficacy in significantly mitigating pollution levels in liquid waste. Furthermore, the MSL approach has been implemented in Indonesia and Thailand, yielding comparable levels of efficacy. According to Zaman and Oktiawan (2020), the increased utilization of the MSL approach across diverse sectors is anticipated due to its notable efficiency and cost-effectiveness. In the MSL system, in addition to employing soil as the primary medium, other media can also be utilized for waste degradation, such as sedimentation sludge derived from the processing unit of PDAM. Based on the findings of Ivontianti et al. (2021), it was determined that PDAM mud exhibits a composition consisting of 49.11% silicon dioxide (SiO_2) and 29.45% aluminum oxide (Al_2O_3). Consequently, this composition renders PDAM mud highly capable of effectively mitigating contaminants present in tofu wastewater.

This is proven by the X-ray Diffraction (XRD) characterization tests that have been carried out measurement analysis reveals the presence of two primary minerals, namely silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), in the PDAM mud, as depicted in Figure2. The mineral composition of SiO_2 and Al_2O_3 is derived from the several steps involved in the coagulation process. During this phase, the addition of coagulants such as alum ($Al_3(SO_4)_3$) and poly aluminum chloride was performed (Nugteren et al., 2017). In addition to their formation through coagulation, SiO_2 minerals can be derived from sediment sludge generated during the filtration of silica rock.

Ivontianti et al. (2021) used the MSL method to use sedimentation mud from the PDAM processing unit as a soil substitute in the leachate processing process, along with a 3 - 5mm zeolite layer structure and a mixture of SMB layers made up of sedimentation mud and charcoal. PDAM sedimentation mud serves as a filter in fine zeolite pores, increasing adsorption surface area and removing organic and suspended particles. Filtration, which reduces the size of zeolite pores, can retain organic compounds and tiny components in liquid waste. Before MSL treatment, the amounts of ammonia, pH, TSS, and COD were 88 mg/L, 7.7, 80 mg/L, and 832 mg/L, respectively. In this study, the optimum residence period was discovered to be 12 hours, which corresponds to the life phase of microorganisms, in which the system enters a stationary phase and achieves stability. The reduction efficiency for each pollutant parameter is as follows: ammonia 96.59%, pH 7.5, TSS 85%, and COD 44.83%. These findings demonstrate that using PDAM sedimentation mud as a soil substitute can reduce levels of ammonia, pH, TSS, and COD contaminants.

2. Methodology

This study employed two variations, specifically variations in Hydraulic Loading Rate (HLR) values, encompassing parameters such as pH, COD, TSS, TDS, and turbidity, and variations in Hydraulic Retention Time (HRT) values, including parameters such as pH, COD, BOD, and TSS. Both versions are employed to assess the efficacy of PDAM sedimentation sludge as MSL material in the degradation of pollutants in wastewater from the tofu industry.

The design of the MSL reactor is derived from the work of Chen and Pat (2021). The reactor is constructed using glass material and has dimensions of 31 cm × 22.5 cm × 60 cm. It is supplied with intake and exit pipes, each having a diameter of 6.4 mm. The MSL reactor is comprised of three distinct layers. The first layer, serving as the base, is composed of pebbles approximately 1-3 cm in size and has a height of 5 cm. This base layer is then overlaid with a plastic net. The second layer is composed of zeolite particles ranging in size from 0.2 to 0.5 cm, with a height of 7 cm. The third layer is comprised of a soil mixture known as the Soil Mixture Block, which includes PDAM sedimentation mud, charcoal, iron filings, and rice husks (Ivontianti et al., 2021). The volume of the Soil Mixture Block is 10 cm × 10 cm × 5 cm (Chen and Pat, 2021).

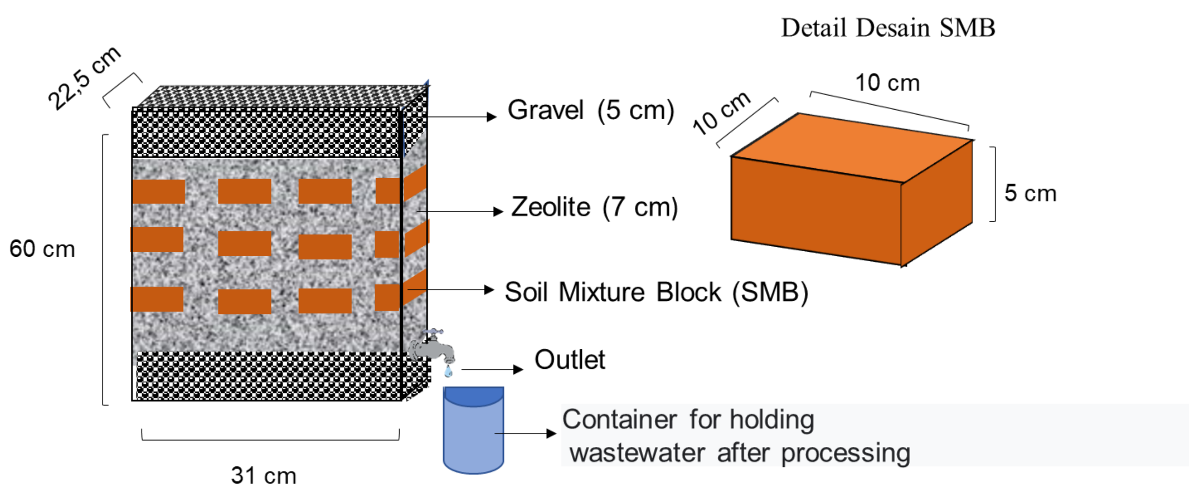


Figure 1. Reactor Design

3. Discussion

3.1 PDAM Sedimentation Mud Mineralogy Analysis Results

The X-Ray Diffraction studies revealed the presence of two prominent minerals in the sedimentation mud of PDAM, as depicted in Figure 2.

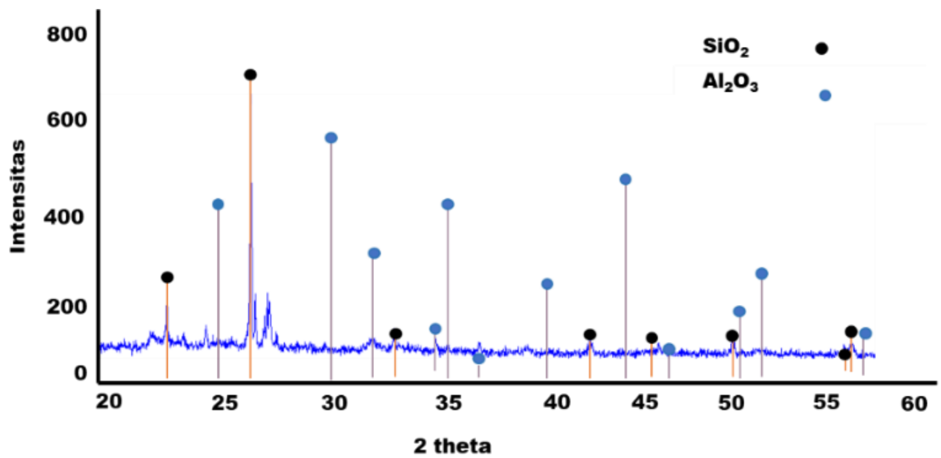


Figure 2. Diffractogram curves from XRD measurements of SiO_2 and Al_2O_3 minerals

The X-ray diffraction (XRD) measurement analysis reveals the presence of two primary minerals, namely silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), in the PDAM mud, as depicted in Figure 2. The mineral composition of SiO_2 and Al_2O_3 is derived from the several steps involved in the coagulation process. During this phase, the addition of coagulants such as alum ($Al_3(SO_4)_3$) and poly aluminum chloride was performed (Nugteren et al., 2017). In addition to their formation through coagulation, SiO_2 minerals can be derived from sediment sludge generated during the filtration of silica rock.

The diffractogram presented in Figure 2 displays the peaks that have emerged at a specific angle denoted as 2θ during the X-ray diffraction (XRD) examination. The SiO_2 mineral curve is indicated by the following data: at an angle of 22°, the intensity is 300 cycles per second (cps); at an angle of 26°, the intensity is 750 cps; at an angle of 33°, the intensity is 100 cps; at an angle of 42°, the intensity is 100 cps; at an angle of 45°, the intensity is 100 cps; at an angle of 50°, the intensity is 100 cps; and at an angle of 56°, two peaks are produced with intensities of 50 cps and 100 cps. The data provided represents the intensity of Al_2O_3 mineral at various angles. At an angle of 25°, the intensity is measured at 450 cps. Similarly, at angles of 30°, 32°, 34 °, 35°, 36°, 40°, 44°, 50 °, 52 °, and 57 °, the intensities are measured at 580 cps, 350 cps, 100 cps, 450 cps, 50 cps, 280 cps, 500 cps, 180 cps, 300 cps, and 100 cps respectively. The primary peak is observed at angles of 26° and 30°, with intensities of 750 and 580 counts per second (cps) respectively. The SiO_2 mineral curve is observed at an inclination of 26° and an intensity of 750 cycles per second (cps). When the angle is 25° and the intensity is 580 cycles per second, it signifies the mineral curve of the Al_2O_3 curve.

The X-ray diffraction (XRD) measurement study presented in Figure 2 reveals that the mud of PDAM consists primarily of two prominent minerals: silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3). Silica has been identified by Ma et al. (2020) as an adsorbent utilized in the process of adsorption. Silica possesses chemical characteristics that enable it to exhibit an affinity for and retain organic molecules when present in a solution. Silica possessing a substantial pore size and surface area has the capacity to sequester organic molecules within its structure via physical or chemical interactions. Silica materials possessing significant porosity and extensive surface area have the capacity to sequester organic molecules by physical or chemical mechanisms, including Van der Waals adsorption, hydrogen bonding, and ionic bonding.

In the study conducted by Zhao et al. (2021), it was found that Al_2O_3 had adsorbent properties, enabling it to effectively adsorb organic molecules onto its surface. This characteristic allows for a reduction in the concentration of organic compounds present in liquid waste. The presence of Al^{3+} ions in sludge, which exhibit alkaline properties, also plays a role in waste neutralization. Within the SMB layer, there occurs a process of cationic exchange between fundamental cations present in the sludge and acidic cations present in the waste, leading to a subsequent alteration in pH levels (Ren et al., 2022; Latrach et al., 2018). The PDAM sedimentation sludge exhibits a significant potential for the degradation of pollutants in tofu wastewater due to its high concentration of SiO_2 and Al_2O_3.

3.2 MSL System Effectiveness with Hydraulic Loading Rate (HLR) variations

Figure 3 illustrates the visual characteristics of tofu manufacturing wastewater, both before and after the experiment, as influenced by differences in hydraulic loading rate (HLR). The visual observation reveals that unprocessed industrial tofu waste often has a foggy appearance. However, subsequent processing, with variations in hydraulic loading rate (HLR) values, results in a cleaner appearance.

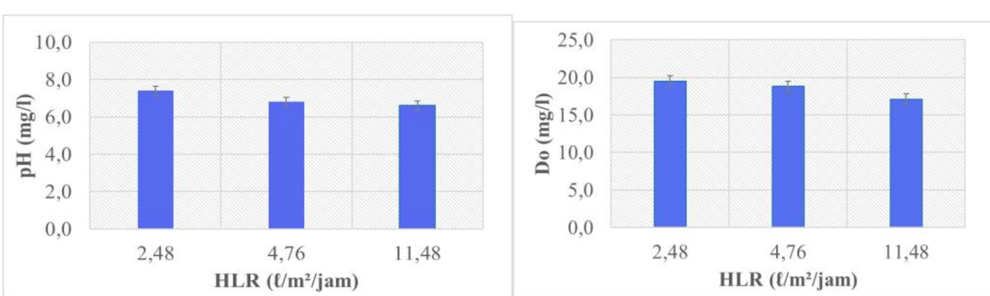
(a) (b) (c) (d) (e)

Figure 3. Tofu industry liquid waste (a) before experiment; (b) initial sedimentation; (c) HLR 11.48 L/m²/Hour; (d) HLR 4.76 L/m²/hour and (e) HLR 2.48 L/m²/hour

Table 1. Results and Effectiveness (%) pH and DO after treatment with variations in HLR values method MSL

Variations HLR (ℓ/m²/hours)	pH	DO (mg/L)	Ef DO (%)
11,48	6,6	17,1	4,90
4,76	6,8	18,8	15,33
2,48	7,4	19,5	19,63

According to the data shown in Table 1, there is an observed inverse relationship between the pH value and the fluctuation in the provided HLR value. As the hydraulic loading rate (HLR) declines, there is an observed increase in the concentration of the pH value. In Figure 4(a), it can be shown that the pH levels were measured as acidic, specifically 6.6 and 6.8, at hydraulic loading rates (HLR) of 11.48 L/m²/hour and 4.76 L/m²/hour, respectively. Subsequently, as the hydraulic loading rate (HLR) was reduced to 2.48 L/m²/hour, there was an observed elevation in the pH concentration to a neutral level of 7.4.



(a) (b)

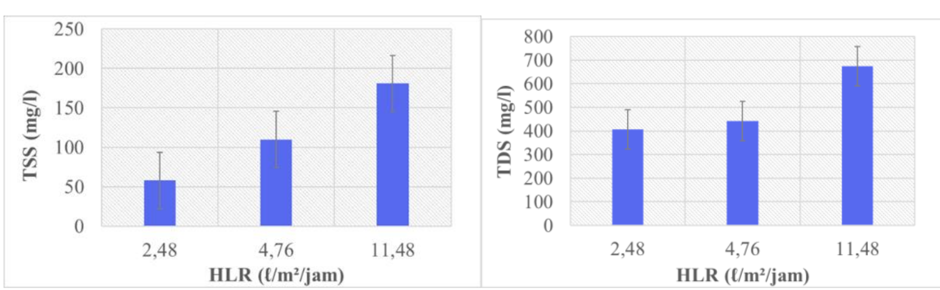
Figure 4. Graph of changes in pH and DO concentrations on variations in HLR values in the MSL system (a) pH concentration and (b) DO concentration.

The rise in pH was attributed to the occurrence of nitrification and denitrification processes inside the SMB layer, resulting in a decrease in waste acidity. The presence of Al^{3+} ions in sludge, which possess alkaline properties, plays a role in the neutralization of waste. Within the SMB layer, there occurs a process of cation exchange between the fundamental cations present in the sludge and the acidic cations present in the trash, leading to a subsequent alteration in pH levels (Ren et al., 2022; Latrach et al., 2018). The DO value exhibits an upward trend when employing a low HLR value, as the magnitude of the HLR value decreases, the oxygen concentration in the wastewater generated from tofu production experiences an elevation. At a hydraulic loading rate (HLR) of 11.48 L/m²/hour, the dissolved oxygen (DO) concentration is measured to be 17.1 mg/L. It has been observed that a decrease in HLR leads to an increase in the DO concentration by around 1.7 - 2.4 mg/L. The observed rise in the HLR ranged from 4.76 L/m²/hour to 2.48 L/m²/hour. At a hydraulic loading rate (HLR) of 4.76 L/m²/hour, the dissolved oxygen (DO) concentration reached 18.8 mg/L. Conversely, at an HLR of 2.48 L/m²/hour, the DO concentration jumped to 19.5 mg/L. The contact time of waste with the MSL material is enhanced by reducing the HLR value, hence leading to an improvement in the efficiency of organic matter removal. According to Song et al. (2018), a significant increase in dissolved oxygen (DO) levels can be observed with a high degree of organic waste clearance.

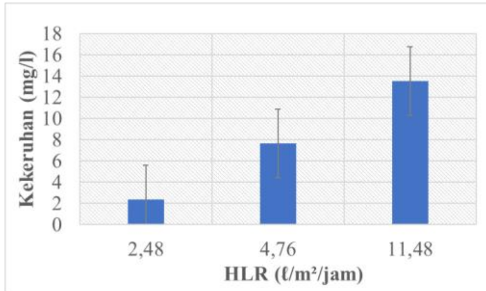
Table 2. Results and Effectiveness (%) TSS, TDS and turbidity after treatment with variations in HLR values method MSL

Variations HLR (ℓ/m²/hours)	TSS (mg/L)	Ef TSS (%)	TDS (mg/L)	Ef TDS (%)	Turbidity (mg/L)	Ef Turbidity(%)
11,48	181	26,12	673	59,01	13,54	98,24
4,76	110	55,10	441	73,14	7,66	99
2,48	58	76,32	407	75,21	2,36	99,69

Table 4.2 presents the measured values of Total Suspended Solids (TSS), Total Dissolved Solids (TDS), and turbidity in tofu manufacturing wastewater. The data indicates that the efficiency of organic matter and nutrient removal in the wastewater treatment process improves when the Hydraulic Loading Rate (HLR) drops. Figure 5 (a), Figure 5 (b), and Figure 5 (c) illustrate the permissible thresholds for TSS, TDS, and turbidity levels, respectively, as determined by the three variations of HLR. According to the data presented in Table 2, the use of different levels of hydraulic loading rates (HLR) has demonstrated the capability to effectively mitigate pollutants. Specifically, the total suspended solids (TSS) exhibited a notable reduction of 76.32%, while the total dissolved solids (TDS) saw a reduction of 75.21%. Furthermore, the turbidity levels were significantly reduced by 99.69%. The data shown in Table 2 demonstrates a substantial reduction in TSS, TDS, and turbidity readings while employing an HLR of 2.48 L/m²/hour.



(a) (b)



(c)

Figure 5. Graph of changes in parameter concentration to variations in HLR values (a) TSS concentration; (b) TDS concentration and (c) Turbidity concentration

The permissible range of total suspended solids (TSS) levels for different hydraulic loading rates (HLR) is illustrated in Figure 4.4 (a). The figure demonstrates that at HLRs of 11.48 L/m^2/hour and 4.76 L/m^2/hour, the corresponding TSS concentrations were 181 mg/L and 65 mg/L, respectively. Furthermore, at an HLR of 2.48 L/m^2/hour, a reduction in TSS concentration was seen, reaching a value of 58 mg/L. Figure 5 (b) displays the Total Dissolved Solids (TDS) values as a function of variations in Hydraulic Loading Rate (HLR). At a hydraulic loading rate (HLR) of 11.48 L/m^2/hour, the total dissolved solids (TDS) concentration was measured to be 673 mg/L. As the HLR value was reduced, there was an observed rise in the rate of drop in TDS concentration. The total dissolved solids (TDS) concentration was measured at two different hydraulic loading rates (HLRs). At an HLR of 4.76 L/m^2/hour, the TDS concentration was found to be 441 mg/L. Conversely, at an HLR of 2.48 L/m^2/hour, the TDS concentration was seen to reach 407 mg/L. The data presented in Figure 5 (c) illustrates a notable decline in turbidity levels in response to variations in hydraulic loading rate (HLR) values. The turbidity value of 13.54 NTU is observed at a hydraulic loading rate (HLR) of 11.48 L/m^2/hour. In the range of HLR fluctuations below 11.48 L/m^2/hour, specifically the turbidity HLR of 4.76 L/m^2/hour and 2.48 L/m^2/hour, the corresponding turbidity values are 7.66 mg/L and 2.36 mg/L, respectively.

The decline in the values of total suspended solids (TSS), total dissolved solids (TDS), and turbidity can be attributed to the phenomenon of adsorption. The organic compounds present in wastewater from tofu production are effectively absorbed by gravel, simulated moving bed (SMB), and zeolite materials. The presence of SiO_2 and Al_2O_3 minerals in PDAM sedimentary rock and sludge materials serves as an adsorbent during the degradation of organic matter and nutrients in tofu industrial effluent. The molecules present in the liquid waste exhibit affinity for the adsorbent material, adhering to its surface due to a combination of physical and chemical interactions. Physical adsorption, also known as physisorption, is a phenomenon characterized by the presence of Van der Waals forces. These forces manifest as weak attractions between the adsorbate and adsorbent. In the context of chemical adsorption, the interaction between the adsorbate and adsorbent is mediated by chemical bonds (Lakherwal, 2017).

Table 3. Results and Effectiveness (%) of COD measurements after treatment with variations in HLR values method MSL

Variations HLR (ℓ/m²/hours)	COD (mg/L)	Ef COD (%)
11,48	212	98,58
4,76	65	99,56
2,48	51	99,66

According to Table 3, the concentration of chemical oxygen demand (COD) in tofu industrial wastewater demonstrates that the efficacy of different hydraulic loading rate (HLR) changes in reducing COD levels is positively correlated with decreasing HLR values. Figure 6 illustrates the allowance for COD levels based on three changes of hydraulic loading rate (HLR) values. According to the findings presented in Table 3, the utilization of different levels of hydraulic loading rates (HLR) has demonstrated the capability to effectively mitigate pollutants, resulting in a significant reduction of chemical oxygen demand (COD) by up to 99.66%. Table 3 presents the observed decrease in the chemical oxygen demand (COD) value, which was found to be highly significant when employing a hydraulic loading rate (HLR) of 2.48 L/m^2/hour.

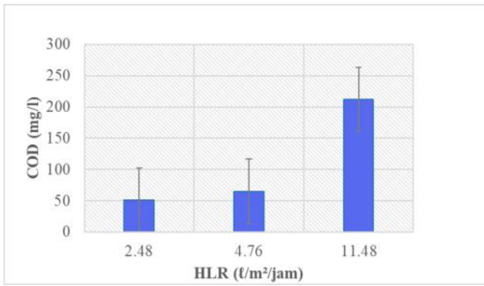


Figure 6. Graph of changes in COD concentration to variations in HLR values

Figure 6 illustrates the relationship between the lowering of chemical oxygen demand (COD) and variations in hydraulic loading rate (HLR). Figure 6 illustrates the initial phase of the MSL processing, specifically the HLR fluctuation of 11.48 L/m^2/hour, accompanied with a COD value of 212 mg/L. In contrast, the chemical oxygen demand (COD) value was observed to be 65 mg/L at a hydraulic loading rate (HLR) of 4.76 L/m^2/hour, while an HLR of 2.48 L/m^2/hour resulted in a COD value of 51 mg/L. This observation demonstrates a clear relationship between the reduction in chemical oxygen demand (COD) concentration and the fluctuations in hydraulic loading rate (HLR) values. A decrease in the hydraulic loading rate (HLR) results in a corresponding decrease in the chemical oxygen demand (COD) value. The observed decline can be attributed to the physicochemical absorption and nitrification processes occurring within the SMB layer and rock strata. The SMB layer and rock strata are involved in the process of ammonium (NH_4^-N) absorption, leading to its conversion into nitrate (NO_3) and subsequent progressive diffusion. Following the process of nitrification, the compound NO_3 undergoes denitrification, resulting in the formation of nitrogen dioxide (N_2O), which then converts into nitrogen (N_2). This sequence of reactions leads to a reduction in the organic matter present in the waste and an increase in the amount of removal of chemical oxygen demand (COD) (Latrach et al., 2016; Song et al., 2018). According to Ho and Wang (2017), the anaerobic layer undergoes filtration, absorption, and nitrification processes, resulting in an increase in oxygen levels. This increase in oxygen facilitates the removal of organic materials and suspended particles. Song et al. (2018) have reported that bacteria found in the anaerobic layer contribute to the degradation of organic matter throughout the decomposition process.

The reduction of the hydraulic loading rate (HLR) has been found to have a positive impact on the retention duration of wastewater within the treatment system. This, in turn, enhances the ability of the system to absorb, react, and eliminate organic matter present in the waste, leading to improved efficiency in reducing pollutant levels (Taouraout et al., 2019). The studies conducted by Ho and Wang (2017), Latrach et al. (2017), and Sbahi et al. (2020) demonstrate that employing low hydraulic loading rates (HLR) in waste treatment processes can yield substantial reductions and enhance overall efficiency.

3.2 The Effectiveness of the MSL System with Hydraulic Retention Time (HRT) Variations

Figure 7 illustrates the visual characteristics of the tofu manufacturing effluent in different hydraulic retention time (HRT) conditions, both before and after the experimental procedure. Figure 7 illustrates the visual differences between tofu industrial waste before and after processing. The untreated waste appears hazy, whereas the processed waste exhibits increased clarity, as indicated by variations in hydraulic retention time (HRT) values.

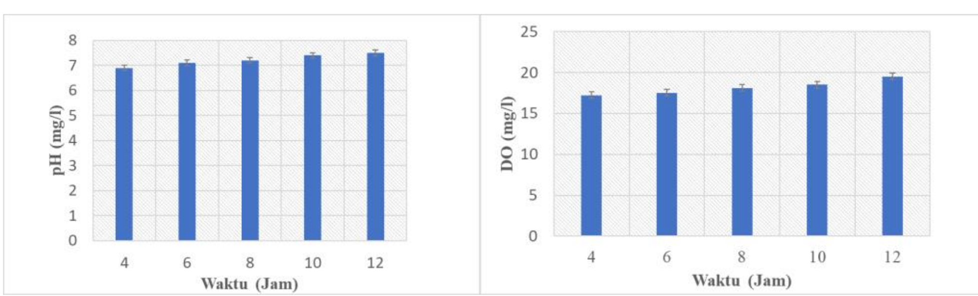
(a) (b) (c) (d) (e) (f)

Figure 7. Tofu industry liquid waste (a) before processing; (b) HRT 4 hours; (c) HRT 6 hours; (d) HRT 8 hours; (e) 10 hours HRT and (f) 12 hours HRT

Table 4. Results and Effectiveness (%) of pH and DO measurements after treatment with variations in HRT values

Variations HRT (hours)	pH	DO (mg/L)	Ef DO (%)
4	6,9	17,2	1,77
6	7,1	17,5	3,55
8	7,2	18,1	7,1
10	7,4	18,5	9,46
12	7,5	19,5	15,38

Table 4 illustrates a positive correlation between the pH value and the observed fluctuations in the provided hydraulic retention time (HRT) value. In Figure 8 (a), it can be observed that there is a successive increase in the pH value as the hydraulic retention time (HRT) value increases. At the 4-hour mark, the pH level was measured to be 6.9, indicating the presence of acidity. However, as the hydraulic retention time (HRT) increased, the pH level gradually shifted towards neutrality. Specifically, at the 6-hour mark, the pH level reached 7.1, followed by 7.2 at 8 hours, 7.4 at 10 hours, and 7.5 at 12 hours.



(a) (b)

Figure 8. Graph of changes in pH and DO concentrations on variations in HRT values in the MSL system (a) pH concentration and (b) DO concentration

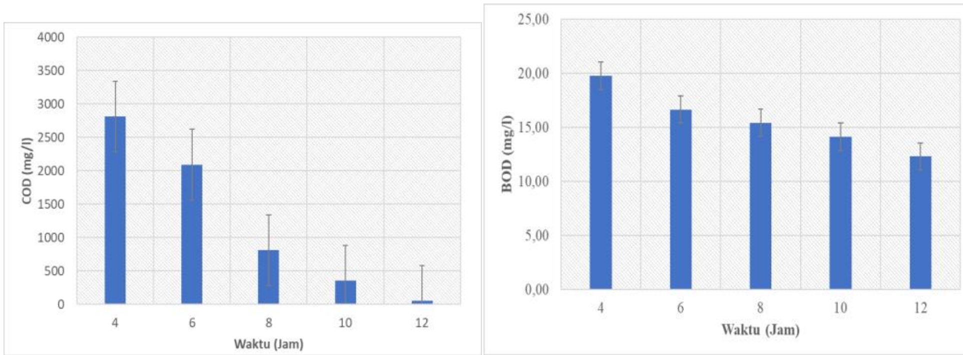
The observed rise in pH can be attributed to the denitrification process that took place within the SMB layer over the hydraulic duration, leading to a reduction in waste acidity (Hong et al., 2019; Ren et al., 2022; Latrach et al., 2017). During the denitrification process, the reduction of nitrate to nitrogen gas occurs. The PDAM sedimentation sludge exhibits a high concentration of protons, which undergo electron absorption when exposed to nitrogen gas. This process leads to ion exchange and thus alters the pH of the tofu industrial effluent from an acidic state to a neutral state.

In Figure 8 (b), the relationship between the concentration of dissolved oxygen in tofu industrial wastewater and the fluctuations in hydraulic retention time (HRT) is depicted. In Figure 8 (b), it can be shown that there is a direct proportionality between the rise in the dissolved oxygen (DO) value and the increase in the hydraulic retention time (HRT) value. The dissolved oxygen (DO) levels at 4 hours and 6 hours were recorded as 17.2 and 17.5, respectively. It was observed that an increase in the hydraulic retention time (HRT) led to an increase in the DO values. The dissolved oxygen (DO) concentration was measured at three different time points: 8 hours, 10 hours, and 12 hours. The DO value recorded at 8 hours was 18.1, while at 10 hours it increased slightly to 18.5. Finally, at 12 hours, the DO value further increased to 19.5. The rise in dissolved oxygen (DO) levels can be attributed to the degrading process taking place inside the SMB layer. Additionally, an increase in hydraulic time leads to a longer duration of direct contact between the trash, the anaerobic layer, and the surrounding air (Hong et al., 2019; Ren et al., 2022).

Table 5. Results and Effectiveness (%) of COD and BOD measurements and after treatment with variations in HRT values

Variations HRT (hours)	COD (mg/L)	Ef COD (%)	BOD (mg/L)	Ef BOD(%)
4	2813	47,53	19,78	21,5
6	2093	60,96	16,66	33,88
8	811	84,87	15,45	38,69
10	355	93,37	14,14	42,69
12	56	98,95	12,32	51,11

Table 5 presents the COD and BOD values for tofu industrial wastewater, illustrating the enhanced efficacy of different hydraulic retention time (HRT) values in the removal of organic matter and nutrients. The results indicate that the effectiveness of this procedure increases as the HRT values are extended. Figure 9 (a) and Figure 9 (b) illustrate the permissible limits for COD and BOD concentrations, respectively, taking into account the fluctuations in Hydraulic Retention Time (HRT) values. According to the data presented in Table 5, the application of different levels of hydraulic retention time (HRT) demonstrates the capability to effectively mitigate pollutants, resulting in a significant reduction in chemical oxygen demand (COD) by 98.95% and biochemical oxygen demand (BOD) by 51.11%. The utilization of a 12-hour hydraulic retention time (HRT) resulted in a substantial reduction in the measured chemical oxygen demand (COD) and biochemical oxygen demand (BOD) values, as depicted in Table 5.



(a) (b)

Figure 9. Graph of changes in the concentration of each parameter on variations in HRT values (a) COD concentrations and (b) BOD concentrations

Figure 9 (a) illustrates the relationship between variations in hydraulic retention time (HRT) values and changes in chemical oxygen demand (COD) concentration in tofu industrial waste. At contact times of 4 hours, 6 hours, and 8 hours, the corresponding COD values were measured as 2813 mg/L, 2093 mg/L, and 811 mg/L, respectively. After a period of 12 hours, the concentration of COD dropped to 355 mg/L and 56 mg/L. This observation indicates that there is an inverse relationship between contact time and COD level, with longer contact times resulting in lower COD levels.

In Figure 9 (b), the observed trend illustrates a decline in biochemical oxygen demand (BOD) concentration as the hydraulic retention time (HRT) values vary. The BOD values at contact times of 4 hours, 6 hours, and 8 hours were recorded as 19.78 mg/L, 16.66 mg/L, and 15.45 mg/L, respectively. It was observed that as the hydraulic retention time (HRT) rose, there was a drop in BOD concentrations, indicating an upward trend. The BOD values recorded during contact times of 10 hours and 12 hours were 14.14 mg/L and 12.32 mg/L, respectively. The decline in biochemical oxygen demand (BOD) is directly correlated with the quantity of organic substances that have undergone biological decomposition. The organic components contained in the trash are degraded by microorganisms that inhabit the anaerobic layer. During this particular phase, there is a phenomenon wherein microorganisms found within the SMB initiate the breakdown of organic molecules, as described by Zhou et al. (2021).

Table 6. Results and Effectiveness (%) of TSS measurements after treatment with variations in HRT values

Variations HRT (hours)	TSS (mg/L)	Ef TSS (%)
4	147	43,46
6	136	47,69
8	124	53,3
10	111	57,3
12	70	73,07

Table 6 presents the total suspended solids (TSS) values of tofu industrial wastewater. The data indicates that the efficacy of different hydraulic retention time (HRT) values in decreasing TSS levels demonstrates an upward trend as HRT values increase. Figure 10 illustrates the allowance for TSS levels, taking into account the fluctuations in HRT values. According to the data presented in Table 6, the utilization of variations in hydraulic retention time (HRT) demonstrates the capability to effectively mitigate pollutants, resulting in a significant reduction in total suspended solids (TSS) by up to 73.07%. Regarding the outcomes obtained from the assessment of the Total Suspended Solids (TSS) value, a substantial reduction was observed while employing a 12-hour Hydraulic Retention Time (HRT), as illustrated in Table 6.

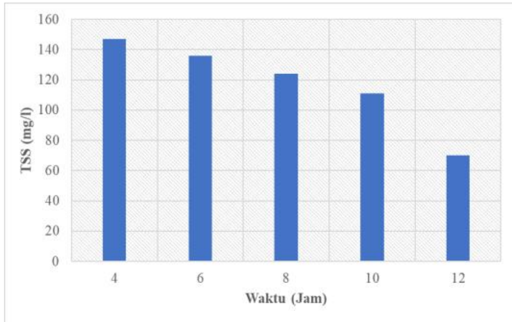


Figure 10. Graph of changes in TSS concentration to variations in HRT values

Figure 10 illustrates the permissible range of Total Suspended Solids (TSS) levels for different variations in Hormone Replacement Therapy (HRT) values. The TSS concentrations for contact durations of 4 hours, 6 hours, and 8 hours were observed to be 147 mg/L, 136 mg/L, and 124 mg/L, respectively. A notable rise, accompanied by an elevation in hormone replacement therapy (HRT) levels, was observed at the 10 and 12-hour time points, specifically measuring 111 mg/L and 70 mg/L, respectively. The enhanced removal of organic compounds and suspended debris in the waste can be attributed to the presence of filtration and adsorption stages within the SMB, zeolite, and gravel layers. Furthermore, it has been observed that extending the hydraulic retention period leads to a higher efficacy of the suspended media bioreactor (SMB) layer in the adsorption of organic matter, hence enhancing its processing efficiency (Ho and Wang, 2017; Koottatep et al., 2018).

4. Conclusion

Based on the results of the research and analysis collected, conclusions can be taken regarding MSL processing using variations in HLR values and variations in HRT values, which are:

1. The use of PDAM sedimentation sludge as MSL material with different HLR values is efficient in decreasing and degrading liquid waste from the tofu industry. The highest level of efficacy was achieved at HLR 2.48 L/m2/hour. The pH and DO change values increased to 19.5 mg/L and 7.4, respectively, with TSS degradation effectiveness reaching 76.32%, TDS degradation reaching 75.21%, turbidity degradation reaching 99.69%, and COD degradation reaching 99.66%.
2. The use of PDAM sedimentation sludge as MSL material with varying HRT values is efficient in decreasing and degrading liquid waste from the tofu industry. The maximum level of efficacy is achieved at a HRT value of 12 hours. The pH and DO change values increased to 19.5 mg/L and 7.5, respectively, while COD degradation was effective at 98.95%, BOD degradation at 51.11%, and TSS degradation at 73.7%.

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