Jurnal Teknik Kimia

Vol. 30, No. 2, 2024, 114-129
e-ISSN: 2721-4885
DOI: https://doi.org/10.36706/jtk.v30i2.2407
Online at http://ejournal.ft.unsri.ac.id/index.php/jtk

Application of integrated adsorption method (oil palm fiber, activated carbon, and ultrafiltration) in hospital wastewater treatment

Mgs. Moh. Fazrin Pramavada[1], Susila Arita[2,*], Isnurhadi[3]

[1]Environmental Management Study Program, Postgraduate Study, Universitas Sriwijaya, Palembang, Indonesia
[2]Chemical Engineering Department, Faculty of Engineering, Universitas Sriwijaya, Palembang, Indonesia
[3]Economic Management Department, Faculty of Economic, Universitas Sriwijaya, Palembang, Indonesia
[*]Corresponding author: susilaarita@ft.unsri,ac,id

Abstract

Hospital wastewater contains various pollutants including organic and inorganic compounds, heavy metals, and microorganisms which pose environmental and health risks. In Indonesia, the volume of hospital wastewater is increasing, whereas wastewater effluent hasn't met wastewater quality standard optimally. Conventional wastewater treatments require high-cost, large areas, long operating times, and produce sludge. Previous studies showed that adsorption and filtration effectively decreased *Biological Oxygen Demand* (BOD), *Chemical Oxygen Demand* (COD), *Total Suspended Solids* (TSS), and total coliform levels of hospital wastewater. Activated carbon is widely used adsorbent, but oil palm fiber offers higher adsorption capacity due to its cellulose and lignin content. It's abundant, renewable, low-cost, and eco-friendly adsorbent. Meanwhile, filtration membrane has high adsorption capacity, but it gets saturated quickly and needs pre-treatment process. This study analyzes the effectiveness of integrated adsorption method in hospital wastewater treatment. It was a quasi-experimental study with one group pre-test post-test design. Wastewater from Hospital X in Palembang was treated with oil palm fiber, activated carbon, and ultrafiltration after being deposited for 24 hours. There were four trials. The combination of oil palm fiber, activated carbon, and ultrafiltration shows promising result with removal efficiency percentage of pH by 8.91 %; BOD by 60.53 %; COD by 57.52 %; TSS by 84.21 %; and *total coliform* by 52.50 %. Each adsorbent has specific role: oil palm fiber significantly decreases BOD (47.37 %) and TSS (80 %) levels; activated carbon effectively decreases COD (58 %) and total coliform (60%) levels; and ultrafiltration effectively decreases TSS level (83.58 %).

Keywords: activated carbon, oil palm fiber, ultrafiltration, wastewater

How to Cite: Pramavada, Mgs. Moh. F., Arita S., Isnurhadi. (2024). Application of integrated adsorption method (oil palm fiber, activated carbon, and ultrafiltration) in hospital wastewater treatment.. Jurnal Teknik Kimia, 30(2), 114-129. http://doi.org/10.36706/jtk.v30i2.2407

1. INTRODUCTION

Hospital is healthcare facility which provides health services including inpatient care, outpatient care, emergency care, and other medical supports(Health Ministry of

Received February 2024, Revised May 2024, Accepted for publication July 2024

Republic Indonesia, 2010). Hospital produces wastewater (Pertiwi et al. 2017). Indonesia produces approximately 376,089 tons of hospital solid waste per day and 48,985.70 tons of hospital wastewater per day. The volume of hospital wastewater in Indonesia has been increasing yearly, whereas wastewater effluent has not met hospital wastewater quality standard optimally (Nurhaliq, Rahman, and Hidayat 2022). Study shows that there are only 53.4 % of hospitals which treat their wastewater. From 53.4 % of hospitals, there are only 57.5 % of hospitals that analyze the quality of the wastewater effluent. The result shows that 63 % of wastewater has met the hospital wastewater quality standard, meanwhile 37 % of wastewater is under the quality standard (Resky et al. 2022). Hospital wastewater is five to fifteen times more toxic than domestic wastewater (Ajala et al. 2022). It contains high level of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), ammonium nitrogen, organic nitrogen, nitrites, nitrates, total phosphorus, and Total Suspended Solids (TSS) with low BOD/ COD ratio. The low BOD/COD ratio indicates that hospital wastewater is difficult to treat with conventional biological treatment processes (Parida et al. 2022). Moreover, hospital wastewater contains heavy metals and new emerging pollutants. It also harbors microorganisms such as viruses, protozoa, fungi, and bacteria, including antibiotic-resistant bacteria, which can lead to water-borne diseases (Khan et al. 2021). Hospital wastewater has significant impacts on human health and the environment. If hospital wastewater is not treated before being discharged into the surrounding environment, it will enter into rivers and will contaminate surface water or groundwater. Hospital wastewater treatment has become an international concern. Conventional wastewater treatments such as activated sludge processes, membrane bioreactors (MBRs), or constructed wetlands can significantly reduce BOD, COD, and TSS levels (Bhandari et al. 2023). However, conventional wastewater treatments only remove about 50 % - 70 % of new emerging pollutants, necessitating any additional treatment processes such as adsorption, ozonation, ultraviolet radiation, and others (Majumder et al. 2021). Moreover, conventional hospital wastewater treatment methods spend high-cost, require large areas, need long operating time, and produce waste such as sludge.

Hospital X in Palembang produces wastewater approximately 850 m^3 per day. The wastewater contains high level of BOD, COD, TSS, and heavy metals. The land area of Waste Water Treatment Plant (WWTP) of Hospital X in Palembang is 380 m^2. The WWTP of Hospital X in Palembang is consisted of sump-pit area, sedimentation area, five Sequencing Batch Reactors (SBR), oxidation pond, sludge collecting area, filtration area, and biology pond. The capacity of the WWTP is 1500 m^3 per day. The WWTP of Hospital X in Palembang uses conventional activated sludge. The conventional activated sludge is an effective wastewater treatment method, but it produces large amount of sludge and needs large area (Ariyanti 2017). Based on previous studies, adsorption and filtration decrease BOD, COD, and TSS levels of hospital wastewater effectively (Ifa et al. 2020; Sasiang, Maddusa, and Sumampouw 2019; Vigiak et al. 2019). Adsorption method by using low-cost and renewable adsorbents is a simple, sustainable, low-cost, and eco-friendly wastewater treatment method (Rashid et al. 2021; Santoso et al. 2020). Activated carbon is one of the most widely used adsorbent for hospital wastewater treatment. Oil palm fiber can also be used as adsorbent. Oil palm fibers are solid wastes produced by oil palm industry. In Indonesia, the abundance of oil palm fibers reach 20 million tons per year. Oil palm fibers contain 22.60 % lignin, 45.80 % cellulose, 71.80 % hemicellulose, 25.90 % pentose, and 1.60 % ash (Khomsatun et al. 2022a). The cellulose and lignin have an adsorption capacity 6.000 times higher than that of activated carbon (Manusawai

2011). Oil palm fiber is abundant, renewable, low-cost, and eco-friendly adsorbent. Several studies show the application of filtration membrane in hospital wastewater treatment (Fitriana et al. 2016; Humairo et al. 2023; Klatt, Beyer, and Einfeldt 2022; Lee et al. 2018). The filtration membrane has high adsorption capacity, but it gets saturated quickly and needs pre-treatment processes such as coagulation, flocculation, and adsorption processes to enhance membrane effectiveness and prolong lifespan.

This study introduces a novel approach of hospital wastewater treatment by integrating oil palm fibers, activated carbon, and ultrafiltration. This approach utilizes the high adsorption capacity of activated carbon, the cost-effectiveness, and sustainability of oil palm fibers. The study aims to analyze the effectiveness of hospital wastewater treatment in removing pollutants by integrating oil palm fibers, activated carbon, and ultrafiltration thereby it provides dual benefits of wastewater treatment and environmental protection for healthcare facilities in line with global efforts towards sustainable development in medical practices.

2. MATERIAL AND METHOD

The study was a quasi-experimental study with one group pre-test post-test study design which was held at Laboratory of Chemical Engineering of Universitas Sriwijaya on November 2023-April 2024. The study used wastewater from Hospital X in Palembang. The raw material was taken by using grab sampling. The hospital wastewater was deposited for 24 hours in sedimentation tank. There were 2 types of adsorbents which were used in this study. The first adsorbent was activated carbon block with length 10 inches (**Figure 1**). Activated carbon block was made from powdered activated carbon which was mixed with food-grade binder. The second adsorbent was oil palm fiber. Oil palm fiber had high cellulose contents with large porosity, average density of 0.13 g/cm^3. Before it was used, oil palm fibers were calcined at 200° C for 3 hours and were transformed into a size of 100 mm (**Figure 1**). This study also used polypropylene sediment filter 0.1 micrometers with length 10 inches (**Figure 1).**

Figure 1. Adsorbents and polypropylene sediment filter. A. Oil palm fiber. B. Activated carbon block. C. Polypropylne sediment filter.

In this study, there were three sets of housing filters. Each set comprised of three housing filters. The first set of housing filters contained oil palm fiber, the second set of housing filters contained activated carbon, and the last set of housing filters contained polypropylene sediment filter as shown in **Figure 2.**

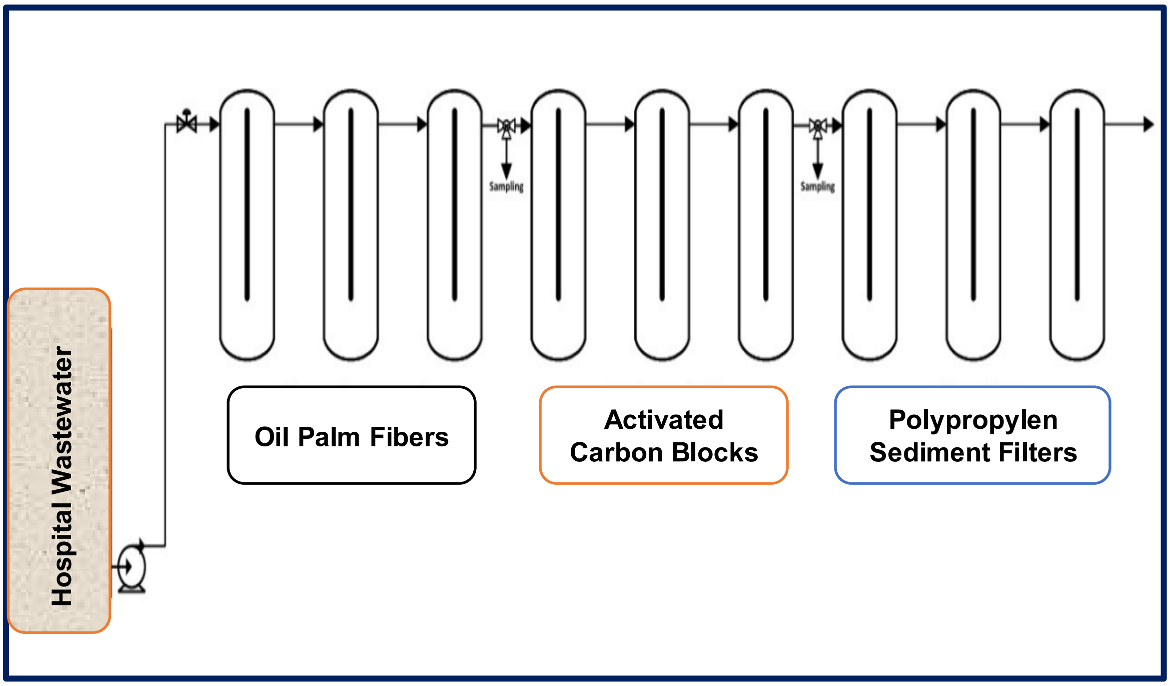

Figure 2. Configuration of integrated adsorption process of hospital wastewater treatments

This study conducted four trials (**Figure 3**). First, the hospital wastewater was flowed to three housing filters. Each housing filter contained activated carbon block. In each housing filter, the wastewater was deposited for 5 min. Then, the sample was taken (AC). It was repeated 3 times. Second, the hospital wastewater was flowed to three housing filters which contained oil palm fibers. Each housing filter contained of 500 g of oil pam fibers. In each housing filter, the wastewater was deposited for 5 minutes. After that, the sample was taken (PF). It was repeated 3 times. Third, the hospital wastewater was flowed to three housing filters which contained oil palm fibers. After that, the wastewater was flowed to three housing filters contained of activated carbon blocks. In each housing filter, the wastewater was deposited for 5 minutes. Then, the sample was taken (PF + AC). It was repeated 3 times. On the last trials, the hospital wastewater was flowed to three housing filters which contained oil palm fibers. Thereafter, the wastewater was flowed to three housing filters contained of activated carbon blocks. Furthermore, it was flowed to three housing filters which contained polypropylene sediment filters. In each housing filter, the wastewater was deposited for 5 min. Then, the sample was taken (PF + AC + UF). It was repeated 3 times. All of the samples were tested at Palembang Public Health Laboratory Center. The Potential of Hydrogen (pH), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and total coliform were analyzed before and after wastewater treatment. The datas were presented in graphs. The study analyzed removal efficiency percentage of pH, BOD, COD, TSS, and total coliform of hospital wastewater.

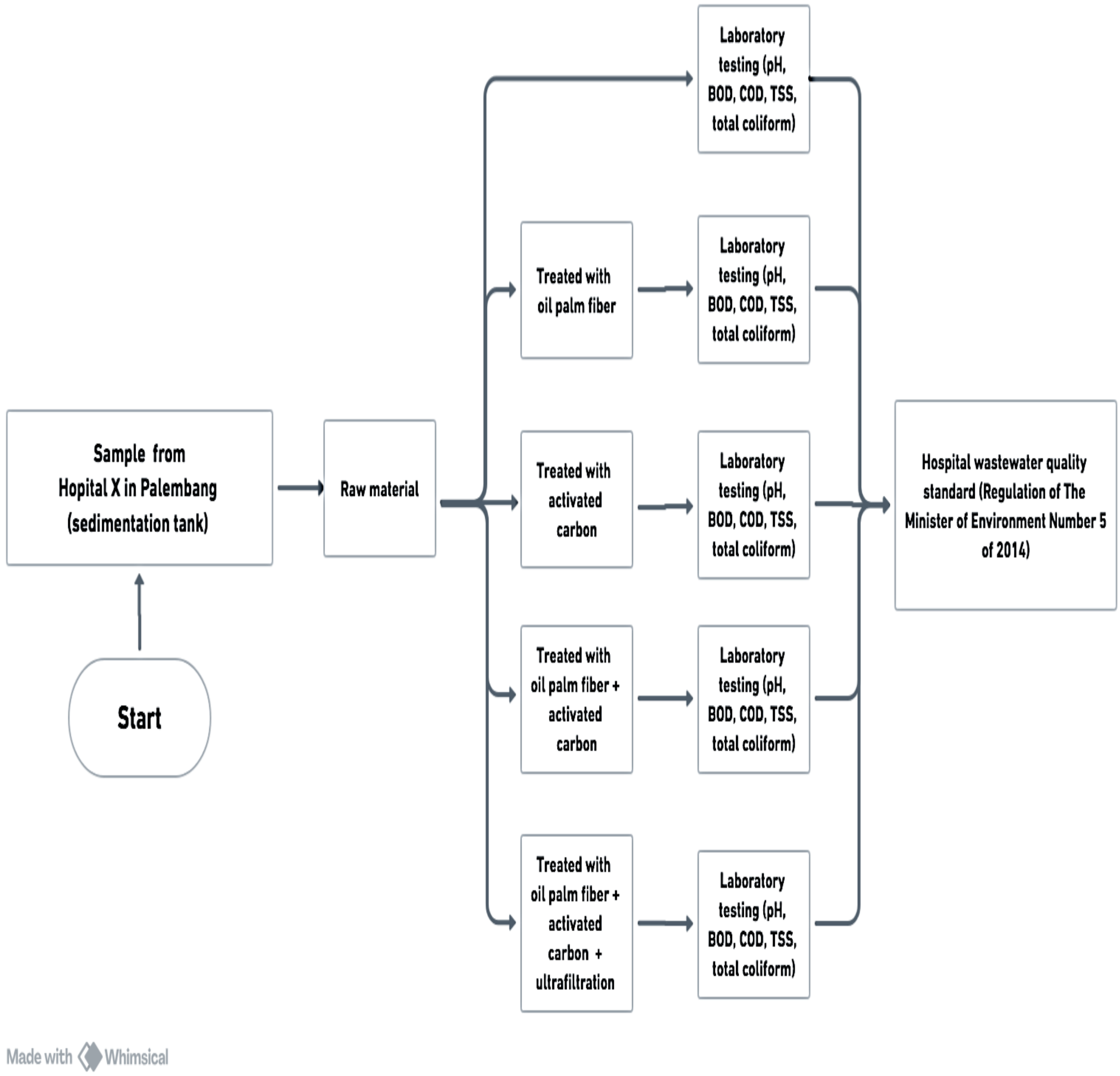

Figure 3. The flowchart of wastewater treatments

3. RESULT AND DISCUSSION

3.1 The Effectiveness of Adsorbent Media on Potential of Hydrogen (pH) Changes of Hospital Wastewater

An essential water quality parameter is Potential of Hydrogen (pH). It indicates the concentration of hydrogen ions of wastewater. Hospital wastewater, as the raw material of the study, was taken from sedimentation tank with pH value 7.74. As shown in **Figure 4**, when the adsorption process was conducted by using oil palm fiber, the effectiveness of pH value changed by 6.33 %. Meanwhile, when the wastewater was treated with activated carbon, the effectiveness of pH value changed by 3.75 %. The integrated adsorption process by using oil palm fiber, activated carbon, and ultrafiltration increased the effectiveness of pH value changed by 8.91 %. However, all of pH values were within a neutral pH range of 7.05–7.45. It meaned that the removal of hydrogen ions and hydroxide ions from the wastewater was not significant, as the initial pH of the raw material was already neutral.

The study that was conducted by Roman, et al in 2020 has shown the same result. The study showed that activated carbon and oil palm fiber decreased pH value of domestic waste from 8 to 7,5. When the microorganisms decomposed more organic compounds, pH value became more acidic (Roman, Bunyani, and Naisanu 2020). Tumimomor et al in 2020 also reported similar result. The study showed filtration decreased pH value of laundry wastewater (Tumimomor, Palilingan, and Pungus 2020). The breakdown of organic compounds produced acidic carbon dioxide. Besides, activated carbon would adsorb the organic compounds of detergent (Aliaman 2017).

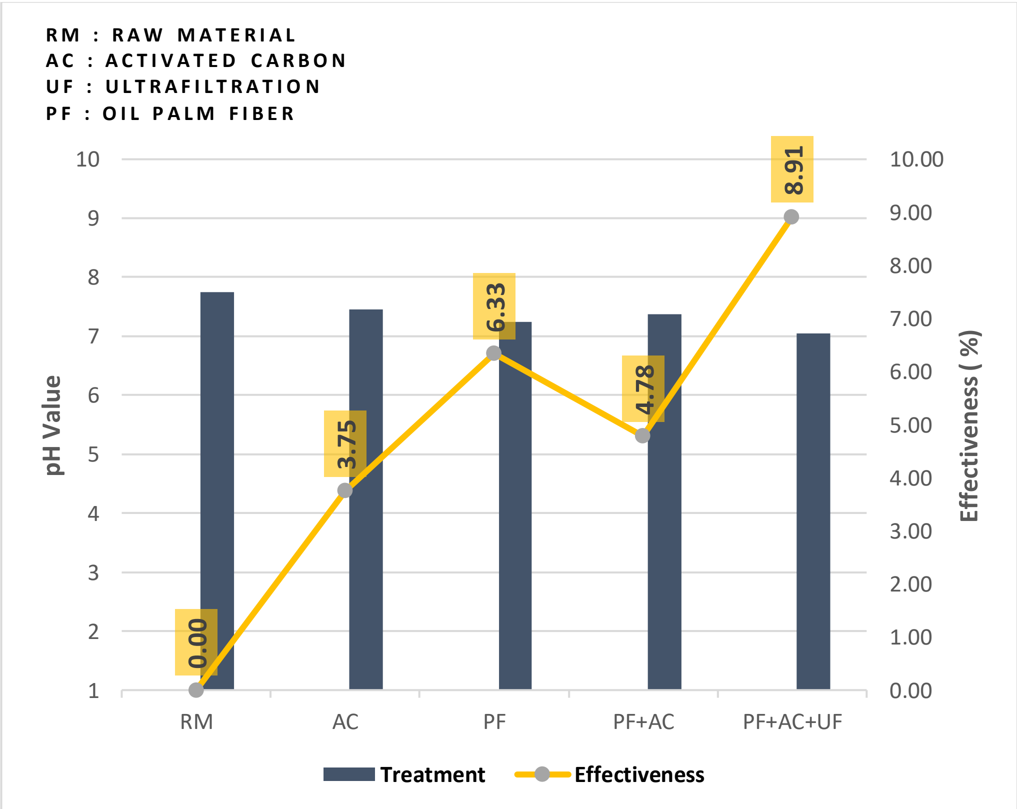

Figure 4. The effectiveness of adsorbents on pH changes of hospital wastewater

The pH value affects the wastewater treatment process. A low pH value (pH < 6) leads to fungal growth. Conversely, a very high pH value (pH > 9) will inhibit the activity of microorganisms (Afriliani, Nurjazuli, and Dewanti 2020). In alkaline condition, activated carbon will have a net negative charge. Alkaline condition decreases adsorption efficiency. The adsorption capability for metal is also influenced by pH value. In neutral pH condition, metal adsorption can occur effectively (Ifa et al. 2020). The study that was conducted by Ariyani, et al in 2020 showed that activated carbon increased pH value of wastewater (Ariyani et al. 2020). The clearer the water, the higher the amount of oxygen that could be dissolved in the water, known as Dissolved Oxygen (DO). High DO levels in water led to a decrease of carbon dioxide produced by microorganism respiration. This resulted in a reduction of hydrogen ions. Then, the pH became more alkaline (Pinem 2019).

3.2 The Effectiveness of Adsorbent Media on Total Suspended Solids (TSS) Removal of Hospital Wastewater

Solid pollutants of wastewater can be classified into floating, settle able, suspended, or dissolved solids. Total solids encompass both Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). TDS refers to solids dissolved in water, whereas TSS consists of solid materials (sand, clay, mud), biotic components (phytoplankton, zooplankton, bacteria, and fungi), and abiotic components which are suspended in water (Afriliani et al. 2020). High TSS level reduces oxygen production in water and disrupts aquatic food chains (Resky et al. 2022).

The wastewater of Hospital X in Palembang had high TSS level (**Figure 5**). In this study, oil palm fiber and activated carbon decreased TSS levels effectively. Oil palm fiber decreased TSS level by 80.11 %. Meanwhile, activated carbon decreased TSS level by 77.51 %. When oil palm fiber was combined with activated carbon, the TSS removal efficiency reached 81.06 %. Moreover, when oil palm fiber was combined with activated carbon and ultrafiltration, the TSS removal efficiency percentage increased to 84.21 % (**Figure 5**). The effectiveness of oil palm fiber and activated carbon were attributed to their physical properties which were characterized by large pore structures that enhanced absorption efficiency. Ultrafiltration played significant role in reducing Total Suspended Solids (TSS) level in wastewater due to its capability to separate macromolecules and colloids from solutions, which the rejection of dissolved substances were heavily depended on their relative size and weight to the membrane pore size. Ultrafiltration membrane was smaller than microfiltration membrane, resulting in higher rejection rates (Klatt, et al., 2022; Bodzek, et al., 2019).

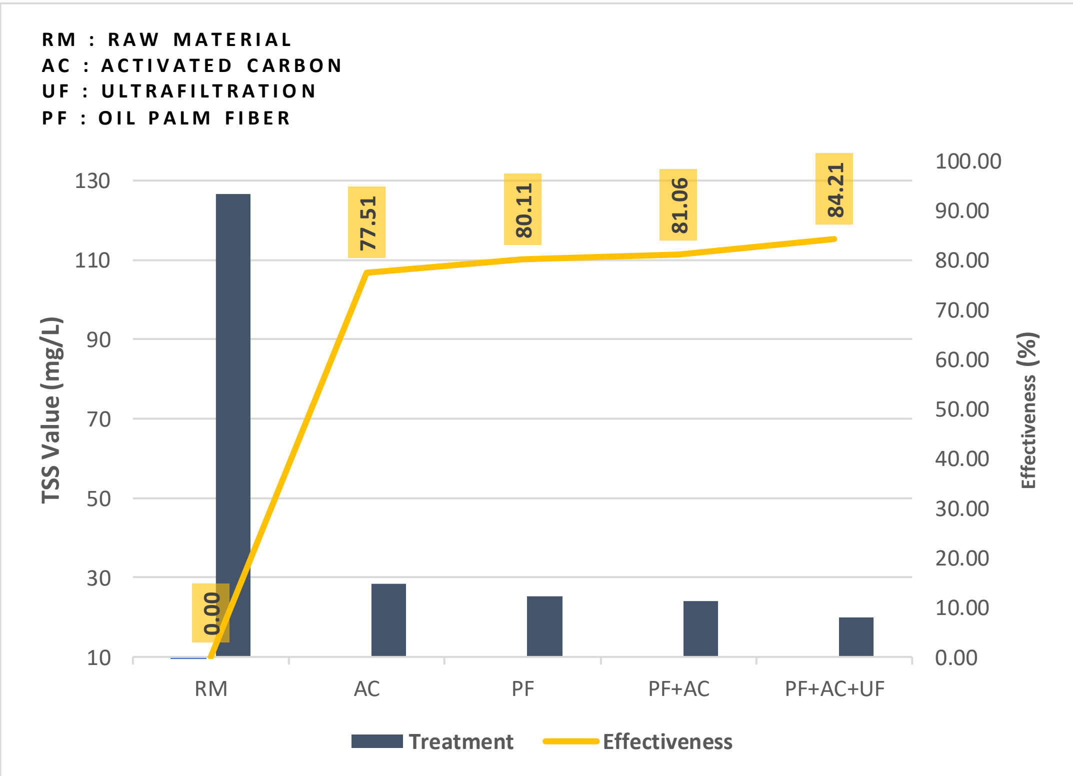

Figure 5. The effectiveness of adsorbents on TSS removal of hospital wastewater

Candra in 2021 conducted study on wastewater treatment by using filtration and adsorption process. The study used combination of gravel, silica sand, oil palm fiber, and activated carbon. It showed that filtration and adsorption decreased TSS levels by 87.72 % (Candra 2021). Similarly, study which was conducted by Amira, et al. in 2022 demonstrated a decrease in TSS levels of restaurant wastewater by 99.73 % after treated with activated carbon, sand, powdered coconut fiber, and gravel. This efficacy was attributed to the pores of powdered coconut fiber, which effectively retained total suspended solids in wastewater (Amira, Utomo, and Pramadita 2022). Besides, the pores of activated carbon could adsorb organic pollutants in wastewater (Kurniawati et al. 2020). The duration of wastewater sedimentation also influenced TSS removal (Afriliani et al. 2020).

Meanwhile, Resky et al in 2022 demonstrated different result. The study showed that TSS level of wastewater increased after it was treated with activated carbon. The increase of TSS level was caused by short sedimentation time. The maximum sedimentation time was 6-8 hours in order to make activated carbon bound the flocs and decreased TSS level (Resky et al. 2022).

3.3 Effectiveness of Adsorbent Media on Biological Oxygen Demand (BOD) Removal of Hospital Wastewater

Biological oxygen demand (BOD) is the amount of dissolved oxygen required by microorganisms to decompose or to oxidize dissolved and suspended organic compounds in water (Hocaoglu et al. 2021; Vigiak et al. 2019). The higher BOD level, the greater the amount of oxygen that is needed by microorganisms to breakdown organic materials. The wastewater of Hospital X in Palembang had high BOD level. The effectiveness of adsorbent media on BOD removal can be seen in **Figure 6.** In this study, oil palm fiber had higher adsorption capacity than activated carbon. Oil palm fiber decreased BOD level with removal percentage efficiency 47.37 %, compared to activated carbon with BOD removal percentage efficiency 21.05 %. When oil palm fiber was combined with activated carbon, the BOD removal percentage efficiency decreased to 40.26 %. On the other hand, when the wastewater was treated with oil palm fiber, activated carbon, and ultrafiltration, BOD removal percentage efficiency reached 60.53 %. Each adsorbent media had an equally important role. It showed that the integrated adsorption method was crucial for wastewater treatment. Oil palm fiber was oftenly used as raw material in the production of activated carbon due to its high lignocellulose content. Oil palm fiber would have higher adsorption capacity if it was converted into activated carbon before being used (Amira et al. 2022; Haryanti et al. 2014; Manusawai 2011).

Candra (2021) combined adsorption and filtration method by using gravel, silica sand, oil palm fiber, and activated carbon to treat laundry wastewater. The study achieved BOD removal percentage efficiency of 83.08 % (Candra 2021). Furthermore, Benyamin, et al (2020) reported similar result. The study combined adsorption and filtration method by using coconut husk, sand, oil palm fiber, activated carbon, and zeolite, resulted in a BOD removal of 63.62 %. Most researchers stated that activated carbon had the ability to absorb organic substances through the pores on its surface, thus achieving a higher BOD removal compared to media with smaller pores (Benyamin and Darmakusuma 2020; Rajan and Anish 2023).

Oil palm fibers also play role in reducing BOD level. Oil palm fiber contains 15.1 % lignin, 51.2 % cellulose, and 28.2 % hemicellulose (Lubis, Nasution, and Zubir 2020). The cellulose and lignin components have an absorption capacity 6,000 times greater than that of activated carbon (Haryanti et al. 2014). Oil palm fiber has 22 % of pores that function to filter organic substances (Humairo et al. 2023). Additionally, oil palm fiber can be used as a growth medium for microorganisms (Manusawai 2011). Microorganisms will convert the organic substances in wastewater into simpler compounds. This hydrolysis process leads to a decrease of BOD levels. However, a study that was conducted by Amira, et al. in 2022 showed different result. This study indicated that the use of coconut fiber was less effective in reducing BOD levels. This was because the organic substances in the coconut fiber could become an influent load or contaminants, thereby reducing filtration effectiveness (Amira et al. 2022).

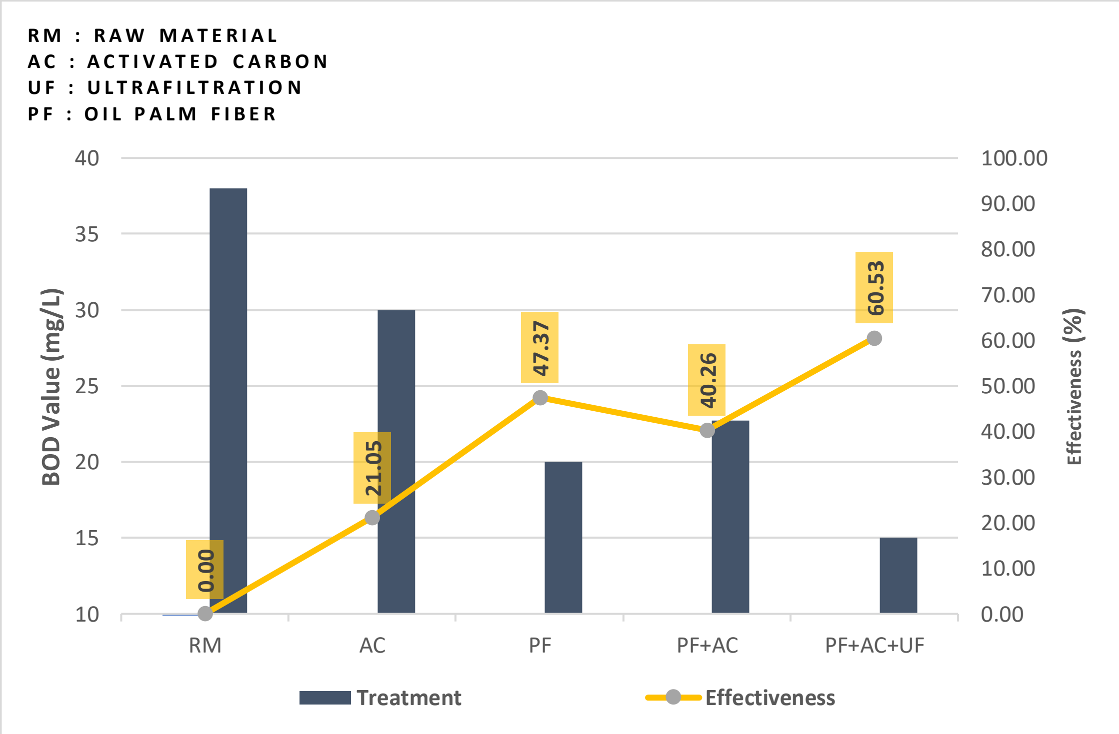

Figure 6. The effectiveness of adsorbents on BOD removal of hospital wastewater

3.4 Effectiveness of Adsorbent Media on Chemical Oxygen Demand (COD) Removal of Hospital Wastewater

Chemical Oxygen Demand (COD) is the amount of oxygen required by oxidizing agents to decompose or to oxidize dissolved organic and inorganic substances in the water, both biologically and chemically (Majumder et al. 2021). COD is a comprehensive indicator of all oxidizable pollutants in sample. COD analysis is used to quantify the level of organic materials that can be oxidized by using strong chemical oxidizers in an acidic medium. The wastewater of Hospital X in Palembang had high COD level. In **Figure 7,** hospital wastewater treatment by using oil palm fibers successfully decomposed dissolved organic and inorganic substances with COD removal efficiency 48.3 %, while activated carbon exhibited a higher COD removal efficiency by 58.82 %. Moreover, the combination of oil palm fiber, activated carbon, and ultrafiltration decreased COD level by 57.52 %. The COD removal efficiency of integrated adsorption method was lower than COD removal efficiency of activated carbon. It was because the activated carbon that was used in the study had larger surface area of pores compared to industrial waste fiber surfaces, as explained by Rashid, et al., 2021. Therefore, its adsorption capacity for decomposing organic and inorganic substances was also greater (Rashid et al. 2021). Besides, activated carbon that was combined with oil palm fiber and ultrafiltration had been saturated with adsorbate (Nurhayati, Sugito, and Pertiwi 2018).

Candra (2021) combined adsorption and filtration method by using gravel, silica sand, oil palm fiber, and activated carbon to treat laundry wastewater. The study achieved COD removal percentage efficiency of 92.79 % (Candra 2021). Similarly, Nururrahmah (2015) reported that oil palm fiber was able to decrease COD level in sago wastewater by 97.95 % (Nururrahmah 2015). The pore structures of oil palm fiber and activated carbon adsorbed the organic compounds. This resulted the decrease of oxygen amount that was needed to oxidize organic substances, thereby decreasing COD levels (Cundari, et al., 2016). Oil palm fiber contains 15.1 % lignin, 51.2 % cellulose, and 28.2 % hemicellulose (Lubis et al. 2020). Cellulose and lignin components absorbed colorants and organic materials in the wastewater. Additionally, oil palm fiber can be used as a growth medium for microorganisms (Manusawai 2011).

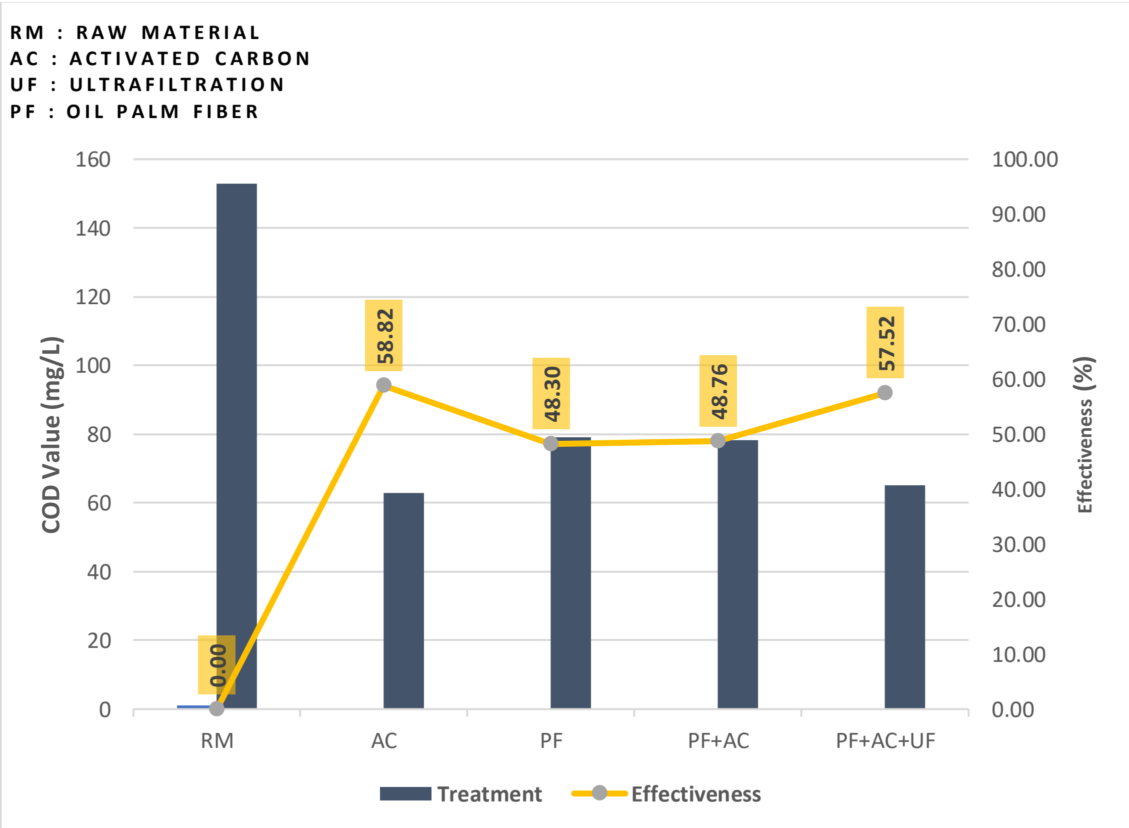

Figure 7. The effectiveness of adsorbents on COD removal of hospital wastewater

Whereas, study that was conducted by Zairiniyati and Khomsatun (2022) reported different result. The study showed that COD level of laundry wastewater increased after it was treated with activated carbon. The effectiveness of COD removal also depended on the size of the adsorbent media; smaller and finer adsorbent size led to higher COD removal efficiency. Additionally, the contact time of wastewater with activated carbon also influenced its effectiveness in reducing COD levels (Khomsatun et al., 2022).

3.5 Effectiveness of Adsorbent Media on Total Coliform Removal of Hospital Wastewater

Total coliform is one of the parameters that is used as an indicator of pathogenic bacterial contamination in water (Fathurohman, Wardani, and Nurlida 2020). The wastewater of Hospital X in Palembang had high total coliform level. In **Figure 8**, activated carbon was shown to be the most effective adsorbent in coliform removal. It decreased total coliform level with removal percentage efficiency of 60 %. Activated carbon had large pores. The pores of activated carbon were consisted of fine capillaries which allowed adsorbed substances to penetrate into these capillary spaces (Rahmawati and Nurhayati 2016).

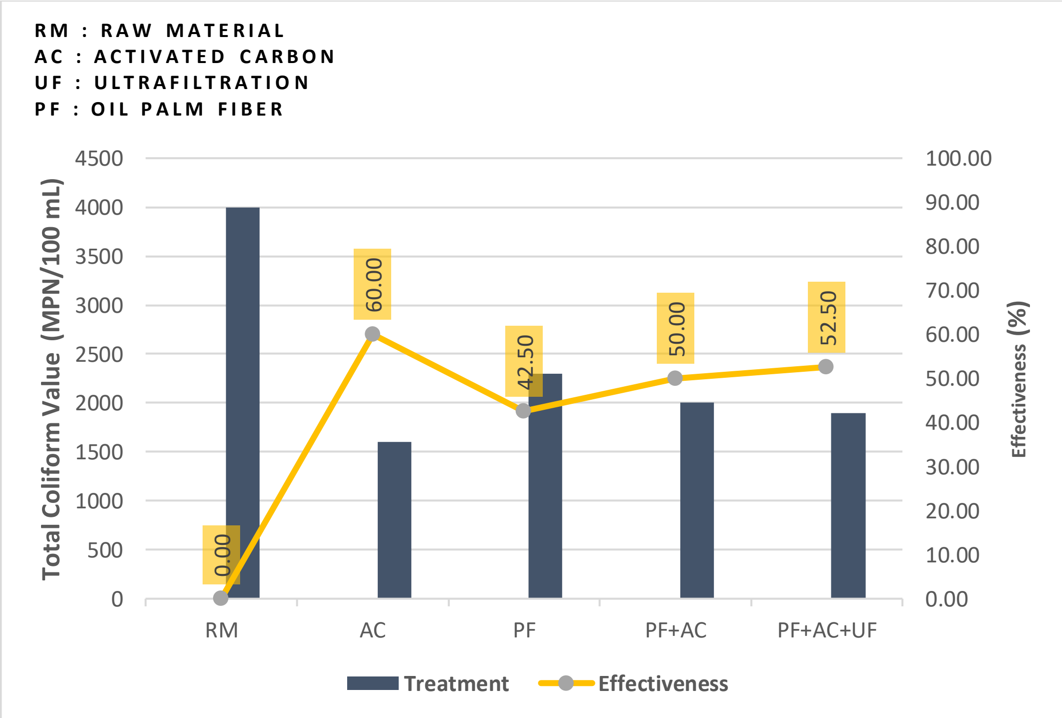

Figure 8. The effectiveness of adsorbents on total coliform removal of hospital wastewater

Activated carbon's pores bound or adsorbed bacterias, thereby reducing the bacterial count in wastewater (Rahmayanti, Laily, and Hamidah 2019). Meanwhile, oil palm fiber decreased total coliform level with removal percentage efficiency of 42.50 %. The pores of oil palm fiber were rougher that activated carbon, allowing E. coli to detach more easily from oil palm fiber. The integrated adsorption method by using oil palm fiber, activated carbon, and ultrafiltration decreased total coliform with removal percentage efficiency of 52.50 %. Although, integrated adsorption method had lower removal percentage efficiency of total coliform than activated carbon, the wastewater effluent had met wastewater quality standard (**Table 1**). Abbadi, et al in 2012 conducted a study of wastewater treatment by using ultrafiltration membrane. The study reported the decrease of total coliform level in wastewater. Spiral wound ultrafiltration membrane was effective in decreasing coliform bacteria because its pore size was smaller than the size of coliform bacteria, thus it would retain the bacteria (Abbadi et al. 2012). Additionally, ultrafiltration membranes also removed protozoa and viruses (Bodzek, Konieczny, and Rajca 2019).

Table 1. The wastewater of Hospital X in Palembang after treated with integrated adsorption method

Water Quality Parameter	Analysis Method	Hospital Wastewater (Raw Material)	Hospital Wastewater Quality Standard (Regulation of The Minister of The Environment Number 5 2014)	Wastewater Quality After Treated with Integrated Adsorption Method	Removal Efficiency (%)
pH	SNI 6989.11:2019	7.74	6-9	7.05	8.91
COD (mg/L)	Spectrofotometry	153	80	65	57.52
BOD (mg/L)	Manometry	38	50	15	60.53
TSS (mg/L)	Gravimetry	126.7	30	20	84.21
Total coliform (MPN/100 mL)	ALPHA 2017	4,000	3,000	1,900	52.5

4. CONCLUSION

The wastewater of Hospital X in Palembang is alkaline with pH value 7.74. Furthermore, the wastewater contains various pollutants with high TSS (126.7 mg/L), BOD (38 mg/L), COD (153 mg/L), and total coliform (4.000 MPN/ 100 mL) level. Integrated adsorption method by using oil palm fiber, activated carbon, and ultrafiltration effectively decrease pH (7.05), TSS (20 mg/L), BOD (15 mg/L), COD (65 mg/L), TSS (20 mg/L), and total coliform (1,900 MPN/ 100 mL) level of hospital wastewater. Each adsorbent has significant role in improving the quality of hospital wastewater. For instance, oil palm fiber effectively decreases BOD and TSS levels with removal efficiency percentage of 47.37 % and 80 % respectively. Activated carbon effectively reduces COD and total coliform level with removal efficiency percentage of 58 % and 60 % respectively.

It is recommended in further research to analyze the influence of contact time variations of the adsorbent media with wastewater. Moreover, the saturation level and the operational mass of adsorbent media have to be analyzed.

ACKNOWLEDGEMENT

I would like to express my infinite gratitude to the Head of the Energy Engineering and Waste Treatment Laboratory as well as my supervisor 1 for the opportunity and all the facilities so that I can carry out the research until the completion and also for the direction and discussion given by the supervisor 2.

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