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The Efficacy of Activated Carbon from Organic Waste in Treating Wastewater Effluent

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Article Info

Abstract

Increasing population growth with high socio-economic development has changed the world landscape. These advancements have resulted to the water quality degradation and inadequate management of solid waste. In addressing these critical issues, a robust water treatment technology is required. Activated carbon (AC) in enhancing the wastewater effluent quality has proven to be a promising and sustainable solution. AC from sugarcane bagasse (SCB), empty fruit bunch (EFB), and rice husk (RH) have been identified as abundant bioresources in Malaysia. These materials possess unique compositions and potential for reuse. The production of AC involves both physical activation through a carbonization process at 600°C and chemical activation through impregnation with $ZnCl_2$. In the study, samples from wastewater effluent were collected and analyzed for several parameters, including total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen. The samples have undergone treatment using activated carbon with various ratios. Here, the removal efficiency of pollutants was determined before and after the batch experiment. It can be denoted that AC, composed of SCB:EFB:RH in a ratio of 1.5:1:1, demonstrated an outstanding performance with an average percentage removal of 97%. A detailed analysis of the physicochemical characteristics of the AC was conducted. The output revealed significant surface modifications and alterations in the functional groups of the AC due to the adsorption process. These findings set a remarkable implication for tertiary treatment in enhancing the quality of effluent and provides valuable insight into implementing sustainable practices in wastewater treatment operations.

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1. Introduction

Access to clean water, sanitation, and hygiene is fundamental for human health and well-being. Malaysia's population rapidly increases yearly, with around 32.73 million for the first quarter of 2020, rising by 0.6 per cent compared to the first quarter of 2019 [1]. Decades of mismanagement, overexploitation of groundwater, and pollution of freshwater sources have increased water demand. In addition, governments are confronted with increasing issues associated with damaged water-related ecosystems, water shortages due to climate change, insufficient investment in water and sanitation, and inadequate cooperation on transboundary rivers [2]. In achieving universal access to potable water, sanitation, and hygiene by 2030, present improvement rates must double. Attaining these goals will save the death of 829,000 people annually caused by diseases directly linked to unsafe water, inadequate sanitation, and poor hygiene practices [3].

Access to water and sanitation are recognized as human rights by the United Nations, emphasizing water's importance to human life. The quality of the water supply is among the most essential components of an ecological system. The existence of a wide variety of plants and animals depends on the water quality. Meanwhile, human activities on land influence the quality of water bodies. The challenges in water availability arose from population growth, increased water demand, and water quality deterioration [4]. As a result, water scarcity will become the impact and must be solved immediately.

Prioritizing developing and maintaining robust wastewater management systems in rapidly populated areas is crucial. It includes investing in wastewater treatment and purification infrastructure, establishing efficient distribution networks and implementing sustainable water resource management practices. Wastewater treatment removes contaminants and pollutants from used water, also known as wastewater, before it is discharged into the environment or reused for various purposes. Wastewater can come from various sources [5], including residential households, industries, commercial establishments, and agricultural activities.

2. Literature Review

Many techniques, including rapid sand filtration (RSF), slow sand filtration (SSF), microfiltration, coagulation, activated carbon, reverse osmosis, and further disinfection, are all viable options for tertiary treatment [6]. Tertiary wastewater treatment may call for further approaches to decrease organics, turbidity, nitrogen, phosphorus, sulphate, metal, and pathogens [7].

An advanced method, such as activated carbon adsorption, has been in use for a long time and has shown that they are efficient for the removal of both existing and newly discovered pollutants. Activated carbon is a versatile adsorbent due to its properties: large surface area and pore volume, diverse pore structure, extensive adsorption capacity, and high surface reactivity. Activated carbon applications include eliminating colour, odour, and taste from water and effluent, the recovery of natural gas, and air purification in inhabited areas such as chemical industries and as catalysts and also used as catalyst supports. Activated carbon can be produced from a variety of carbonaceous sources. The source materials' inherent character and production methods determined the structural, chemical, adsorptive, and catalytic properties of activated carbon [8].

On the other hand, using organic waste material as activated carbon can save ecosystems from degradation. Organic waste materials generated from various industries or agricultural activities are often considered waste products with limited value [9]. Converting these organic wastes into activated carbon avoids their disposal in landfills and provides a valuable application. Using organic waste-activated carbon promotes a circular economic approach, reducing waste generation and encouraging resource efficiency instead of allowing organic waste to decompose and release methane, a potent greenhouse gas.

Therefore, this paper aims to fabricate an activated carbon material from organic waste, which can be explored for sustainable and cost-effective materials for tertiary treatment. The research objective was to assess the quality of water discharged from the wastewater treatment plant (WWTP) outlet at Universiti Teknologi MARA, Campus Dengkil. Secondly, the performance of activated carbon in percentage removal before and after effluent treatment has been evaluated. Lastly, the morphology of activated carbon has been assessed. The batch experiment results have been discussed further in the paper.

3. Material and Methods

The method of activated carbon preparation involves low-cost material and renewable resources such as sugarcane bagasse (SCB), empty fruit bunch (EFB) and rice husk (RH). These organic materials are largely produced in Malaysia. Using organic activated carbon in wastewater treatment plants can contribute significantly to achieving multiple Sustainable Development Goals (SDGs). This target can be achieved by removing contaminants, including organic compounds, heavy metals, and emerging pollutants. Moreover, the activated carbon materials facilitate achieving clean and safe water, thus supporting SDG 6 targets [2].

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The research framework has been outlined (see Fig. 1) to show the progress of its inception, reflecting the study's objective.
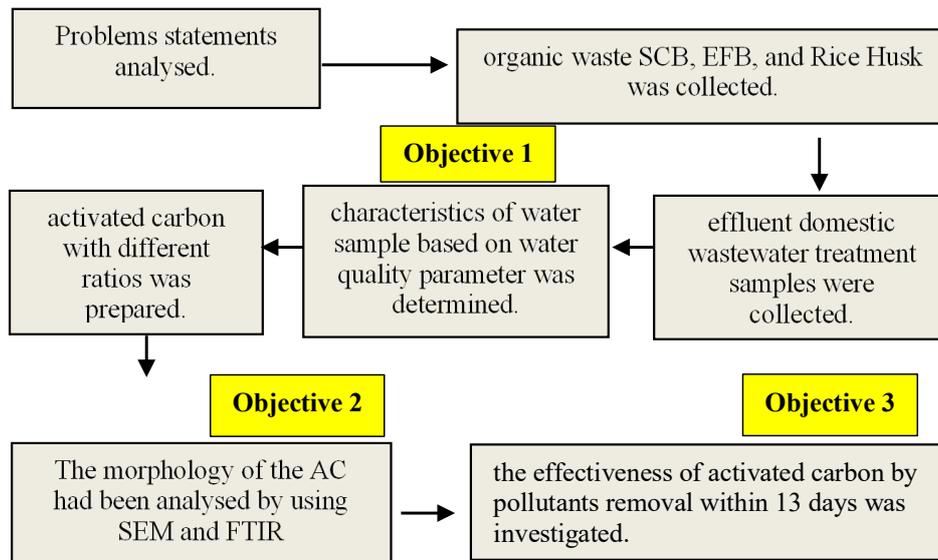

Fig. 1 *Flow chart of the research framework*

3.1 Collection of Samples

Domestic wastewater samples were obtained from the effluent wastewater treatment (WWTP) facility at Universiti Teknologi MARA, Campus Dengkil, in Selangor, Malaysia, as shown in Fig. 2. The sample was collected in the 20 L container at the effluent discharge outlet on May 11 2023. In-situ testing was carried out to ascertain dissolved oxygen's temperature, pH, and concentration at the outlet. The samples were later taken to the laboratory for testing to determine the biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen levels on the same day of collection.

Fig. 2 *Location of Universiti Teknologi MARA, Campus Dengkil, Selangor, Malaysia (2.86 °N, 101.6 °E)*

3.2 Preparation of Activated Carbon

The SCB, EFB, and rice husk were the raw materials used to produce the activated carbon. EFB was acquired from the Malaysian Palm Oil Board (MPOB) in Bangi, Selangor. At the same time, the rice husks were bought from an

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agricultural farm. On the other hand, the SCB was obtained from the local night market (see Fig. 3). For the preparation of the activated carbon, the weight of the SCB used was 5 kg, the EFB used was about 5 kg, and the weight of the rice husk used was around 1 kg. The samples were sterilized with distilled water and allowed to dry for 24 hours in an oven under 100 °C. The fibres were ground into small pieces and sieved into 1.5 – 1.8mm.

A recent study provides the basis for the procedure used to make AC [10]. The SCB, EFB and rice husk were first heated to 600 °C in a furnace for one hour to carbonize them. In doing this, an aqueous solution of zinc chloride ($ZnCl_2$) weighing 100 g/L was used. The aqueous solution of zinc chloride was then mixed with the char. After mixing the ingredients thoroughly for an hour, the apparatus was left to cool down. Later, the oven was turned on, and the temperature was set to 105 °C. The mixture was allowed to dry in the oven for a whole day. The activated carbon was allowed to cool to room temperature. The materials were washed with distilled water to eliminate undiluted zinc chloride (see Fig. 4).
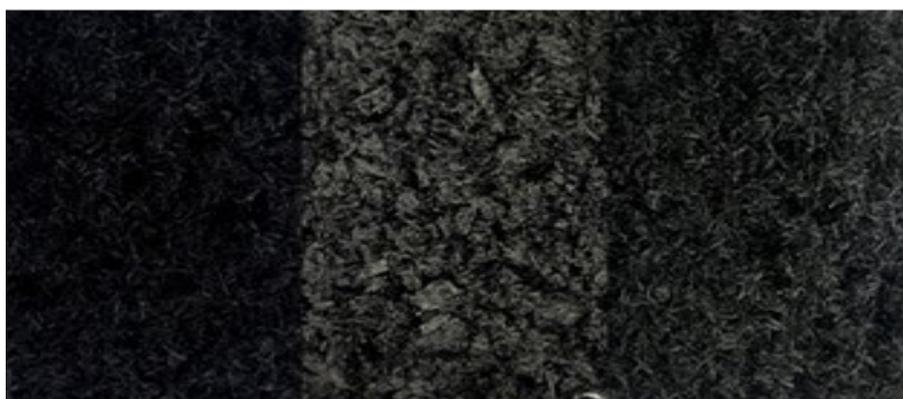

Fig. 3 *Raw Sample EFB (A), SCB (B) and RH (C)*

Fig. 4 *AC Produced from EFB (left), SCB (centre) and RH (Right)*

3.3 Experimental Set-Up

After the fabrication of the AC employing SCB, EFB, and rice husk, the batch experimental setting was prepared. The components, which consisted of SCB, rice husk, EFB, and a mix of activated carbon from different types, were weighed and divided into six unique ratios. Beakers with capacities of 1L each were made and labelled with the following ratios of (SCB: EFB: RH), 0:1:1, 0.5:1:1, 1:1:1, and 1.5:1:1, and the final beaker serving as a control and

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containing no activated carbon. The ratio of activated carbon has been selected to be used to assess the performance of these ratios and compared with other research studies (11). Each beaker was filled with 1 L of effluent from the WWTP samples. After that, the activated carbon was put into each beaker in the proportion corresponding to the individual weight of the AC, as given in Table 1. The wastewater sample was put into the beaker containing varied concentrations of AC, and the mixture was allowed to go through the adsorption process while aerated.

Water quality indicators, such as pH, COD, BOD, TSS, ammonia nitrogen, nitrite-nitrogen, and nitrate-nitrogen, were subjected to laboratory testing over 13 days, and the results were regularly monitored. As shown in Fig. 5, the wastewater sample was aerated using an air pump during this period. The process of aeration is one of the many possible methods often used in water treatment. The sample's dissolved oxygen quantities will rise because of aeration, making it possible for the water to purify itself [12].

Table 1 *Weight of activated carbon*

Ratio	Weight(g)						
	Sugarcane (SCB)	Bagasse	Empty Bunch (EFB)	Fruit	Rice (RH)	Husk	Total weight (g)
0:1:1	0		5		5		10
0.5:1:1	2.5		5		5		12.5
1:1:1	5		5		5		15
1.5:1:1	7.5		5		5		17.5

Fig. 5 *Activated carbon in the wastewater sample*

3.4 Experimental Procedure

The physical, chemical, and biological parameters of wastewater, such as pH, temperature, dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonia-nitrogen, nitrate-nitrogen, and nitrite-nitrogen were analyzed. All the testing procedures are based on standard methods [13]. After that, the criteria were compared with the Standard of Malaysian Sewerage Industry Guidelines [14]. The results of all the parameters involved in treating the sample effluent were presented as raw data and day 0. After day 13, the sample was taken out for Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) analysis.

4. Result and Discussion

4.1 Characteristics of The Wastewater Treatment Effluent

The wastewater characteristics were compared to the Malaysian Sewerage Industry Guidelines for Standard A [14]. Table 2 shows the effluent characteristics in the WWTP Universiti Teknologi MARA samples, Campus Dengkil. The effluent produced during the wastewater treatment process is discharged to the river tributary

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located within the catchment area of the Langat River. Standard A has been decided upon since the effluent was released into the Langat River's upper stream [14].

Table 2 *Characteristics of wastewater treatment*

Parameters	Effluent Wastewater Treatment	Standard of Malaysian Sewerage Industry Guidelines [13]
Temperature (°C)	24.37	40
pH	6.94	6-9
TSS (mg/L)	25.33	50
DO (mg/L)	7.03	-
BOD$_5$ (mg/L)	0.004	20
COD (mg/L)	59.33	120
Ammonia-nitrogen (mg/L)	0.1	10
Nitrate-nitrogen (mg/L)	0.01	20
Nitrite-nitrogen (mg/L)	0.009	-

The characteristics of the effluent wastewater treatment performed at Universiti Teknologi MARA, Campus Dengkil and the standards recommended by the Malaysian wastewater industry are compared and contrasted in Table 2. According to the preliminary findings, some metrics reveal a low value compared to the Guidelines for the Standard of the Malaysian Sewerage Industry [14]. The total suspended solid (TSS) is 25.33 mg/l, much lower than the normal threshold of 50 mg/l. In addition, the value of BOD is 0.004 mg/l, much lower than the normal threshold of 20 mg/l. The value of COD is now at 59.33 mg/l, which is also lower than the standard that has been established, which is 120 mg/l. Nitrate-nitrogen at a value of 0.1 mg/l was measured, much lower than the normal limit of 20 mg/l. Compared to the standard value of 10 mg/l, Ammonia-nitrogen is much lower, coming in at 0.1 mg/l. The temperature, pH, dissolved oxygen (DO) data and nitrite-nitrogen are correspondingly 24.37 ° C, 6.94, 7.03 mg/L, and 0.005 mg/L.

pH is a measure of acidic or alkaline solution level. It measures the concentration of hydrogen ions (H$^+$) in a solution. The pH scale ranges from 0 to 14, with pH 7 being neutral. A pH of less than 7 indicates acidity, and a pH greater than 7 indicates an alkaline level. When the pH value is high in wastewater effluent, it reveals that the water is alkaline. pH above 8.5 can cause damage to wastewater microorganisms, making them unable to degrade organic matter properly [15]. Additionally, a high pH level can lead to the formation of calcium carbonate precipitates, which can clog pipes and treatment apparatus.

On the other hand, when the pH value is low in wastewater effluent, it implies that the water is acidic. Toxic water has a pH that is either very low or extremely high. Most fish will perish at a pH level below 4, and very few creatures can survive in water with a pH level below 3 or over 11 [11]. A low pH poses a significant threat to the survival of amphibians because their skin is particularly susceptible to the effects of pollutants. However, based on the initial testing of the wastewater effluent obtained, it was 6.94, considered safe and nearly neutral. The pH value obtained for the untreated wastewater effluent was also 7.81, which is still in the standard range and considered safe [11]. pH is an important parameter to monitor in wastewater effluent as it can significantly impact the performance of treatment processes. A high or low pH level can cause damage to microorganisms and equipment, leading to decreased treatment efficiency.

In addition, total suspended solids (TSS) are the method most often used to quantify the quantity of organic and inorganic particles in wastewater effluent. TSS is an important parameter to measure in wastewater effluent because it indicates the water's potential to cause adverse environmental and health impacts on the receiving water bodies. A high concentration of TSS in wastewater effluent can cause the degradation of receiving waters, leading to a decrease in light penetration and a threat to aquatic life [11]. It can also cause clogging and reduce wastewater treatment systems and pipes efficiency. According to Table 2, the initial reading obtained is 25.33 mg/L, much lower than the standard [14], which is considered safe.

Next is the COD value obtained for the initial testing of the wastewater effluent. COD represents the amount of oxygen required to oxidize all the organic and inorganic substances in a wastewater sample. High COD levels in effluent indicate high levels of organic pollutants, which may lead to serious environmental impacts and health concerns. Furthermore, increasing COD levels in effluent can decrease the efficiency of microorganisms responsible for removing nitrogen from wastewater treatment systems. A previous study identified that the negative impact of COD on the nitrogen removal process was particularly significant in the presence of toxic

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compounds [15]. Based on Table 2, the COD value obtained is 59.33 mg/L. This value is below the standard maximum allowable of 120 mg/L and can be considered safe for the environment [13].

Meanwhile, BOD value is also very crucial in wastewater effluent. BOD represents the oxygen microorganisms consume as they break down organic matter in the wastewater. High BOD levels in the effluent can lead to environmental problems, such as reduced dissolved oxygen levels in receiving waters harming aquatic life [16]. The BOD value for the initial reading is 0.004 mg/L, which is lower than the standard value, which is 20 mg/L. A low value of BOD_5 indicates that the wastewater effluent is safe.

Nitrification, on the other hand, is a significant process in wastewater treatment as it is responsible for converting ammonia-nitrogen to nitrate-nitrogen and subsequently to nitrite-nitrogen. Nitrification is important because it helps to remove nitrogen from wastewater, which can harm the environment if discharged into water bodies. Specifically, nitrogen discharge into aquatic environments can result in overgrowth of algae, eutrophication, and other environmental problems. According to [17], excessive nitrogen discharge into water bodies like lakes, rivers, and oceans can lead to "dead zones" where harmful algae blooms deplete oxygen levels, harming fish and other aquatic organisms. Based on Table 2, the value of ammonia-nitrogen, nitrate-nitrogen and nitrite-nitrogen are 0.1 mg/L, 0.01 mg/L and 0.005 mg/L respectively. These values are lower than the standard [14], 10 mg/L and 20 mg/L, respectively.

However, the value of nitrite-nitrogen is not stated in the standard [14]. Microorganisms carry out the process known as nitrification, which involves the sequential oxidation of reduced nitrogen molecules, most notably ammonia-nitrogen, into nitrite-nitrogen and then nitrate-nitrogen. One of the contaminants that may be found in wastewater is ammonia-nitrogen, which is produced as a byproduct during the natural breakdown of organic nitrogen. Nitrite-nitrogen concentrations often fall in response to increased ammonia-nitrogen levels. High amounts of ammonia-nitrogen exist in the water bodies, and the biological oxygen demand (BOD) in the river will rise, leading to a decrease in the amount of oxygen dissolved in the water bodies.

4.2 Performance of Activated Carbon

The batch experiment is broken down into six distinct ratios of SCB:EFB: RH. These ratios include 0:1:1, 0.5:1:1, 1:1:1, 1.5:1:1, and finally, a sample that does not contain activated carbon (0:0:0). A ratio of 1 equals 5 grams of material. The data on Day 0 showed the wastewater without any AC.
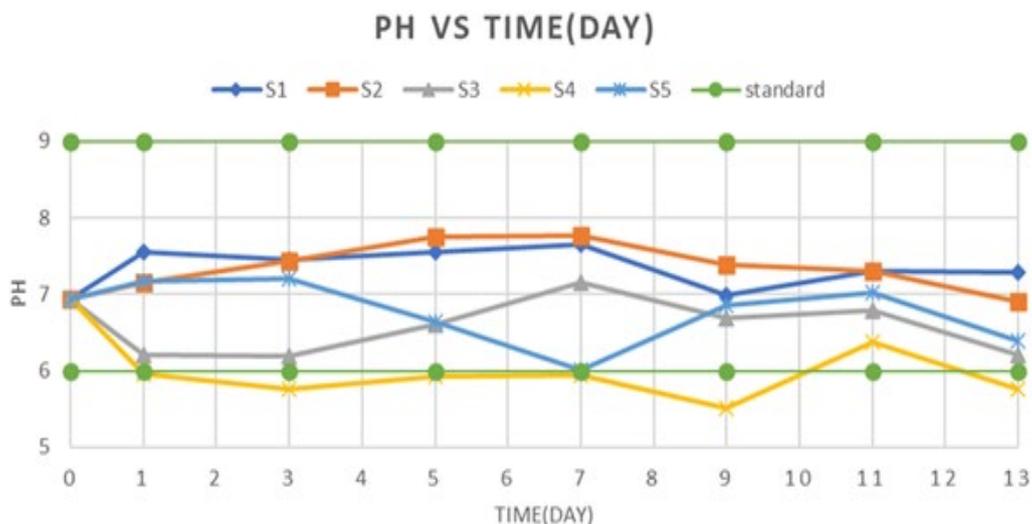
4.3 pH

Fig. 6 *pH against time (Day)*

Based on Fig. 6, the graph shows all the batches within the standard range [14] except S4, which is below the standard range [14] on day 3, 5.76, and day 9, 5.52. However, after day 9, the pH of S3 increases to the standard range [14] and declines again on day 13, which is 5.77. The pH of wastewater samples treated with activated carbon can fluctuate daily due to several factors, including the composition of the wastewater, the type and properties of the activated carbon, and the carbon adsorption capacity for different contaminants.

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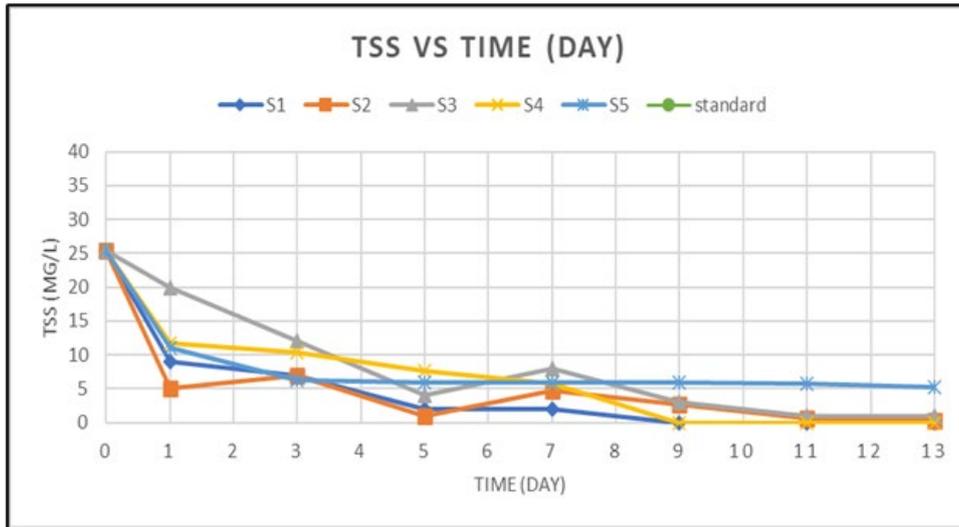
4.4 Total Suspended Solid (TSS)

Fig. 7 *Total suspended solids (TSS) against time (day)*

Based on Fig. 7, all the samples show a declination of the TSS value on day one and continue to day 5. However, the S2 with a ratio (0:1:1) and S3 with a ratio (1:1:1) fluctuate and decrease again after day 7. However, according to Fig. 7, the TSS value for S1 and S4 shows 0 mg/L after day nine. The fluctuation and subsequent decrease in TSS values during activated carbon wastewater treatment is a common phenomenon. The initial fluctuations in TSS values may be due to the adsorption of suspended solids by the activated carbon, followed by desorption or release of some of these solids back into the wastewater [18]. However, as the treatment continues, the activated carbon becomes saturated with suspended solids, leading to a more consistent and gradual decrease in TSS values.
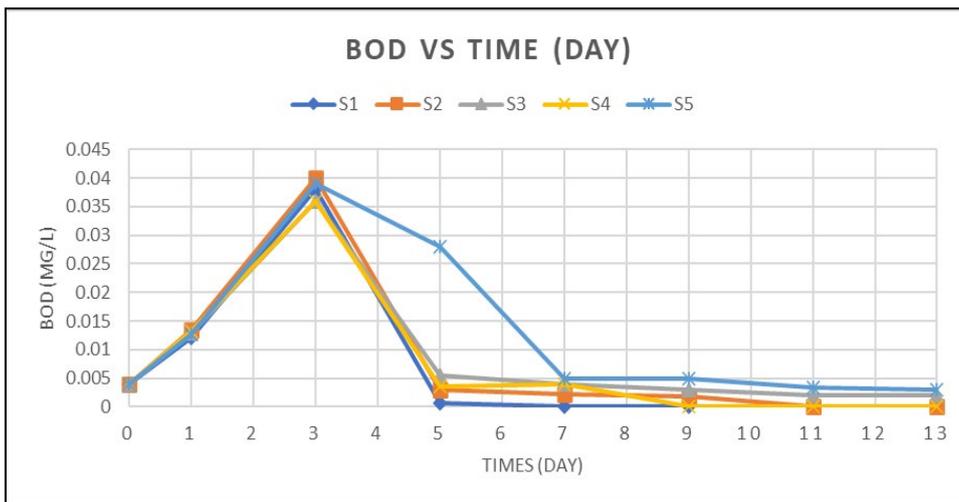
4.5 Biological Oxygen Demand (BOD)

Fig. 8 *BOD against time (Day)*

Based on Fig. 8, all the batches increase proportionally from day 0 to day three and are seen to decline sharply from day 5 to day 7. Fig. 8 shows that the S1, S2 and S3 achieve 100% percentage removal of BOD on day 7. Day 11 and day nine, respectively. S3, on the other hand, still managed to remove 50% of the BOD on day 13. Besides, S5 only achieved 25% of the BOD removal percentage. This value is expected for the S5 as the sample contains no activated carbon. However, more research is needed to find the activated carbon's behaviour in adsorbing BOD.
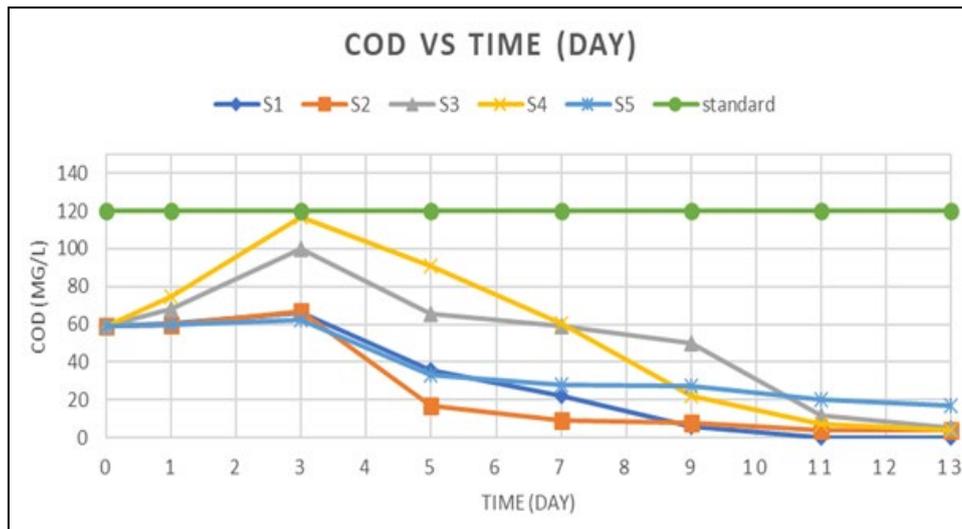
4.6 Chemical Oxygen Demand (COD)

Fig. 9 *COD against time (Day)*

Based on Fig. 9, we can see that all the batches increase in COD value from day 1 to day 3 and decrease again after day 3. The highest COD value recorded is S4 on day 3. In general, COD values are not expected to increase during the initial stages of activated carbon treatment of wastewater. Using activated carbon typically decreases COD values over time as the activated carbon adsorbs organic matter from the wastewater.

Some early studies have reported an initial increase in COD values during activated carbon wastewater treatment, but recent studies have not observed this phenomenon [11]. It is important to note that the efficiency of the activated carbon treatment process can depend on several factors, including the quality and characteristics of the wastewater, the type and dose of activated carbon used, and the contact time [8]. Optimization of these factors can ensure the desired treatment outcomes. Despite an increment in the COD value initially, the COD value kept decreasing until day 13. S1, S2, S3 and S4 recorded high COD percentage removal, 99.98%, 93.22%, 91.22%, and 93.22%, respectively. However, S5 is expected to have a lower removal percentage due to no activated carbon added to the sample.
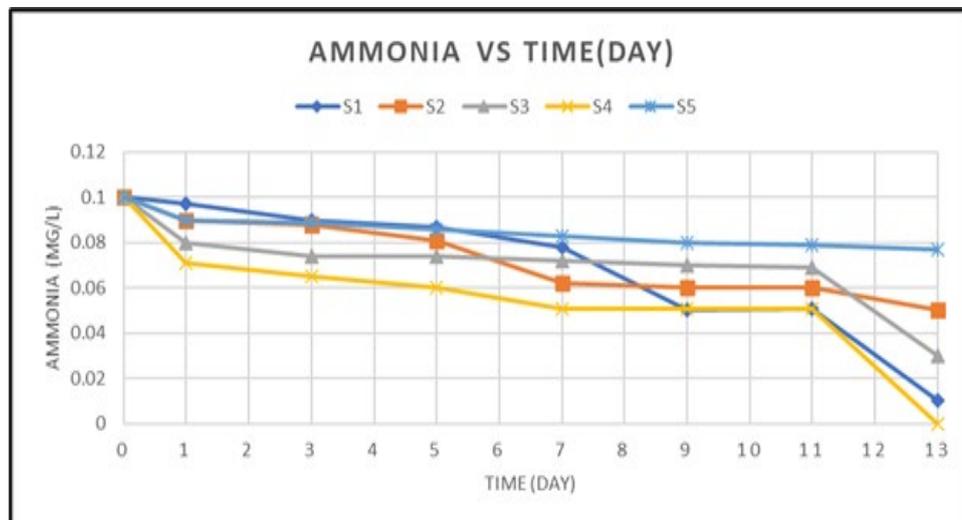
4.7 Ammonia-nitrogen

Fig. 10 *Ammonia-nitrogen against time (day)*

Based on Fig. 10, the ammonia-nitrogen value keeps decreasing from day 0 to day 13. S4 with the ratio of SCB:EFB: RH (1.5:1:1) recorded the lowest value, 0 mg/L of ammonia-nitrogen, on day 13. S4 recorded the highest removal percentage of ammonia-nitrogen, which is 100%. Removing organic matter and ammonia-nitrogen via

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nitrification and denitrification could be accomplished using biologically activated carbon as a treatment [19]. Thus, the value of ammonia-nitrogen is expected to decrease after being absorbed by the activated carbon.
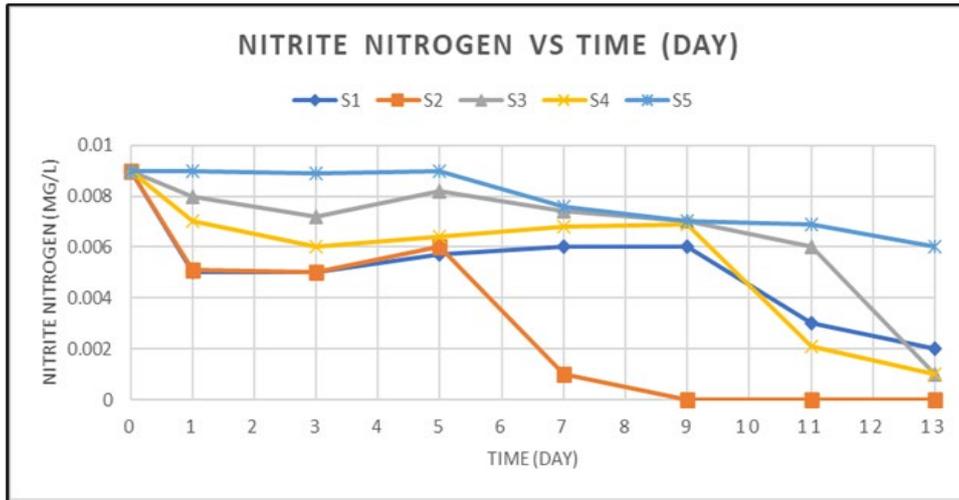
4.8 Nitrite-nitrogen

Fig. 11 *Nitrite-nitrogen against time (day)*

Based on Fig. 11, the value of nitrite-nitrogen for all the batches decreases from day 0 to day 3, except S5, which is constant until day 3. After day 3, the graph shows an increment of the nitrite-nitrogen value. S2 and S4 increased until day 5, which recorded values of 0.006 mg/L and 0.008 mg/L, respectively. However, S1 and S4 show the nitrite-nitrogen value increment from day 3 until day 9. The increment value indicates the wastewater sample's nitrification process that involves converting ammonia-nitrogen ($NH4^+$) to nitrite-nitrogen ($NO2^-$). The nitrite-nitrogen production may affect the increment value in the sample—all the batches show a reduction of nitrite-nitrogen on day 13.

Regarding percentage removal, S2 recorded 100% percentage removal of nitrite-nitrogen, while S2 and S4 both recorded 88.88% percentage removal. S1 recorded 77.7% percentage removal, and finally, S5 without activated carbon recorded the least percentage removal, only 33.33%. The removal of the nitrite-nitrogen in the sample indicates the effectiveness of activated carbon in capturing the nitrite-nitrogen in the sample.
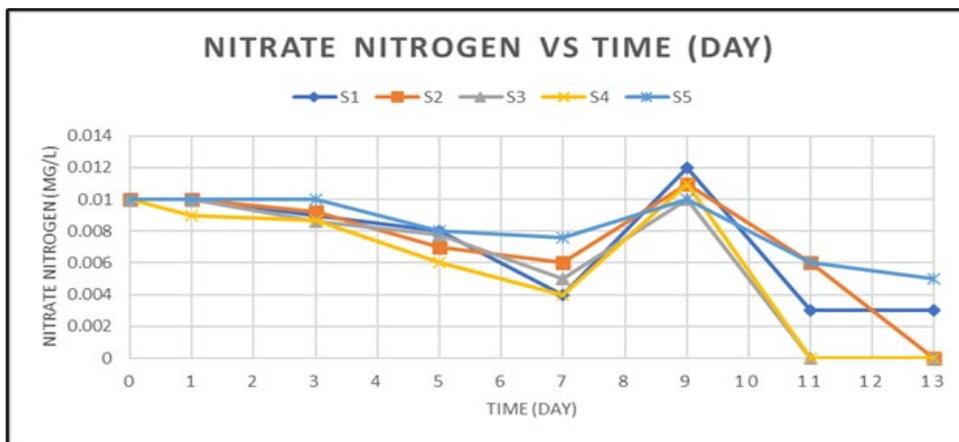
4.9 Nitrate-nitrogen

Fig. 12 *Nitrate-nitrogen against time (day)*

Based on Fig. 12, all the nitrate-nitrogen values decrease from day 0 to day 7. The reduction value of nitrate-nitrogen is due to the activated carbon. A study found that activated carbon could remove up to 94.7% of nitrate-nitrogen from wastewater [16]. When water containing nitrate-nitrogen flows through a column of activated carbon, the nitrate-nitrogen molecules encounter the carbon surface. The carbon has a very large surface area, meaning there are many places for the nitrate nitrogen molecules to attach [8]. According to the graph, the value of nitrate-nitrogen for all the batches increases again after day seven until day 9. The increase in nitrate-nitrogen

value may be due to the production of nitrate-nitrogen through conversion from nitrite-nitrogen to nitrate-nitrogen by Nitrobacter bacteria.
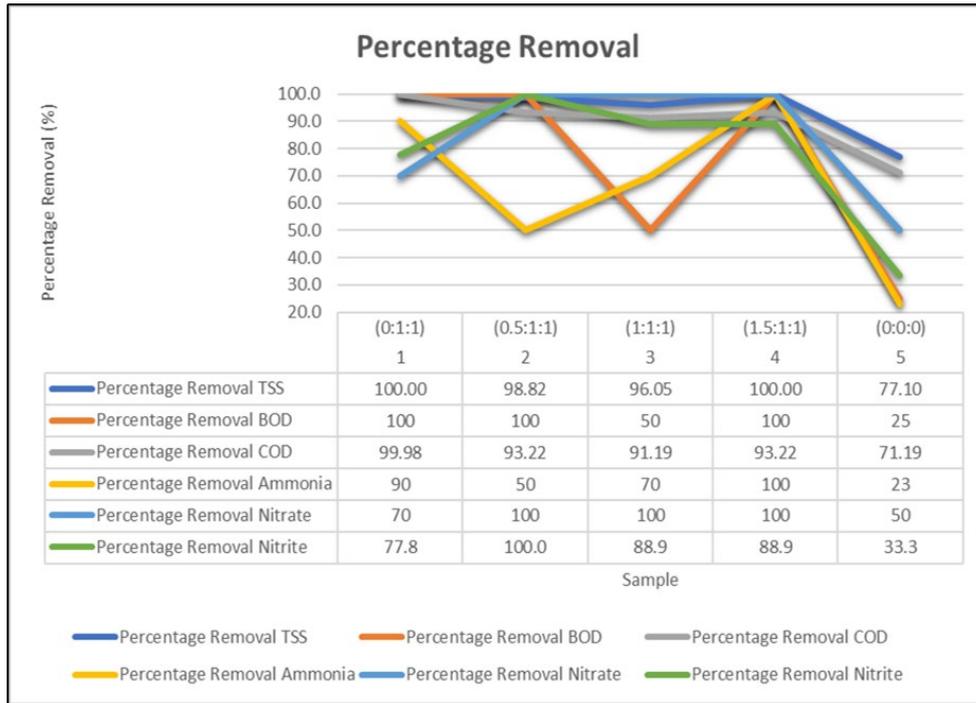
4.10 Percentage Removal

Percentage Removal	(0:1:1) 1	(0.5:1:1) 2	(1:1:1) 3	(1.5:1:1) 4	(0:0:0) 5
Percentage Removal TSS	100.00	98.82	96.05	100.00	77.10
Percentage Removal BOD	100	100	50	100	25
Percentage Removal COD	99.98	93.22	91.19	93.22	71.19
Percentage Removal Ammonia	90	50	70	100	23
Percentage Removal Nitrate	70	100	100	100	50
Percentage Removal Nitrite	77.8	100.0	88.9	88.9	33.3

Fig. 13 *Percentage removal for each parameter*

Table 3 *Average percentage removal for each parameter*

Sample	S1	S2	S3	S4	S5
Average Percentage Removal (%)	89.6	90.3	82.7	97.0	46.6

Based on Fig. 13 and Table 3, The highest average removal percentage goes to S4 (1.5:1:1), which is 97%. The second highest percentage is S2 (0.5:1:1), which accounts for 90.3%. Next, the third highest percentage is S1 (0:1:1), 89.6%. The second lowest percentage goes to S3 (1:1:1), 82.7% and the lowest average removal is S5, which only accounts for 46.6%. Sample S1 shows the highest value since the ratio of sugarcane bagasse is 1.5, which is the highest amongst the other batches. Activated carbon made from sugarcane pulp may attain a 95% removal efficiency [20]. The research results, therefore, show that using sugarcane bagasse pulp is a successful way to remove colours from aqueous solutions. In addition to this, previous research supported that sugarcane bagasse AC formed by physical activation was an efficient and effective adsorbent that could remove Pb(II) from an aqueous solution [21]. S5 is expected to be the lowest average percentage removal due to no activated carbon in treating the sample.

4.11 Scanning Electron Microscope (SEM)

As depicted in Fig. 14, the figure on the left shows the rice husk's activated carbon structure before the adsorption process under 900x magnification is observed. The pore structure on the surface of the AC looks smoother and well-arranged compared to the surface of the AC on the right, which portrays the pore structure looking rough and not smooth. It indicates that wastewater treatment can modify the pore structure of activated carbon. Water can fill the small pores and block some larger ones, making the carbon less porous. Additionally, water can react chemically with the carbon surface, causing pore walls to swell and become less porous. However, the extent of these changes and the effect on pore structure and size distribution depend on several factors, such as the activated carbon type, pretreatment, and wastewater treatment conditions [19].

Meanwhile, in Fig. 15, similar morphology can be seen on the left figure, EFB before adsorption looks smooth, and the pores appear more arranged. On the other hand, the right figure appears to be rougher, and the pore structure barely appears. This result agreed with a previous study, which stated that before adsorption, the

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surface morphology of the proposed activated carbon should typically be smooth and populated with numerous pores. In contrast, after adsorption, the surface morphology of the activated carbon was rougher, indicating that organic pollutants had attached to the activated carbon surface [22].

Based on Fig. 16, the AC structure of SCB activated carbon on the left looks smoother on the surface, while the surface structure of the figure on the right appears rougher and worn out. Wastewater treatment can cause surface erosion and wear of activated carbon, resulting in changes in the morphology of the carbon surface. Recent studies have reported the observation of worn-out pores on the surface of activated carbon after water treatment [23]. One study reported that the wastewater treatment resulted in the detachment of microparticles from the activated carbon's surface, leading to irregular pores formation [24]. Another study found that wastewater treatment caused surface erosion and fragmentation of the activated carbon particles [25].
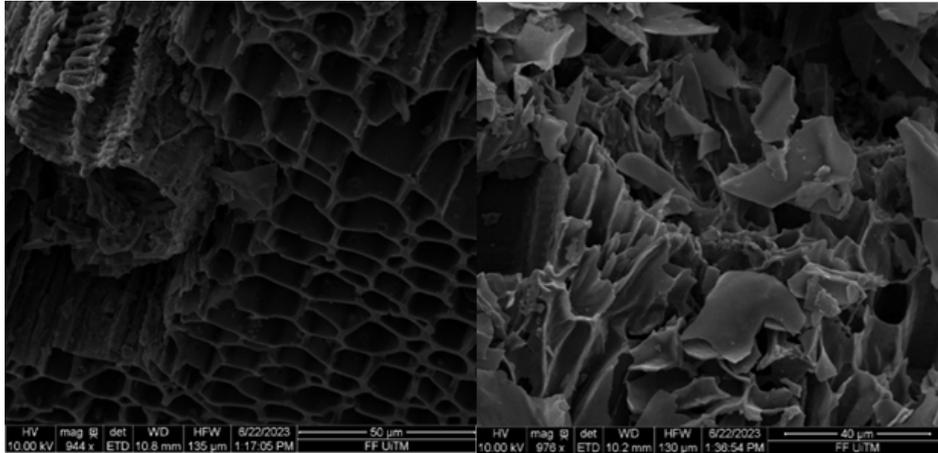

Fig. 14 *The surface of rice husk activated carbon under SEM, which (left) is AC adsorption and (right) after adsorption*
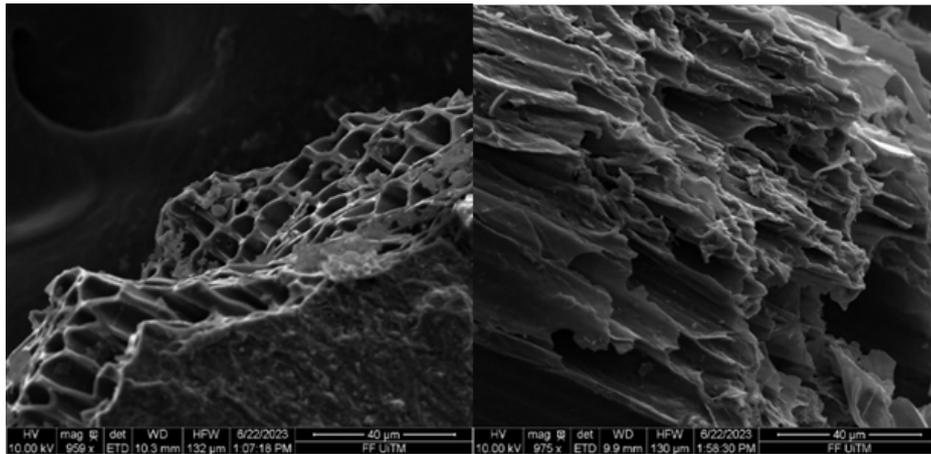

Fig. 15 *The surface of EFB-activated carbon under SEM, which (left) is AC before adsorption and (right) after adsorption*

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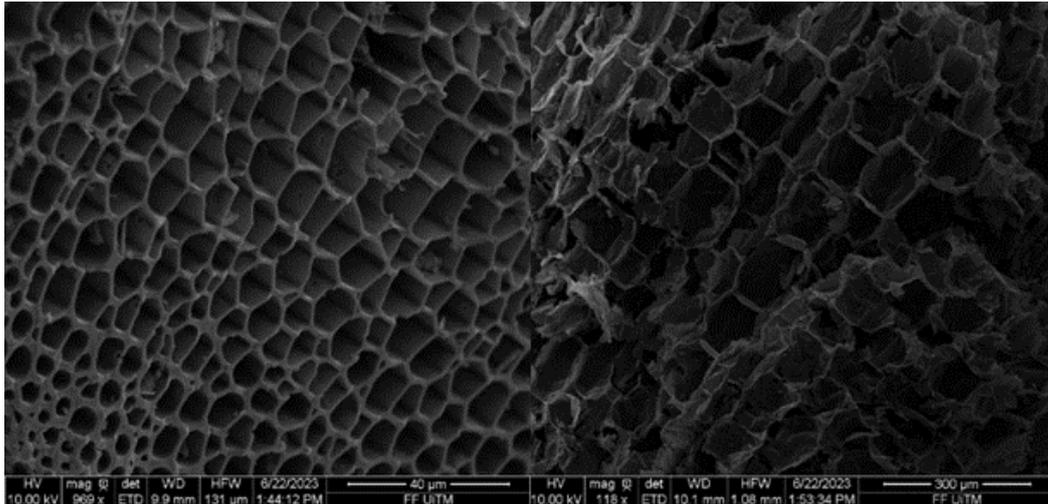

Fig. 16 *The surface of SCB activated carbon under SEM, which (left) is AC before adsorption and (right) after adsorption*

4.12   Fourier-Transform Infrared Spectroscopy (FTIR)

Fourier-transform infrared spectroscopy (FTIR) is a technique that can be used to investigate changes in the functional groups and chemical structure of activated carbon before and after water treatment. Changes in functional groups as wastewater treatment can cause alterations in the functional groups of activated carbon due to metal ion or organic matter adsorption [26]. For example, after treatment, the functional group's peak intensities increased in the activated carbon [27]. The spectrum shift, peak reduction, and disappearance can be used to determine if various functional groups affected adsorption [28]. Fig. 17 and 18 depicts the FTIR spectrum obtained for activated carbon before and after adsorption.

Figs 17 and 18 show a peak transmittance value at band 3375 cm^{-1} (before) and 3379 cm^{-1} (after) adsorptions. The value between this range indicates the presence of a single hydrogen bond [27]. The value within this range confirms the presence of hydrate (O-H) and ammonium (N-H) groups. The C-H bond is also present on both before and after adsorption-activated carbon, which is 2940 cm^{-1}. Meanwhile, the carbon dioxide O=C=O formation on the region (2000 – 2500 cm^{-1}) after adsorption, which appears at band 2348 cm^{-1}, can also be observed. This band appears on adsorption band C≡C. Besides, a stretching C=C group also appears in the range (1670 – 1620 cm^{-1}) of 1634 cm^{-1} before adsorption and 1644 cm^{-1} after adsorption. Bending C=C appears on bands 969 cm^{-1} and 962 cm^{-1} before and after adsorption. Thus, from the FTIR result, it can be concluded that the adsorption process does alter the molecular structure of activated carbon after water treatment.
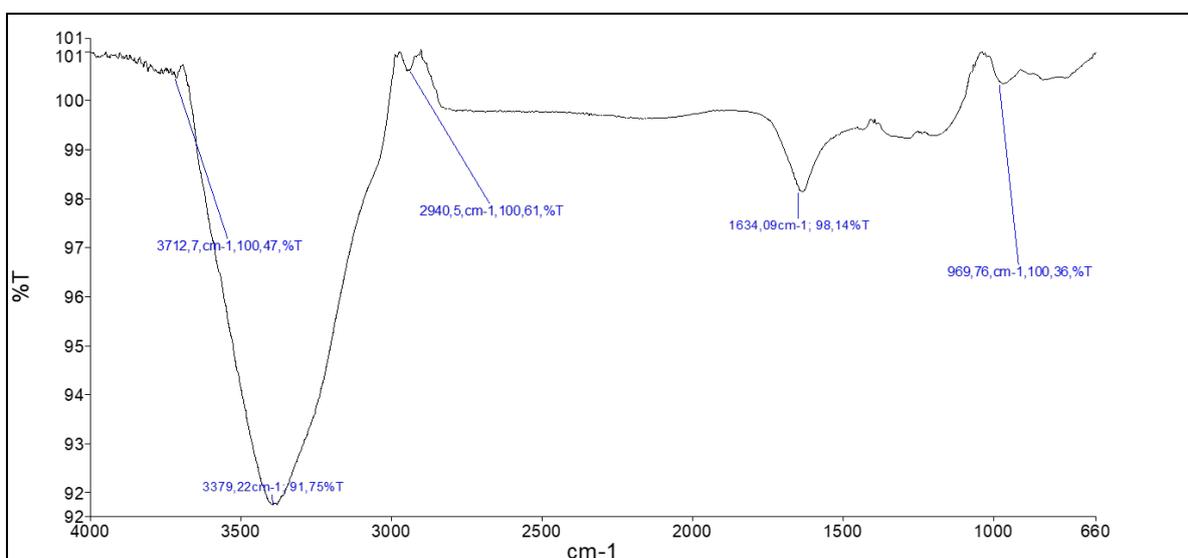

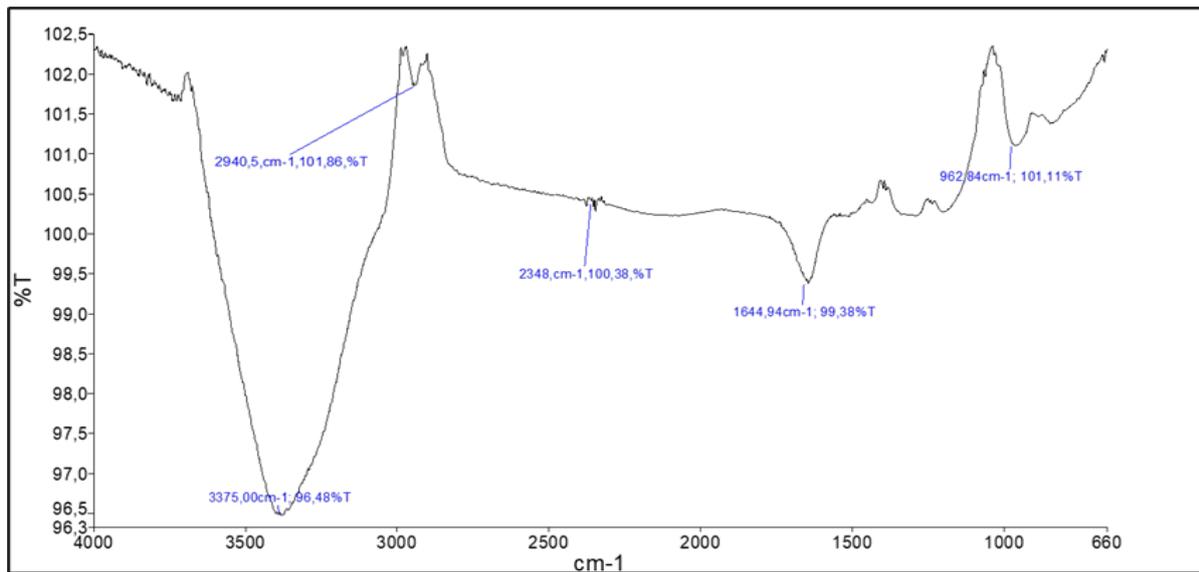**Fig. 17** *FTIR spectra of activated carbon before adsorption*

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Fig. 18 *FTIR spectra of activated carbon after adsorption*

5. Conclusion

It can be concluded that S4 with activated carbon ratio (1.5:1:1), which refers to (SCB:EFB:RH) activated carbon, exhibited superior average percentage removal of 97% in reducing COD, BOD, TSS, ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen. After that, they were followed by S2, S1, S3 and S5, which account for average percentage removal of 90.3%, 89.6%, 82.7% and 46.6%, respectively. The result shows that natural materials of activated carbon adsorbents have the potential to be effective catalysts in pollutant removal. The adsorbents used in the study were inexpensive, with sugarcane bagasse and rice husk being potential agricultural waste materials. Thus, utilizing these materials can contribute toward cost reduction and provide an eco-friendly solution compared to non-biodegradable materials.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** *Norhafezah Kasmuri, Dzikri Japri;* **data collection:** *Dzikri Japri;* **analysis and interpretation of results:** *Norhafezah Kasmuri, Dzikri Japri, Nurfadhilah Zaini;* **draft manuscript preparation:** *Norhafezah Kasmuri, Dzikri Japri, Khuriah Abdul Hamid, Satoto Endar Nayono, Amin Mojiri. All authors reviewed the results and approved the final version of the manuscript.*

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