

# Development of Filter Media from Kenaf Fiber

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**Abstract**— This study focused on developing filter media from kenaf fiber to be used in filtration of anaerobic digestion effluent. The use of low cost kenaf fiber as the filter media is a good replacement for the expensive conventional filter. The kenaf fiber is tested for its capability in post-treating the palm oil mill effluent (POME) which is a type of wastewater produced from production of palm oil. Neutral and alkali effluent were prepared to study the effect of different pH towards water quality parameters and particle size distribution of the effluent. Calcium carbonate was used to modify the pH into alkali. Neutral effluent referred to the original pH of the sample collected without any chemical addition. Suspended solids, colour, turbidity, chemical oxygen demand (COD) and heavy metals were the parameters for water quality that need to be measured. Spectrophotometer is used to measure suspended solids, colour, COD while turbidity meter is used to measure turbidity. Heavy metals are traced using inductively coupled plasma optical emission spectrometry (ICP-OES) and the particle size distribution was analyzed using particle size analyzer. The result shown that chemical modification towards the effluent caused membrane fouling to the kenaf filter and resulted in low water quality of the filtered effluent for pH 8. Hence, chemical modification by using calcium carbonate is not a promising alternative to further treat the anaerobic digestion effluent.

**Keywords**— Filtration, Kenaf fiber, Palm oil mill effluent

## I. INTRODUCTION

Malaysia uses palm oil as an alternative to vegetable oils in daily life application. Malaysia is known among the largest exporter for palm oil. As reported by Malaysian Palm Oil Board (MPOB), in 2011, the plantation area for oil palm in Malaysia reached 5 million hectares due to an increase in world's demand for fats and oils [9]. Palm oil is regarded as the major player for fats and oils trade due to its highest yield per hectare as compared to soya bean, sunflower seed and rapeseed [9]. The palm oil is extracted from oil palm fruits at the palm oil mills which then produces crude palm oil (CPO). The production of CPO resulted in waste production such as empty fruit bunches, palm press fibre, palm kernel cake and palm oil mill effluent (POME).

POME is a highly polluting wastewater with high viscosity and appeared as thick brownish [1]. Raw POME creates unpleasant odor and its colloidal suspension mainly consists of 95-96% water, 0.6-0.7% oil, 4-5% total solids and 2-4% suspended solids which come from debris of palm fruit mesocarp [19]. It is estimated that for each tonne of CPO produced, the amount of wastewater resulted from sterilizer condensate, separator sludge and hydrocyclone wastewater were 0.9, 1.5 and 0.1 m<sup>3</sup> respectively [19]. As POME is referred as wastewater, proper discharge procedures is essential to ensure that the POME would not bring a detrimental effect towards the environment. In 1978, the Environmental Quality Regulations were enacted detailing the POME discharge standards with biochemical oxygen demand (BOD) as the key parameter. At first, the final discharge of POME

was set to 100 parts per million (ppm). However, in 2006, the Department of Environment (DOE) has imposed a more rigid condition of 20 ppm for BOD. This indicates how serious the effect of improper treatment of POME has led to the environmental issues for the past few years which is governed by high demand for CPO.

Several treatments have been employed in treating POME. In Malaysia, the most employed treatment for POME is the anaerobic digestion (AD) in which the complex organic matters in POME is degraded under the absence of oxygen [12]. Anaerobic digestion utilized the bacteria to consume the organic matters which then led to the production of value-added product known as biogas. Other alternatives for POME treatment methods include aerobic treatment, membrane treatment system and evaporation methods [12].

The wastewater resulted from AD is referred as the anaerobic digestion effluent. The post-treatment of this effluent is crucial to meet the discharge standard. One of the ways is to treat this effluent using membrane filtration. Recent study conducted by [16] showed that an advance process of ultrafiltration and reverse osmosis for membrane filtration resulted in clean water production from the raw thick brownish POME. The membrane filtration in combination with physicochemical process such as adsorption can help to reduce suspended solids and heavy metals with smaller particle size distribution. During the past few years, various natural and synthetic adsorbents such as chitosan, zeolite, activated carbon and coconut shell carbon has been used in adsorption of the effluent [2]. However, the use of kenaf fiber as the potential adsorbent has not yet been fully examined for treating the anaerobic digestion effluent.

Kenaf (*Hibiscus cannabinus* L.) is annual herbaceous crop of the Malvaceae family that also include cotton and okra [5]. The kenaf fiber was obtained from the stalk which is composed of many individual smaller fibres known as bast fibers [5]. In the older days, the kenaf fibers were primarily used as a cordage crop and livestock feed. Through recent research and development, the kenaf fibers were exploited to be used in pulp and paper industry, for oil absorption and to date, in the filtration. Kenaf fibers were chosen as it is a good replacement for synthetic adsorbents such as activated carbon and silica gel. The cost for kenaf is lower compared to the conventional synthetic ones [8]. Kenaf fiber is classified as non-toxic as it is obtained from natural resource and will not appear in toxic form after adsorption as compared to activated carbon [8].

Potential uses of kenaf fiber as filter media has been shown through many studies conducted in previous years. Most studies focused on using kenaf fibers as adsorbents in adsorption of heavy metals such as chromium (VI) [11] and copper (II) [3]. Besides, [6] used ground kenaf core to test for its capability as filtration aid and [13] modified the kenaf to obtain citric acid modified kenaf core fibers for removal of methylene blue from aqueous solution. Meanwhile, [8] used hydrochloric acid (HCl) to produce acid treated kenaf fiber char which was then used in batch adsorption of basic dye. Despite all these, there is not yet research being conducted by focusing to alter the parameter of the effluent such as pH. Most of the research stated focused on modifying the kenaf fiber. Thus, it is a great opportunity to test effectiveness of altering the pH of the effluent prior to filtration and analyzing the

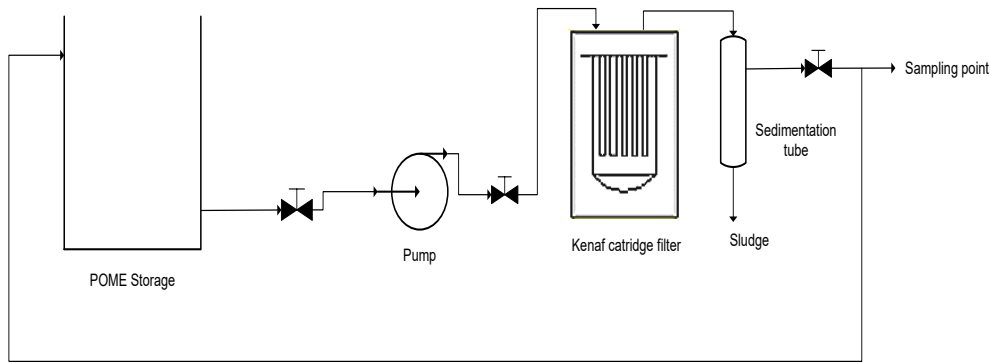


Fig. 1. Process flow diagram of the filtration system

effect to filtration and the filter media.

In this research, the filtration membrane system was used to filter the anaerobic digestion effluent by utilizing the kenaf fiber as the filter media. The effluent discharge from the filtration will be tested for its water quality. Color, turbidity, suspended solids, chemical oxygen demand (COD) and heavy metals are the aspects that need to be analyzed for the water quality. Besides, particle size distribution will also be analyzed to estimate the average size of the particles in the effluent before and after the filtration. The analysis was conducted to test the potential of kenaf fiber as filter media in filtrating the anaerobic digestion effluent. In the experiment, the pH of the effluent was adjusted to reach pH 8 prior to filtration to test the effectiveness of alkali-treated effluent in filtration through the filter media. The result is then compared with the filtration carried out for the original pH of the effluent which is determined to be pH 7.

## II. METHODOLOGY

### A. Materials

The POME was obtained from Felda Sungai Tengi Palm Oil Mill in Kuala Kubu Baru, Selangor. The POME was collected after anaerobic digestion process and referred as effluent. The effluent was stored under room temperature until the day of the experiment. The membrane filtration system was prepared by winding the preformed kenaf fiber mat around a plastic mesh tube to form the kenaf fiber cartridge. The kenaf fiber cartridge was tighten with cable ties to prevent from unwinding. The kenaf fiber cartridge was then put into the housing and being closed using the lid. For alkali-treated effluent, calcium carbonate was used to alter the pH of the effluent into pH 8.

### B. Experimental set-up

The experiment was first conducted for effluent with the pH 7. Before filtration, 200 ml of the effluent was collected and labeled as POME 7,0 to be analyzed. The number seven indicated pH 7 while zero represented zero minute which mean unfiltered effluent. The membrane filtration system was set-up as shown in Figure 1. Based on Fig. 1, the effluent in the storage container is pumped into the filter. After it passed through the filter, the effluent then flow into the sedimentation tube. After filtration, the effluent is referred as filtered effluent. From sedimentation tube, the filtered effluent is then being recycled back into the storage container. This filtration is run continuously and 200 ml sample was collected at five minutes intervals starting after one cycle of filtration is completed for a total time of 25 minutes. One cycle is denoted as when the filtered effluent started to flow out from the sedimentation tube and entered the storage container. The sampling point was the outlet stream from the sedimentation tube. Five samples of filtered effluent collected were labeled as POME 7,5, POME 7,10, POME 7,15, POME 7,20 and POME 7,25. As

stated before, number seven was intended for pH 7 while five, 10, 15, 20 and 25 represented five minutes, 10 minutes, 15 minutes, 20 minutes and 25 minutes respectively. The samples were then sent for water quality measurement and particle size distribution analysis.

The experiment is then repeated by using the alkali-treated effluent. Before filtration, the effluent was treated with calcium carbonate to adjust the pH into 8. Calcium carbonate is added and being thoroughly mixed with the effluent. After the alkali treatment, the effluent is then referred as alkali-treated effluent. Then, 200 ml of the alkali-treated effluent was collected and labeled as POME 8,0. The same experimental procedures then followed and the samples collected were labeled as POME 8,5, POME 8,10, POME 8,15, POME 8,20 and POME 8,25. The samples of the filtered alkali-treated effluent were also sent for the same analysis.

### B. Water Quality Measurement and Particle Size Distribution

The samples from the experiment were then sent for analysis. The analysis conducted were water quality measurement and particle size distribution. For water quality measurement, the aspects of interest were suspended solids, color, turbidity, COD and heavy metals. Particle size distribution was conducted to estimate the size of the particles in the POME.

Suspended solids, color and COD were measured using spectrophotometer. Suspended solids measurement followed the Photometric Method (Hach Method 8006) with suspended solids 630 program and distilled water as the blank sample. Next, color measurement followed the Platinum-Cobalt (PtCo) Standard Method (Hach Method 8025) with 465 nm as the wavelength. Meanwhile, for COD, the measurement followed the USEPA Reactor Digestion Method (Hach Method 8000) that consists of the reactor digestion procedure and colorimetric procedure. As for turbidity, the measurement were conducted using HACH 2100P turbidity meter and the result is expressed in nephelometric turbidity units (NTU). For heavy metals, inductively coupled plasma optical emission spectrometry (ICP-OES) is used to trace the heavy metals. Last but not least, particle size distribution were analyzed using particle size analyzer.

III. RESULTS AND DISCUSSION

A. Suspended solids

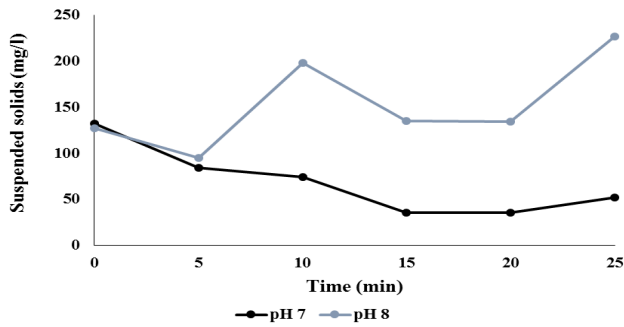


Fig. 2. Suspended solids concentration for pH 7 and pH 8

Fig. 2 shown the suspended solids concentration for pH 7 and pH 8. For pH 7, the suspended solids concentration decreased steadily from initial concentration of 132 mg/l to the lowest value of 35 mg/l after 20 minutes of filtration. For the last five minutes, the suspended solids concentration rose to 52 mg/l. For pH 8, the result shown a fluctuating pattern which illustrate the inconsistency of the suspended solids concentration in the filtered effluent. From the initial value of 127 mg/l the concentration dropped gently to 95 mg/l. A sudden increased was observed at 10 minutes with a value of 198 mg/l and fell to 135 and 134 mg/l for 15 and 20 minutes respectively. The concentration rocketed to the highest value of 227 mg/l at 25 minutes. When comparing the different pH, there was large margin created after 5 minutes of filtration and pH 8 shown higher amount of suspended solids than pH 7.

B. Colour

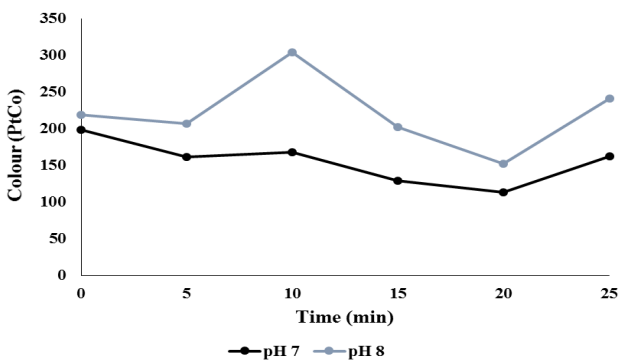


Fig. 3. Colour concentration for pH 7 and pH 8

Fig. 3 shown the colour concentration for pH 7 and pH 8. The colour concentration for pH 7 is lower than pH 8. The colour concentration for pH 7 fluttered slightly from the initial value of 198 PtCo to 161, 168, 129 PtCo for five, 10 and 15 minutes respectively. At 20 minutes, the colour concentration continued to decrease to 113 PtCo and went up to 162 PtCo at 25 minutes. For pH 8, there was slight decrease in the colour concentration at the beginning with values of 219 PtCo for zero minute to 207 PtCo for 5 minutes. A dramatic shift was observed for the color concentration at 10 minutes with a value of 304 PtCo which was the highest value. The color concentration then dropped suddenly to 202 and 152 PtCo for 15 and 20 minutes respectively. At the end of the filtration, the color concentration has gained substantially to 241 PtCo.

C. Turbidity

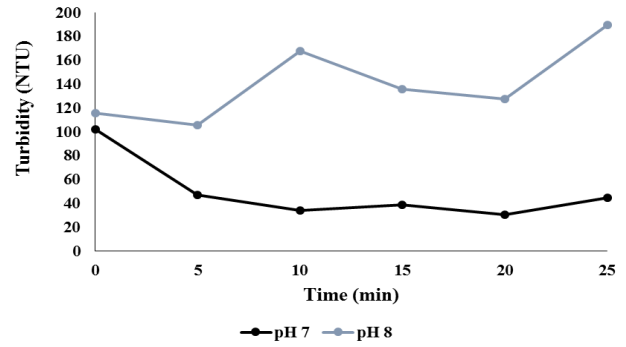


Fig. 4. Turbidity reading for pH 7 and pH 8

Fig. 4 shown the result for turbidity reading of pH 7 and pH 8. The result also shown the same pattern as suspended solids and colour. The graph also illustrate pH 8 having higher reading than pH 7 and created a wide gap between these two results. For pH 7, the turbidity declined steeply from 102 NTU to 47 NTU at the first five minutes. Small changes in the turbidity were then detected after five minutes. The values undulated from 34, 39, 31 to 45 NTU for 10, 15, 20 and 25 minutes respectively. For pH 8, unsteady result were obtained with the values fluctuated from 116, 106, 168 to 136 NTU for zero, five, 10 and 15 minutes respectively. At 20 minutes, the turbidity declined to 128 NTU and soared to 190 NTU at 25 minutes.

By referring to Figs. 2, 3 and 4, with focus on pH 8, significant changes were observed at 10 minutes and 25 minutes which correspond to the highest value. During the respected time, when suspended solids concentration increased, the colour concentration and turbidity also increased. This indicate that there are strong relationship between suspended solids, colour and turbidity. It can be said that the amount of suspended solids determine the colour and turbidity of the effluent.

According to [17], samples are either filtered or centrifuge to remove suspended solids in it. The amount of suspended solids remained after filtration can affect the absorption and scattering of light for turbidity measurement. Turbidity can then interfered with the colour determination. By focusing on pH 8, sudden increase in the suspended solids concentration at 10 minutes is due to the unsteady flow of the effluent to the filter which is caused by the pump. In this filtration system, magnetic drive pump is used. Addition of calcium carbonate for altering the pH has caused the effluent to become more turbid and cloudy. This increases the amount of suspended solids in the effluent thus causing higher solids loading to the filter.

The absence of stirrer to continuously mix the effluent in the storage for Fig. 1 caused the particles in the effluent to sediment at the bottom. Addition of calcium carbonate is not only function to adjust the pH. According to [4], calcium carbonate also acts as a natural flocculants to assist in settling of the suspended solids in POME. The positively charged  $Ca^{2+}$  from calcium carbonate created an ionic interaction with the particulate matters in the effluent which is mainly negatively charged to form flocs. Since the effluent is pumped at the bottom of the storage, the flocs also flow into the pump. [15] stated that magnetic drive pump do not tolerate particulate and sediment in pumped fluid. [15] listed few problems when particulate and sediment is drawn into the pump. Such problems include blockage to the galley and ports supplying lubrication in the pump and can gouges through the separation shroud and lead to pump leakage. Pump leakage reduces the efficiency of the pump and eventually lead to the unsteady flow of the pumped effluent into the filter. This is the reason for the suspended solids to suddenly increase from 95 to 198 mg/l from five minutes to 10 minutes after filtration. Hence, the colour and turbidity also reached high peaks at Figs. 3 and 4 respectively in correlation with the suspended solids concentration.

Another point of interest for pH 8 were the results at 25 minutes. The suspended solids concentration increased at 25 minutes to the highest value of 227 mg/l. The final concentration is higher than the initial concentration of 132 mg/l. This is due to the pump efficiency as being discussed before together with membrane fouling. [14] stated that membrane fouling is a condition in which particles deposit on a membrane surface or in the membrane pores. In this case, colloidal foulants were created as the cake layer on the kenaf filter. [18] stated that this highly dense deposit layer are blocking the membrane pores that resulted in less porosity of the membrane. The occurrence of membrane fouling degrade the performance of the membrane and affect the quality of the filtered effluent which explain the sudden increase of suspended solids concentration at 25 minutes for pH 8. In other hand, the kenaf filter is no longer able to filter the incoming effluent effectively after 20 minutes. Thus, backwashing can be introduced into the filtration system to encounter this problem. Another way to mitigate the membrane fouling is through developing a membrane filtration process in combination with physicochemical process such as adsorption or coagulation [18]. Through the research conducted by [18], the membrane fouling is reduced effectively by using polyaluminum chloride with an optimal concentration of 10 mg/l. [18] also stated that increasing dosage of the adsorbents/coagulants did not promise to alleviate membrane fouling as these materials can potentially become foulants themselves.

D. Chemical oxygen demand (COD)

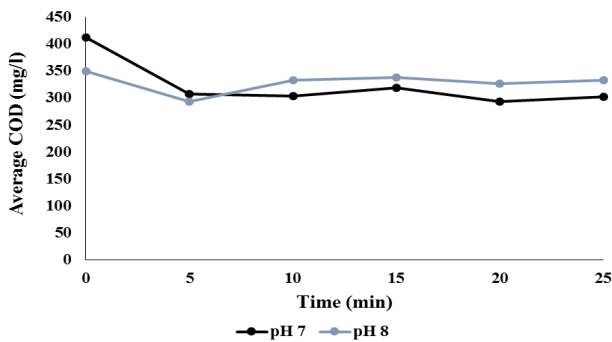


Fig. 5. Average COD concentration for pH 7 and pH 8

Fig. 5 shown the average COD concentration for pH 7 and pH 8. The result for both pH only shown a slight decrease of COD at the first five minutes. The reading were then essentially unchanged till 25 minutes. Since the POME sample was collected after anaerobic digestion, the result shown low COD concentration as compared to the raw POME. Typically, the COD concentration in raw POME is in the range of 15,000-100,000 mg/l with average of 51,000 mg/l [7]. As mentioned by [10] anaerobic digestion is capable on reducing the COD up to 95.1-98.7%. This correlate with the result shown in Fig. 5. [10] also conducted a research by using ultrasonic cavitation technology as an alternative technique to treat the POME. The POME collected was a pre-treated POME which was then subjected to the triple frequency ultrasonic reactor. [10] conducted a preliminary study to select the optimum pH and understand the impact of it to the POME treatment. The selected pH was in the range of 2-9 and the results shown that neutral and alkaline solutions of POME are less affected by the ultrasound in reducing the COD. This result can also be applicable in this study as the COD from the filtration did not change drastically for both pH 7 and pH 8. Instead, [10] suggested that acidic condition is more favourable as acidic pH shows predominant effect in reducing the COD of POME.

E. Particle size distribution

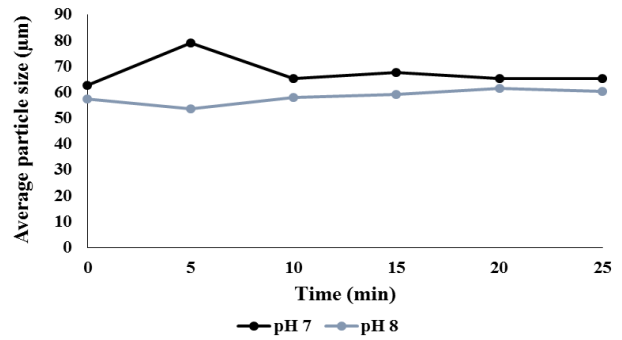


Fig. 6. Average particle size for pH 7 and pH 8

Fig. 6 shown the average particle size for pH 7 and pH 8. Only slight changes were observed at five minutes for both pH. For pH 7, the average particle size increased from 62.6 to 79.02 µm from zero to five minutes. Then, the average particle size started to fluctuate steadily from 10 minutes onwards from 65.22, 67.61, 65.33 to 65.43 µm. In contrary, pH 8 shown a slight decreased in average particle size from 57.37 to 53.67 µm. Starting from 10 minutes, the average particle size continued to increase till 20 minutes from 57.89, 59.17 to 61.47 µm. The average particle size then fall to 60.45 µm at 25 minutes. From overall, the average particle size for pH 7 is larger than pH 8. One of the reason is due to the membrane fouling as discussed earlier. Addition of calcium carbonate to the effluent increases the suspended solids concentration that lead formation of flocs sediments. During filtration, the flocs sediment are retained at the kenaf filter thus reducing the amount of suspended solids in the permeate effluent. The amount of solids particles in the effluent then contributes to the particle size in the effluent [20].

F. Heavy metals

Figs. 7 through 16 shown the heavy metals concentration traced by the ICP-OES. Among these heavy metals, silver (Ag), strontium (Sr), chromium (Cr) and vanadium (V) are usually not presented in raw POME as illustrated by [7]. However, these metals only appeared in low concentration and some were not presence in pH 8 such as Ag and Sr. Meanwhile, Cr and V only contributed to little amount in the effluent with average of 2.66 ppm (pH 7) and 3.27 ppm (pH 8) for Cr. Average concentration of V were 5.40 ppm and 4.29 ppm for pH 7 and pH 8 respectively. [7] listed the average concentration for other heavy metals found in raw POME; Mg (615 ppm), Ca (439 ppm), Fe (46.5 ppm), Mn (2.0 ppm), Cu (0.89 ppm) and Zn (2.3 ppm). The concentration of these heavy metals after filtration were lower than in the raw POME. This shows that filtration using kenaf fiber as filter media did manage to filter these heavy metals.

1. Silver (Ag)

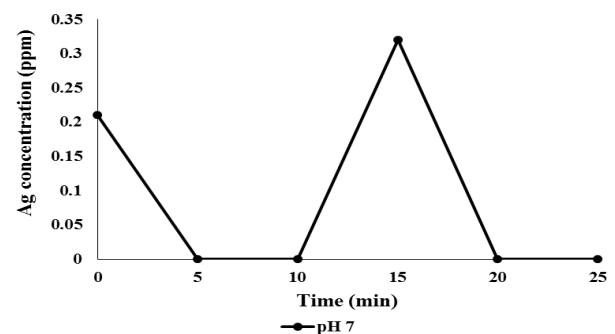


Fig. 7. Silver concentration for pH 7. The silver is not detected in pH 8.

2. Calcium (Ca)

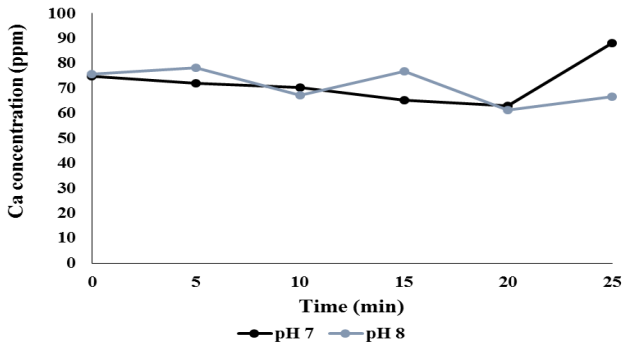


Fig. 8. Calcium concentration for pH 7 and pH 8

3. Chromium (Cr)

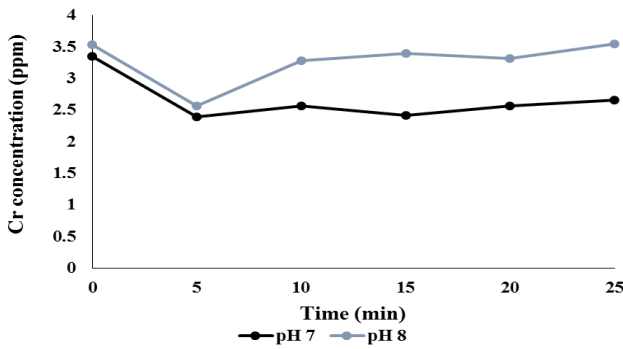


Fig. 9. Chromium concentration for pH 7 and pH 8

4. Copper (Cu)

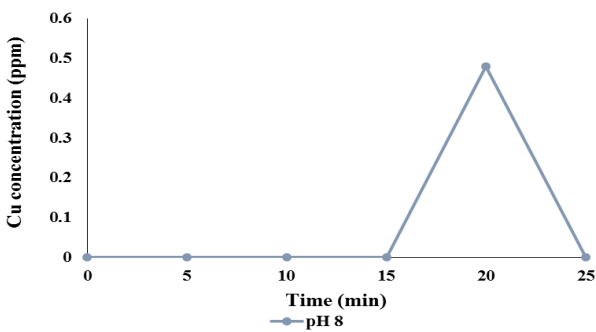


Fig. 10. Copper concentration for pH 8. The copper is not detected in pH 7.

5. Iron (Fe)

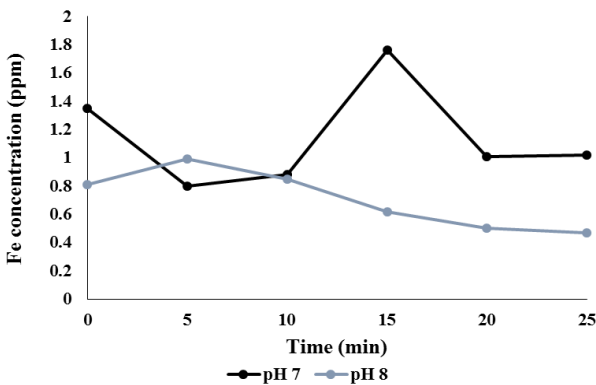


Fig. 11. Iron concentration for pH 7 and pH 8

6. Magnesium (Mg)

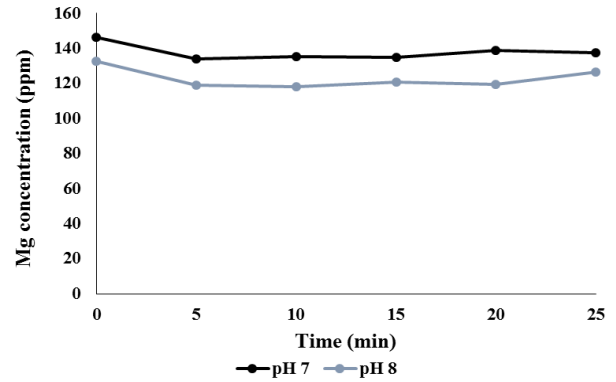


Fig. 12. Magnesium concentration for pH 7 and pH 8

7. Manganese (Mn)

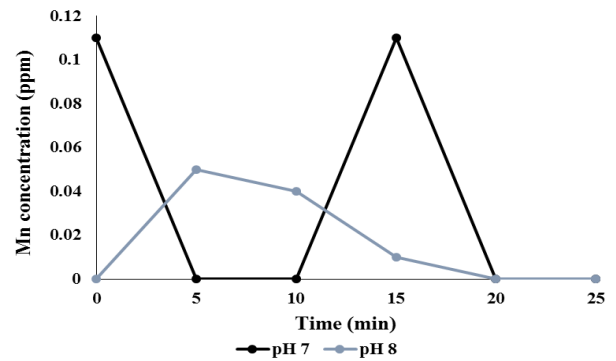


Fig. 13. Manganese concentration for pH 7 and pH 8

8. Strontium (Sr)

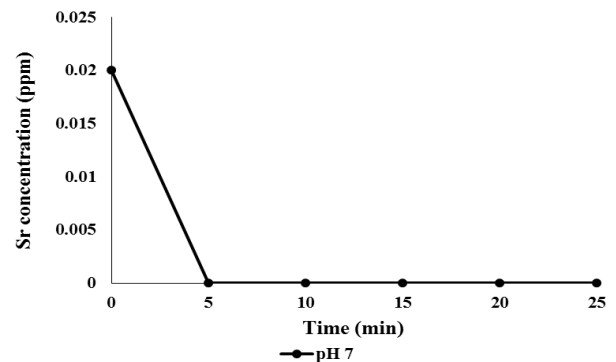


Fig. 14. Strontium concentration for pH 7. The strontium is not detected for pH 8.

9. Vanadium (V)

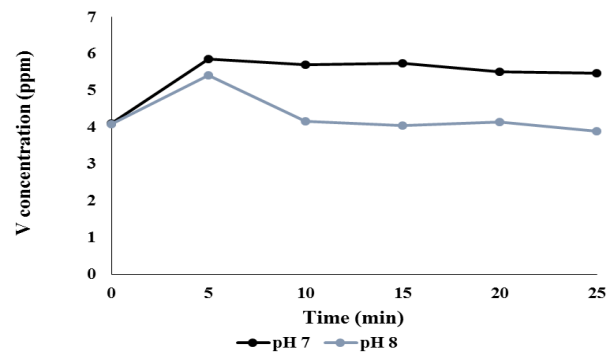


Fig. 15. Vanadium concentration for pH 7 and pH 8

## 10. Zinc (Zn)

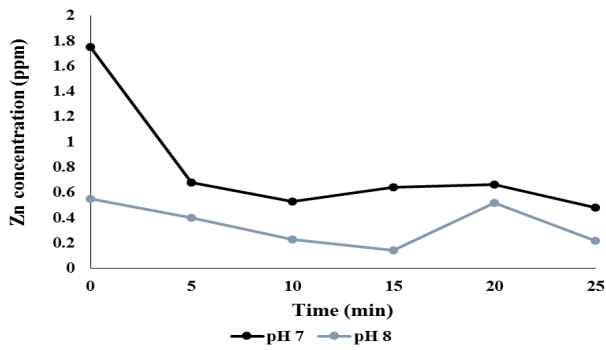


Fig. 16. Zinc concentration for pH 7 and pH 8

## IV. CONCLUSION

In conclusion, the filter media from kenaf fiber was successfully developed to be used in the filtration of anaerobic digestion effluent. The alkali effluent was prepared using addition of calcium carbonate into effluent and being compared to the neutral effluent in terms of water quality parameters and particle size distribution. For water quality, measurement of suspended solids, colour and COD were successfully conducted using spectrophotometer. Turbidity was also successfully determined from turbidity meter. The amount of suspended solids in the filtered effluent correspond to the colour and turbidity of the filtered effluent. Membrane fouling resulted from flocs sediment at the kenaf filter contributed to the higher concentration for each of the parameter for pH 8. There were no significant changes occur for COD before and after filtration for both alkali and neutral effluent. The average particle size for pH 7 was determined to be higher than pH 8. This is because large portion of the particles in the effluent of pH 8 was retained at the kenaf filter as flocs sediment. Ten heavy metals were traced from the effluent which were Ag, Cu, Mn, Sr, Cr, Fe, V, Zn, Ca and Mg. All of these metals still fall under the considerable amount and did not possessed threat to the environment. The membrane fouling condition concluded that treatment with alkali is not a good alternative to further treat the anaerobic digestion effluent.

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## References

- [1] Ahmad, A. L., Chong, M. F., & Bhatia, S. (2009). *A comparative study on the membrane based palm oil mill effluent (POME) treatment plant*. Journal of Hazardous Materials. 171:166-174
- [2] Ahmed, Y., Yaakob, Z., Akhtar, P., & Sopian, K. (2015). *Production of biogas and performance evaluation of existing treatment processes in palm oil mill effluent (POME)*. Renewable and Sustainable Energy Reviews. 42:1260-1278
- [3] Hasfalina, C., Maryam, R., Luqman, C., & Rashid, M. (2012). *Adsorption of Copper (II) From Aqueous Medium In Fixed-Bed Column By Kenaf Fibres*. APCBEE Procedia. 3:255-263
- [4] Hassan, M. A., Phang, L. Y., Rahman, N. A. A., Yoshihito, S., Ariff, A., Karim, M. I. A. (2001). *Effect of Different Chemical Treatments on the Settleability of Palm Oil Mill Effluent*. Pertanika Journal of Tropical Agriculture and Science. 24(2):79-85
- [5] Janick, J., & Whipkey, A. (2002). *Kenaf Yield Components and Plant Composition*. Trends in new crops and new uses. ASHS Press. 348-357
- [6] Lee, S. A., & Eiteman, M. A. (2001). *Ground kenaf core as a filtration aid*. Industrial Crops and Products. 13(2):155-161
- [7] Madaki, Y. S., & Lau, S. (2013). *PALM OIL MILL EFFLUENT (POME) FROM MALAYSIA PALM OIL MILLS: WASTE OR RESOURCE*. International Journal of Science, Environment and Technology. 2(6):1138-1155
- [8] Mahmoud, D. K., Salleh, M. A. M., Karim, W. A. W. A., Idris, A., & Abidin, Z. Z. (2012). *Batch adsorption of basic dye using acid treated kenaf fibre char: Equilibrium, kinetic and thermodynamic studies*. Chemical Engineering Journal. 181-182:449-457
- [9] Malaysian Palm Oil Board (MPOB). (2014). Oil Palm & The Environment. Retrieved from <http://www.mpob.gov.my/en/palm-info/environment/520-achievements>
- [10] Manickam, S., Zainal Abidin, N. B., Parthasarathy, S., Alzorqi, I., Ng, E. H., Tiong, T. J., ... Ali, A. (2014). *Role of H2O2 in the fluctuating patterns of COD (chemical oxygen demand) during the treatment of palm oil mill effluent (POME) using pilot scale triple frequency ultrasound cavitation reactor*. Ultrasonics Sonochemistry. 21(4):1519-1526
- [11] Omidvar Borna, M., Pirsaeheb, M., Vosoughi Niri, M., Khosravi Mashizie, R., Kakavandi, B., Zare, M. R., & Asadi, A. (2016). *Batch and column studies for the adsorption of chromium(VI) on low-cost Hibiscus Cannabinus kenaf, a green adsorbent*. Journal of the Taiwan Institute of Chemical Engineers. 68:80-89
- [12] Poh, P. E., & Chong, M. F. (2009). *Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment*. Bioresource Technology. 100:1-9
- [13] Sajab, M. S., Chia, C. H., Zakaria, S., Jani, S. M., Ayob, M. K., Chee, K. L., ... Chiu, W. S. (2011). *Citric acid modified kenaf core fibres for removal of methylene blue from aqueous solution*. Bioresource Technology. 102(15):7237-7243
- [14] Shantanu C. (n.d.). Stevia Extraction Technology. Retrieved from <https://www.steviashtantanu.com/stevia-membrane-based-extraction>
- [15] Sondalini M. (n.d.). Experiences with Magnetic Drive Pumps. Retrieved from <https://accendoreliability.com/experiences-magnetic-drive-pumps/>
- [16] Tabassum, S., Zhang, Y., & Zhang, Z. (2015). *An integrated method for palm oil mill effluent (POME) treatment for achieving zero liquid discharge – A pilot study*. Journal of Cleaner Production. 95:148-155
- [17] WEINER, R. F., & MATTHEWS, R. A. (2003). *Measurement of Water Quality*. Environmental engineering. Amsterdam: Butterworth-Heinemann. 108-113
- [18] Wu, B., An, Y., Li, Y., & Wong, F. S. (2009). *Effect of adsorption/coagulation on membrane fouling in microfiltration process post-treating anaerobic digestion effluent*. Desalination. 242(1-3):183-192
- [19] Wu, T. Y., Mohammad, A. W., Jahim, J. M., & Anuar, N. (2007). *Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling*. Biochemical Engineering Journal. 35:309-317
- [20] Alrawi, R. A., Ab Rahman, N. N., Ahmad, A., Ismail, N., & Mohd Omar, A. K. (2013). *Characterization of Oily and Non-Oily Natural Sediments in Palm Oil Mill Effluent*. Journal of Chemistry. 1-11.