Treatment of Aging Leachate Using Biochar from Tapioca Skin

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***Abstract*— Biochar is believed to have the ability in treating aging leachate through contaminants adsorption mechanism due to its favorable physical or chemical surface characteristics. Biochar derived from tapioca skin was heated to a temperature of 300°C and analyzed for BET surface area. Jar test apparatus was used to study the ability of biochar in TSS, turbidity, color, COD and heavy metals removal. Through this study, pH of solution, biochar dosage and retention time were varied. Based on the result obtained, the surface area of biochar was 2.0131 m^2/g with pore volume of 0.005343 cm^3/g. Moreover, it was found that high pH solution can cause significant reduction of TSS, turbidity, color, COD and heavy metals concentration. However, variation in biochar dosage and retention time did not bring great impact to the pollutants removal in leachate. Various modifications should be done on the biochar surface to activate it and improve its efficiency through various contaminants removal so that allowable discharge standard requirement for leachate is met.**

Keywords*— leachate; biochar; adsorption; heavy metal; turbidity

1. INTRODUCTION

The characteristics of solid waste such as reactive, erosive and explosive can encounter human health and the environment problem. According to Lee *et al*. (2016), generally there are 1.3 billion tons per year of global municipal solid waste is expected to increase to almost 2.2 billion tons per year by the year of 2025 where this problem is getting more complex since the weight, volume and composition of municipal solid waste keep on increasing day by day. Waste production also increased significantly due to the increase in population growth following the changes in habits consumption.

To overcome this problem, landfilling is believed to manage 95% of the total solid waste collection worldwide since this method of ultimate disposal of solid waste is the cheapest in term of its capital cost and exploitation. By nature, physically, chemically and biologically complex heterogeneous system of sanitary landfill will underly hydrological conditions, reduce the composition and compaction, temperature, moisture content together with the seasonal variations.

Nonetheless in Malaysia, the huge environmental issue is mainly caused by the management of waste for the reason that this handling process of continuously increase solid waste generation is mostly lean on landfill as its main waste disposal practice (Moh and Abd Manaf, 2017). As discussed by Shehzad *et al.* (2015), these problems are mostly due to the technical support destitution, unhinged of financial stability and the haphazard planning of economic, social and institution where these improper waste management caused severe degradation towards public health through the air and water quality they consumed (Ma and Hipel, 2016).

Since landfilling is the most used final waste disposal method around the world, it is important to treat the percolation of rainwater either on or off site for the whole life of the landfill site that percolates through the site of landfill since the liquid generated through the percolation of precipitation through an open landfill or through the cap of a finished site will contribute to leachate formation (Barmi and Amrit, 2016). This kind of waste water having high strength of complex mixture such as dissolved hazardous organic compounds, ammonia, heavy metals and inorganic salts which can bring negative impact to the environment due to their high toxicity content. Along the year, leachate shows high variability in their quantity and quality causing the efficient treatment line for all situations very difficult (Silva *et al.,* 2017).

Leachate generation quantity is typically related directly with external water volume that enters the landfill site area. The seeping of contaminated leachate into the ground causes the groundwater, surface water and soil to be contaminated. Age of landfill become the major importance on landfill leachate composition where it is then categorized into three which are young, intermediary and mature (Renou *et al*., 2008).

Young landfill leachates aging less than 5 years is characterized by high concentration of heavy metals due to higher metal solubility. Moreover, it contains high percentage of volatile fatty acids from the main fermentation products through rapid anaerobic fermentation. This acid fermentation is usually generated by high moisture or water content in solid waste early stage of the landfill lifetime which is called as acidogenic phase (Oumar *et al.,* 2016). Young leachate will posseses high COD concentration which is greater than 5000 mg/L with low NH_3 concentration of less than 400 mg/L.

Intermediate or methanogenic phase occurs as landfill matures during the age of 5 to 10 years. Microbes that are methanogenic develop in the waste where volatile fatty acids are then converted into biogas and the major organic fraction in leachate are now dominated with non-biodegradable (refractory) compounds such as humic substances.

In contrary to young leachate, stabilize or old leachate has low BOD concentration with greater NH_3-N concentration as compared

with concentration of COD. Stabilize leachate is particularly challenging for biological method since it comprises of large high-molecular-weight of organics fraction such as humic and fulvic acids. The only heavy metal which is lead will increase in concentration when there are increment in pH value as it will form very stable complexes with humic acids. Hence, there will be inconsequential impact on landfill leachate decontamination through the conventional biological treatment methods because the factor of biodegradable leachate will plummet as the landfill age increases (Wang et al., 2016).

Surprisingly, biochar has been used as a powerful adsorbent in treating wastewater where its lower porosity and surface area contribute to effective adsorption process of diverse organic and inorganic contaminants in soil and water such as lead, zinc and many more. Biochar is defined as a fine-grained porous substance having carbon-rich properties which is produced through the pyrolysis under the limitation of oxygen conditions at nearly low temperatures (<700˚C). Moreover, biochar also is a predominantly stable, obstinate organic carbon compound, produced when biomass as feedstock is heated to a temperature ranging between 300˚C to 1000˚C, under low oxygen concentrations (Tang *et al.,* 2013). Specifically, slow pyrolysis process with longer exposure time to heat from minutes to hours at temperature below 450˚C favors the production of biochar while fast pyrolysis with few seconds reaction time at high temperature of 500˚C favors bio-oil production (Brassard *et al.,* 2016).

Biochar can be made from biomass especially agricultural wastes such as rice husk, fruit peels, corncarb and many more since they are considered low in cost, extensively and abundantly available throughout the world and available as source of biomass energy and precursory material of biochars. Moreover, converting wastes into biochar has become an effective solution for waste management in order to prevent problems related to ground-water contamination or air pollution (Thines *et al.,* 2017). According to the International Biochar Initiative Organization, it is estimated that about 80% of all crop and forestry residues will be converted to biochar and energy by the year of 2050 (Zhang *et al*., 2015).

Different contaminants like heavy metals and organic pollutants will have a different behavior of biochar adsorption since it is correlated with the contaminants properties. Besides that, specific surface area, porous structure, mineral components and functional groups of various biochar are among the factors helping in the adsorption mechanism (Mohan *et al*., 2014). Adsorption mechanism by biochar for heavy metals involved integrative effects of some interactions such as electrostatic attraction, ion exchange, physical adsorption, surface complexation and precipitation. On the other hand, the main mechanisms for organic contaminations adsorption onto biochar are electrostatic interaction, hydrophobic effect, hydrogen bonds and pore-filling.

Therefore, this study has three main objective. First, study is done to investigate the feasibility of biochar derived from tapioca skin in treating aging lechate by analyzing biochar surface area and its pore volume. Secondly, study is done to determine the effect of pH solution, biochar dosage as adsorbent in treating aging leachate together with retention time. Finally, study is conducted to monitor the effectiveness of biochar through the comparison of initial and final concentration of COD, TSS, color, turbidity and heavy metals in treating aging leachate.

2. METHODOLOGY

2.1 Biochar Preparation

Tapioca skin was used as feedstock for biochar production. It was obtained freely from Ros Kerepek, Kanchong Darat, Banting. 250.0 g of dried tapioca skin wrapped in an aluminum foil to limit oxygen concentration during the heating process in a furnace at 300ºC for an hour. Heated biochar was then crushed or grinded to reduce its size and increase its surface area.

2.2 Biochar Characterization

The grinded biochar derived from tapioca skin was brought for characterization on its specific surface area and pore volume. Specific surface area characterization was done by using nitrogen multilayer adsorption through a fully automated Brunauer-Emmett-Teller (BET) 3FLEX Micromeritics.

2.3 Leachate Sample and Dilution

Sample of raw leachate to be treated was obtained from Jeram Sanitary Landfill located at Selangor. This 160-acre sanitary landfill has been operated for 8 years where the amount of waste collected is about 2500 ton per day. Raw leachate was then diluted with distilled water with ratio of 1:4. Color, Total Suspended Solid (TSS) and Chemical Oxygen Demand (COD) of the raw and treated leachate were analyzed using spectrophotometer while turbidity value was tested using turbidimeter.

2.4 Experimental Apparatus and Methods

Three beakers were prepared with each beaker containing 250 mL diluted leachate. pH for each beaker was adjusted by adding sodium hydroxide or hydrochloric acid to give alkaline or acidic condition respectively. Each beaker will be having pH 5, 9 and 10 respectively. Constant 1.0g of biochar was weighed using a weighing balance and added into each of the three beakers. All beakers containing diluted leachate and biochar were then stirred by using Jar Test apparatus. The stirrer speed set for the first 5 minutes was 150 rpm while stirrer speed for the remaining 30 minutes was set to 100 rpm. After 35 minutes of stirring process, the mixture was let to settle down for at least 1 hour. Biochar was separated from leachate solution by filtration with a filter paper. All leachate in beakers were being observed for its color and turbidity. The beaker with pH having clear mixture and with low turbidity value (NTU) was observed and recorded. The Jar Test experiment was repeated by using constant best pH that can contribute into the lowest turbidity value but with different dosage (2.0 g, 4.0 g and 6.0 g) of biochar.

Moreover, the effect of biochar with different retention time on leachate color, turbidity, TSS, COD and heavy metals content were also carried out. Two bottles were provided and each of the bottles were filled with 100 ml diluted leachate. 2g of biochar was being weighed and poured into both bottles. The bottles were then placed on the table without any mixing mechanism applied. After 24 hours, biochar in one of the bottle was being removed through filtration by using filter paper. The filtered leachate was then brought for TSS, turbidity, color and heavy metals. The same steps were repeated for another bottle after 48 hours retention time achieved.

2.5 Heavy Metals Analysis

Analysis of the heavy metals concentration in the treated leachate were quantified using Inductively Coupled-Plasma Optical Emission Spectrophotometry (ICP-OES), iCAP 6000 Series by Thermo Scientific. The following five metals in the leachate sample were analyzed: Al, Fe, Mg, K, Na with the following

wavelength lines of the ICP-OES analysis used for elemental determination: Al 167.08 nm, Fe 259.94 nm, Mg 279.55 nm, K 766.49 nm and Na 589.00 nm

3. RESULTS AND DISCUSSION

3.1 Physical characterization of biochar

Carbon-based adsorbent materials play a large role in the remediation of contaminated leachate, in this case. It is important to consider the physical characteristics of the adsorbent and how it relates to its specific application. By using BET surface area analyzer, it was found that the raw biochar derived from tapioca skin has a surface area of 2.0131 m^2/g and pore volume of 0.005343 cm^3/g. The surface area of biochar produced from tapioca skin which pyrolyzed at 300^oC is quite small if compared by using another biomass such as peanut shell at 700^oC pyrolysis temperature. Hence, high BET surface area is influenced by high temperature (Ahmad *et al*., 2014). Biochar can be made using a variety of different biological materials and heat treatment, hence it is important that suitable feedstock and thermal conversion temperature were used in order to fit "form to function" in terms of leachate treatment.

3.2 *Analysis of raw leachate sample*

Oxidation of ferrous to ferric form together with the formation of ferric hydroxide colloids and complexes of fluvic/humic substances has contributed to the dark brown color of leachate (Jumaah *et al*, 2016). The other physico-chemical characteristic of raw leachate obtained from Jeram Sanitary Landfill such as pH, turbidity, TSS, color, COD and heavy metals concentration are tabulated in Table 1 below together with the allowable standards by EQA 1974.

Table 1: Characteristics of raw leachate obtained from Jeram Sanitary Landfill

Parameter	Unit	Raw Leachate	Allowable Condition for Leachate Discharge by EQA 1974 Standard 2009
Color	Pt-Co	5282.33	100
COD	mg/L	186.4	400
pH	-	8.65	6-9
TSS	mg/L	76.33	50
Turbidity	NTU	13	-
Al	ppm	1995.72	NA
Fe	ppm	1.76	5.0
K	ppm	690.28	0.05
Mg	ppm	14.28	NA
Na	ppm	234.75	NA

3.1 The effects of pH solution on TSS, turbidity, color, COD and Heavy Metals

Raw leachate obtained from Jeram Sanitary Landfill has been analyzed and it was found that there was a concentration of 76.33 mg/L TSS in the sample. When the leachate was treated with different pH (pH 5, 9 and 10) solution but with constant dosage of 1.0 g biochar, the concentration of TSS seems to decrease as the pH increase as shown in Fig. 1 (a). The initial concentration of 76.33 mg/L TSS had dropped to 25 mg/L when treated with pH 5. The TSS concentration was then again decreased when the pH of solution was 9 and 10, giving final TSS concentration of 18.67 mg/L and 14 mg/L respectively.

Moreover, the raw sample of leachate was analyzed and indicated that the turbidity value was 13 NTU. When leachate was treated with constant biochar dosage of 1.0 g but with different pH values (pH 5, 9 and 10), the removal turbidity efficiency was enhanced with the increasing in pH values. From Fig. 1 (b), the turbidity value reduced from 13 NTU (raw leachate sample) to 10 NTU, 9 NTU and 7 NTU when treated with pH 5, pH 9 and pH 10 respectively. It can be observed that the greatest reduction in turbidity value was at the highest pH of 10 or the most alkaline solution.

Color of raw leachate obtained from Jeram Sanitary Landfill has been analyzed and the color was found to be 5282.33. Then, effect of different pH values had been examined towards the color of the leachate produced. From Fig. 1 (c), it was found that when constant 2.0 g of biochar dosage was used with different pH values of 5, 9 and 10, the color of leachate reduced from 879.67, 856.00 and 795.33 respectively. Here, as the pH of solution increased, the color of the leachate also decreased.

As can be seen, as the pH of solution was increased, the TSS concentration, turbidity and color of leachate decreased significantly. This is because alkaline solution can contribute into large reduction amount of TSS, turbidity and color that initially available in the leachate. Since biochar having carboxylate, -COOH and hydroxyl, -OH as oxygen-functional groups, these functional groups behavior will change with the increase of pH solution. At acidic pH, these functional groups are protonated and become positively charged thus favoring the adsorption of anions contaminants. On the other hand, as the pH increases to alkaline solution, there will be lesser competition of metal ions and protons for binding sites. Due to the protonation of functional groups, more binding site will be released. Hence, cations contaminants are easily captured by biochar surface at higher pH range (Tan *et al.,* 2015).

However, it's different when COD was studied against different pH values. As can be seen in Fig. 1 (d), at pH 5, COD concentration was 165.77 mg/L. pH 9 solution decreased the COD concentration to 160.93 mg/L and as the pH increased again to 10, COD value was 164.03 mg/L. COD is a measurement of chemical organic compound contributed by the presence of chemicals, petroleum, solvents and cleaning agents in water body. These compound or pollutants get spilled and mixed, broke down and add additional strain on oxygen demand in water. From the result obtained, it can be said that the values of COD were fluctuated. This may be due to some organic compound such as benzene or pyridine available in the leachate sample which were resistant to dichromate oxidation and may give falsely low COD value. However, there were not so much differences in the changes of COD value as the pH of solution was increased.

Elements of heavy metals identified in the sample obtained from Jeram Landfill leachate were only Aluminium (Al), Iron (Fe), Potassium (K), Magnesium (Mg) and Sodium (Na). Al usually contained in recycle products such as cans, pots, and other waste generated but rarely recorded whereas Fe is a metal that is usually found as one of the highest source that contributed to soil and water contamination.

Based on the Environmental Quality (Control of Pollution from Solid Waste Transfer Station and Landfill) Regulations 2009, the acceptable conditions for discharge of leachate for Iron (Fe) and Potassium (K) are 5.0 ppm and 0.05 ppm respectively. However, data for allowable discharge of leachate containing Aluminium

(Al), Magneisum (Mg) and Sodium (Na) are not available. Hence, discussion will be focused on the concentration of Iron and Potassium whether it can be discharged or not based on their allowable discharge standards.

For various pH as parameter, the results shown in Fig. 1 (e) found out that element of Iron (Fe) in the leachate that has been treated with pH 5, 9 and 10 can be discharged since it did not exceed the allowable leachate discharge standard. However, the element of potassium containing on the treated leachate using all pH solution of 5, 9 and 10 cannot be discharged because it exceeded the allowable leachate discharge standard for Potassium.

Most of the concentration of Al, K, Fe and Mg were decreasing in their concentration as the pH of solution increasing. As the pH increased, competition of metal ions and protons for binding sites is less. Due to the protonation of functional groups, more binding site will be released. Hence, cations contaminants which is mostly heavy metals are easily captured by biochar surface at higher pH range. However, increasing in the pH solution causing the significant increment of sodium (Na) concentration. Addition of sodium hydroxide into solution will breaks apart into Na^+ and HO^-, the HO^- will then capture the H^+ ions in the solution turning it into water which makes the solution less and less acidic with each drop of sodium hydroxide into the leachate solution. That was the reason contributing to higher sodium concentration as the pH of solution was increased.

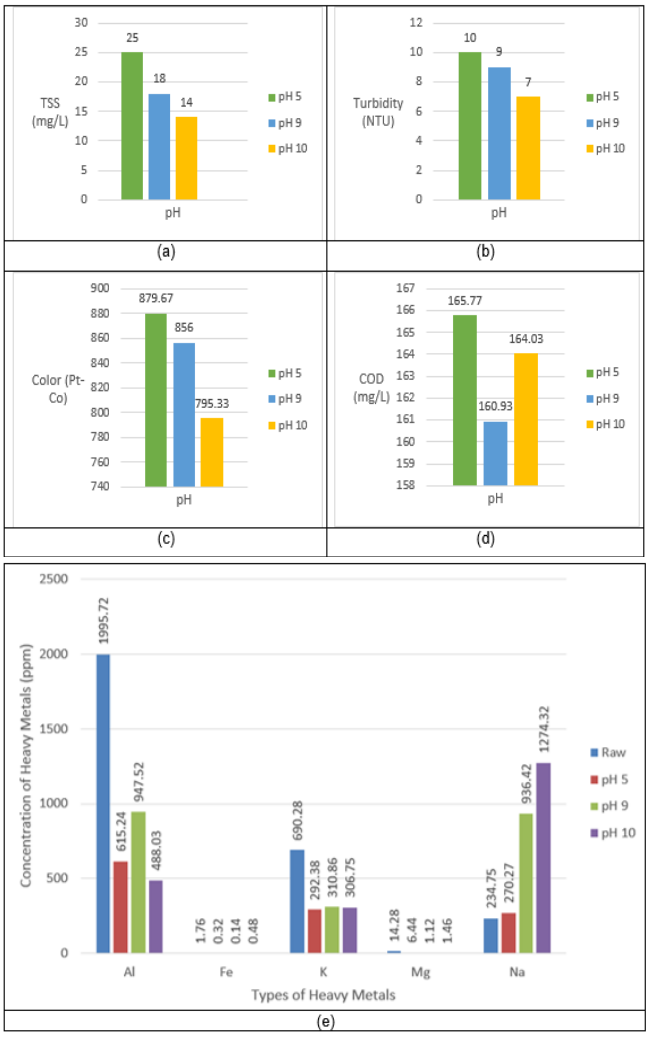


Fig. 1: Effect of different pH values on (a) Total Suspended Solid; (b) Turbidity; (c) Color; (d) Chemical Oxygen Demand (COD); (e) Heavy Metals

3.2 The effects of biochar dosage on TSS, turbidity, color and COD

However, in order to investigate whether different dosage of biochar can contribute into reduction of TSS or not, the effects of biochar dosing towards TSS had been also studied. Since the most alkaline solution (pH 10) shows great reduction in TSS as in earlier discussion, the leachate was maintained at pH 10 but was treated with different biochar dosage of 1.0 g, 2.0 g, 4.0 g and 6.0 g. Based on Fig. 2 (a), it can be seen that as the dosage of biochar increased, the concentration of TSS also increased from 14 mg/L for 1.0 g, 22.33 mg/L for 2.0 g of biochar, 27.33 mg/L for 4.0 g of biochar and 35 mg/L at 6.0 biochar dosing.

Moreover, the effect of different biochar dosage was also investigated on the turbidity value. It was found in Fig. 2 (b) that as the biochar dosing increased, the turbidity value also increased. This was due to the increase in suspended solid of biochar itself. When 1.0 g of biochar used at constant pH of 10, the turbidity is 7 NTU. As the amount of biochar increased to 2.0 g, 4.0 g and 6.0 g, turbidity values became 11 NTU, 13 NTU and 18 NTU respectively.

Besides that, as the dosage of biochar increased, the color of the leachate also increased. This is because, when only 1.0 g of biochar was added into the leachate sample, the color was 795.33, when 2.0 g of biochar was added, the leachate color was 852.00. When 4.0 g and 6.0 g of biochar was added, the color was 862.00 and 889.33 respectively.

Through this finding, it can be said that as the biochar dosage increase, the TSS, turbidity and color also increase. This is because as biochar dosage increases, adsorption mechanism of contaminants which can contribute to the leachate TSS, turbidity and color will decrease. It was due to the unsaturated adsorption sites during the process of adsorption. The adsorption sites become overlapped as the consequences of the increase in biochar particles. Since the surface area of biochar is already small as analyzed through BET analyzer, together with the increment in biochar particle, it will shield the binding sites from contaminants thus lowering the contaminants removal per unit of biochar.

However, it's different when COD was studied against different biochar dosage. As can be seen in Fig. 2 (d), at 1.0 g biochar, COD concentration was 164.03 mg/L. When dosage was increased to 2.0 g, 4.0 g and 6.0 g, the COD concentration value were 164.47 mg/L, 163.7 mg/L and 163.87 mg/L respectively. This was due to the experimental error occurred during the project was conducted, where sample was actually digested using a COD digester through strong oxidant under acidic condition for about one hour. The sample should then be left cooled for at least 3 to 4 hours. However, the reading of COD values were taken directly after two hours where the tube was still warm, thus giving fluctuate reading values of COD.

As for heavy metals in Fig. 2 (e), different biochar dosage used can reduce the concentration of Al, Fe, K and Mg. Since only dosage of biochar was varied but constant alkaline pH of 10 was used, heavy metals quite been effectively adsorbed into the biochar. However, element of Sodium was still increased as the pH of solution increase due to the addition of Sodium Hydroxide itself. Element of Iron (Fe) in the leachate that had been treated with biochar both for 24 hours and 48 hours retention time can be discharged since it did not exceed the allowable leachate discharge

standard. However, the element of potassium containing on the treated leachate using biochar for 24 hours and 48 hours retention time cannot be discharged because it exceeded the allowable leachate discharge standard for Iron.

Mineral components in biochar plays an important role in the adsorption of heavy metals process. Usually, the ability removal of heavy metals will vary with different biochar feedstocks sources and mineral components in the biochar. Other than that, the oxygen-containing functional group is more important than the surface area of biochar in the adsorption of heavy metals onto biochar. This is because the abundant surface functional groups on the surface of biochar will contribute to a strong interaction with heavy metals such as electrostatic interaction, ion exchange and surface complexation (Mohan *et al.,* 2014).

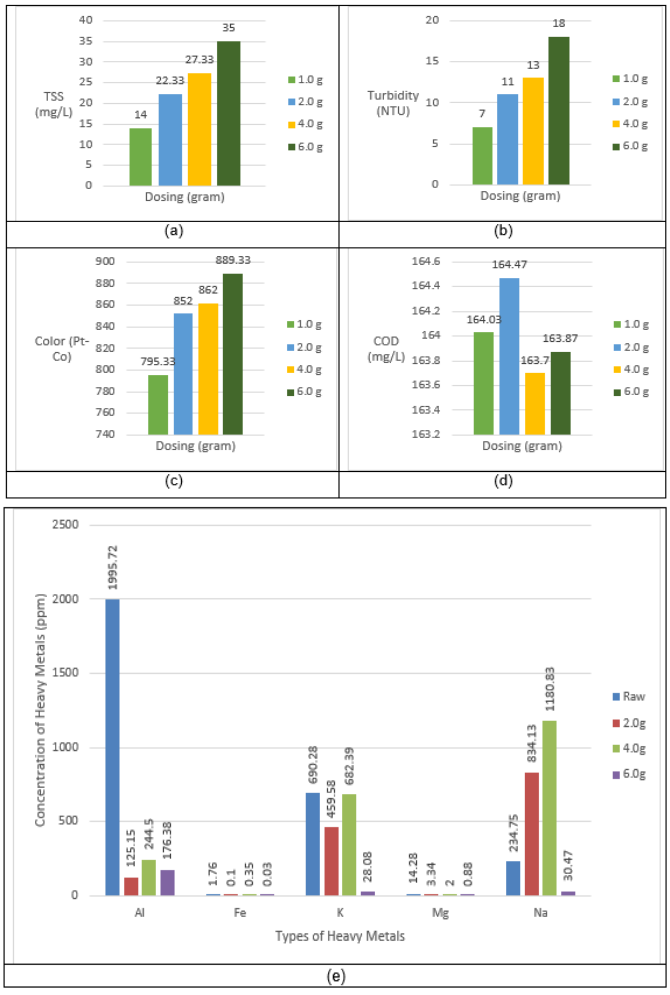


Fig. 2: Effect of different biochar dosage on (a) Total Suspended Solid; (b) Turbidity; (c) Color; (d) Chemical Oxygen Demand (COD); (e) Heavy Metals

3.3 The effects of retention time on TSS, turbidity, color and COD

For retention time as parameter, it can be proved that as the retention time longer, the concentration of TSS also increase from 26.67 mg/L for 24 hours and 28.33 mg/L for 48 hours retention time as can be seen in Fig. 3 (a).

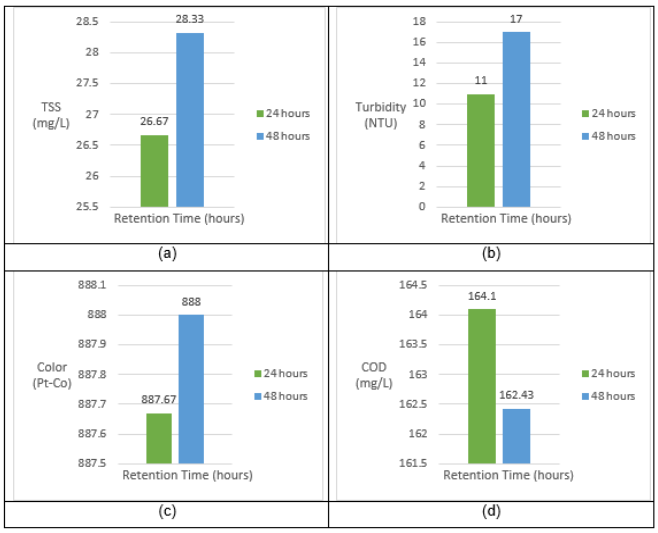
Moreover, when 2.0 g constant biochar was let to settle in a bottle filled with leachate without any mixing mechanism applied, the turbidity also increases from 11 NTU to 17 NTU for 24 hours to 48 hours retention time respectively as in Fig. 3 (b).

Effect of biochar on different retention time also has been studied towards color changes of leachate. From Fig. 3 (c), it can be proved that as the retention time longer, the leachate color also increased from 887.67 for 24 hours to 888.00 for 48 hours retention time. There was only significantly small increment in the changes of leachate color for retention time as parameter.

Practically, there were no mixing mechanism applied during this study for retention time as parameter which did not allowed the contaminants to be distributed throughout the solution and adsorbed by biochar. However, theoretically, particles in a liquid (leachate solution) will vibrate, move about and slide past each other. This particle movement can cause the sweeping or distribution of contaminants which then can be adsorbed onto biochar. Supposedly, as the retention time increased, there will be more TSS, turbidity and color reduction as the retention time increases. Unfortunately, since the surface area of biochar was too small, contaminants cannot fully accommodate the available free surface area of the biochar. Thus, TSS, turbidity and color increased slightly as the retention time increased. Only COD concentration slightly decreased as time passed by.

Since there was no addition of either sodium hydroxide or hydrochloric acid into solution for pH adjustment, there was also no significant impact on the heavy metals concentration for different retention time as in Fig. 3 (e). Small reduction in heavy metals concentration can be seen for Fe, K and Mg. Moreover, Sodium did not show any significant reduction in heavy metals concentration when retention time increase from 24 to 48 hours. Only Al shows highest reduction in heavy metals concentration values where 1995.72 mg/L raw Al leachate sample were reduced to 512.56 mg/L and 219.96 mg/L as retention time changed from 24 to 48 hours respectively.

Iron (Fe) in the leachate that has been treated with biochar both for 24 hours and 48 hours retention time can be discharged since it did not exceed the allowable leachate discharge standard. However, the element of potassium containing on the treated leachate using biochar for 24 hours and 48 hours retention time cannot be discharged because it exceeded the allowable leachate discharge standard for Iron.



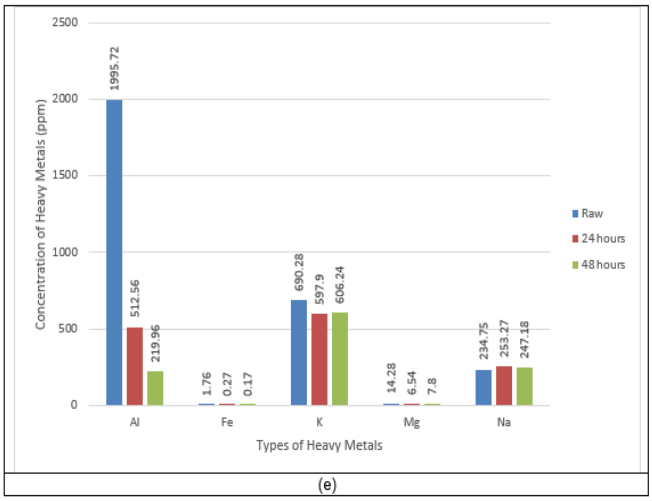


Fig. 3: Effect of different retention time on (a) Total Suspended Solid; (b) Turbidity; (c) Color; (d) Chemical Oxygen Demand (COD); (e) Heavy Metals

4. Conclusion

This research has achieved objectives targeted at this start of this study. It can be concluded that the best pH solution that can lower value of turbidity, color, TSS, COD and heavy metals was the most alkaline pH 10. This was because cations contaminants were easily captured by biochar surface at higher pH range However, in the study of different biochar dosage on the effects of contaminant removal in leachate, it can be concluded that concentration of TSS, turbidity, COD, color and heavy metals will increase as biochar dosage increased due to the overlapping of adsorption sites as the consequences of the increase in biochar particles.

Higher retention time should contribute to higher adsorption of pollutants by biochar through the liquid particle movement of the leachate sample that sweep away impurities onto the biochar. Unfortunately, as the surface area of biochar was too small, impurities are hardly accommodated the free surface area of biochar hence causing high value of TSS, turbidity, color, COD and heavy metals in the solution as retention time increased from 24 to 48 hours.

Since this is only a preliminary study of biochar, physical and chemical modifications are needed to activate biochar so that it will have great capacity in the pollutants removal of leachate. Thus, it is recommended to use high pyrolytic temperature of biochars which is greater than 500^{O}C. This is because at higher pyrolytic temperature, organic matters of biomass were completely carbonized, lead to the increase in biochar's surface area, pH and increase in the development of nanopores thus enhance the adsorption rate of various contaminants. Moreover, it is recommended to use another different biomass as feedstock in producing biochars instead of using tapioca skin such as orange peel, peanut shell and soybean stover. This is because these biomasses are easily available and can contribute into formation of high surface area and pore volume when heated to high temperature pyrolysis. Besides that, it is also recommended to use Hydrothermal Carbonization (HTC) instead of pyrolysis process. HTC can produce much more oxygen-containing groups on biochar surface due to lower degree of carbonization of biomass compared to pyrolysis method. Finally, it is recommended to use only optimum dosage of biochar in treating aging leachate because high biochar dosage will only cause non-uniform adsorption process since adsorption sites become overlapped as the consequences of the increase in biochar particles finally lead to high turbidity, color and TSS concentration. With the increasing interest of scientific research and future engineering applications of biochar for the treatment of wastewater or leachate, an integrated understanding of biochar's function in aqueous solution is urgently needed.

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