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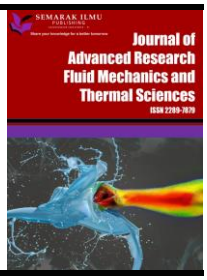

Heat-Treated Zeolite as Effective Adsorbent for Final Treatment of Palm Oil Mill Effluent

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ABSTRACT

Malaysia is known for its high oil palm production, which results in a significant amount of palm oil mill effluent (POME). Improper treatment or direct discharge of untreated POME can have significant impacts on water pollution. The objective of this study was to investigate the potential of zeolite as an adsorbent for the efficient treatment of POME. The initial physical and chemical properties of POME, sourced from the aerobic pond of a local palm oil mill in Terengganu, were determined before conducting two series of experiments using adsorption methods. In the first series of experiments, natural zeolite was used under different conditions, including treated zeolite thermally treated at 150°C for two hours and untreated natural zeolite. The results showed that heat-treated natural zeolite was more efficient in removing suspended solids, colour, and turbidity, with removal efficiencies and adsorption capacity of 66.2% (2.39 mg/g), 80.5% (21.50 mg/g), and 86.8% (0.77 mg/g), respectively. In the second series of experiments, the effects of various parameters affecting the adsorption process, such as adsorbent dosage and pH, were investigated. The optimum conditions for adsorbent dosage and pH were found to be 4 g/L and pH 4, respectively. The percent removal of all parameters reached over 70% with a peak time of 240 min. The adsorption isotherm was also studied, and it was found that the adsorption process was in good agreement with the Langmuir adsorption isotherm model. The study showed that adsorption treatment with natural zeolite was effective in removing turbidity, color, and TSS in POME wastewater. In addition, zeolite is a readily available and inexpensive adsorbent.

1. Introduction

The number of oil mills has increased greatly, from an original 10 mills in 1960 to 410 mills in 2008. At least 44 million tons of POME are produced annually in Malaysia, largely due to the government's initiative to market Malaysian palm oil products to the world [1]. Although the palm

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oil industry contributes significantly to the country's income, it also poses a serious problem to the environment. Currently, the industry, especially in Malaysia, faces enormous challenges in achieving acceptable levels of POME release because water treatment technology is expensive, depends on skilled personnel, and is more difficult to operate due to the large volume of contaminated wastewater [2]. Direct discharge of raw sewage POME or without proper treatment can be the main cause of water pollution. From previous studies by Darajeh *et al.,* [3] POME is one of the major sources of water pollution in Malaysia due to its high biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Treatment of POME requires special treatment, so various methods have been introduced, including aerobic and anaerobic digestion, ultrafiltration membrane separation, up-flow anaerobic sludge fixed film (UASFF) reactor, aerobic oxidation based on activated sludge process, chemical coagulation and flocculation, adsorption, hydrolysis, solvent extraction, electrocoagulation, and electroflocculation [4]. Although there are various technologies for treating POME, the operation of the wastewater treatment plant is often difficult due to the strict regulations that must be followed.

The most widely used POME treatment method in Malaysia is the conventional ponding system. The conventional ponding system is generally used for wastewater treatment because of its lower operating costs compared to other technologies. In addition, the ponding system consists of de-oiling tanks, anaerobic ponds, acidification ponds, and aerobic ponds. Although the Malaysian palm oil industry mostly practices the POME treatment option of ponding, from the previous study by Hossain *et al.,* [5] has listed the several limitations of these treatment methods, including the long residence time for destruction, lack of operational control, and uncontrolled emissions of the potent greenhouse gas methane. The other treatment methods used in the treatment of POME are adsorption processes. The adsorption process has proven to be effective in removing paints, COD, suspended solids, and organic and non-organic contaminants from industrial processes. Adsorption technology is another approach that is particularly recommended for the removal of pollutants in wastewater when natural, low-cost materials, essentially available in the form of industrial or agricultural wastes, have the potential to act as low-cost sorbents, such as citrus peels, eggshells, fly ash, zeolite, clay, natural zeolite, and coconut shell charcoal [6]. A recent study by Saad *et al.,* [7] has shown that the combination of magnetic field and adsorption by activated carbon provides attractive options for conventional wastewater treatment techniques, especially from POME. The use of activated carbon as an adsorbent for various environmental applications to remove organic pollutants is very efficient due to its high adsorption capacity. However, activated carbon is quite expensive and the powder form is difficult to handle and maintain [8]. Moreover, the integration of the magnetic field in the adsorption process leads to better results in wastewater treatment. In recent decades, researchers have argued that magnetism has its own unique properties that can help in water purification by affecting the physical and chemical impurities in water [9].

Therefore, effective treatments with low-cost technologies are very necessary and important to discharge large volumes of POME at an acceptable level. In this study, the use of natural zeolite as an adsorbent for the treatment of POME through the applied method of the adsorption process. Natural zeolite is also known as clinoptilolite. It is a natural clay that has a high potential for use as an alternative adsorbent in wastewater and is less expensive compared to activated carbon. Based on the previous study, the use of zeolite as an adsorbent in adsorption technology is very successful because zeolites are safe, naturally occurring aluminosilicate crystals that have a three-dimensional structure consisting of [SiO_4] arrays and [AlO_4] tetrahedral units that form a honeycomb structure with pores (also called tunnels, channels, or voids) of about 0.1-2 nm in diameter in the material by sharing oxygen atoms in various common arrangements [10]. This zeolite as adsorbent has been studied by various researchers for its ability to remove heavy metals from POME, aqueous solutions

and industrial wastewater under different experimental conditions [11-13]. Instead of heavy metal removal, this study focuses on POME treatment to improve water quality by minimizing pollutant factors in POME before release to the environment. Several parameters are evaluated to determine the optimal conditions for the treatment of zeolites for wastewater treatment.

2. Methodology

2.1 Sampling

Palm oil mill effluent (POME) was obtained at aerobic pond from a local palm oil mill Malaysia. The sample of POME was collected using polyethylene containers and cooled at room temperature (25±1◦C) before preserving it at 4◦C to avoid biodegradation. The sample was stored in Water and Wastewater Laboratory located in Faculty of Ocean Engineering Technology and Informatics at Universiti Malaysia Terengganu, Terengganu, Malaysia.

2.2 Adsorbent Preparation and Characterisation

Zeolite A (powder) was purchased from Obsessive_Agro, Malaysia. It contains trace elements silica (II) oxide, aluminum (III) oxide, ferum (II) oxide, titanium (II) oxide, calcium oxide, magnesium oxide, potassium oxide and sodium oxide. First, the natural zeolite was crushed until it passed through No.50 sieves to obtain a very uniform size distribution. It was then washed with distilled water and heat treated at 150°C for 2 h (heat-treated zeolite) dried in the electric oven before being cooled in a desiccator and used for characterization and experiments. The zeolites, both heat-treated and untreated, were characterized to determine their membrane functional group. This was done by Fourier transform infrared spectroscopy (FTIR) using a Perkin Elmer Spectrum FTIR spectrophotometer. FTIR analysis was performed in a wavelength range from 4500 to 450 cm^{-1}. Scanning electron microscopy (SEM) (SEM HITACHI S26000N) was used to study the morphology and structure of the adsorbents. During sample preparation for SEM, each sample was placed on a stub and then coated with a thin layer of gold using the JFC 1600 automatic coater. This technique is important to avoid damage or burning of the samples by the electron beam.

2.3 Batch Adsorption

To determine the performance of the adsorption process in the present or absent of the magnetic field, the batch adsorption study was conducted for removal of color, TSS and turbidity at the different contact time (30, 60, 120,180,240,300, and 360 min). In this experiment, a fixed volume of 100ml of POME was placed in 250 ml flasks. For the first stage of analysis, the effect of treatment towards adsorbent was evaluated its performance in POME treatment, therefore, the zeolite dose was fixed to 3g/L for treated and untreated zeolite. After that, the conical flask was placed on top of the orbiter shaker at the shaking speed (150 rpm). The sample is then pulled at the end time interval using pipette glass. After that, the sample was filtered and filtrated used to determine the concentration of TSS, color, and turbidity of treated POME according to the standard method by Zielińska and Galik [14].

Subsequently, based on the separate set of adsorption experiments in using treated and untreated zeolite, the best experiment will be selected as a result of the above experiments. The adsorption process combined with magnetic field experiments was performed in well tight 250mL flasks at 25◦C at the fixed volume of POME is 100mL. This experiment was conducted to determine the effect of the pH and zeolite doses for the removal of color, turbidity, and TSS of POME. Therefore,

this experiment was carried out at the effect of different pH (4, 5, 6, 7, 8, and 9) at the fixed zeolite doses (4g/100mL) and time (240min). Besides that, the effect of different zeolite doses (1, 2, 3, and 4g) was performed at varying contact time (30, 60, 120,180, 240, 300 and 360min).

The experiment was conducted in triplicate to obtain more accurate mean data. The percentage removal and the amount of each parameter that is adsorbed by zeolite will be calculated by the following Eq. (1) and Eq. (2):

$$\% \text{ Removal } = \frac{\text{Co}-\text{C}_\text{e}}{\text{C}_\text{O}} \text{x } 100 \tag{1}$$

$$\text{q}_\text{e} = \frac{(\text{C}_\text{O}-\text{C}_\text{e})\text{V}}{\text{m}} \tag{2}$$

where C_o and C_e are the initial and equilibrium concentration of each parameter in solution respectively; q_e is the amount of each parameter adsorbed at equilibrium, V is the solution volume (L), and m is the mass of zeolite.

2.4 Adsorption Isotherm Study

Isotherm study is used to describe how molecules adsorbate distributed between liquid phases and solid phases and it is important for system design. The adsorption of POME on natural zeolite was examined using two mathematical equations which are Langmuir, and Freundlich models.

The Langmuir isotherm assumes that homogeneous adsorption occurs on the surface of the adsorbent. Therefore, isotherm is used to explain the monolayer adsorption mechanism that occurs on an active site defined by Vilela *et al.,* [15]. Eq. (3) expresses the Langmuir adsorption isotherm:

$$\frac{\text{C}_\text{e}}{\text{q}_\text{e}} = \frac{\text{C}_\text{e}}{\text{q}_\text{m}} + \frac{1}{\text{k}_\text{L}\,\text{q}_\text{m}} \tag{3}$$

where C_e and q_e are the concentration at equilibrium (mg/L) and the number of pollutants adsorbed at equilibrium (mg/g), respectively, k_L is the Langmuir constant (L/g), and qm (mg/g) represents the capacity of the monolayer sorption at equilibrium. The Langmuir isotherm constant (RL) can be calculated as in Eq. (4):

$$\text{R}_\text{L} = \frac{1}{1+\text{k}_\text{L}\,\text{C}_\text{O}} \tag{4}$$

where the Langmuir constant is defined as k_L.

The Freundlich model is used to describe heterogeneous and multilayer surface adsorption by Adeola *et al.,* [16]. Eq. (5) and Eq. (6) express Freundlich isotherm:

$$\text{q}_\text{e} = \text{K}_\text{F}(\text{C}_\text{e})^{\frac{1}{\text{n}}} \tag{5}$$

$$\text{In } \text{q}_\text{e} = \text{In } \text{k}_\text{F} + \left(\frac{1}{\text{n}}\right) \text{InC}_\text{e} \tag{6}$$

where k_F the efficiency of absorption, 1/n is the intensity of absorption, (Non-Linear levels between the concentration of the solution and the adsorption is considered as n.

3. Results

3.1 Physical and Chemical Characteristics of POME

Table 1 shows the standard discharge limit by Mohamad *et al.,* [17] the physicochemical characteristics of POME (from anaerobic pond) subjected to coagulation treatment. The obtained properties of POME show that pH was 8.80 with COD of 427 mg/L, the turbidity of 128 NTU, TSS of 248 mg/L, TDS of 1852.50 mg/L, ammonia of 79.79 mg/L and colour of 1465 PtCo. The initial measurement of the POME sample resulting in a high TDS and colour level. In the previous study by Ramli *et al.,* [18] the result of physicochemical of untreated POME from SIME Darby plantation was about 1080 mg/L COD, 399 NTU turbidity, pH 5.5 and 8.0 mg/L of NH3N. The values of physicochemical parameters depend on duration of POME discharge and sampling location (treatment ponds). It was also found that the parameters BOD and SS were significantly affected by monthly rainfall which in dry season (February) the highest BOD (36,200 mg/L) and lowest SS (10,522 mg/L) were recorded by Jumadi *et al.,* [19].

Table 1
Physical and Chemical Characteristics of POME

Parameters	This study	Standard discharge limits [17]	Unit
pH	8.80	5-9	-
Turbidity	128	-	NTU
Color	1465	-	PtCo
TSS	248	400	mg/L
TDS	1852.50	-	mg/L
Ammonia	79.79	150	mg/L
COD	427	400	mg/L

3.2 Characterization of Adsorbent

The prepared of adsorbent zeolite were characterised using Fourier transform infrared analysis (FT-IR). The surface morphology was done by using a scanning microscope (SEM) analysis. In this part of the study, the changes in microparticles of natural zeolite were observed. Figure 1 shows the surface of natural zeolite.

Zeolites are a versatile class of crystalline materials widely used as catalysts, adsorbents, and ion exchangers. These materials are characterized by their uniformly sized pores, usually 3 to 10 Å in diameter. Because of this unique property, zeolites can exhibit remarkable molecular recognition, discrimination and organization properties with a resolution of less than 1 Å. The properties of zeolites strongly depend on their pore structure, hydrophilic and hydrophobic properties, and the nature of their pore openings [20]. Based on Figure 1, SEM analysis from the natural zeolite revealed particles of the natural zeolite are plate-shaped and overlapping which is demonstrated as lamellar texture materials [21]. The SEM image of the natural zeolite sample shows the heterogeneity of particle size. On the other hand, by increasing the partitioning ability shows a separate plate or bar (some micron size) is not a single crystal grain of zeolite, but only the aggregate is carried out by finer mineral grains by finer grains of the mineral. The phenomenon of zeolite cleavage can be associated with the main reason of mesoporosity [22]. Considering the level of cleavage degrees, which range from one to hundreds of atomic diameters in the zeolite mineral grains, the space within the grains can occupy a significant part of the total volume of the zeolite rocks even without micro-inclusions and other secondary porosity factors [23].

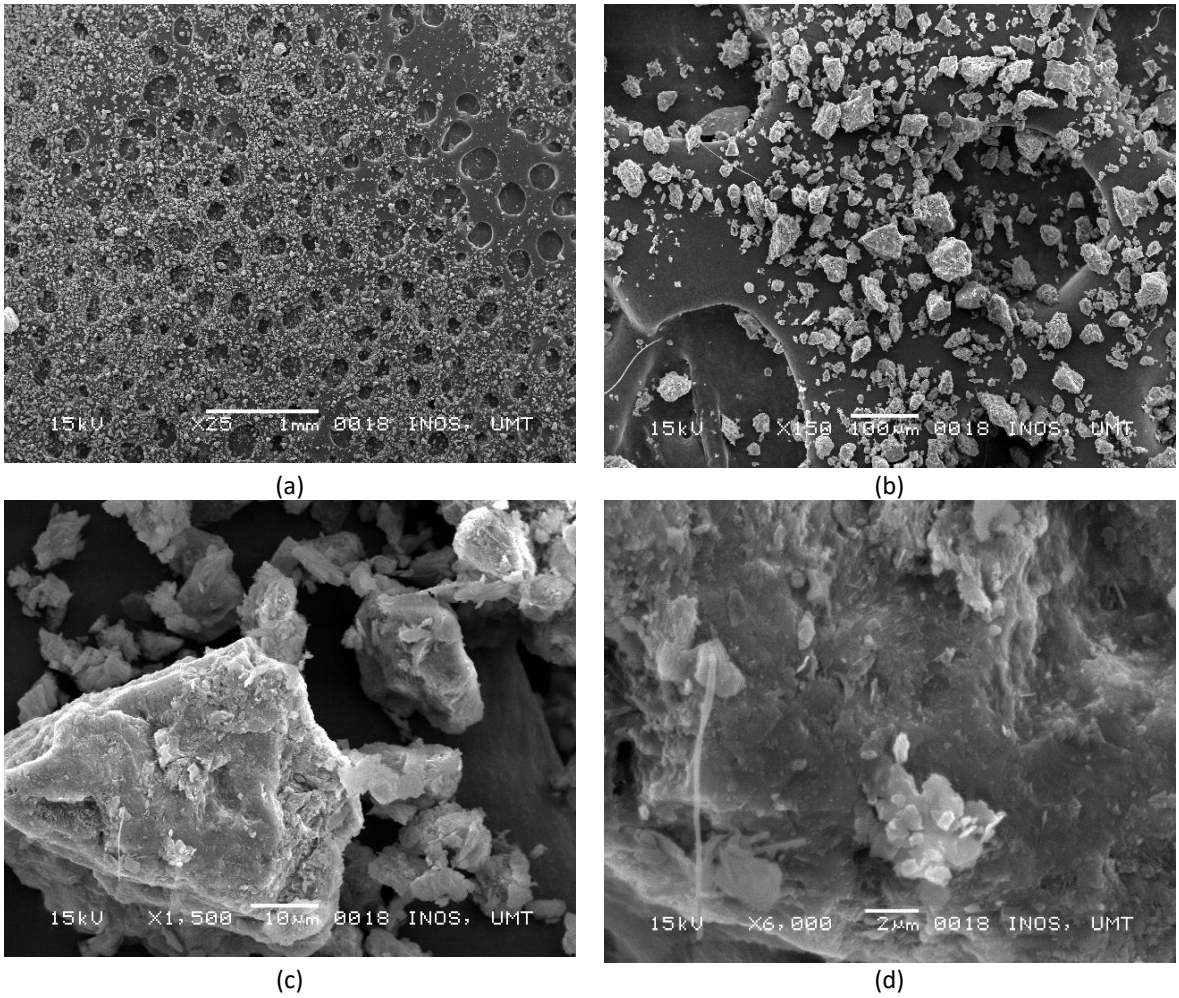


Fig. 1. Basic structure microparticles of natural zeolite at different magnification, a) x 25, (b) x 150, (c) x 1500, and (d) x6000

Fourier transform infrared spectroscopy (FTIR) is a technique for obtaining an infrared spectrum of absorption or solid emissions, liquids, or gasses. The FT-IR spectrum of natural zeolite studied in the range 500-4000 cm^{-1} is shown in Figure 2.

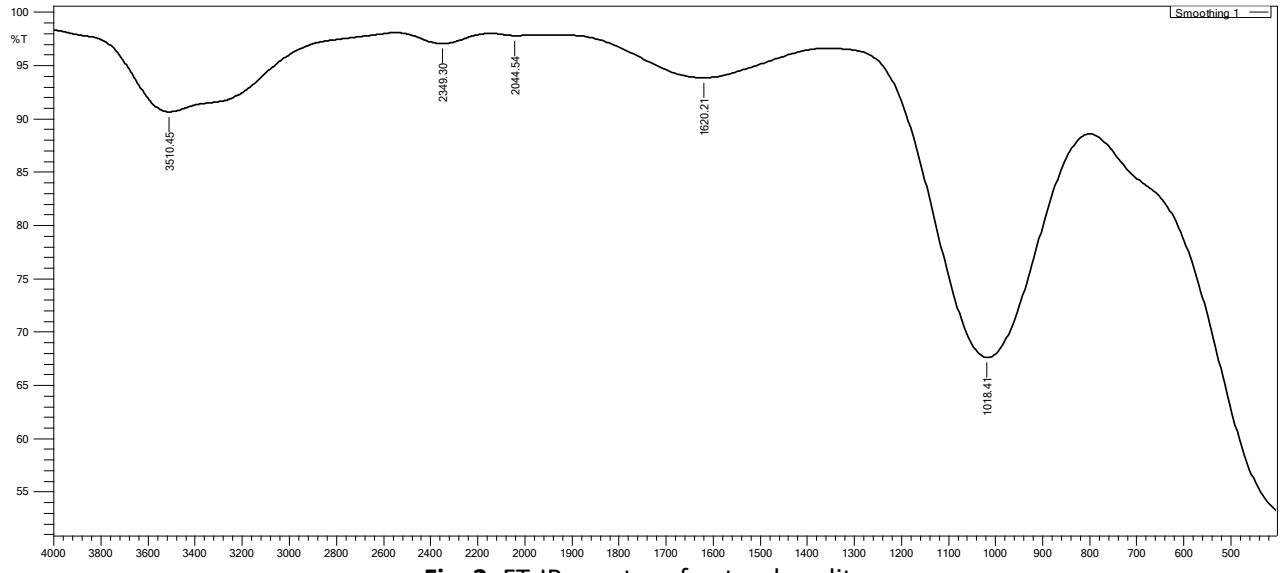


Fig. 2. FT-IR spectra of natural zeolite

The broad absorption band has shown that the zeolites are clearly hydrated, as illustrated by a discrete water absorption band in the range between 3510 and 1620 cm^{-1}. Based on Figure 2, it can be seen that the stretching band is centered at 3510 cm^{-1}associated with the symmetric hydroxyl function (OH) and 1018 cm^{-1} with water molecules associated with Na and Ca in channels and cages in the zeolite structure. Peaks were observed at 2349-2045 cm cm^{-1} indicating the triple bond region (C≡C). Moreover, another band appears near 1018 cm^{-1} corresponding to the non-symmetric stretching mode of the internal T-O bonds in the TO4 tetrahedra (T=Si and Al). This result is the same as that obtained by Mansouri *et al.,* [24]. The vibrations generated by Al-O bonds are described by the intensity at 1018 cm^{-1}. It is important to mention that the vibrations associated with Si-O and O-Al bonds, which are common in tectosilicates, are very strong, indicating that the zeolite has a large surface area [25].

3.3 Adsorption Study

3.3.1 Batch adsorption of POME using thermal-treated zeolite and untreated zeolite

The adsorption process was carried out using treated and untreated natural zeolite under different conditions. The treated natural zeolite is the zeolite which was subjected to thermal treatment at 150°C for 2 h and dried in electric furnace, and the untreated natural zeolite is without thermal treatment. A fixed zeolite dosage of 3 g/L and 150 rpm was used for the experiment where different contact times were varied. Figure 3 shows the removal efficiency of TSS, color and turbidity between heat treated and untreated zeolite.

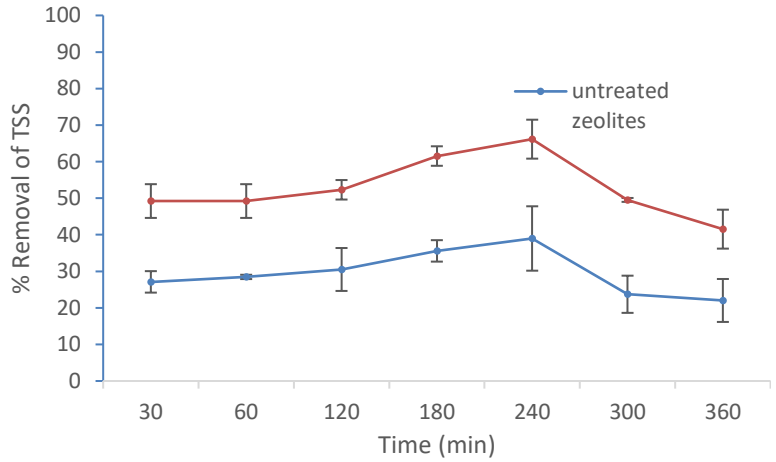


Fig. 3. The efficiency of untreated and treated zeolites as adsorbent for TSS removal at different contact time

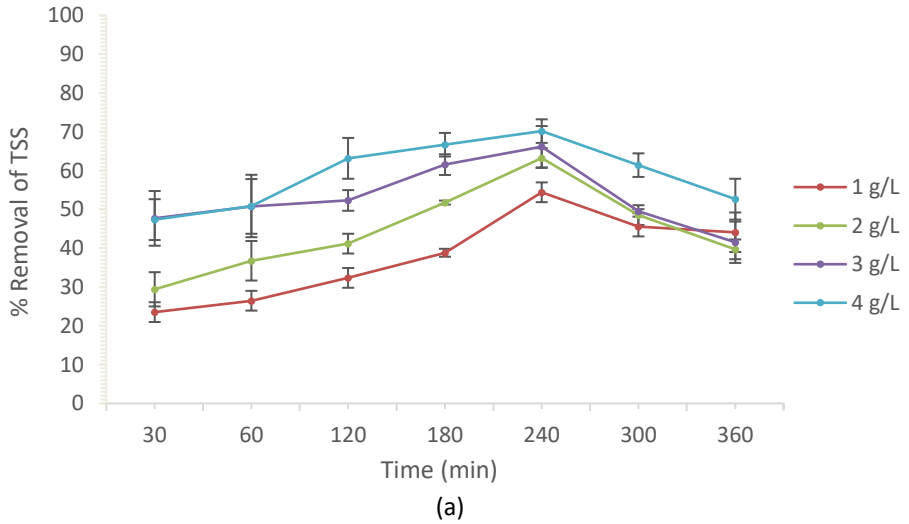
As shown in Figure 3, the highest removal efficiency of TSS, color and turbidity were achieved at contact times 240 minutes with 66.2% (2.39 mg/g), 80.5% (21.5 mg/g) and 86.8% (0.77 mg/g) for treated zeolite exceed the untreated zeolite with only 40.7% (1.33 mg/g), 71.2% (20.1 mg/g) and 78.2% (0.68 mg/g). Therefore, it can be concluded that the percentage removal of three parameters using treated natural zeolite is more efficient than using untreated natural zeolite for the adsorption process in POME wastewater. This is due to the reason that thermal treatment at high temperature on zeolite and temperature used can enhance pore volume by removing water molecules and organics from pore channels [26,27]. Water contained in the zeolite cage and channel contributes 10 – 25% to the total zeolite mass [28].

Therefore, the dehydration process of natural zeolite is important to allow efficient use of zeolites in water treatment. In addition, the volume changes upon heating differ among zeolites depending on the tetrahedral framework and the cation type outside the framework. Characterization of zeolite by reversible hydration at low temperature, i.e., below 200 °C, is usually accompanied by a strong change in the framework, followed by irreversible changes due to the breaking of T-O-T bonds before complete dehydration [29]. The dehydration properties of zeolites (and the amount of H_2O) are highly dependent on the cation outside the framework, especially its hydration energy [30]. The temperature and pressure of dehydration are determined by the energetics, which is H_2O in the zeolite channel. In many cases, an H_2O molecule is held with different semidiscrete energy resulting from its interactions with extraframework cation in the different sites of crystallographic. For example, the molecule that coordinates Ca^{2+} is stronger and has higher temperatures than those that align the ion K^+ because the hydration energy of Ca^{2+} is higher [22,31].

3.3.2 Effect of adsorbent doses

Adsorbent dosage is another important parameter affecting the efficiency of pollutant removal in wastewater. Different zeolite dosages and times were used for the experiment using the treated natural zeolite. The zeolite doses were varied from 1g/L to 4g/L and the contact times of 30 min, 60 min, 120 min, 180 min, 240 min, 300 min and 360 min were performed accordingly as shown in Figure 4. From the diagram, it can be seen that the dosage of adsorbent is the common factor affecting the success of adsorption.

Increasing the adsorbent dosage has the effect of reducing turbidity, color, and TSS. From the figure, the best results were obtained at 4 g/L adsorbent for TSS, turbidity and color. Percent removal increased with increasing dosage up to 4 g/L and reached TSS, color and turbidity at 70.2% (1.67 mg/g), 83.9% (26.82 mg/g) and 87.1% (0.86 mg/g), respectively. In general, adsorption is related to the phenomenon of specific surface area and surface selectivity, where specific surface area is defined as the total surface area available for adsorption [32]. In addition, surface selectivity can be divided into a hydrophilic or hydrophobic layer. Natural zeolite is negatively charged, which is due to isomorphic substitution. The replacement of one atom by another of the same size in the crystal lattice without disturbing or changing the structure of the mineral crystals [33]. In this way, the negative charges neutralize the cations in a solution, which eventually deposit on the surface of the adsorbent. An additional dosage of the adsorbent contributes to the increase of the surface, which increases the contact area [34].



(a)

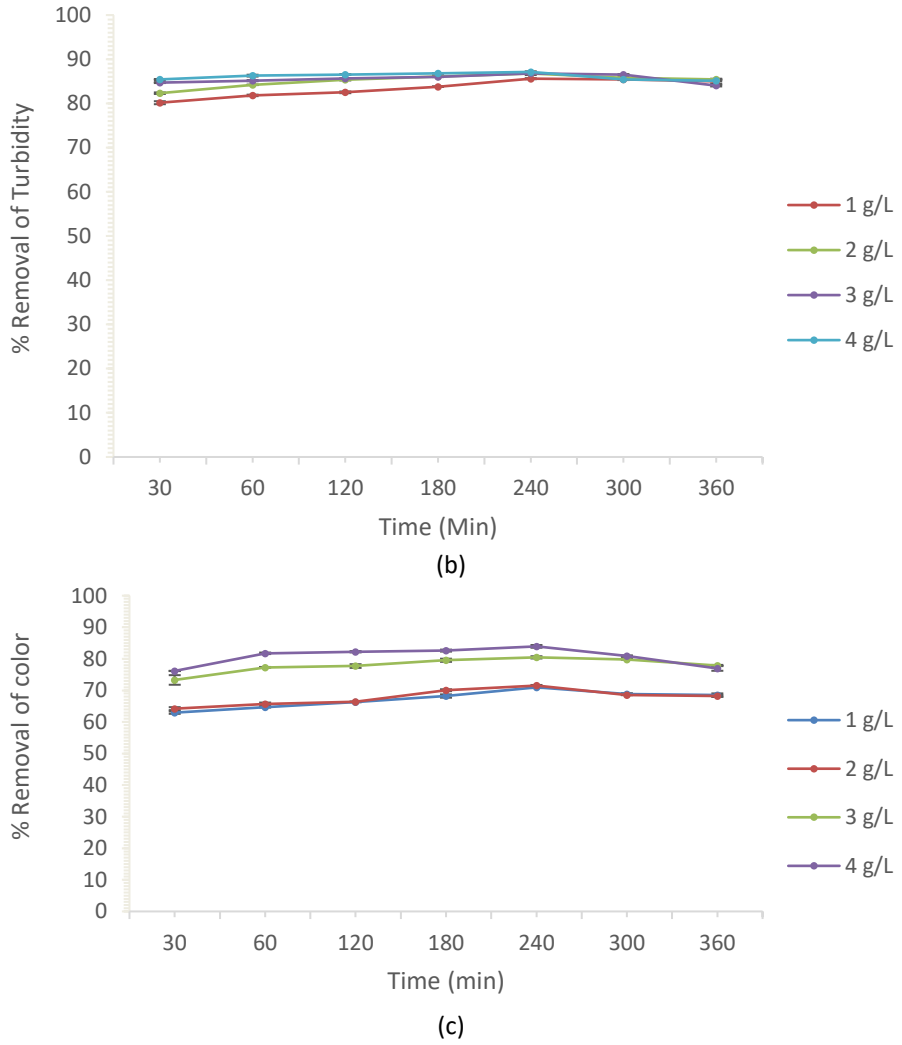


Fig. 4. Effect of adsorbent dosages on percentage removal of (a)TSS; (b) turbidity; and (c) color for different contact times for adsorption process

3.3.3 Effect of pH

In this experiment, the pH of POME was adjusted from pH 4 to pH 9 at a fixed zeolite dose of 4 g in 0.1 L POME and contact time. The initial pH of the solution was adjusted with 1.0 molarity of HCl or NaOH. As shown in Figure 5, two phenomena were observed. First, the graph of percent removal of TSS tends to decrease after pH 6. Second, the color and turbidity parameters increase at pH 4 and decrease at pH 5 and then increase again. This shows that pH significantly affects the charge of the adsorbent surface and the degree of ionization during the adsorption process [35].

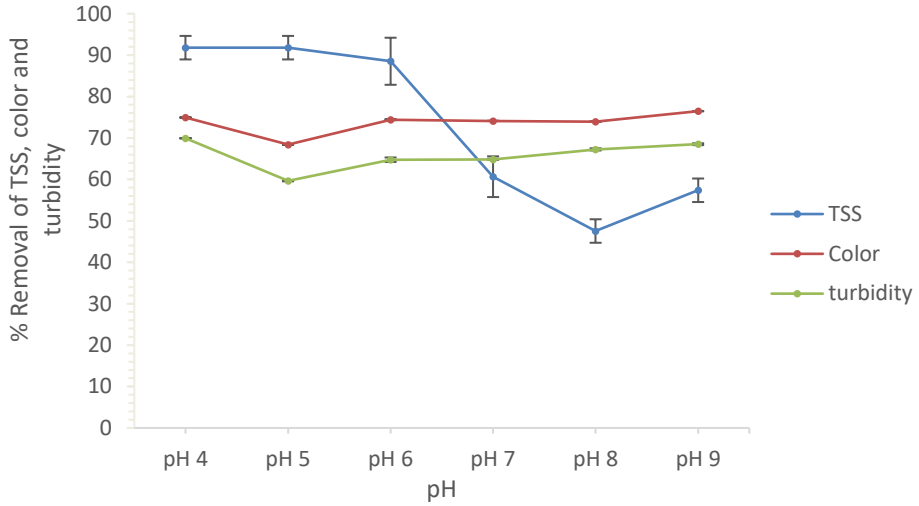


Fig. 5. Effect of pH on percentage removal of TSS, color, and turbidity. (Condition: Weight of adsorbent 4g, 0.1 L of POME solution)

From the results obtained, pH 4 is the optimal pH because it has the highest efficiency in removing TSS, color, and turbidity, although there are small differences with color removal at pH 9. The percent reduction of TSS, color and turbidity at pH 4 are 91.8% (2.33 mg/g), 74.9% (29.02 mg/g) and 69.9% (0.65 mg/g), respectively. It can be concluded that the best quality of the supernatant was obtained in the acidic range. This result is supported by a previous study by Deptula *et al.,* [36] in which it was reported that the addition of acid reduces the surface charges, thus eliminating the interparticle forces and promoting the electrostatic attraction that enhances the destabilization of the colloid particles [25]. This explains that in different acids, the particles in the sample of POME are an unstable suspension and adsorb among themselves. In addition, changes in pH also affect the electrical charges of the particles, which affects particle stability [37]. Changes in the pH of the environment can lead to changes in the surface charge of the adsorbent and also affect the color attractivity. Adsorption can be affected by the pH of the solution by controlling the surface charge of the adsorbent and the degree of ionization of the adsorbates present in the solution. The activities of an adsorbent are due to different functional groups: Carboxyl (- COOH), Sulfonyl (- S-O), Amine (- NH_2), and Hydroxyl (- OH) [38].

3.4 Isotherm Study

In general, isotherms are used to represent the equilibrium between a liquid and a solid phase. Isotherms are also generally understood to be the relationship between the equilibrium number of adsorbed substances on the surface of the sorbent and the residual concentration of adsorbed substances in the solution [39]. In the present study, Langmuir and Freundlich models were used to describe the equilibrium data. The results are shown in Table 2, and the modeled isotherms are plotted in Figure 6, Figure 7, and Figure 8 in terms of total suspended solids, color, and turbidity, respectively.

Table 2
Adsorption isotherm constants for Freundlich and Langmuir isotherm for adsorption of TSS, Color and Turbidity using natural zeolite

Freundlich Isotherm				
Parameters	KF	N	R2	
Total Suspended Solids (TSS)	0.41163	0.74522	0.98543	
Color	0.19633	0.32846	0.99958	
Turbidity	0.21689	0.65321	0.99626	
Langmuir Isotherm				
Parameters	qm (mg/g)	b (L/mg)	R2	RL
Total Suspended Solids (TSS)	43.24265	-6.78192	0.99078	0.03160
Color	32.12885	-0.15846	0.99997	0.03510
Turbidity	1015.77600	-0.45314	0.99948	0.00120

Relating R^2 of value, the better correlation between isotherms and experimental data can be found. Based on Figure 6, it presented that the adsorption data were well fitted with Langmuir isotherm, with R2= 0.99078 compared to Freundlich isotherm (R2=0.98543) for total suspended solid.

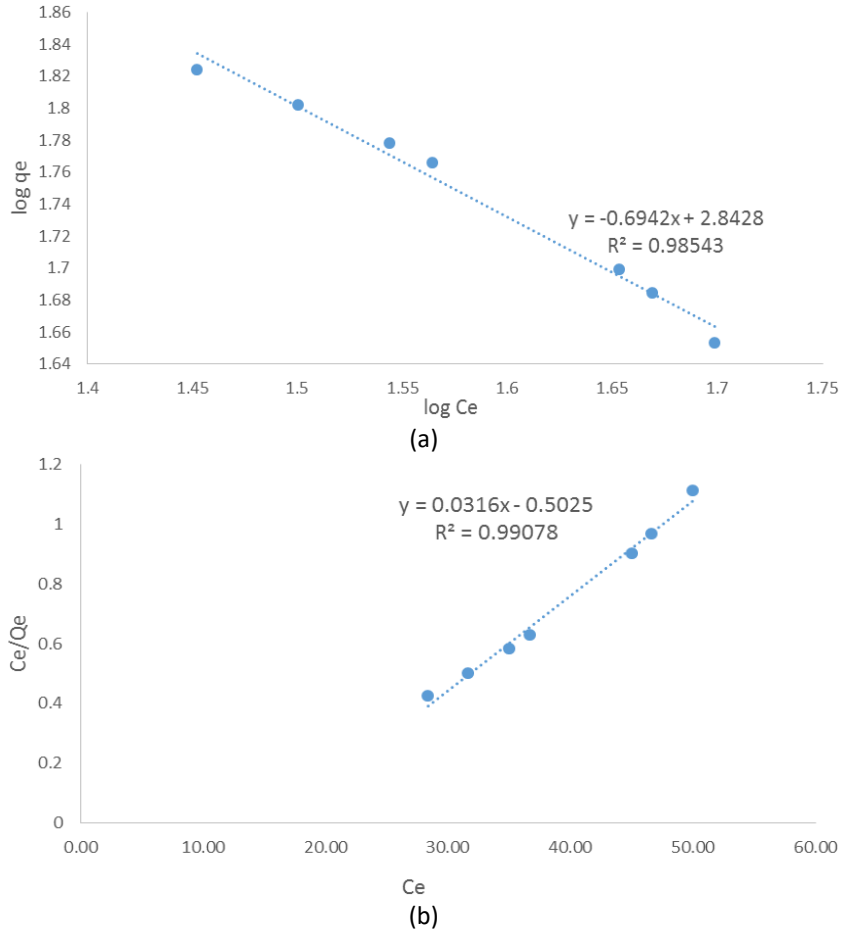


Fig. 6. Freundlich (a) and Langmuir (b) adsorption isotherm models of TSS adsorption onto natural zeolite

Meanwhile, the linear plots of Ce/Qe vs Ce (Figure 7) show that the adsorption of color on zeolite also obeys the Langmuir isotherm model which R2=0.99997 compared to Freundlich isotherms (R2=0.999658). The R2 near to 1 indicated that the model completely fit and explained all variance.

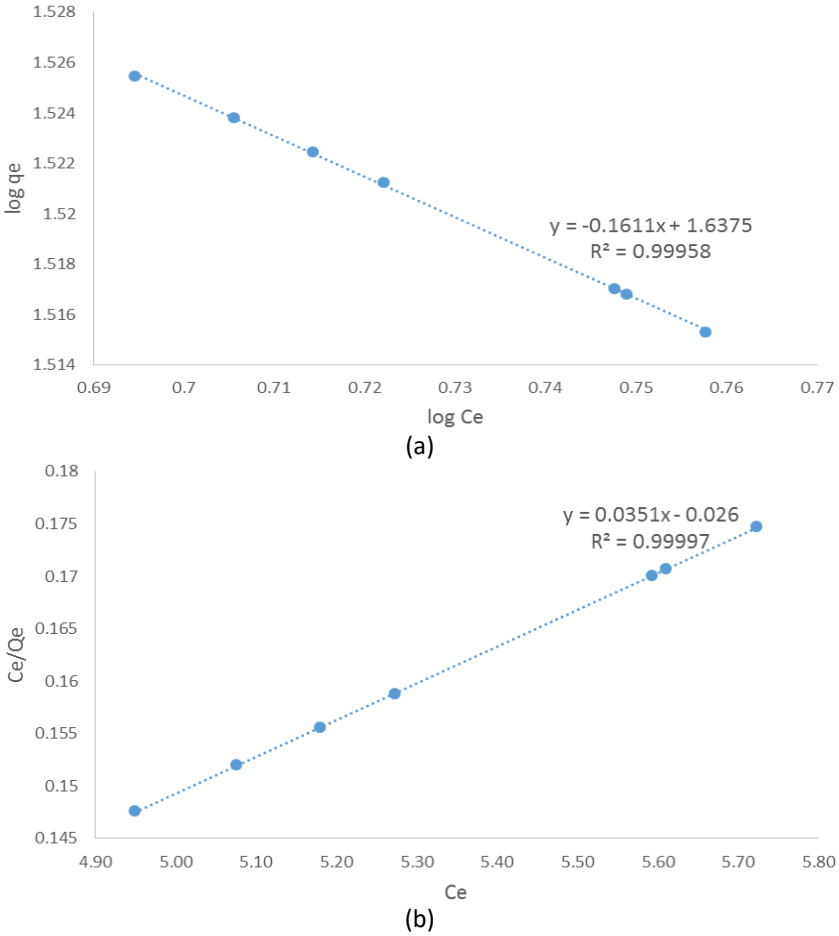


Fig. 7. Freundlich (a) and Langmuir (b) adsorption isotherm models of color adsorption onto natural zeolite

Besides that, the adsorption isotherm for turbidity also shows a better correlation of the experimental data to the Langmuir model (R^2= 0.99948) which R^2 greater than Freundlich model (R^2=0.99626) (Figure 8).

As can be seen, the two models have good linearity with a relatively high R2 value. R2, which is closer to 1, was the best fit for the adsorption isotherm. So, this adsorption tends to follow the Langmuir isotherm models. This means that there is an active site on the surface of the adsorbent proportional to the extended surface area that can adsorb only one molecule, and that adsorption is limited to the formation of a single layer [29,40]. Nevertheless, the Langmuir with R^2 (0.99997) for the color shows the best agreement with the experimental adsorption data. The R_L value indicates that the shape of the isotherms is either unfavorable (R_L > 1), linear (R_L = 1), good (0 < R_L < 1), or irreversible (R_L = 0), as summarized in Table 3. The R_L values of 0.03160, 0.03510, and 0.00120 (Table 2) for TSS, color, and turbidity, respectively, indicate that the adsorption of TSS, color, and turbidity on natural zeolite was favorable (0<R_L<1) which is had a strong interaction each other. Also, the lower value R_L at higher start-up initial concentration indicates that the adsorption is more favourable at higher concentrations [41].

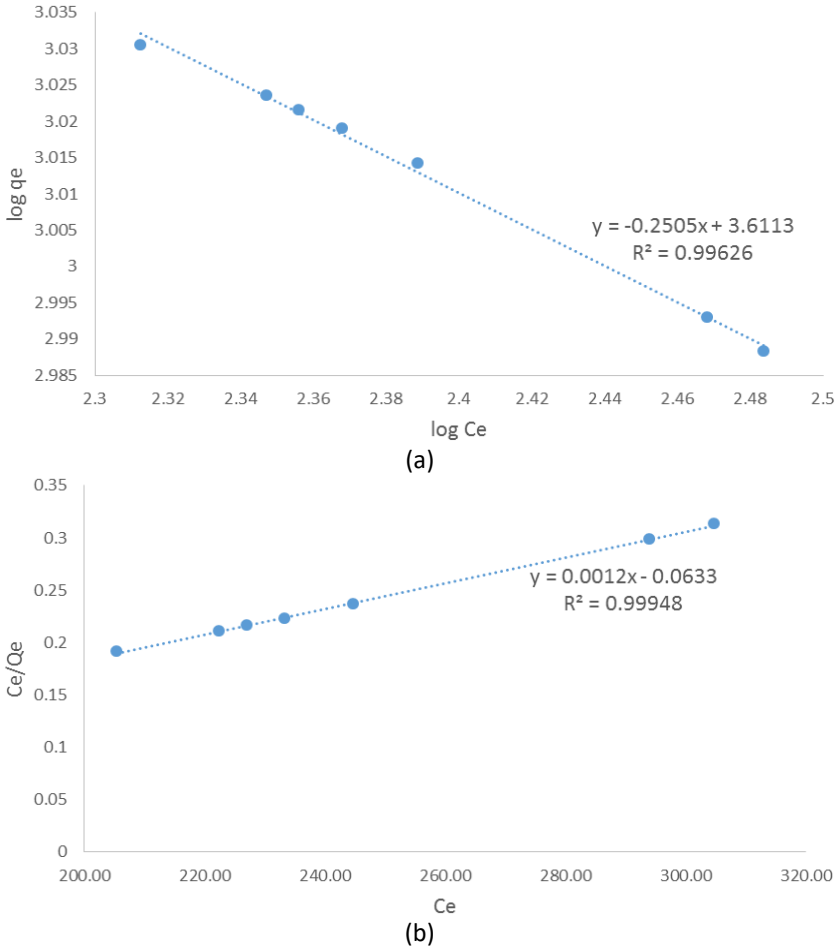


Fig. 8. Freundlich (a) and Langmuir (b) adsorption isotherm models of turbidity adsorption onto natural zeolite

Table 3
Meaning of the Langmuir dimensionless constant separation factor or equilibrium parameter (RL) for the adsorption process

R_L Value	Nature of adsorption process using the Langmuir model
$R_L>1$	Unfavorable
$R_L=1$	Linear
$0<R_L<1$	Favorable
$R_L=0$	Irreversible

However, the values of the isotherm parameter b for the Langmuir model shown in Table 2 are negative due to the negative axis intercept of the graph. This is an indication that the model does not meet the assumption in which it was set up, the process of conformity cannot be explained by the model. The same result was found in the previous studies. The reason may also be the complexity of the different components of the system, and in many cases the competition between the sorbates must be taken into account, which leads to a lack of equilibration in some models [28]. Moreover, the maximum capacity of adsorption is observed for all. It is observed that the maximum adsorption capacity Q_m of turbidity is higher than the other parameters, which are 1015.78 mg/g. Moreover, the regression values (R^2) clearly show that the sorption process is in better agreement with the Langmuir isotherm model for this adsorbent Table 2. From the tabulated data, it can be seen that the adsorption was homogeneous rather than heterogeneous and single rather than multilayer for all the cations studied.

4. Conclusions

From the obtained results, it can be concluded that the heat treated zeolite more perform as adsorbent for POME treatment with the optimal operating condition was experimentally determined in terms of dosage and pH: 4 g/L and pH 4, respectively. The data agreed well with the Langmuir isotherm instead of the Freundlich isotherm. The experimental results showed that the natural zeolite can be considered as a good adsorbent for the treatment of wastewater POME under suitable operating conditions Future work must focus primarily on modifying adsorbents to improve their effectiveness as a promising approach to manage POME effluent and preserving the environment for future generations.

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