Performance of Horizontal Roughing Filter for Colour Removal of Palm Oil Mill Effluent Using Natural Adsorbent

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Abstract

Palm oil wastewater treatment was investigated via a filtration process using raw and calcinated limestone. The column studies were conducted using different limestone sizes (4, 12, and 20 mm), calcination temperature (800 °C and 600 °C) and various filtration rates (20, 60, and 100 mL/min) and a comparison was made with raw limestone under similar conditions. The response surface methodology using central composite design was employed to optimize the process parameter. The experimental data was analyzed via the analysis of variance to identify the interaction between the parameters and the dependent parameter. The results showed that the colour removal increased with an increase in temperature (800 °C) for filtration rate of 20 mL/min, the retention time of 317 min and the smaller size (4 mm) of limestone and decreased with an increase in the filtration rate and size of raw limestone. Based on the achieved results, the optimum condition for colour removal was at temperature 800 °C (61%), 600 °C (56%) and raw limestone (49%) respectively with the same experimental setup (flow rate of 20 mL/min and limestone size of 4 mm). According to the statistical analysis, quadratic models demonstrated significant values (0.000) for the response (colour). Freundlich and Langmuir isotherms also provided good correlation coefficient for the colour removal. The data conforms to the Langmuir isotherm with the best fit model ($R^2=0.7$).

Keywords: Calcination; Raw Limestone, Central Composite Design, Isotherm study, Palm Oil Mill Effluent

1. Introduction

Palm oil industry is considered as an agro-based industry that provides positive economic impact worldwide and to Malaysia specifically (Nasrullah et al. 2017; Bello and Raman 2017). It is reported that the worldwide production of palm oil was over 70 million metric tonnes in 2018, and it is anticipated to exceed 75 million metric tonnes in 2020 (Hayawin et al. 2020). The production of one tonne of crude palm oil needs 5-7.5 tonnes of water and more than half of it is discharged as wastewater called palm oil mill effluent (POME) (Dashti et al. 2020; Sani et al. 2020; Bello et al. 2017). Palm Oil Mill Effluent (POME) is characterized as a thick liquid that contains high organic contents with brownish colour and strong smell. It also contains Biochemical Oxygen Demand (BOD), Oil and Grease (O&G), high concentration of Chemical Oxygen Demand (COD), Suspended Solid (SS) and total solids. The discharge of POME without proper treatment imposes serious pollution to the environment (Hossain et al. 2019;
Bashir et al. 2019; Fereidonian et al. 2018). The colour is formed by refractory compounds of natural organic matter, such as tannins, phenolic compounds, and melanoidin (generated by heating organic oil from the extraction process) (Limkhuansawan and Chaiprasert 2010). The discharge of brownish colour wastewater into the water bodies can cause adverse effects to aquatic lives by filtering the light passing through which results in less photosynthesis activity and less dissolved oxygen in the water (Ratpukdi 2012). The most usual technology to treat POME is the biological treatments using aerobic or an anaerobic ponding process, due to its low operating cost (Lawal et al. 2020). On the other hand, the biological treatment is a long process, since it requires an extended treatment time to degrade the organic particles (Kim et al. 2020; Chung et al., 2018; Lek et al. 2018). Moreover, lack of regulative control on emission of greenhouse gases caused by biological treatment process is the main drawback of the available and existing POME treatment process (Khadaroo et al. 2019). The process of biological wastewater treatment is ranked as the second-largest producer of greenhouse gases in Malaysia. Gases produced by the biological treatment process are odorous and corrosive as they contain ammonia and hydrogen sulfide (Mat et al. 2020; Hossain et al. 2019; Bakar et al. 2018). The ponding system is also influenced because of the excessive organic load and low pH in addition to the colloidal nature of the suspended solids in POME (Nahrul et al. 2017). Consequently, COD, residual BOD, turbidity and SS concentration in treated POME do not meet the standard discharge constraints for industrial effluents provided by Department of Environment (DOE), Malaysia (Jagaba et al. 2020; Bashir et al. 2019; Dashti et al. 2019). Alternative methods were applied on POME treatment such as membrane, membrane bioreactor, physicochemical, ozonation, and aerobic systems. However, these systems were not implemented in large scale due to operational problems such as scum formation, sludge flotation, or high-energy requirements from the treatment system (Saeed et al. 2015). In this research, we used POME from a polishing pond. After measuring the parameters, it was confirmed that physical treatment could be used because the amount of BOD over COD was less than 0.1.

The features such as being chemical-free, being high solid retention capacity, having simple management and low-cost maintenance are the highlighted benefits of Roughing Filter (RF) (Khazaei et al., 2016). Usually, RFs are filled with the media of diameter ranging from 4 mm to 30 mm and operate at low hydraulic load varying from 0.3 m h⁻¹ to 1.5 m h⁻¹ (Zeng et al. 2018; Khezri et al. 2015). During RF process, particles are removed if they are smaller than the filter media. The particle removal is efficient when particles are successfully transported and attached on the surface area of the media (or collector). This is defined by the approach to design deep-bed filters and is an estimate using colloid filtration theory (CFT) (Watanabe et al. 2002). When a particle is carried by gravitational settling from its fluid streamline to a collector surface, sedimentation (ηG) takes place. Sedimentation can be calculated by (1) (Watanabe et al. 2002):

$$\eta_G = \frac{(\rho_p - \rho_f) g d_p^2}{18 \mu v}$$

In (1), the fluid density, particle density, gravitational constant and the average particle diameter are presented by $\rho_f$ (gm/cm³), $\rho_p$ (gm/cm³), g (cm/ s²) and $d_p$ (cm) respectively. $\mu$ (gm/cm/s) is the fluid dynamic viscosity and v (cm/s) is the fluid approach velocity.

Due to porosity, various physicochemical properties and particularly surface area of the filter media plays an important role on RFs process (Lin et al. 2008). Various materials have been used as filter media, such as broken brick, various gravel, charcoal (Ochieng et al. 2006), sand (Lin et al., 2008) and plastic (Nkwonta 2010). Limestone is one of the most well-known media utilized in RF. The physical structure of limestone deteriorates quickly when it is calcinated at the temperature of 600 °C. Under mentioned condition, both the peak stress and the coefficient of elasticity decrease quickly which results in more cracks, porosities and enlargement of the surface area (Dashti et al. 2019; Zhang et al. 2017), and finally, leads to more absorption ability. This research aims to reduce the colour in polishing pond of POME using calcinated limestone. Hence, the conditions for calcinating various sizes of limestone in different flow rates were optimized using Central Composite Design (CCD) and Response Surface Methodology (RSM). The novelty of this research lies in the use of the calcinated limestone to improve adsorption capabilities. Filter performance was
also systematically studied with the aim of developing an effective new treatment technology for POME polishing pond.

2. Materials and Methods

2.1 POME Sampling, Analysis and Preservation

The final discharge effluent of an open anaerobic pond (polishing pond), belonging to MALPOM Industries located in Malaysia, was selected to be used in this research. Hanna HI8314 portable pH meter was used to measure the pH of the POME on-the-location of MALPOM. During the process of sampling and transporting POME to the laboratory, in order to keep it away from light exposure, 25-L black and air-tight container was used. In the laboratory, the POME was immediately stored in cooling room (4 °C) to be preserved for future biological activities. The COD removal was evaluated based on APHA Standard Method 5220D, program 435 COD HR, HACH DR/ 2800 spectrophotometer while turbidity was measured by the method 2130B (APHA 2005) using HACH 2100Q Turbidimeter. The colour was determined by the method 2120C (APHA 2005), Platinum-Cobalt Standard. Ammonia nitrogen-Nessler method coupled with HACH DR/ 2800 spectrophotometer were used to measure Ammonia nitrogen.

2.2 Filter Design and Operation

The horizontal filter is an acrylic column which is 75 cm wide, 20 cm long, and 9 cm high (Table 1). Raw and calcinated limestones with various sizes are used as a filter media during the process. The column study was run by passing the POME through the horizontal filter (Fig. 1a) with 3 different filtration rates of 100, 60 and 20 mL/min. In order to create different flow rates, Masterflex pump with capacity of 2000 mL/min was used to carry POME from the tank to the horizontal roughing filter. The filtration process was carried out by taking samples from the inlet and the outlet both prior to and after the retention time for different filter media sizes and flow rates over seven successive days.

Colour removal efficiency percentage from POME was calculate by the following equation:

\[ P = \frac{C_0 - C_1}{C_0} \times 100 \]  

where \( C_0 \) (PtCo) and \( C_1 \) (PtCo) represent the concentration of colour in influent and effluent of POME, respectively.

2.3 Calcination Limestone Process

The natural limestone used in the experiment was produced by a marble factory in Ipoh, Malaysia. The limestone is crushed into 3 different small sizes of 20, 12 and 4 mm. After that, they were sieved to be uniform in terms of size, between 4 mm and 20 mm using a sieve. They were washed to remove any impurities and then dried at room temperature for 24 hours. By means of a stainless-steel furnace with inner length and diameter of 1.5 cm and 2.5 cm, respectively, and outer length of 50 cm. The furnace was equipped with 2 different gauges. One for adjusting gas flow and the other one for controlling the temperature (Fig. 1b). A Teflon tube piped the furnace to the gas tank. In the course of the calcination process, nitrogen gas (Well Gas Company) with the flowrate of 200 cm³/min was flowing to the tank. A scanning electron microscope (SEM) (Carl Zeiss Supra -35 VP, Germany) was used to measure morphology of the surface area for both raw and calcinated limestone. Moreover, to evaluate the total surface area metrics such as pore volume and pore size, the Brunauer-Emmett-Teller (BET) process (ASTM D3037) was applied for the three media. X-ray fluorescence (XRF) was also used to measure the elemental composition of all three media.

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Fig. 1. Horizontal roughing filter schematic (a) and calcination experimental diagram (b).

### 2.4 Data Analysis

RSM was used to analyse the colour removal efficiency of POME. Two independent variables namely, the flow rate (20-100 mL/min) and the limestone size (4-20 mm) were selected to obtain the colour removal efficiency. Each experiment was run 13 times. Experimental range of each variable was between their minimum and maximum level as requested by CCD. The colour removal efficiency was treated as the dependent response (Y). To recognize the sufficiency of the models, both independent factors and dependent response were optimized using analysis of variance (ANOVA). Similar to previous works, for quantifying the effects of two different factors, a second-order polynomial quadratic model (3) was used (Fereidonian Dashti et al. 2018; Zhong et al. 2014; Hay et al. 2012).

\[
Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i<j}^{k} \beta_{ij} X_i X_j + \cdots + e \tag{3}
\]

In (3), \( Y \) is the dependent parameter (colour) and \( X_i \) and \( X_j \) represent the independent parameters. Subscript 0 is a fixed coefficient while the coefficients of higher order are denoted by \( i, ii, \) and \( ij \).
3 Results and Discussion

3.1 POME Properties

The POME used was characterized by 4000 Pt Co colour, 2750 mg/L COD, pH 8.3 and 652 mg/L SS, and collected from United Palm Oil Mill Sdn. Bhd in Nibong Tebal, Pulau Pinang of polishing pond (last pond of biological treatment) as presented in Table 3. Generally, raw palm mill wastewater is acidic (pH 3 - 4) and high in temperature. COD and BOD of fresh POME are in the range of 50,000 mg/L and 25,000 mg/L, respectively. Moreover, SS and Dissolved Solids (DS) are remarkably high value components of POME (Garritano et al. 2018). Hence, the polishing pond characteristics in the current work was different from the conventional raw POME. All the parameters evaluated in this work were measured following the Standard Methods for Water and Wastewater Examination (APHA 2005). The temperature and the pH were measured in the field while ammonia nitrogen, turbidity, BOD, COD, colour and SS were analyzed via laboratory analyses. Measuring the mentioned parameters supported physical treatment due to the amount of BOD over COD which was less than 0.1 (\(\frac{BOD}{COD} < 0.1\)). The concentration of \(\frac{BOD}{COD}\) revealed the rate of degradation and biodegradability of wastewater organic components. To determine proper strategies for the wastewater treatment plan, stable zone, biodegradable area, toxic region and finally the \(\frac{BOD}{COD}\) zones proposed by Samudro and Mangkoedihardjo (2010) were used. The amount of BOD and COD in the wastewater helps evaluate the organic matter content in effluent, where an elevated \(\frac{BOD}{COD}\) ratio demonstrates the incidence of biodegradation (Huang et al. 2017; Aziz 2011).

3.2 Media Properties

Chemical components shown in Table 4 belong to XRF results of raw and calcinated limestone. According to Table 4, the two main components of limestone are calcium oxide and magnesium oxide (Dashti et al. 2019). It is concluded that calcinated limestone has fewer impurities (iron, silica) in comparison with raw limestone. The findings of this work agree with the results from previous works (Wang et al. 2016; Ramezani et al. 2017).

3.3 Morphology Analysis of the Surface Area

A previous study (Côté and Konrad 2009) showed that the mechanical and porous properties of limestone are quickly changed when the temperature rises from 200 °C to 500 °C. This is because, in the mentioned temperature range, decomposition and expansion occur in minerals which cause water evaporation inside the stone. This evaporation results in physical and chemical changes among some minerals (Cai et al. 2017; Ozguven and Ozcelik 2014) and these changes cause new cracks in the stone which generate, propagate and coalesce pores. When the temperature rises from 500 °C to 600 °C, almost all amount of moisture in the limestone evaporates. A huge number of stomata, cracks and powder are created, and only few unbroken crystal ribbons remain both during and at the end of calcination process in 800 °C temperature (Chen et al. 2009; Kavosh 2015) as shown in Fig. 2. Furthermore, Chen et al. (2009) validated that the occurrence of coalescence during the calcination process converted the smaller pores into larger pores which improved the adsorption capability of the limestone. The porosity of the limestone was reduced, and its apparent weight was increased in the temperature of above 1000 °C as validated by Kilic (2014). Fig. 2 depicts the morphologies of the raw and calcinated limestone in the temperature of 600°C and 800°C. BET results show that surface area and total pore volume in calcinated limestone were higher than raw limestone as shown in Table 5. These findings agree with previous research (Fereidonian Dashti et al. 2018; Chen et al. 2017).
3.4 Process Optimization of Colour Removal

In this study, the quadratic model was used to measure colour removal efficiency. The results of the Analysis of Variance (ANOVA) for POME colour removal under different flowrates and sizes for raw and calcinated limestone are shown in Tables 6, 7, and 8, respectively. The mean squares were afforded by dividing the sum of squares of every two variations by the error of variance shown by the Degrees of Freedom (DF). The F-value of the different models was assessed by dividing the mean squared of models by residual mean. The $R^2$ coefficient represents the ratio of the regression sum of squares to the total sum of squares. A $R^2$ value close to 1 is a favourable and agrees with previous research (Ghafari et al. 2009). A desired model could be achieved by minimum $R^2$ value of 0.80 (Dashti et al. 2020).
and Fereidonian Dashti et al. 2018). Meanwhile, the Lack-of-Fit (LoF) was insignificant. An insignificant LoF is preferable because the primary objective of this study is to create a model that fits the experimental data (Dashti et al. 2019; Pambi and Musonge 2016). In this research due to pure error, all three models were insignificant for both the calcinated and raw limestone response. Tables 6 to 8 report that the Coefficient of Variance (CV) ratio is less than 10% for all three quadratic models. It should be kept in mind that a CV more than 10 percent imply a reproducible model. Comparing the average prediction error to the range of the predicted values at the design points is called Adequate Precision (AP) and ratios greater than 4 indicate an adequate model discrimination. Moreover, predicted models can be used to navigate the design space defined by the CCD when AP values are higher than 4 for the achieved responses. According to the findings and based on (4) to (6), A (raw and calcinated limestone (mm), B (flow rate ml/min), and A² were significant for all three models. Actual factors of models and trace the effect of their changes in the process on removal efficiency of the colour in POME can be calculated by (4) to (6). Model adequacy is normally evaluated by applying diagnostic plots provided by Design Expert software, such as the predicted versus actual value and the normal residual probability plots in Fig. 3. The expected colour removal efficiency values achieved from the actual experimental data and that of the model were in good agreement with 3 models (Bhatti et al. 2011; Wang et al. 2014). Fig. 4 illustrates the plot of disruption of the comparative effects of two independent variables on the efficiency of colour removal for 3 models. In Fig. 4, a sharp curvature for the flow rate (mL/min) (A) and limestone particle size (mm) (B) is observed, showing that the colour removal efficiency response was slightly sensitive to both process variables.

Colour Removal %= 53.52 - 0.07A - 0.52B - 1.74A² - 0.02B² + 3.90AB  
Colour Removal % = 54.97 + 0.57A - 3.19B - 5.32A² + 0.10B² - 3.90AB  
Colour Removal % = 67.66 + 0.12A - 2.46B - 2.39A² + 0.04B² + 3.12AB

![Predicted vs. Actual](a)

![Predicted vs. Actual](b)
Fig. 3. Actual predicted plot of colour removal using: (a) raw limestone; (b) calcinated limestone at 600 °C; and (c) calcinated limestone at 800 °C.
3.5 Performance of Filters

Table 2 lists the results of 36 runs for the CCD experimental design of all 3 models. 3-D plots are created to investigate the effect of two factors namely, size and flow rate on the colour removal efficiency. According to the results and based on (4) to (6), both particle size of limestone and flow rate have a significant effect on response. Fig. 5 shows that the colour removal efficiency increased with the reduction of flow rate and limestone particle size, which agrees with the results reported by Daee et al. (2019) and Maung (2006). The optimum colour removal efficiencies obtained by applying roughing filter with particle size of 4 mm and flow rate of 20 mL/min were 49% for raw limestone, and 58% at 600 °C and 61% C at 800 °C for calcinated limestone, respectively. Therefore, increasing the pore volume, the surface area of limestone and the temperature improve the colour removal efficiency, as also validated by Chen et al. (2009). In the course of the roughing filter process some suspended particles were settled through the settling process due to their gravity. A particle requires less time to travel along the settling distance and stick to or absorb onto the media layer if the flow rate is faster (Khezri et al. 2015; Dastanai et al. 2007). Nkwonta (2010) pointed out that the flow rate has a significant influence on colour removal. Effective colour removal in roughing filters are achieved with low flow rates because low flow rates are critical to retain particles that are gravitationally deposited to the surface of the media. Affam and Adlan (2013) investigated the removal of colour from leachate using vertical up-flow filtration technique by combination of three different media sizes (i.e., 4-8 mm, 8-12 mm and 12-18 mm) and five different filtration rates (100 mL/min, 80 mL/min, 60 mL/min, 40 mL/min and 20 mL/min). The filter media were stacked in descending sizes from bottom to top for all experiments. The results showed that removal efficiency was improved from 36% to 62% for colour removal at flow rate of 20 mL/min.

**Fig. 4.** Colour removal plot using: (a) raw limestone; (b) calcinated limestone at 600 °C; and (c) calcinated limestone at 800 °C
(a)

(b)
Fig. 5. Response surface for colour removal efficiency using: (a) raw limestone; (b) calcinated limestone at 600 °C; and (c) calcinated limestone at 800 °C

3.6 Numerical Optimization

In this work, some parameters such as limestone size, temperature and flow rate have significant effects on POME treatment and can improve colour removal efficiency for certain conditions. Therefore, in order to find the best values of independent variables that present optimum values for colour removal, RSM was applied. Each of the independent factors is exclusively tuned in an attempt to earn the optimum value for colour removal (Bashir et al. 2010; Hosseini 2012; Aziz et al. 2011; Ahmad et al. 2005). Table 9 shows the limitations of each variable and the desired response. When desirability is 1 or close to 1, the best outcome of the experiment and the most optimum conditions for each solution can be selected for further validation (Hosseini 2012). In this work, the range of flow rate and size of limestone were from 20 to 100 mL/min and from 4 to 20 mm, respectively. As Table 9 reports, optimum removal efficiency and desirability were achieved by the lower range of limestone size (4 mm) and flow rate (20 mL/min). Table 9 also reports that the responses of different model predictions are closely agreeing with the results of laboratory experiment.

3.7 Adsorption Isotherms

Qualitative information of the special relation between the amount of adsorbate mass on the surface of adsorbent and the concentration of adsorbent in addition to the kind of solute-surface interaction are described by adsorption isotherms (Khandaker et al. 2020). The current work used two different isotherms, namely Freundlich and Langmuir, to fit the equilibrium data acquired from the actual experiments. Theoretically, the assumption of the Langmuir isotherm is that the adsorbate covers the homogeneous surface of adsorbent in a monolayer (Jawad et al. 2020). The Langmuir isotherm is presented in (7):
In (7), the rate of adsorption, adsorption capacity, adsorbate equilibrium concentration and the quantity of adsorbate are denoted by \( b \) (L/mg), \( Q \) (mg/g), \( C_e \) (mg/L) and \( x/m \) (\( q_e \)) (mg/g), respectively. According to Table 10, the Langmuir model sufficiently fits the equilibrium data. The equilibrium parameter \( (R_l) \) (Balark et al. 2017) can also be used to explain the Langmuir isotherm features (8):

\[
R_l = \frac{1}{(1 + b C_0)}
\]  

(8)

In (8), the initial colour concentration and the Langmuir constant are denoted by \( C_0 \) (mg/L) and \( b \), respectively. Isotherms can be categorized into three different categories based on the value of favorable \( (R_l < 1) \), linear \( (R_l = 1) \), and unfavorable \( (R_l > 1) \) (Isa et al. 2007). Table 10 shows favorable adsorption process for colour for all types of limestone. The main underlying theory of the Freundlich isotherm model is the assumption that the adsorption process occurs on heterogeneous surfaces and can be presented as the empirical (9) (Dashti et al. 2020):

\[
\log q_e = \log K + \frac{1}{n} \log C_e
\]  

(9)

where, \( q_e \) = colour amount adsorbed per unit of mass adsorbent (mg/g); \( C_e \) = adsorbate equilibrium (mg/L); \( n \) = adsorption intensity; and \( K \) = adsorption capacity (mg/g). A favorable adsorption mechanism \( (\frac{1}{n} < 1) \) increases adsorption capacity while a weak adsorption capacity is the result of an unfavorable adsorption mechanism \( (\frac{1}{n} > 1) \) (Aziz et al. 2008 and Hossain et al. 2019). \( R^2 \) and \( K \) values for the Freundlich isotherm based on linear regression correlation (9) are listed in Table 11 and are shown in Fig. 7. Findings of this work validated that the Langmuir isotherm model fits the experimental data better than the other model (Fig 6). Another outcome is that the colour coated the surface of the adsorbent in a monolayer fashion and homogenously. This is caused by the higher \( R^2 \) value acquired using Langmuir isotherm (0.735) compared with the Freundlich isotherm (0.622) (Fig. 6 and 7). Keong (2012) achieved colour removal of leachate (Q) equal to 1.070 Pt Co/g and 0.065 Pt Co/g; and \( b \) values of 5.36×10^{-3} /Pt Co and 5.44×10^{-3}/Pt Co for calcinated limestone at 400 °C and 200 °C, respectively. The values of \( R^2 \) for Freundlich model were 0.751 and 0.605 in comparison to Langmuir model which were 0.502 and 0.376 for calcinated limestone at 400 °C and 200 °C. Pala and Erden (2004) used lime for leachate treatment. They found out that Langmuir isotherm was more satisfactory \( (R^2=0.97) \) for colour removal compared to Freundlich model.
Fig 6. Langmuir Isotherm for Colour adsorption: (a) raw limestone, calcinated limestone at 600 °C; (b) and calcinated limestone at 800 °C; (c)
Fig 7. Freundlich Isotherm for colour adsorption: (a) raw limestone, calcinated limestone at 600 °C; (b) and calcinated limestone at 800 °C; (c)
4. Conclusions

This research focused on development of a low-cost, eco-friendly and functionalized material to remove colour from palm oil mill effluent (POME). More specifically, the optimum conditions of colour removal from polished POME were investigated using calcinated and raw limestone in a horizontal roughing filter process as filter media. The interaction between the variables (flow rate and limestone size) and experimental parameter had been used to enhance the colour removal using response surface methodology. Optimum variables, according to the model, consisted of calcinated limestone at 800 °C with the size of 4 mm and a flow rate of 20 mL/min. The mentioned settings led to 61% colour removal, while only 18% was achieved when using raw limestone with the size of 20 mm and flow rate of 100 mL/min. A particle requires less time to travel along the settling distance and stick to or absorb onto the media layer if the flow rate is fast. According to the achieved results, when the size of filter media is small and the flow rate is low, more colour removal is achieved. Furthermore, the Langmuir isotherm yielded $R^2$ of 0.735 and fitted well the adsorption data in this study.

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Conflict of Interest

The authors notify that there are no conflicts of interest.

Availability of data and materials

All authors agreed that all data and materials as well as software support our published and comply with field standards

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The research leading to these results received funding from Universiti Sains Malaysia Short-Term Grant under Grant Agreement No (304/PAWAM/60311001)

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Methodology: Ali Huddin Ibrahim
| Abbreviations and Chemical Symbols |
|------------------------------------|
| ANOVA                             | Analysis of variance          |
| AP                                | Adequate Precision            |
| APHA                              | American Public Health Association |
| AWWA                              | American Water Works Association |
| BET                               | Brunauer-Emmett-Teller        |
| BOD                               | Biological oxygen demand      |
| CaO                               | Lime                          |
| CaCO₃                             | Calcium Carbonate             |
| COD                               | Chemical oxygen demand        |
| ºC                                | Degrees celsius               |
| CCD                               | Central composite design      |
| CL                                | Calcinated limestone          |
| CV                                | Coefficient of variance       |
| DOE                               | Department of Environment     |
| Fe₂O₃                             | Ferric oxide                  |
| Fig                               | Figure                        |
| g                                 | Grams                         |
| ha                                | Hectare                       |
| HRF                               | Horizontal roughing filter    |
| HRT                               | Hydraulic retention time      |
| Kg                                | Kilogram                      |
| L                                 | Liters                        |
| LOF                               | Lack of Fit                   |
| LS                                | Limestone                     |
| Mm                                | Millimeters                   |
| Mg/L                              | Milligrams per liter          |
| MgO                               | Magnesium oxide               |
| m²/g                              | Square meter per gram         |
| %                                 | Percent                       |
| POME                              | Palm oil mill effluent        |
| pH                                | Potential hydrogen            |
| RL                                | Raw Limestone                 |
| RSM                               | Response Surface Methodology   |
| SD                                | Standard deviation            |
| SEM                               | Scanning electron microscopy  |
| SiO₂                              | Silicon dioxide               |
| SS                                | Suspended Solid               |
| XRD                               | X-Ray Diffraction             |
| Cc/g                              | Cubic centimeter per gram     |
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