Aloe vera as a natural flocculant for palm oil mill effluent (POME) treatment – characterisation and optimisation studies

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Abstract. In the present study, fenugreek and aloe vera were investigated for the removal of turbidity (TUR), total suspended solids (TSS) and chemical oxygen demand (COD) from POME by using a central composite design (CCD) in the Design Expert software. The effects of three factors such as pH, coagulant dosage and flocculant dosage were analysed using jar test experiment and optimised using response surface methodology (RSM). The optimum results obtained from process optimisation analysis were pH 4, 24.13 g of coagulant dosage and 20 ml of flocculant dosage that are sufficient to remove 82.78 % of TUR, 83.40 % of TSS and 32.95 % of COD. The maximum error between the optimised values and the experimental values (82.78 % for TUR, 83.08 % for TSS and 33.76 % for COD) were below 4 %, indicating that satisfactory agreement was achieved. This showed that modelling and optimisation of the coagulation-flocculation process can be achieved by RSM approach. From analytical studies, it was found that the interactions between coagulant-flocculant and colloidal particles involve the mechanisms of charge neutralisation, adsorption and bridging, due to the active components such as amine (N-H) and hydroxyl (O-H) groups contained in the fenugreek and aloe vera.

Keywords: Aloe vera, Central Composite Design, Flocculation, Palm oil mill effluent, Response Surface Methodology

1. Introduction

Malaysia is one of the world’s biggest producers and exporters of palm oil and palm oil products [1]. It covers 28 % world palm oil production and 33 % world exports [52]. Besides, Malaysia also produces oils and fats that accounts for 11 % of the world’s production and 27 % of export trade [54]. Hence, Malaysia plays a crucial role in fulfilling the increasing demand for oils and fats. Oil palm cultivation in Malaysia covers 4.49 million hectares of land which produce 17.73 million tonnes of palm oil from the fruit flesh and 2.13 tonnes of palm kernel oil from the seeds [53]. It is estimated that 1 tonne of palm kernel oil is produced from every 10 tonnes of palm oil [2]. During the palm oil processing, palm oil mill effluent (POME) is mainly generated from oil extraction, washing and cleaning [58]. For example, about 1000 kg of fresh fruit bunches (FFB) are used for oil extraction using high temperature steam and water, and consequently produce 600-700 kg of POME [3]. Moreover, every 10-35 tonnes of FFB is generated from 1 hectare of oil palm, with more than 70 % by weight of FFB is discarded as waste [4].
These indicate that high amount of polluted wastewater is generated, and POME treatment is essential to prevent environmental pollution.

Raw POME is a highly viscous liquid waste that is brown in colour and comes with unpleasant odour. It is non-hazardous due to absence of chemicals addition in oil extraction process, naturally high in organic content which include mixture of cellulosic wastes, carbohydrates and oils, which are highly polluting to the environment [5]. It is generated from palm oil processing which comprises of oil palm trunks (OPT), oil palm fronds (OPF), empty fruit bunches (EFB), palm pressed fibers (PPF), palm kernel shells, palm kernel cake and liquid sludge discharge [6]. POME is a hundred times more polluting than the municipal sewage, resulting from high concentration of oil and grease (4,000 mg/L), COD (50,000 mg/L), BOD (25,000 mg/L) and total solids (40,500 mg/L) [2]. Furthermore, it is highly toxic to aquatic life as well as possesses significant pollution impact to the surrounding environment. Therefore, POME must be treated according to the discharge standard limit set by the Department of Environment (DOE) to prevent deterioration of the environment quality. The discharge limit in Malaysia is a minimum of 50 mg/L and 20 mg/L for BOD, depending on the location of palm oil mill [7].

In Malaysia, more than 85% of oil palm mills utilise ponding system that include a series of anaerobic, facultative and aerobic to treat POME because is it more cost effective and much easier to operate. This system requires large surface area of land with long retention time, producing unpleasant odour and greenhouse gas emissions [8]. In fact, such system is unable to consistently meet the standard industrial discharge limit for POME [9]. Thus, an economically and environmentally friendly technology using coagulation and flocculation process is proposed for the POME treatment to complement the ponding system, in order to speed up the treatment process and achieve the discharge limits. This technology is one of the most commonly and widely used in industries to remove colloidal particles in water and wastewater system due to effectiveness and simplicity of the operation [10]. Coagulation process involves the charge neutralisation that produce small flocs, whereas flocculation encourages agglomeration of large flocs under the gentle stirring. Based on Brownian movement in water, the surface charges on the colloidal particles are mainly negative, causing repulsion that inhibit the agglomeration between the particles.

In order to overcome the aforementioned drawback, chemical coagulant and flocculant are added to enhance the destabilisation and agglomeration process, forming larger flocs that can be separated by sedimentation or filtration Sethu et al., [11]. This is due to the various mechanism involved such as charge neutralisation and bridging. Both coagulant and flocculant which is mainly positively charged neutralise the negative charged of the colloidal particles. The most commonly used chemical as coagulant-flocculant is alum (Aluminium sulphate). However, it will cause negative impact on health and the environment. By using it in coagulation-flocculation process will lead to high procurement costs, ineffectiveness in low temperature, variation of pH value and large amount of chemical sludge produced in treated water [12]. In addition, prolonged exposure to water consumption with high level of aluminium residuals will cause Alzheimer’s diseases which resulted from the penetration and accumulation of the residuals into the human body and the brain respectively [13].

Studies have been carried out by researchers to find alternative ways to suppress the use of chemical coagulant-flocculant by proposing a cost-effective and environmentally friendly treatment system for POME. It involves the use of toxic free, natural abundance and cost effective of natural plant-based materials extracted from the seeds, leaves, fruits or peels of a plant for the coagulation and flocculation process. The sludge produced from this treatment has fertilizing properties because of the high concentration of degradable organic matter [5]. A study reported by Fatah and Wahab [12] on utilising dragon fruit foliage as natural coagulant for the treatment of the three-phase decanter POME has resulted in removal percentage of 99.2 % for TUR, 98.8 % for TSS and 48.7 % for COD. Another study which uses eggplant seed as natural coagulant was conducted by Oubrayme et al. [14] to treat the produced water in petroleum industry, removing 99.42 % of TUR and 92.18 % of COD. Other than that, fenugreek and aloe vera have been found to have good potential as natural coagulant and flocculant in wastewater treatment, but limited studies were conducted by researchers. For example, fenugreek seeds can remove 76.8 % of TSS and 77.6 % of TUR for POME treatment at dosage and pH of 800mg/L and 4 respectively.
[11]; Esther-Irma et al. [15] reported that the maximum removal efficiency achieved by aloe vera in surface water clarification for TUR, TSS and colour are 72%, 91% and 15% respectively; for textile wastewater clarification, aloe vera removes 92.3% of TUR, 76.8% of COD, 83.5% of BOD and 57.9% of TSS [16]; and aloe vera with calcium chloride remove 88% of fluoride in drinking water treatment [17].

Fenugreek, scientifically known as Trigonella foenum-graecum which belongs the Leguminosae family and mainly grown as multipurpose crop in Asia, Europe, Africa and Australia [18]. It is well known for its food flavouring and medicinal uses for appetite stimulation, anti-inflammatory, antioxidant, antidiabetic and anticancer [19]. According to Wani and Kumar [20], the active compounds exist in fenugreek consists of 23-26% protein, 6-7% fat and 58% carbohydrates with 25% of it is dietary fiber, that is effective in enhancing the coagulation process. In order to improve the quality of wastewater, aloe vera as natural flocculant is used to enhance the interparticle interaction to form larger flocs which will be separated through sedimentation or filtration. Aloe vera is a perennial succulent plant that comes from the family of Xanthorrhoeaceae and subfamily of Asphodeloideae as per the Angiosperm Phylogeny Group III System [21]. It grows especially in the tropical and subtropical area, and is widely used in the medical, pharmaceutical, cosmetic and nutritional purposes [21]. Aloe vera plant has thick, fleshy, sharp leaves that are joined together at the stem, resembling a rosette pattern [22]. Each aloe vera leaf consists of three main parts such as epidermis, latex layer and parenchyma. In this research, the focus will be on the parenchyma where the mucilaginous gel can be found. It includes 98.5 wt. % water and 1.5 wt. % of bioactive compounds such as carbohydrates, proteins, enzymes, vitamins, minerals, organic acids, phenolic substances and phytosterols [21]. However, these chemical compositions in the parenchyma will vary according to the separation techniques, variation of climate conditions and cultivation methods [23]. The existence of monomers, oligomers and polymers in carbohydrates enhance the bridging mechanism in flocculation process. The mucilaginous gel also contains polysaccharides that have strong affinity towards water, leading to intramolecular interactions between polysaccharides molecules and water molecules [24]. As a result, aggregation is formed during the coagulation-flocculation process.

The aim of this research was to study the effectiveness of fenugreek seed and aloe vera as natural organic coagulant and flocculant for the treatment of POME. Experiments were conducted using jar test to study the coagulation-flocculation process. Parameters such as pH, coagulant dosage and flocculant dosage were varied to determine the optimum removal efficiency of turbidity (TUR), total suspended solids (TSS) and chemical oxygen demand (COD) from treated POME. Response surface methodology (RSM) is applied in this study to design the experiment with minimum number of experimental trials and justify the output response towards the nominal and target study requirements. After finalising the optimum conditions, the experiment was repeated at the proposed condition to examine the outcomes from RSM prior conducting analytical analysis such as zeta potential analysis and Fourier transform infrared spectroscopy (FTIR) for further verification of the potential of fenugreek seed and aloe vera in treating the POME.

2. Materials and Methods

2.1. Palm Oil Mill Effluent (POME) Collection

POME samples were obtained from the final pond of the facultative lagoon at KLK Tuan Mee Oil Palm Mill, Sungai Buloh, Selangor Darul Ehsan, Malaysia. The sample collected was the effluent from the oil palm mill at the final pond prior discharging into the environment. It was collected in an airtight plastic container, covered with black plastic bag to avoid direct light exposure from biodegrading the sample due to microbial decomposition. The POME was stored for 12 hours in the laboratory refrigerator.
2.2. Fenugreek Seed Powder Preparation
Fenugreek seeds were obtained from a nearby local market in Semenyih. The seeds were crushed into coarse powder using pestle and mortar. Then, the coarse powder was ground into fine powder of size range 80 – 100 µm using the ultra-centrifugal mill. The fenugreek powder was collected in sample bottle and then stored at the desiccator to prevent re-humidification and mould formation.

![Fenugreek seeds and ground powder](image1.png)

**Figure 1.** Fenugreek seeds ground into fenugreek seeds powder.

2.3. Aloe Vera Solution Preparation
Fresh aloe vera leaves were obtained from aloe vera plants. The leaves were first rinsed with distilled water to remove impurities. Then, the gel (inner part of the leaves) was obtained by removing the green epidermis of the leaves. The gel was cut into smaller pieces and blended with juice blender to get the aloe vera solution. The solution was collected in the beaker and covered with parafilm. It was then stored in the refrigerator to prevent spoilage in a short term. Moreover, it minimised the growth rate of microorganisms.

![Aloe vera plant and gel](image2.png)

**Figure 2.** Removal of aloe vera's epidermis to obtain the aloe vera gel solution.

2.4. Jar Test Experiment
A jar test was conducted using the Philipps and Bird flocculator that consists of six impellers as shown below. This flocculator was located at Engineering Research Building (Block N) in University of Nottingham Malaysia.
Figure 3. (a) Phipps and Bird flocculator; and (b) Phipps and Bird flocculator with beakers covered with parafilm for sedimentation process.

The POME sample was poured into a bucket prior transferring 500 ml each into six 1 L beakers to ease the control of the amount of sample required and minimise spillage. The pH of the sample in each beaker was adjusted to the desired value, ranging from 4 to 9. The initial sample readings for TUR, TSS and COD were measured and recorded. Then, the beakers were put under the agitators, making sure that the impellers were immersed in the POME sample. After that, the dosage used for fenugreek powder and aloe vera solution were varied and added during the rapid mixing and slow mixing stage respectively. Rapid mixing was applied for 5 minutes at 200 rpm for coagulation process, followed by slow mixing for 20 minutes at 30 rpm for flocculation process. This is the typical time range used in a jar test for coagulation and flocculation studies [11]. After that, the beakers were set aside for 4 hours to allow the settling of solids before withdrawing 15 ml of supernatant each into six conical centrifuge tubes from each beaker. The supernatant was then measured and recorded to obtain the final readings of TUR, TSS and COD.

Table 1. Summary of jar test variables.

| Variables       | Speed (rpm) | Time (min) |
|-----------------|-------------|------------|
| Rapid Mixing    | 200         | 5          |
| Slow Mixing     | 30          | 30         |
| Sedimentation   | -           | 240 (4 hrs)|

Figure 4. (a) Untreated POME; (b) Treated POME at optimal condition.
2.5. Chemical Analysis

The pH of the POME sample was manipulated using hydrochloric acid (HCl) and sodium hydroxide (NaOH), followed by measuring using pH meter. HCl and NaOH were diluted to concentration of 9 M and 10 M respectively using equation (1). The molar mass of each solute was taken from the labelled container.

\[
\text{Molarity} = \frac{\text{Moles of Solute}}{\text{Litres of Solution}} = \frac{\text{Grams of Solute}}{\text{Molar Mass Solute} \times \text{Litres of Solution}} \tag{1}
\]

As the removal efficiency of the POME using fenugreek-aloe vera was evaluated by calculating the removal percentage of TUR, TSS and COD as presented in equation (2). TUR and TSS readings of treated POME were measured and recorded using turbidity meter and HACH DR2800 spectrophotometer respectively. Before analysing the COD, 2 ml of the treated POME from each beaker was extracted using pipette into 50 ml volumetric flask to dilute the concentration of treated POME. This dilution step was required due to the high concentration of the treated POME that was out of the range for spectrophotometer detection. Then, 1 ml of the mixed solution each was homogenised with high range plus (HR+) Hach COD vials separately. After that, the mixture in vials were heated in a HACH DRB200 Digestor at 150 °C for 2 hours. The COD readings were measured and recorded by using HACH DR2800 spectrophotometer after heated and cooled, where the readings are TUR, TSS and COD of the treated POME.

\[
\text{Removal Efficiency, \%} = \frac{\text{Initial Reading} - \text{Final Reading}}{\text{Initial Reading}} \times 100\% \tag{2}
\]

2.6. Experimental Design and Data Analysis

Design Expert version 11.1.2.0 software (Sate Ease, Minneapolis, USA) was used for regression and graphical analysis, statistical experiments design and data analysis. Response surface methodology (RSM) is a collection of mathematical and statistical techniques useful for modelling and analysis of responses affected by several factors [25]. It can be classified into two groups that are Box-Behnken design and central composite design (CCD). However, CCD is used in this research due to its advantages for allowing the experimental designer to understand the effect of factors on responses based on the levels selected for each factor [26]. Both CCD and RSM were applied to optimise the operating variables such as pH, coagulant dosage and flocculant dosage.

A \(2^3\) full-factorial design for three independent factors, consisting of 8 factorial points coded to the usual ± notation, 6 axial points and 6 replicates at centre points were conducted, given a total of 20 experimental runs for each response. Mathematically, formula in equation (3) was used to calculate the number of experimental runs to be conducted [25].

\[
N = 2^n + (2 \times n) + n_c \tag{3}
\]

where \(N\) is the number of experimental runs; \(n\) is the number of factors; and \(n_c\) is the number of centre points set between 2 and 6. Assuming that 6 points were set for the calculation, the range and levels of the experimental design were presented in table 2. In order to obtain the lowest and highest level of axial points, alpha (\(\alpha\)) value was first calculated using the formula of \(2^{n-4}\), where \(n\) is the number of factors. Then, the resulted \(\alpha\) values was substituted into equation (4) [14].

\[
X = \mu \pm \alpha \left( \frac{\text{High Level} - \text{Low Level}}{2} \right) \tag{4}
\]

where \(X\) is the lowest/highest axial point; and \(\mu\) is the mean of the high level and low level.
Table 2. Range and levels of the variables tested in the CCD design.

| Variables                  | Symbol | Range    | Lowest Level (-α) | Low Level (-1) | Zero Level (0) | High Level (+1) | Highest Level (+α) |
|----------------------------|--------|----------|-------------------|---------------|----------------|-----------------|-------------------|
| pH                         | A      | 4-9      | 2.29552           | 4             | 6.5            | 9               | 10.7045           |
| Coagulant Dosage (mg/L)    | B      | 10-30    | 3.18207           | 10            | 20             | 30              | 36.8179           |
| Flocculant Dosage (mg/L)   | C      | 10-20    | 6.59104           | 10            | 15             | 20              | 23.409            |

A second order polynomial model was used in this study to optimise the variables such as pH, coagulant dosage and flocculant dosage in coagulation-flocculation process. The responses such as TUR, TSS and COD were used to develop an empirical model that correlated with the respective variables using the second-degree polynomial equation as shown in equation (5) [27].

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

(5)

where \( Y \) is the predicted response; \( \beta_0 \) is the constant coefficient; \( \beta_i \) is the linear coefficients; \( \beta_{ii} \) is the quadratic coefficients, \( \beta_{ij} \) is the interaction coefficient; \( X_i \) and \( X_j \) are the coded variables values; \( n \) is the number of the independent test variables; and \( \epsilon \) is the random error. The results obtained were analysed by the analysis of variance (ANOVA). The experimental factors and interaction between the variables and responses can be explained by the determination coefficient, \( R^2 \) that expressed the best model fit. The \( R^2 \) values measured the variability of the observed response values through analysis of Fischer’s ‘F’ test and P-value (probability). The P-value was evaluated by using 95% confidence level. Finally, counter plots and regression equation were analysed and solved separately to obtain the optimal values of the variables.

3. Results and Discussion

3.1. Regression Analysis and Model Fitting

For the current study, more experiments are required to obtain the optimal removal efficiencies due to the ‘multivariable system’ that will consume large amount of time and high operating cost. This is because jar test only allowed one factor at a time to be evaluated and manipulated, with the other factor remains as constant, without considering the interaction between factors. It is important to include the interaction between different factors to obtain the optimal removal efficiencies with optimum condition of the combined factors that derived from the interactions. Therefore, RSM is implied to evaluate the relative significance of several factors to overcome the complex condition.

The relationship between the factors (pH, coagulant, and flocculant dosage) and the responses (TUR, TSS and COD) for the coagulation-flocculation process is analysed by RSM. Table 3 shows 20 sets of the experimental runs from CCD where the experimental values (EV) of the responses are obtained from the coagulation and flocculation process as well as their corresponding coded level.
Table 3. CCD design results for the three experimental variables in coded and actual values.

| Run | Factors | Responses |
|-----|---------|-----------|
|     | A       | B         | C         | TUR (%) | TSS (%) | COD (%) |
|     | pH      | Coagulant Dosage (g) | Flocculant Dosage (ml) | EV | Coded | EV | Coded | EV | Coded |
| 1   | 6.5     | 0         | 20        | 0       | 15      | 0   | 66.04 | 61.54 | 27.47 |
| 2   | 4       | -1        | 30        | +1      | 20      | +1  | 82.78 | 83.08 | 32.06 |
| 3   | 6.5     | 0         | 20        | 0       | 15      | 0   | 67.65 | 65.05 | 23.73 |
| 4   | 9       | +1        | 10        | -1      | 20      | +1  | 32.35 | 12.21 | 8.55  |
| 5   | 4       | -1        | 10        | -1      | 20      | +1  | 75.80 | 81.54 | 33.76 |
| 6   | 6.5     | 0         | 20        | 0       | 15      | 0   | 64.17 | 63.08 | 28.22 |
| 7   | 6.5     | 0         | 20        | 0       | 15      | 0   | 65.51 | 64.40 | 25.18 |
| 8   | 4       | -1        | 10        | -1      | 10      | -1  | 75.24 | 81.10 | 28.73 |
| 9   | 6.5     | 0         | 20        | 0       | 15      | 0   | 66.58 | 61.32 | 26.71 |
| 10  | 2.2955  | -α        | 20        | 0       | 15      | 0   | 72.46 | 77.80 | 22.45 |
| 11  | 6.5     | 0         | 20        | 0       | 6.59104 | -α  | 62.03 | 58.46 | 20.16 |
| 12  | 6.5     | 0         | 36.8179   | +α      | 15      | 0   | 73.80 | 72.53 | 11.69 |
| 13  | 9       | +1        | 30        | +1      | 20      | +1  | 37.70 | 38.68 | 22.65 |
| 14  | 9       | +1        | 10        | -1      | 10      | -1  | 30.21 | 30.11 | 18.84 |
| 15  | 6.5     | 0         | 20        | 0       | 15      | 0   | 66.04 | 64.40 | 23.57 |
| 16  | 10.704  | +α        | 20        | 0       | 15      | 0   | 20.05 | 19.34 | 8.02  |
| 17  | 4       | -1        | 30        | +1      | 10      | -1  | 81.18 | 82.20 | 30.06 |
| 18  | 6.5     | 0         | 3.18207   | -α      | 15      | 0   | 30.75 | 32.09 | 12.37 |
| 19  | 6.5     | 0         | 20        | 0       | 23.409  | +α  | 69.25 | 67.25 | 27.82 |
| 20  | 9       | +1        | 30        | +1      | 10      | -1  | 35.83 | 36.92 | 9.94  |

The results obtained for each response was analysed by ANOVA, including Fischer’s ‘F’ test and P-value as shown in table 4. The analysis shown that each response for all the models is significant at 95% confidence level by using quadratic model, implying that the F-statistic is significant. Besides, the model F-value and lack of fit f-value have a low percentage chance that both of these large values could occur due to noise. If the model P-value and lack of fit P-value are less than 0.05 (P-values of regression ≤0.05), these indicate that the model terms are also statistically significant. Thus, the model is correlated with the factors and responses. The lack of fit determines whether a regression model is a poor fit for data [55]. It may due to the poor choice of variables, poor experimental design or important terms are not included in the model. So, model is considered lack of fit when there are large residuals or errors occurred when fitting the model [57]. In addition, the coefficient terms such as pH (A), coagulant dosage (B), flocculant dosage (C), the interactive terms (AB, AC, BC) and square terms (A², B², C²) with ≤0.05 are significant to the response while terms with ≥0.05 are considered to have no effect on the removal of TUR, TSS and COD.
### Table 4. Analysis of variance (ANOVA) results for the three responses (turbidity, TSS and COD).

| Source | Sum of Square | DOF | Mean Square | F-Value  | P-Value  | Remarks |
|--------|---------------|-----|-------------|----------|----------|---------|
| Response 1: TUR | | | | | |
| **Model** | 6759.91 | 9 | 751.10 | 14.96 | 0.0001 | significant |
| A | 5222.08 | 1 | 5222.08 | 103.98 | < 0.0001 | |
| B | 678.93 | 1 | 678.93 | 13.52 | 0.0043 | |
| C | 24.56 | 1 | 24.56 | 0.4889 | 0.5003 | |
| AB | 0.4753 | 1 | 0.4753 | 0.0095 | 0.9244 | |
| AC | 0.4278 | 1 | 0.4278 | 0.0085 | 0.9283 | |
| BC | 0.0741 | 1 | 0.0741 | 0.0015 | 0.9701 | |
| **A²** | 606.08 | 1 | 606.08 | 12.07 | 0.0060 | |
| **B²** | 273.54 | 1 | 273.54 | 5.45 | 0.0418 | |
| **C²** | 1.96 | 1 | 1.96 | 0.0390 | 0.8474 | |
| **Residual** | 502.21 | 10 | 50.22 | | | |
| Lack of Fit | 495.56 | 5 | 99.11 | 74.51 | 0.0001 | significant |
| Pure Error | 6.65 | 5 | 1.33 | | | |
| **Cor Total** | 7262.13 | 19 | | | | |
| Response 2: TSS | | | | | |
| **Model** | 7099.45 | 9 | 788.83 | 14.48 | 0.0001 | significant |
| A | 6129.13 | 1 | 6129.13 | 112.53 | < 0.0001 | |
| B | 528.19 | 1 | 528.19 | 9.70 | 0.0110 | |
| C | 26.33 | 1 | 26.33 | 0.4834 | 0.5027 | |
| AB | 16.94 | 1 | 16.94 | 0.3110 | 0.5894 | |
| AC | 0.2964 | 1 | 0.2964 | 0.0054 | 0.9426 | |
| BC | 0.1512 | 1 | 0.1512 | 0.0028 | 0.9590 | |
| **A²** | 272.88 | 1 | 272.88 | 5.01 | 0.0491 | |
| **B²** | 132.23 | 1 | 132.23 | 2.43 | 0.1503 | |
| **C²** | 7.04 | 1 | 7.04 | 0.1293 | 0.7266 | |
| **Residual** | 544.64 | 10 | 54.46 | | | |
| Lack of Fit | 532.09 | 5 | 106.42 | 42.40 | 0.0004 | significant |
| Pure Error | 12.55 | 5 | 2.51 | | | |
| **Cor Total** | 7644.09 | 19 | | | | |
| Response 3: COD | | | | | |
| **Model** | 931.41 | 9 | 103.49 | 3.53 | 0.0311 | significant |
| A | 578.68 | 1 | 578.68 | 19.74 | 0.0012 | |
| B | 0.9951 | 1 | 0.9951 | 0.0339 | 0.8575 | |
| C | 36.52 | 1 | 36.52 | 1.25 | 0.2905 | |
| AB | 3.88 | 1 | 3.88 | 0.1323 | 0.7237 | |
| AC | 2.66 | 1 | 2.66 | 0.0906 | 0.7696 | |
| BC | 49.85 | 1 | 49.85 | 1.70 | 0.2215 | |
| **A²** | 80.57 | 1 | 80.57 | 2.75 | 0.1284 | |
| **B²** | 176.30 | 1 | 176.30 | 6.01 | 0.0341 | |
| **C²** | 7.70 | 1 | 7.70 | 0.2625 | 0.6195 | |
| **Residual** | 293.20 | 10 | 29.32 | | | |
| Lack of Fit | 274.09 | 5 | 54.82 | 14.34 | 0.0055 | significant |
| Pure Error | 19.11 | 5 | 3.82 | | | |
| **Cor Total** | 1224.61 | 19 | | | | |

Notes: A - pH; B - Coagulant Dosage; and C - Flocculant Dosage.
The empirical model in term of coded factor from ANOVA are shown in table 5. Based on Oubrayme et al. [14], the positive sign of the quadratic equation implies synergistic factor effect while negative sign implies antagonistic factor effect. Hence, the results show that the equation for each response is significant and satisfactory.

Table 5. Empirical model in term of coded factors for each response.

| Responses | Final Equation in Terms of Coded Factors |
|-----------|-----------------------------------------|
| TUR       | 65.92 - 19.55A + 7.05B + 1.34C - 0.2437AB + 0.2313AC + 0.0963BC - 6.49A² - 4.36B² + 0.368C² |
| TSS       | 63.17 - 21.18A + 6.22B + 1.39C + 1.46AB + 0.1925AC + 0.1375BC - 4.35A² - 3.03B² + 0.6991C² |
| COD       | 25.60 - 6.51A + 0.2699B + 1.64C + 0.6963AB - 0.5762AC + 2.50BC - 2.36A² - 3.50B² + 0.7309C² |

Notes: A - pH; B - Coagulant Dosage; and C - Flocculant Dosage.

Table 6 illustrates other statistical parameters. The coefficient of R² provides the proportion of the total response variation predicted by the model, indicating ratio of sum of squares caused by regression (SSR) to total sum of squares (SST) [27]. It measures the global fit of the model [14]. The R² coefficient value that close to 1 is desirable and reasonable agreement with adjusted R² is required to ensure a satisfactory adjustment of the model to the experimental data [27]. The adjusted coefficient of R² (Adj. R²) compares the models with different number of independent variables [14]. It is observed that the R² coefficient for removal of TUR, TSS and COD are 0.9308, 0.9287 and 0.7606 respectively. The values for removal of TUR and TSS are close to 1 and have a satisfactory adjustment of the quadratic model to the experimental data than the removal of COD. Non-significant model terms appear when the predicted R² (Pred. R²) and Adj. R² differ dramatically. Based on table 6, the value of Pred. R² and Adj. R² are not significantly different which confirm the accuracy of the model.

Adequate precision (AP) compares the range between predicted values at the design points and average prediction error. AP ratio greater than 4 shows that the predicted models can be used to navigate CCD design space. The ratio for TUR, TSS and COD are 13.7318, 13.6548 and 6.0840 respectively as shown in table 6, indicating an adequate signal to navigate the design space. The predicted versus the actual values plots of responses removal are presented in figure 5 which it provides the justification for model satisfactoriness. These plots imply an adequate agreement between the experimental data and model data. Based on figure 5, the actual values for TUR, TSS and COD are distributed relatively near to the straight line, indicating that the model data fits well with the predicted values.

The coefficient of variance (CV) is the ratio between standard error of estimate and mean value of the observed response that determine the model reproducibility.

Table 6. Fit statistic for each response.

| Responses | R²       | Adj. R²   | Pred. R²  | AP      | SD   | Mean | CV % |
|-----------|----------|-----------|-----------|---------|------|------|------|
| TUR       | 0.9308   | 0.8686    | 0.4804    | 13.7318 | 7.09 | 58.77| 12.06|
| TSS       | 0.9287   | 0.8646    | 0.4692    | 13.6548 | 7.38 | 58.61| 12.59|
| COD       | 0.7606   | 0.5451    | -0.8260   | 6.084   | 5.41 | 22.10| 24.50|
3.2. Process Analysis

The three-dimensional (3D) surface plots and its corresponding two-dimensional (2D) contour plots for the coagulation-flocculation process are shown in figure 6 to figure 8 as a function of two factors at a time, holding the third factor at fixed levels. Several factors such as pH, coagulant dosage and flocculant dosage are observed to optimise the treatment performance by using the fenugreek and aloe vera.

3.2.1. Effects of pH. pH must be controlled at the beginning of the experiment due to its important role in establishing the optimum condition for coagulation-flocculation process. The pH of the POME was adjusted from 4 to 9 to investigate the performance of the treatment process using fenugreek seed and aloe vera as natural coagulant-flocculant. It is observed that the variation of pH affects the removal efficiency of TUR, TSS and COD to some extents as per the (a), (b), (c) and (d) in figure 6, figure 7 and
For example, at low pH value yielded high removal efficiency of TUR, TSS and COD. This implies that there is a reduction in negatively charged colloidal particles and increases the number of hydrogen ions (H⁺) on its surface. Hence, it generates larger flocs from agglomerating with the positive charged coagulant-flocculant. From zeta analysis, the zeta potential for fenugreek seed and aloe vera are in negative values. However, the zeta potential of fenugreek seed is higher than aloe vera by 13.212 mV. This shows that a higher dosage of fenugreek seed than aloe vera is needed to become positively charged. In addition, hydrogen bonding is much stronger for fenugreek than aloe vera due to the higher density charged [28]. RSM shows a good result in removing the contaminants, indicating that there are interactions between the positively and negatively charged particles. This can be explained by the adsorption of fenugreek with the H⁺ ions contained in the POME at low pH, given that HCl is added at the beginning of the experiment. At the same time, it generates positively charges on its surface by neutralising the negatives of colloidal particles. Therefore, high dosage of fenugreek is required to neutralise and agglomerate the colloidal particles. Eventually, the adsorption of active sites on the fenugreek will decrease. More active sites are necessary to enhance the removal efficiency by adding aloe vera into the POME to further promote the agglomeration process.

Besides, the interactions involve the negatively charged of coagulant-flocculant with Na⁺ from NaOH added at the beginning of the experiments. The same scenario happened as mentioned earlier. However, the higher the pH value, the lower the removal efficiencies for TUR, TSS and COD. This may due to the fenugreek and aloe vera that are more selectivity to H⁺ than Na⁺ [29]. As a result, the lowest pH value of 4 over the applied range of pH, is required to obtain such optimum removal. Similar trends conducted by Obiora-okafo [30] explained that high removal efficiency at low pH values are predominant in removing organic contaminants from acid dyes. Another example that shows that natural coagulant are effective at low dosage, conducted by Daud, Ghazi and Ahamad [31] that uses wheat germ as natural coagulant in treating POME reveals high removal percentage of TUR, TSS, COD and colour at pH 2.

3.2.2. Effects of Coagulant Dosage. Coagulant dosage is one of the important factors that affect the performance of the coagulation-flocculation process. The amount of coagulant dosage required is highly dependent on the concentration of contaminants in wastewater [32]. It is added with a constant rapid mixing rate of 200 rpm for 5 mins. The coagulant dosage is varied from 10 to 30 g to determine the highest removal for TUR, TSS and COD. According to figure 6 and figure 7, it is observed that the higher the coagulant dosage, the higher the removal efficiency for TUR and TSS, indicating the effectiveness of fenugreek seed as natural coagulant in treating POME. This high removal efficiencies at high dosage are associated with adsorption mechanisms that increase the electrostatic forces between the positively and negatively charged particles, generating small and fragile flocs (also known as micro-flocs) [33]. The coagulant serves as condensation nuclei and the colloidal particles agglomerate in the form of residuals [30].

Besides, the COD removal efficiency increased as the dosage increases from 10 to 20 g and then decreases from 20 to 30 g. This proves that a positive impact of COD removal is observed at lower dosage and a negative impact at higher dosage. This negative impact can be explained by the presence of soluble organic compounds in fenugreek. The effectiveness of fenugreek seed in removing COD from POME is mainly due to the charge neutralisation and adsorption mechanism (also known as bridging mechanism) [30]. Fenugreek seed is positively charged after reacting with HCl, allowing strong adsorption affinity and charge neutralisation to occur on the negatively charged colloidal particles in POME. The high concentration of coagulant will minimise the optimum dosage. This is caused by overdosing of coagulant in the wastewater which deteriorates the supernatant quality in POME. In this case, ‘re-stabilisation’ of colloidal particles happened that restrict further adsorption and bridging mechanism due to the saturation of active sites.

After eliminating the negative effects and obtain the highest removal for all three responses (82.78 % for TUR, 83.08 % for TSS and 33.76 % for COD), an optimum coagulant dosage is chosen at 24.13 g which agrees with the outcome from the process optimisation of RSM. The effectiveness of fenugreek
seed as natural coagulant can be further verified by the studies conducted by Mohd Najib et al. [34] that have removed 94.97 % TUR, 92.7 % TSS and 63.11 % COD. Fenugreek seed was also applied in studied conducted by Sethu et al. [11] which removed 77.6 % TUR, and 76.8 % TSS.

3.2.3. Effects of Flocculant Dosage. The interaction between the small floc formation after the coagulation process and the remaining colloidal particles in POME generate bigger flocs formation during the flocculation process. In order to improve the quality of supernatant in POME, aloe vera is added at the slow mixing stage of 30 rpm for half an hour. During the slow mixing stage, it facilitates the contacting process from micro-flocs to larger and heavier flocs formation [33]. This phenomenon occurred due to the increasing bonds between the micro-floc particles. This decreases the concentration of colloidal particles in POME while increases the aggregates growth. Also, the size of the particles continues to increase that lead to macro-flocs formation that can be further separated by sedimentation, flotation or filtration. It can be seen from figure 6 to figure 8 that the higher the flocculant dosage, the higher the removal efficiency for TUR, TSS and COD. The usage of aloe vera as natural flocculant can be further verified by Yewégnon et al. [35] that reported the removal efficiency for aloe vera was found to be 72 % of TUR and 91 % of TSS. Hence, an optimum flocculant dosage is chosen at 20 ml which agrees with the outcome from the process optimisation of RSM.

A similar trend of observations can be observed from Kumar [36] and Esther-Irma et al. [15] that wastewater treatment using aloe vera significantly decreases TUR and TSS in treated wastewater. However, there is a very small change on the apparent colour of treated water. Therefore, it is concluded that aloe vera does not suppressed the organic matter presence in the water that accountable for the visibility of colour. This study has been proven as shown in figure 4, where the colour of POME becomes clearer at the end of the experiments. With the addition of aloe vera in wastewater, pH decreases indicated that aloe vera is acidic in nature. Another observation on the conductivity analysis carried out, it is deduced that the amount of aloe vera added influences the conductivity of treated water. The conductivity of treated water reduces as dosage of aloe vera increases. On top of that, the colour removal for untreated water is lower than TUR and TSS, indicating that aloe vera removes suspended particles more than colloidal particles. This further verified the effectiveness of aloe vera as natural flocculant in removing high concentration of suspended particles from water and wastewater treatment.

The performance of aloe vera as effective natural flocculant is attributed to the compounds present such as tannins, saponins, flavonoids and quinones that responsible in enhancing the flocculation process. Based on the physico-chemical analysis conducted by Adugna and Gebresilasie [16], the fiber contained in aloe vera is able to adsorb the fat present in wastewater, and consequently reducing the highly loaded organic matter. In addition, a study on aloe vera composition reveals the existence of polysaccharides [23]. This fact is also proven in Fourier Transform Infrared (FTIR) Spectroscopy Spectral Analysis. The solubility of polysaccharides in water determines the interaction between molecules which promote the aggregation process. Polysaccharides contain multi-hydroxyl groups that have strong affinity towards water as well as strong interaction between polysaccharides molecules through hydrogen bonding. Guo et al. [24] demonstrated the interaction between polysaccharides molecules and water molecules are energetically favourable for soluble polysaccharides; while intramolecular interactions between polysaccharides molecules are much stronger for polysaccharides with poor solubility of water, causing aggregation of molecules and eventually precipitation. The formation of precipitation in coagulation-flocculation process can be clearly seen from figure 4.
Figure 6. Response surface plot (a), (c), (e); and contour plot (b), (d), (f) for TUR removal.
Figure 7. Response surface plot (a), (c), (e); and contour plot (b), (d), (f) for TSS removal.
Figure 8. Response surface plot (a), (c), (e); and contour plot (b), (d), (f) for COD removal.
Inefficient performance of flocculation process will occur due to overdosing of either coagulant or flocculant. Therefore, it is important to determine the appropriate dosage required to achieve the targeted performance for wastewater treatment. By comparing the relationship between coagulant dosage and flocculant dosage based on the response surface plots, the higher the coagulant dosage, the lower the flocculant dosage required in the treatment process. This is due to the higher charge density of fenugreek particles that have removed most of the contaminants before aloe vera is added. But, for the removal of COD, it can be seen from figure 8(e) that the coagulant dosage increases and then decreases at flocculant dosage of 20 ml. This may be caused by the soluble organic compounds of fenugreek powder that prevent the active sites from adsorption. Based on the discussions made, it can be concluded that the require dosages of coagulant and flocculant are 24.13 g and 20 ml respectively, to achieve high removal of contaminants.

3.2.4. Zeta Potential Analysis. Zeta potential is one of the controlling parameters that affects the stability of colloid particles during the process of coagulation-flocculation. It measures the electrochemical equilibrium at the particle-liquid interface as well as the magnitude of electrostatic attraction or repulsion between particles [51]. In accordance to Chemistry LibreTexts [51], it is also known as the electrical potential in the interfacial double layer of surface particles, which is found at the slipping plane. The magnitude of zeta potential ranges from +100 mV to -100 mV. High degrees of stability occur outside the range of +30 mV to -30 mV, while magnitude between +25 mV to -25 mV promote agglomeration of particles in wastewater due to the intraparticle interactions such as van der Waals, hydrophobic interactions and hydrogen bonding [37].

The particles in colloidal suspension such as POME are usually negatively charged which have proven from the results of zeta potential analysis as per table 7. The treated POME and raw POME from the facultative pond are in the negative region and gives a negative net charge on the particles surface. However, there is a reduction in magnitude from 15.5 mV to 0.882 mV, showing that the negative net charges decrease the effectiveness of aloe vera and fenugreek as well. This led to charge neutralisation which is required in the coagulation-flocculation process. This scenario happened due to the positive charge of fenugreek and aloe vera that attract the opposite charge of colloidal particles in POME that reduce the electrostatic repulsion between particles and consequently increase the formation of flocs.

Based on table 7, the resulted analysis for both fenugreek and aloe vera are in negatively charged. These negatively charges neutralise the high acidity of the POME which it contains high concentration of hydrogen ions (H⁺), given that HCl is added and remained in the POME. Generally, zeta potential for fenugreek and aloe vera become more positive as it reacts with H⁺, simultaneously increasing the pH. Hence, the particles of fenugreek and aloe vera are in positively charged. As a result, fenugreek and aloe vera are more favourable to treat wastewater at lower pH as discussed earlier. On top of that, it is observed that the magnitudes of materials are within the range of +25 mV to -25 mV which has mentioned earlier, proving that the agglomeration of particles occurs due to intraparticle interactions. As a result, the positive charge of fenugreek and aloe vera have further verified the effectiveness as natural coagulant and flocculant respectively in treating the POME.

| Material                           | Zeta Potential (mV) |
|-----------------------------------|---------------------|
| Fenugreek                         | -13.700             |
| Aloe Vera                         | -0.488              |
| Treated POME (from final pond of oil palm mill) | -0.882 |
| Raw POME                          | -15.500             |

3.2.5. Fourier Transform Infrared (FTIR) Spectroscopy Spectral Analysis. FTIR is implied in this research to study the functional groups present in the fenugreek seeds (coagulant) and aloe vera (flocculant). Based on figure 9, the spectrums range between a wavelength of 400-4000 cm⁻¹ and show
a distinct difference between the compounds present in the fenugreek seeds and aloe vera. Typically, aloe vera showed fewer and broader bands as compared to fenugreek. The obvious peak patterns observed in figure 9(b) showed three spectral regions: 3700-2800 cm\(^{-1}\), 1800-1500 cm\(^{-1}\) and 900-400 cm\(^{-1}\). The broad adsorption spectrum observed between 3700-2800 cm\(^{-1}\) and the peak at 3259.13 cm\(^{-1}\) indicates the stretching of amine (N-H) group and hydroxyl (O-H) group, showing the presence of carbohydrate monomers such as mannose and uronic acid [21]. Furthermore, the strong and broad band centered within 1800-1500 cm\(^{-1}\) at 1636.6 cm\(^{-1}\) is associated with the asymmetric and symmetric -COO that signify the presence of carboxylate compounds in aloe vera [21]. The adsorption peak at 600.94 cm\(^{-1}\) between the wavelength range 900-400 cm\(^{-1}\) is due to the C-H out-of-plane deformation of carbohydrate monomers [21].

The adsorption spectrum of fenugreek seeds is shown in figure 9(a). The peak at 3278.99 cm\(^{-1}\) with adsorption band of 3500-3000 cm\(^{-1}\) indicates the N-H and O-H stretching vibrations that consist of protein amide A and starch fiber respectively [38]. The existence of shoulder band at 3009 cm\(^{-1}\) corresponds to the secondary amide, leading to Fermi resonance that resulted from N-H stretching with either of the overtone of amide II band in trans-amides or combination band of C=O stretching and N-H in plane binding in cis-amides. The peaks at 2924.81 cm\(^{-1}\) and 2855.07 cm\(^{-1}\) between 3000-2500 cm\(^{-1}\) specify the asymmetric and symmetric C-H stretching vibrations. The appearance of C-H group is related with aromatic rings, namely CH\(_2\) groups in fatty acids [39]. It is observed from figure 9(a) that many oscillations of peaks occur after 1800 cm\(^{-1}\). The C=O stretching vibration of lipid occurred at medium intensity of 1743.15 cm\(^{-1}\). The appearance of strong bands at 1638 cm\(^{-1}\), 1545.42 cm\(^{-1}\) and 1235.97 cm\(^{-1}\) shows the stretching of C=O (amide I), N-H (amide II) bending and N-H (secondary amide III) bending respectively. In the area of 1200-900 cm\(^{-1}\) such as the bands at 1141.4 cm\(^{-1}\) and 1025.37 cm\(^{-1}\) indicate the presence of starch. Studies carried out by El-Bahi [38] deduces that fenugreek mostly include protein, lipids, ash, fibers and soluble sugar.

From the above analysis, the similarities for fenugreek seeds and aloe vera can be concluded from the existence of N-H and O-H groups that indicate the presence of proteins, fatty acids, carbohydrates and lignin components [39]. The treatment of POME using coagulation-flocculation process involves the hydrogen bonding between O-H groups of polysaccharide and functional group of contaminants. In addition, the concentration and solubility of protein are correlated in removing the TUR and TSS from wastewater. For example, the higher the protein concentration and solubility, the higher the removal efficiencies of TUR and TSS.
3.3. Process Optimisation Analysis

Process optimisation analysis using Design Expert software was conducted to maximise the removal efficiency of TUR, TSS and COD. It explores the combination of factor levels and at the same time fulfill the criteria set on each factor and response [56]. Numerical optimisation was utilised where the goals were set ‘in range’ for each factor and ‘maximise’ for each response. This is to obtain the highest removal efficiency for each response within the desired range. The goals combined into an overall desirability function which is to maximise the effectiveness of the function [30]. The highest desirability value of 0.993 is obtained for the optimum factors and responses, given the desirability range from 0 to 1. The results obtained from this optimisation were compared with the optimum experimental values as presented in table 8. Obiora-okafo [30] reported that the maximum percentage error between the predicted and experimental values which is less than 4 shows that the model can predict the experimental results well. It is observed that the percentage errors are below 1, showing a good agreement between the predicted value and experimental value. This indicates that implementation of RSM in the coagulation and flocculation process are very effective in obtaining the optimum removal efficiencies that is almost similar as the results obtained from the experiments.
Table 8. Optimisation and comparison between the predicted and experimental optimum values.

| Factor | Coagulant Dosage (g) | Flocculant Dosage (ml) | pH | Response |
|--------|----------------------|------------------------|----|----------|
|        |                      |                        |    | TUR (NTU) | TSS (mg/L) | COD (mg/L) |
|        |                      |                        | 4  | %PV | %EV | %PV | %EV | %PV | %EV |
|        |                      |                        |    | 82.78 | 82.78 | 83.40 | 83.08 | 32.95 | 33.76 |
| % Error|                      |                        |    | 0    | 0.32 | 0.81 |

Notes: %PV = Predicted value in percentage from model; %EV = Experimental value in percentage

Desirability = 0.993

3.4. Process Performance Evaluation

The performance of using fenugreek seeds and aloe vera as natural coagulant and flocculant were evaluated. The results obtained from the process optimisation were compared with other types of natural flocculants. The optimum results of TUR, TSS and COD for each respective material used in wastewater at optimum pH and dosage were summarised in table 9.

Table 9. Summary of optimum conditions for each material used in wastewater treatment.

| Materials                  | pH  | Dosage  | TUR Removal % | TSS Removal % | COD Removal % | Effluent Type                          |
|----------------------------|-----|---------|----------------|---------------|--------------|----------------------------------------|
| Aloe Vera                  | 4   | 20 ml   | 82.78          | 83.40         | 32.95        | POME                                   |
| Banana Pith                | 4   | 0.1 kg/m3 | 98.50          | 96.03         | 54.30        | Polluted River Water [40]              |
| Banana Stem Juice          | 7   | 90 ml   | 98.50          | 88.60         | 80.10        | Spent Coolant Wastewater [41]          |
| Cassia Obtusifolia Seed Gum| 7.2 | 0.17 g/L | -              | 89.60         | 55.40        | Raw Pulp and Paper Mill Effluent [42]  |
| Chickpea                   | 6.69| 2.60 g/L | 85.50          | 88.50         | 50.80        | POME [43]                              |
| Chitosan                   | 6   | 370 mg/L | 97.70          | 91.70         | 42.70        | POME [44]                              |
| Dragon Fruit Foliage       | 2   | 300 mg/L | 99.20          | 98.8          | 48.7         | POME from three-phase decanter [12]    |
| Moringa oleifera           | 6   | 70 mg/L | 63.70          | 62.05         | 38.60        | Oil Refinery Wastewater [45]           |
| Okra                       | 6   | 3.20 mg/L | 97.24          | -             | 85.69        | Textile Wastewater [46]                |
| Opuntia Ficus-indica       | 5   | 2.6 mg/L | 91.26          | -             | 64.77        | Textile Effluent [47]                  |
| Rice Starch                | 3   | 2 g/L   | -              | 84.10         | 17.40        | POME [48]                              |
| Tapioca Starch             | 12  | 0.1 g/L | 99.00          | -             | 87.00        | Semiconductor Waste [49]               |

It can be deduced that the performance of aloe vera is acceptable and comparable with other natural flocculants. It can be observed that the removal efficiencies of TUR and TSS for natural flocculants are quite high with low removal efficiency of COD. This is because the high solubility of organic compounds is generated from natural flocculants after adding directly into the flocculation process. This high content of organic compounds increases the microbial activity, and consequently increases the COD content in wastewater [50]. Therefore, the effectiveness in removing COD is significantly lower.
than TUR and TSS. In order to improve the removal efficiency of COD, the active components exist in the natural flocculant must be extracted and tested its properties separately from the coagulation-flocculation process.

4. Conclusion
RSM with CCD was utilised to study the various effects such as pH, coagulant dosage and flocculant dosage on TUR, TSS and COD removal percentage from POME. The optimum combination of the operating parameters that yields the optimum TUR, TSS and COD removal was determined. The results clearly showed that the removal efficiencies are highly influenced by the operating parameters. Based on the process optimisation analysis, the maximum removal efficiency for TUR, TSS and COD are 82.78 %, 83.40 % and 32.95 % respectively. An optimal condition of pH 4, 24.13 g of coagulant dosage and 20 ml of flocculant dosage were obtained from the compromise of the three desirable responses. The maximum error is below 4 % which indicate that the predicted value in agreement with experimental value. This proves that modelling and optimisation of the coagulation-flocculation process can be achieved by RSM approach. It is an economical way of obtaining the maximum amount of information in a short period of time with minimum number of experimental trials.

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