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Stabilized sanitary landfill leachate treatment using anionic resin: Treatment optimization by response surface methodology

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ABSTRACT

The treatability of stabilized sanitary landfill leachate via synthetic anion exchange resin (INDION FFIP MB) was investigated. An ideal experimental design was conducted based on central composite design using a response surface methodology to assess individual and interactive effects of critical operational variables (i.e., anionic dosage; contact time; shaking speed) and pH on treatment performance in terms of color, chemical oxygen demand (COD), suspended solid (SS), and turbidity removal efficiencies. Optimum operational conditions were established as 30.9 cm^3 anionic dosage, 90 min contact time, 150 rpm shaking speed, and pH 3.1. Under these conditions, the color, COD, SS, and turbidity removal efficiencies of 91.5, 70.3, 93.1, and 92.4% were experimentally attained and were found to fit well with the prediction model. According to these results, stabilized leachate treatment using INDION FFIP MB could be an effective alternative in the administration of color, COD, SS, and turbidity problems of landfill leachates.

1. Introduction

In Malaysia, sanitary landfill is the most common disposal method – not to mention the simplest and cheapest-for municipal solid wastes [1]. Approximately 95% of the collected municipal solid wastes (approximately 17,000 tons daily) are disposed in more than 230 landfills. One typical problem associated with landfill disposal is the generation of leachates. Normally, landfill leachates contain large amounts of organic and inorganic matter such as chemical oxygen demand (COD), biological oxygen demand (BOD), ammonium nitrogen, suspended solids (SS), turbidity, color, and heavy metals. Leachates can travel away from the landfill and cause severe pollution to groundwater aquifer and neighboring surface water. Accordingly, landfill leachate production and management are recognized as critical problems linked to the environmental processing of sanitary landfills [2–8].

Leachates from stabilized landfills contain lower levels of pollutants compared to young leachates (i.e., leachates from landfills of less than five years). Typically, young leachates are characterized by high BOD5 (4000–40,000 mg/L), high COD (6000–60,000 mg/L), NH_3–N (<400), BOD5:COD ratio typically $\leq$1.0, and pH range from 4.5 to 7.5 [9,10]. Studies have shown that landfills older than five years produce stabilized leachates with low biodegradability. In this stage, leachates produce large amounts of non-biodegradable organic compounds with high molecular weights, such as humic and fulvic substances, that are not easily degradable. Stabilized landfill leachates are normally characterized by moderately high strengths of COD (500–4500 mg/L), low BOD (20–550 mg/L), high NH_3–N (>400), a pH range of 7.5–9.0, and a BOD5:COD ratio of <0.1 [9,10]. Due to its characteristics, a stabilized leachate is difficult to treat using biological processes [3,6].

Several technologies of water and wastewater treatment have been applied to treat leachates. These include aerobic and anaerobic biological treatment [11,12]; chemical precipitation [13,14]; coagulation–flocculation [8,15,16]; adsorption using various adsorbents [5,17,18]; reverse osmosis (RO) for the removal of heavy metals, suspended/colloidal materials, and dissolved solids [19,20]; membrane processes [11,21]; chemical and electrochemical oxidation processes [7,22,23]; and ion exchange [24–26].

Ion exchangers refer to insoluble solid materials that carry transferable cations or anions. In an electrolyte solution, ions switch with a stoichiometrically equivalent amount of other same-sign ions when used with an ion exchanger [27]. Solid ion-exchange particles are classified as natural-inorganic particles (zeolites) and synthetic-organic resins [28]. Synthetic ion-exchange resins are widely and effectively applied by many for removing metal ions from water and wastewater [29–35]. Recently, the ion exchange technique has received considerable attention for the removal of organic substances (i.e., humic and fulvic substances) [36] and ion substances. According to Tan and Kilduff [37], and Li and SenGupta [38], ion-exchange resins are effective in eliminating natural and synthetic organic compounds that contain weak-acid functional groups such as carboxylic acid groups.

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To date, very few studies have been conducted on the treatment of stabilized leachates using the ion exchange technique. Most of them have been focused on the removal of ions, or using ion exchange applications, as a polishing step in the treatment of landfill leachates [39]. Primo et al. [39] investigated ion exchange as a polishing step after electrochemical oxidation for nitrate removal from landfill leachates using anionic resin. Different types of ion exchangers have been used for the removal non-biodegradable organic matter from landfill leachates that are effluent after biological treatment [17].

Majone et al. [24] effectively employed ion exchange technique for the removal of Cd (II) and Ni (II) from landfill leachates. However, a review of literature has shown that the ion exchange resin is rarely employed in landfill leachate treatments, particularly, for non-biodegradable matters (measured as COD) and color. In addition, optimization of pollutant removal efficiency via anionic resin using statistical methods for experimental design and data analysis has not been documented in literature. Therefore, this study focuses on the treatment of stabilized leachates generated from Pulau Burung Landfill Site (PBLS) in Penang, Malaysia. In the present study, response surface method (RSM) using the Design Expert 6.0.7 software was employed for the optimization of color, COD, SS, and turbidity reduction (dependent variables) from stabilized leachates via anionic resin (INDION FFIP MB). The runs were designed in accordance with the central composite design, and then carried out using a batch technique. Four factors, namely, anionic dosage, contact time, shaking speed, and pH, were selected as operational (independent) variables. The main objectives were to optimize the process and to investigate the factors influencing the removal efficiency, as well as to build up the equations describing the color, COD, SS, and turbidity removal efficiency from stabilized leachates with respect to operational conditions using RSM and CCD.

2. Materials and methods

2.1. Pulau Burung landfill site (PBLS) characteristics

PBLS is located within the Byram Forest Reserve at latitude 5°12′03″N and longitude 100°25′24″E in Penang, Malaysia. The site has an area of 62.4 ha, of which 33 ha are currently operational and receiving 1800 tons of municipal solid waste daily [7]. PBLS started its operation in 1991 as a semi-aerobic system complying with Level II sanitary landfill standards by establishing a controlled tipping technique. In 2001, PBLS was upgraded to a Level III sanitary landfill by employing controlled tipping with leachate recirculation [40]. The stabilized leachates from this landfill are characterized as a dark-colored liquid with pH greater than 7.0, and with high concentrations of NH_3–N, high COD value, and low BOD/COD ratio [7].

2.2. Anion exchange resin characteristics

The commercially available synthetic resin, INDION FFIP MB (Ion Exchange Ltd., India), was used in this study as an anionic exchanger resin. The selected resin and its physicochemical properties are presented in Table 1. INDION FFIP MB was selected due to its characteristics. It is a strong base anion exchange resin that can be used in its hydroxide and chloride forms, and can be applied in a wide operational pH range.

2.3. Experimental procedures

Stabilized leachate samples (20 L per sample) were collected three times during the period January to May 2009 from the aeration pond at PBLS. The samples were transported to the laboratory and stored in a refrigerator at 4 °C prior to experimental use in order to avoid biological activities and alterations in the sample. Before the experiments, the resin was washed with distilled water to remove adhering dirt. The washing was followed by filtration using GC-50 filter papers (Advantec Toyo Kaisha Ltd., Japan) with 0.45 μm pore size, vacuum-pumped, and then dried at room temperature [25].

Table 1
Main physicochemical properties of the studied resins.

Property	INDION FFIP MB
Type	Strongly base anion exchange resin
Matrix	Cross-linked polystyrene and isoporous type
Functional group	Quaternary amine ($-N+R_3$)
Ionic form (as supplied)	Chloride
Maximum operating temperature	60 °C (OH^- form); 90 °C (Cl^- form)
Operating pH range	0–14
Particles size range	0.45–0.55 mm
Total exchange capacity	1.2 mequiv./mL
Appearance	Brown to dark brown

Properties given by the manufacturer.

All experiments were conducted by shaking 100 mL of the leachate sample in a 300 mL volumetric flask using an orbital shaker (Bioblock Scientific Agitator 74578). The operation parameters used were contact time, amount of exchanger resin, shaking speed, and pH. After each run, the supernatant was filtered by GC-50 filter prior to the conduct of tests for color, COD, SS and turbidity. Chemical analyses were carried out in accordance with the standard methods for the examination of water and wastewater [41]. Thirty experiments incorporating the four factors were employed using the Design Expert 6.0.7 software. All experiments and measurements were done in triplicate to ensure repeatable results. Removal efficiency was obtained using the equation

$$\text{Removal}\,(\%) = \frac{(C_i - C_f)}{C_i} \times 100 \qquad (1)$$

where C_i and C_f are the initial and final concentrations of the parameters, respectively.

2.4. Analytical methods

All tests were conducted in accordance with the standard methods for the examination of water and wastewater [41]. Color concentration was measured by DR 2010 HACH spectrophotometer based on the Method No. 2120C. COD concentration was determined using the closed reflux and colorimetric method of Method No. 5220D. Suspended solids were determined by DR 2010 HACH spectrophotometer based on Method No. 2540D. Turbidity was measured by DR/2010 set at 860 nm according to Method No. 8237. Color was measured as platinum cobalt (Pt-Co).

2.5. Experimental design and analysis

The central composite design was established with the help of the Design Expert 6.0.7 software for the statistical design of experiments and data analysis. The RSM was used to determine the optimum process parameter levels. RSM is a collection of mathematical and statistical techniques that are helpful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [42,43].

The four significant process variables considered in this study were: anionic exchanger dosage (X_1), contact time (X_2), shaking speed (X_3), and pH (X_4). The actual values of process variables and their variation limits were selected based on the values obtained in preliminary experiments and coded as shown in Table 2. Performance of the process was evaluated by analyzing the response of

Table 2
Experimental range and levels of independent process variables.

Independent process variables	Code	Real values of coded levels		
		−1	0	1
Dosage (cm^3)	X_1	5	20	35
Contact time (min)	X_2	5	47.5	90
Shaking speed (rpm)	X_3	0	75	150
pH	X_4	3	5.65	8.3

Table 3
Characteristics of stabilized landfill leachate taken from PBLS (January to May 2009).

Parameters	Values
Chemical oxygen demand (mg/L)	2380–2850
BOD (mg/L)	40–160
NH_3–N (mg/L)	1820–2200
Color (Pt-Co)	5330–5760
Turbidity (FAU)	128–162
SS (mg/L)	114–131
pH	8.3–9.10
Conductivity (μS/cm)	22,250–25,060

color, COD, SS and turbidity removals efficiencies. The total number of experiments with four factors was obtained as 30 ($=2^k+2k+6$), where k is the number of factors (=4). Twenty-four experiments were enhanced with six replications at the design center to assess the pure error. As there are only three levels for each factor, the appropriate model is the quadratic model Eq. (2):

$$Y = \beta_0 + \sum_{j=1}^{k}\beta_j X_j + \sum_{j=1}^{k}\beta_{jj}X^2 + \sum_{i}\sum_{<j=2}^{k}\beta_{ij}X_iX_j + e_i \qquad (2)$$

where Y is the response, X_i and X_j are variables, β_0 is a constant coefficient, β_j, β_{jj} and β_{ij} are interaction coefficients of linear, quadratic and the second order terms respectively, k is the number of studied factors, and e_i is the error. Generally, the quadratic model is used to predict optimal conditions. Analysis of variance (ANOVA) was used for graphical analyses of the data to obtain the interaction between the independent (process) variables and the dependent variables (responses). The quality of the fit polynomial model was expressed by R^2 (coefficient of determination), and its statistical significance was checked by the F-test. Model terms were estimated the probability (P-value) with a 95% confidence level [8]. Three-dimensional plots were obtained for color removal, COD removal, SS removal and turbidity removal.

3. Results and discussion

As shown in Table 3, stabilized leachates generated from PBLS had a high concentration of COD with high-intensity color due to the presence of high molecular weight organic compounds. The concentration of NH_3–N was also high in raw leachates (1820–2200 mg/L). However, low BOD_5 values were observed (80–160), which gives a low BOD_5:COD ratio of <0.1. Due to its characteristics, Pulau Burung raw leachates are recognized highly stabilized leachates with low biodegradability. Therefore, physico-chemical treatment processes are required.

3.1. Experiment results

Thirty experimental conditions of the runs organized by the CCD were conducted in the laboratory to determine corresponding results (responses). Process performance was evaluated by analyzing the experimental results of all responses. Effects of the experimental conditions (anionic dosage, contact time, shaking speed, and pH) on the responses were monitored; they are presented as three-dimensional (3D) surface plots in Figs. 1–4. In Fig. 1a, minimum removal performance of color (29%) was observed at 5 cm^3 dosage, 90 min contact time, 0 rpm shaking speed, and pH 8.3, while maximum removal efficiency of color was 69.4% at 35 cm^3 dosage, 90 min contact time, 150 rpm shaking speed, and pH 8.3. Fig. 1b shows that color removal increased with an increase in dosage and decrease in pH. With a dosage of 35 cm^3, contact time of 90 min, shaking speed of 150 rpm, and pH of 3, the maximum color removal efficiency was 94%.

Fig. 2a and b shows the effect of operational parameters on COD removal efficiency. COD removal increased with rise in dosage, shaking speed, and contact time. With an influent of pH 3, the anionic dosage of 35 cm^3, contact time of 90 min, shaking speed of 150 rpm, the maximum COD removal efficiency was 72%. Minimum COD removal (18.2%) was obtained with an influent pH of 8.3, anionic dosage of 5 cm^3, contact time of 5 min, and shaking speed of 0 rpm. Fig. 3 represents the effect of operational variables on SS removal efficiency, where 61.3% of SS was removed at an anionic dosage of 35 cm^3, contact time of 90 min, shaking speed of 150 rpm, and pH of 8.3. Maximum SS removal efficiency (92.4%) was obtained with an anionic dosage of 35 cm^3, contact time of 90 min, shaking speed of 150 rpm, and pH of 3.0. Using an anionic dosage of 5 cm^3, contact time of 5 min, shaking speed of 0 rpm, and pH of 8.3, the SS removal efficiency was 26.5%. The effect of experimental conditions on turbidity removal efficiency is presented as 3D surface plots in Fig. 4. The figure indicates that turbidity removal efficiency increases when the anionic dosage, contact time, and shaking speed are increased, while removal efficiency is increased when pH value is decreased. Maximum turbidity removal efficiency was 91.8% at an anionic dosage of 35 cm^3, contact time of 90 min, shaking speed of 150 rpm, and pH of 3.0.

The abovementioned results indicate that anion exchange resin can be effectively used for the reduction of color, COD, SS, and tur-

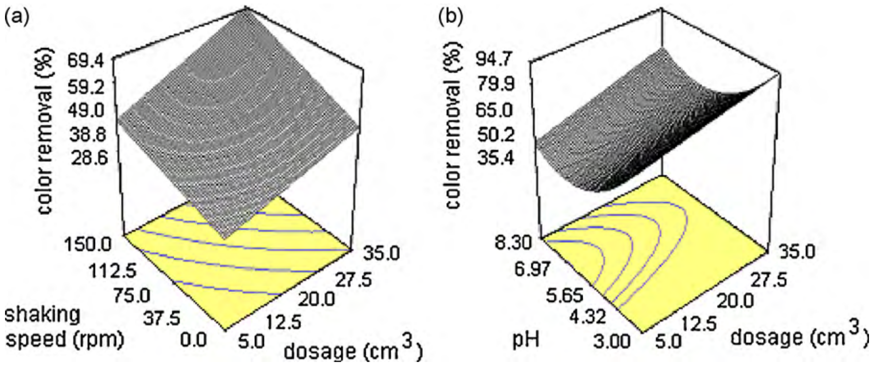


Fig. 1. 3D surface plots for color removal efficiency: (a) the effect of anionic dosage and shaking speed on color removal (contact time: 90 min; pH: 8.3); and (b) the effect of anionic dosage and pH on color removal (contact time: 90 min; shaking speed: 150 rpm).

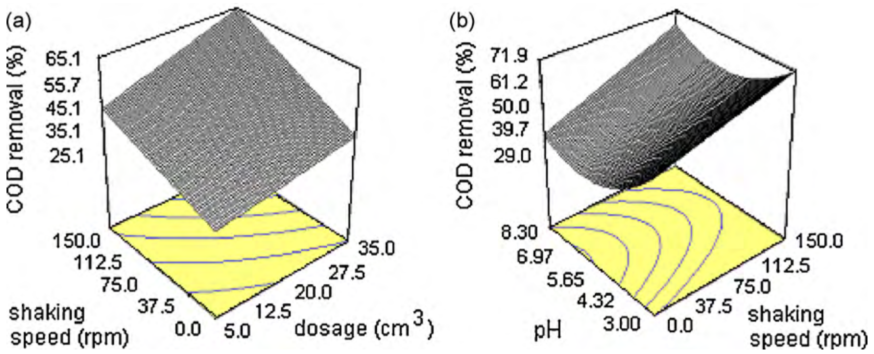


Fig. 2. 3D surface plots for COD removal efficiency: (a) the effect of anionic dosage and shaking speed on COD removal (contact time: 90 min; pH: 8.3); and (b) the effect of shaking speed and pH on COD removal (contact time: 90 min; dosage: 35 cm^3).

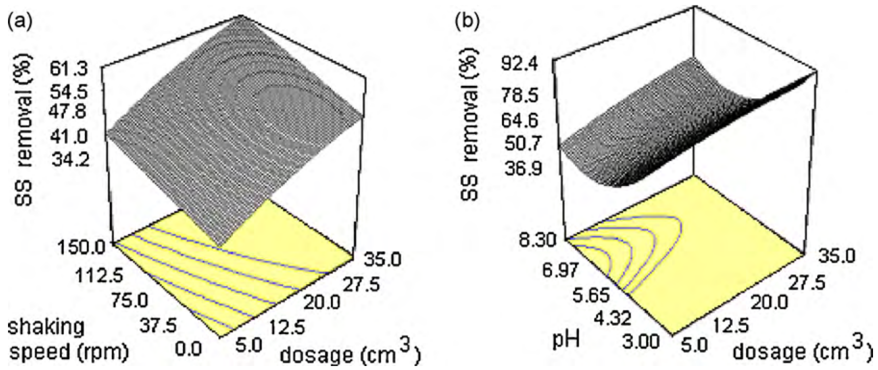


Fig. 3. 3D surface plots for TSS removal efficiency: (a) the effect of anionic dosage and shaking speed on TSS removal (contact time: 90 min; pH: 8.3); (b) the effect of dosage and pH on TSS removal (contact time: 90 min; shaking speed: 150 rpm).

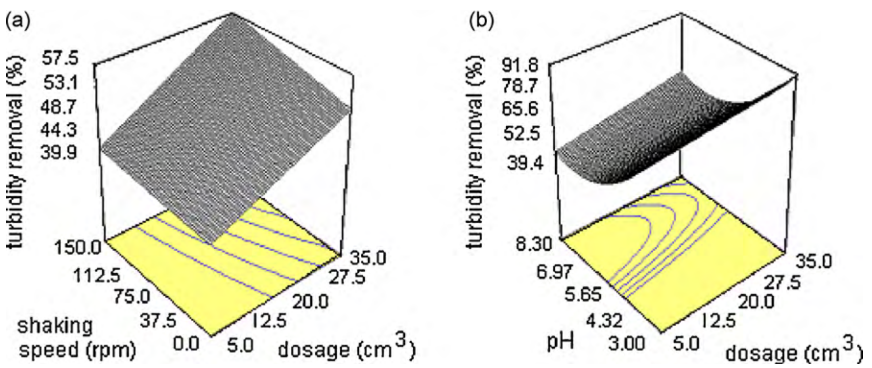
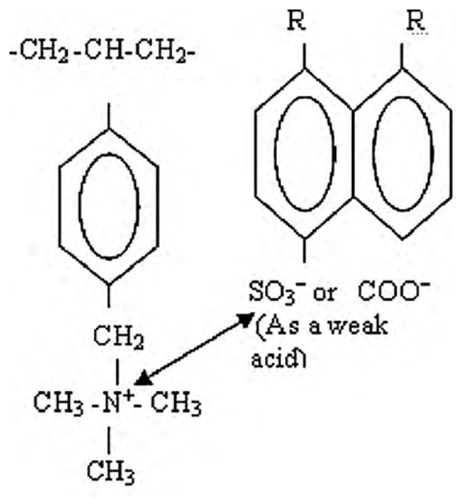


Fig. 4. 3D surface plots for turbidity removal efficiency: (a) the effect of anionic dosage and shaking speed on turbidity removal (contact time: 90 min; pH: 8.3); and (b) the effect of dosage and pH on turbidity removal (contact time: 90 min; shaking speed: 150 rpm).

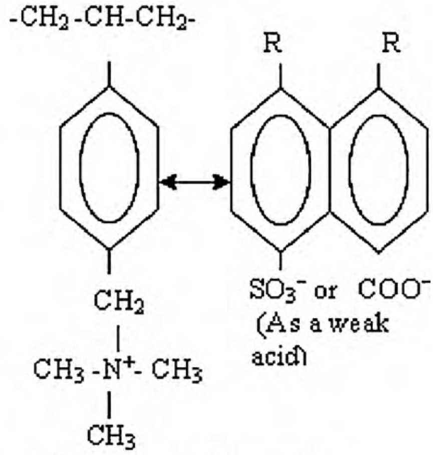
bidity from stabilized landfill leachates. It is well known that the removal of color and COD – considered as complicated pollutants from stabilized leachates – is an indicator of non-biodegradable organic substance reduction, particularly humic and fulvic substances. The obtained results are compatible with other studies that have investigated the performance of anionic resin with organic compounds [17,38,44]. Bolto et al. [44] indicated that anion exchange resin can be effectively used for removing organic substances from drinking water. According to them, quaternary ammonium resins containing polar groups are especially effective for this process. According to Li and SenGupta [38] and Gottlieb [45], many synthetic and natural organic substances contain weak acids containing carboxylic or sulfonic acid groups. These substances are soluble and exist as ions in the aqueous phase. Removal of organic compound occurs in two ways, as illustrated in Fig. 5 [38]; their characteristics can be described as follows:

(i) Ion exchange (polar attractions): This involves counterion displacement from the anionic resin phase and electrostatic interaction between the positively charged quaternary ammonium functional group of the exchange resins and the negatively charged carboxylic or sulfonic groups.
(ii) Physical adsorption (non-polar attractions): This involves Van der Waals interactions between the non-ionic head and the ion exchanger's hydrophobic polystyrene matrix.

Consequently, appropriate balance of polar and non-polar regions in the resin structure is required [44]. Uptake of the hydrophobic ionizable organic compounds that contain two primary constituents, namely, non-polar aromatic head groups and ionic charges via anion exchange resin, essentially follows an ion exchange stoichiometry. However, ion exchange selectivity is governed by the size of the non-polar head group and ionic charge [38].



(i) Ion Exchange



(ii) Physical Adsorption

Fig. 5. A schematic illustration the mechanism of dissolved synthetics and natural organic compounds uptake via anion-exchange-mediated: (a) ion exchange and (b) physical adsorption.

In Germany, the removal of natural organic compounds by anionic resin was investigated by Fettig [36]. Up to 60% of the organic substances were removed by anionic resin. Similarly, approximately 59% of COD were removed from landfill leachates after biological treatment via anion exchange resin [17].

3.2. Analysis of variance (ANOVA)

The application of RSM offers an empirical design to relate the response and test variables based on parameter estimation [42]. By applying the factorial regression analysis on the experimental data, responses and factors can be related by polynomial equations. Final quadratic models obtained for each response has been expressed by the following second-order polynomial equations. X_1, X_2, X_3 and X_4 are model terms that represent the operation variables.

ANOVA results for responses which are presented in Table 4 confirm the adequacy of the quadratic model (the Model Prob > F is less than 0.05). F-value of the models implied that the model is significant for inversed color, COD, SS, and turbidity removal percentage. Adeq Precision measures the signal to noise ratio and a ratio greater than 4 is desirable. As a result, Adeq Precision for the color,COD, SS, and turbidity removals were 52.11, 23.43, 74.49 and 46.27, respectively. The values indicate that adequate signals for the models can be used to steer the design space [46]. The values of correlation coefficient (R^2) of color, COD, SS, and turbidity removal model were 0.9906, 0.9224, 0.9973 and 0.9893, respectively. This indicates that only 0.94, 7.76, 0.27 and 1.07%, respectively, of the total variation could not be explained by the observed model, and expresses well enough quadratic fits to navigate the design space. The R^2 should be at least 0.80 for a good fit of a model. The R^2 value obtained in the present study for these response variables was higher than 0.80, indicating that the regression models explained the reaction well [47].

Fig. 6 shows the normal probability plots of the studentized residuals for (a) color removal, (b) COD removal, (c) SS removal, and (d) turbidity removal. A normal probability plot of residuals indicates whether the residuals follow a normal distribution, in which case the points will follow a straight line. Some scattering is expected even with normal data [48,49]. It can therefore be concluded from Fig. 6 that the data is normally distributed. The predicted versus actual value plots of responses are presented in Fig. 7. Fig. 7 indicates a good agreement between real data and the data obtained from the model. The coefficient of variance (CV) as the ratio of the standard error of estimate to the mean value of the observed response defined the reproducibility of the model. If CV of the model is greater than 10%, then the model can be considered reproducible [8,48]. According to Table 4, all models are considered reproducible.

3.3. Optimization of experimental conditions

Response surface methodology (RSM) was used to identify values of the independent variables that produce optimum values of the responses. Each independent variable was individually increased or decreased in an attempt to find the maximum responses. Then, the combination of these optimum variables was selected as the conditions for obtaining the overall maximum [49]. The optimization of experimental conditions was identified by considering color removal, COD removal, SS removal, and turbidity removal higher than the arbitrarily chosen constraint values mentioned in the plots. Two optimum conditions were predicted by Design Expert 6.0.7. According to the model, the optimized conditions occurred at anionic dosage of 30.9 cm^3, contact time of 90 min, shaking speed of 150 rpm, and pH of 3.1, and resulted in 92.4, 68.84, 92.2 and 90.6% removal of color, COD, SS, and turbidity, respectively. The second predicted optimum conditions were chosen for the treated sample without pH adjustment. By applying an anionic dosage of 35 cm^3, contact time of 74 min, shaking speed of 150 rpm, and pH of 8.3, 69.38, 65.07, 61.33, and 57.5% removal of color, COD, SS, and turbidity were achieved. An experiment was then performed to verify the optimum results. Table 5 shows that the responses obtained from the model prediction closely agree with the results obtained from the laboratory experiment.

$$\text{Color removal} = 42.66 + 8.30X_1 + 4.74X_2 + 6.68X_3 - 20.51X_4 - 4.34X_2^2 + 21.61X_4^2 + 2.40X_1X_3 + 2.53X_1X_4 + 2.41X_2X_4 + 2.90X_3X_4 \quad (3)$$

$$\text{COD removal} = 38.32 + 8.18X_1 + 4.16X_2 + 9.23X_3 - 6.04X_4 - 8.02X_2^2 + 13.63X_4^2 + 3.01X_1X_3 + 2.61X_3X_4 \quad (4)$$

$$\text{SS removal}=43.60+5.71X_1+2.07X_2+3.28X_3-22.00X_4-1.80A^2+1.70X_2^2+21.60X_4^2+0.68X_1X_3+3.23X_1X_4+1.94X_2X_4+1.32X_3X_4 \quad (5)$$

$$\text{Turbidity removal} = 48.47 + 4.83X_1 + 1.71X_2 + 1.94X_3 - 20.51X_4 + 16.56X_4^2 + 1.13X_1X_3 + 2.02X_1X_4 + 1.37X_2X_4 \quad (6)$$

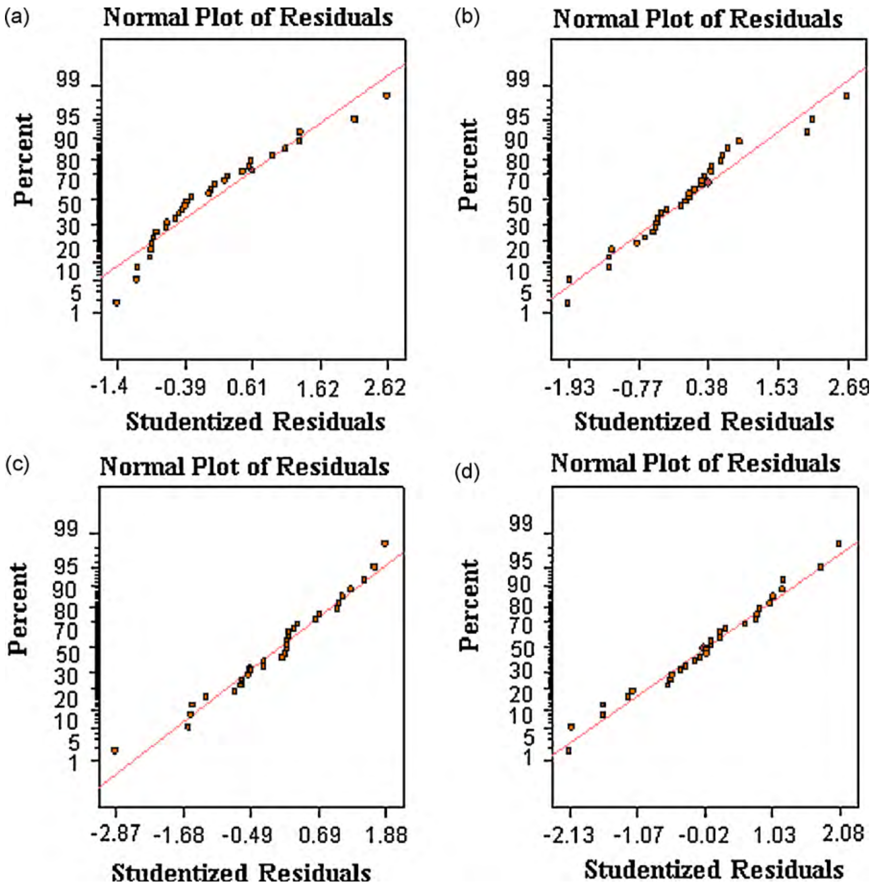


Fig. 6. Design–expert plot: normal probability plot of residuals for (a) color removal, (b) COD removal, (c) SS removal, and (d) turbidity removal.

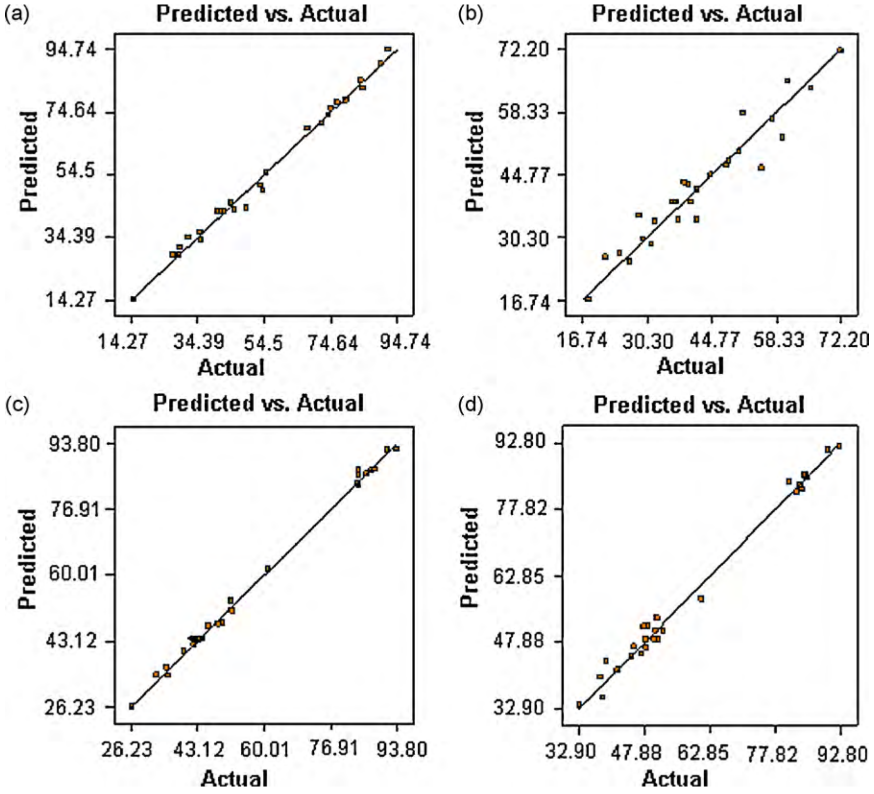


Fig. 7. Design–expert plot: predicted vs. actual values plot for (a) color removal, (b) COD removal, (c) SS removal, and (d) turbidity removal.

Table 4
ANOVA results for response surface quadratic model analysis of variance.

	Source	Sum of square	Degree of Freedom	Mean Square	F value	$P > F$
Color removal (%)	Model	12,966.6	10.0	1296.7	199.4	<0.0001
	Residual	123.6	19.0	6.5		
	Lack of fit	120.5	14.0	8.6	13.9	0.0044
	Pure error	3.09	5	0.619		
	SD = 2.55, C.V. = 4.81, PRESS = 287.6, $R^2 = 0.9906$, $R^2_{adj} = 0.9856$, Adeq Precision = 52.11					
COD removal (%)	Model	4621.7	8.0	577.7	31.2	<0.0001
	Residual	388.57	21.0	18.50		
	Lack of fit	377.78	16.0	23.61	10.9	0.0076
	Pure error	10.79	5.0	2.16		
	SD = 4.30, C.V. = 10.3, PRESS = 951.28, $R^2 = 0.9224$, $R^2_{adj} = 0.8929$, Adeq Precision = 23.43					
SS removal (%)	Model	13,181.8	11.0	1198.35	608.3	<0.0001
	Residual	35.46	18.0	1.97		
	Lack of fit	31.34	13.0	2.41	2.9	0.1212
	Pure error	4.11	5.0	0.82		
	SD = 1.40, C.V. = 2.48, PRESS =133.57, $R^2 = 0.9973$, $R^2_{adj} = 0.9957$, Adeq Precision = 74.49					
Turbidity removal (%)	Model	10,203.0	8.0	1275.38	243.5	<0.0001
	Residual	109.98	21.0	5.24		
	Lack of fit	102.41	16.0	6.40	4.2	0.0594
	Pure error	7.57	5.0	1.51		
	S.D. = 2.28, C.V. = 3.91, PRESS = 285.22, $R^2 = 0.9893$, $R^2_{adj} = 0.9853$, Adeq Precision = 46.27					

Table 5
Optimum response results from model prediction and laboratory.

Conditions	Responses (removal (%))			
	Color	COD	SS	Turbidity
Optimization (at pH 3.10)				
Model prediction results	92.4	68.84	92.2	90.58
Laboratory results	91.5	70.3	93.1	92.4
Optimization (at pH 8.3)				
Model prediction results	69.38	65.07	61.33	57.5
Laboratory results	67.8	60.9	64.1	61.1

3.4. *Process efficiencies and limitations*

Due to their unique properties, such as on excellent ion exchange and adsorption, synthetic anion exchange resin was effectively employed in the post-treatment process for the removal of negative ion contaminants [39] and recalcitrant organic substances [17] from the treated landfill leachates. Anionic resin has the ability to remove polar and non-polar contaminants [44]. In this study, an anion exchanger was effectively used as a pre-treatment process to treat stabilized landfill leachates for color, COD, SS, and turbidity. Moreover, by comparing with other techniques applied for Pulau Burung stabilized leachate treatment, the obtained results were found to be promising: 91.5, 70.3, 93.1, and 92.4% removal of color, COD, SS, and turbidity, respectively. Only 86.4 and 62.8% of color and COD, respectively, were removed via alum coagulant [8]. Treatment by electrochemical oxidation resulted in 68% COD and 84% color removal [7]. However, approximately 86.4% of COD was adsorbed from the same leachate using a carbon-mineral composite [4].

According to the present study, treatment of stabilized leachates via anion exchange resin displays some desirable benefits, including good removal efficiency, ease in operation, low running cost, and low energy consumption. However, this application has some limitations, including the overall treatment cost needed to cover the total resins required, inability of anionic resin to exchange the positive ion substances such as NH_3–N due to its mobile ion charge. In addition, this technology is not suitable for young leachate treatment since biological treatment could be effectively used prior to an ion exchange. In this study, the treated effluent was observed to contain >600 mg/L of COD, which does not meet the discharge standard in Malaysia (100 mg/L). Thus, this effluent must undergo retreatment [50]. In order to overcome this problem, a suitable balance of polar and non-polar regions in the resin structure during the manufacturing process is required [44] to match stabilized leachate characteristics. A new combination for treatment system consisting of both anionic and cationic exchangers could be more efficient and effective for the reduction of dissimilar ion substances as well as non-polar compounds from stabilized landfill leachate.

4. Conclusions

In the present study, the stabilized landfill leachate treatment, which uses the anion exchange resin (INDION FFIP MB), was optimized. This novel approach was accomplished by focusing on the influence of operating variables (i.e., anionic dosage, contact time, shaking speed, and pH) with the use of RSM with CCD. Moreover, an interaction study among all the components was investigated by employing RSM. According to the present study, the anion ion exchange resin was found effective for the removal of color, COD, SS, and turbidity at optimum efficiencies of 91.5, 70.3, 93.1, and 92.4%, respectively. This occurred at an anionic dosage of 30.9 cm^3, contact time of 90 min, shaking speed of 150 rpm, and pH of 3.1. Without any pH adjustment, 67.8, 60.9, 64.1, and 61.1% removal of color, COD, SS, and turbidity, respectively, were achieved, which are consistent with predicted results. The approximating functions for all responses were attained with high degrees of fit ($R^2 = 0.92$). Based on statistical analysis, all models proved to be highly significant with very low probability values (<0.0001). However, although results indicate that this method can be a valuable and effective alternative technique for the treatment of stabilized leachates, the COD values of the final effluent are incidentally above the limits allowed by Malaysian laws.

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