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(RESEARCH ARTICLE)

Response surface central composite design optimization of soluos dumpsite leachate treatment using agricultural biowaste

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Abstract

Process optimization plays a very important role in the process industries as it helps to miximise desire output by minimizing the cost of process variables. The aim of this work is to carry out response surface central composite design optimization of Soluos dumpsite leachate treatment using agricultural biowaste. Leachate collected from Soluos dumpsite in Lagos was treated using adsorbent prepared from *Muas sapientum* peels by studying the effects of adsorbent dosage and contact time on the percentage removal of total dissolved solids (TDS) with the aid of design expert software version 10.0.3. The developed second order regression model was adopted in comparison with the linear and two factor interaction ($2F1$) model based on its coefficient of determination (R^2) value and its adequacy by analysis of variance (ANOVA). 80.34 percentage removal of TDS was achieved under experimental process at contact time of 120 mins and dosage of 1 g/100mL while 81.134 percentage removal of TDS was obtained under simulation process at contact time of 63.469 mins and dosage of 0.994 g/100 mL. the values obtained under simulation condition were adopted as the optimum conditions. The developed second order regression model predicted the experimental data up to 98.10 percent confidence level hence it is a true representation of the treatment process and can be used to navigate the design space and optimization process of treatment of Soluos dumpsite leachate.

Keywords: Biowaste; Dumpsite; Leachate; Optimization and treatment.

1. Introduction

The treatment of leachates which are generated as a result of biochemical reactions which take place during biological, physical and chemical decomposition within the wastes in the presence and absence of oxygen is very crucial because of its negative impact in the environment [1]. The composition of leachates varies is very prominent in determining the treatment process [2 – 4]. The use of biowastes for treatment of leachates should be given adequate attention because of their eco – friendliness, low cost of production and a way of getting rid of waste from the environment.

Treatment of leachates using agricultural biowastes under optimum conditions enables to achieve the best treatment for the leachates. Many scholars have worked on optimum treatment of leachates [5 - 11]. Zawawi et al (2016) [1] optimized leachate treatment with granular zeolite and feldspar. The optimization revealed the optimum condition for agitation speed was 150 rpm, the optimum pH ranged between 6 and 6.5 and the optimum mix ratio of feldspar and zeolite was 20: 20. Huda *et al.* (2017) [9] investigated on optimization of electrocoagulation process for the treatment of landfill leachate using response surface methodology. The investigation showed percentage removal of 90.23 and

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46.12 for colour and chemical oxygen demand (COD) respectively at optimum condition of 7.73, 1.16 cm and 1 g for pH, electrode distance and electrolyte concentration respectively.

Tawfiq *et al*. (2019) [8] worked on factorial design and optimization of landfill leachate treatment using tannin based natural coagulant. The work indicated that at optimum condition of tannin dosage of 0.73 g and pH of 6, the percentage removal for totoal suspended solids (TSS), colour removal, COD and ammoniacal nitrogen were 60.7, 90.7, 52.8 and 66.3 respectively. Tawfiq et al. (2020)[4] evaluated the different treatment processes for landfill leachate using low – cost agro – industrial materials. The evaluation revealed that the combined leachate and palm oil mill effluent treatment process yield the highest percentage reduction in the physicochemical parameters and heavy metals considered in the work. Perez and Espina (2021) [11] carried out comparative study on the treatment of leachate from a mine waste dump with two agricultural biowastes. The study revealed both coffee grounds and walnut shell can be used for leachate treatment than walnut shell at pH greater than 5 and contact time of 3 hrs.

It is obvious from the available literature that the optimization treatment of Soluos dumpsite leachate in Lagos State especially in term of TDS has not been given adequate attention. Therefore the aim of this work is to carry out response surface central composite design optimization treatment of Soluos dumpsite leachate treatment in term of TDS using *Musa sapientum* peels agricultural biowaste. *Musa sapientum* peels are agricultural biowastes which contribute to the volume of waste in the dumpsites. Using *Musa sapientum* peels for treatment of dumpsite leachates reduces the volume of wastes which might get to dumpsites thereby decreasing the volume of leachate which will be generated from the dumpste wastes which justifies this work. The treatment of leachates averts the inherent dangers the leachate posed to surface and groundwater as well as vegetation which further justifies this work.

2. Methodology

2.1. Preparation of Adsorbent

Musa sapientum peels agricultural biowastes were sourced from a local market in Epe area of Lagos State, Nigeria. The peels were washed with water to remove any undesirable material. The peels were carbonized at a temperature of 600 ^{o}C for a period of 1 hr in furnace. The char product was then cooled with water at – 4 ^{o}C and then transferred into an oven for further drying at temperature of 110 ^{o}C. The impregnation of the activated carbon was carried out with tetraoxosulphate (vi) (H_2SO_4) (10 % by weight) followed by heating in the absence of air. The resultant moist paste was charged into the furnace and heated for 1 hr at a temperature of 110^{o}C until a constant weight of activated carbon was obtained. The chemical activation was done to remove the tar in the pores of the activated carbon. The activated carbon was then rinsed thoroughly with distilled water to remove the remaining H_2SO_4. The activated carbon was dried in an oven at a temperature of 110^{o}C for 3 hrs. The prepared activated carbon was then crushed with the aid of a mortar to size of 100 mesh.

2.2. Leachate Collection and Characterisation

Raw leachate was collected from Solous dumpsite in Alimosho Local Government area of Lagos State, Nigeria. Soluos dumpsite was choosen for collection of leachate among the four major dumpsites in Lagos State because of the Alimosho general hospital and Lagos State mini water corporation directly adjacent to the dumpsite. The TDS of the raw leachate was done using the standard methods for examination of water and wastewater prescribed by American Public Health Association (APHA, 2005) [12].

2.3. Experimental Design

Table 1 Summary of experimental design

Factor	Unit	Minimum	Maximum
Absorbent dosage (B)	g / 100 mL	0.1	1.0
Contact time (A)	hr	30	120

Response Surface Methodology (RSM) is a mathematical tool which provides better optimisation response and understanding of an experiment bty supplying the software with proper information which then gives an accurate prediction response [13 – 14]. The experiment was designed using response surface central composite design (RSCCD) modeling technique of Design Expert software version 10.0.3. 13 various experimental runs were generated for the two factor design. The summary of the design parameters is shown in Table 1 where the minimum and maximum depict the lowest and highest values used for the experimental design.

2.4. Treatment of Soluos Dumpsite Leachate

13 various beakers, each with 100 mL of leachate were labeled L 1 – L 13. Different adsorbent dosages ranging between 0.1 and 1.0 g/ 100 mL were added to the leachate in the beakers. The beakers and the contents were agitated with a shaker at 150 rpm for various contact time varying between 30 and 120 mins after the mixtures were left to settled and then filtered. The concentrations of TDS in the filtrated were determined using the standard methods for examination of water and wastewater prescribed by American Public Health Association [12]. The percentage removal of TDS, θ , for each experimental run was calculated using Equation (1).

$$\theta = \left(\frac{c_O - c_i}{c_o} \right) \times 100 \quad (1)$$

Where c_o is the initial concentration of TDS in raw leachate [=] mg/L and c_i is the concentration of TDS in treated leachate [=] mg/L.

2.5. Statistical Analysis of Treatment of Soluos Dumpsite Leachate

Experimental data were analysed with the aid of Design Expert version 10.0.3 software to generate regression analysis, ANOVA and response surface plot of the variable factors. The regression models and the adequacy of the models were tested by comparing the R^2, the predicted R^2 and the adjusted R^2 value [15]. The predicted responses of percentage removal of TDS were plotted against the experimental responses of percentage removal of TDS in order to determine the correlation between the predicted and experimental responses.

2.6. Optimization Technique

RSCCD numerical optimization technique using desirability function was applied to the developed regression model. The upper limits were 1 g/100 mL and 120 mins for dosage and contact time respectively while the lower limits were 0.1 g/ 100 mL and 30 mins respectively. The optimization was targeted to maximize the percentage removal of TDS from the Soluos dumpsite leachate in the range of dosage and contact time.

3. Results and discussion

Table 2 Response Surface Analysis

Experimental runs	Contact time (A) (mins)	Adsorbent dosage (B) (g/100 mL)	% Removal of TDS
1	30	0.1	49.67
2	75	0.55	71.23
3	75	0.55	71.23
4	75	1	80.34
5	75	0.55	71.23
6	120	0.1	59.24
7	30	1	76.85
8	120	0.55	66.96
9	75	0.55	71.23
10	75	0.1	55.57
11	120	1	80.34
12	75	0.55	71.23
13	30	0.55	62.34

Table 2 depicts the experimental design and response surface analysis for percentage removal of TDS from Soluos dumpsite leachate. The dosage ranged between 0.1 AND 1.0 g/100 mL while the contact time varied between 30 and 120 mins. The percentage removal of TDS ranged between 49.67 and 80.34. The least percentage removal of TDS achieved was 49.67 at contact time of 30 mins and dosage of 0.1 g/100 mL while the highest percentage of TDS removal was 80.34 at contact time 120 mins and dosage of 1 g/100 mL.

3.1. Statistical Analysis and Modelling

Table 3 shows the model summary statistics which focuses on the model maximizing the R^2, adjusted R^2 and the predicted R^2 [14]. From Table 3, the linear model has standard deviation, R^2 adjusted R^2 and predicted R^2 value of 3.05, 0.9101, 0.8921 and 0.8435 respectively. The 2FI model has the same values for standard deviation, R^2 and adjusted R^2 as that of linear model but the predicted R^2 value was 0.7988 which differed from that of linear model. The second order regression model has standard deviation, R^2 adjusted R^2 and predicted R^2 value of 1.68, 0.9810, 0.9675 and 0.8662 respectively. It is clear from Table 3 that the second order regression model has the highest R^2 value of 0.9810, the least standard deviation of 1.68 and the difference between adjusted and predicted R^2 value was 0.1013 which was less than 0.2. According to Alaya – Ibrahim *et al.* (2018) [13] and Salami *et al.* (2021) [14], a model can be adopted to fit experimental data if the difference between the adjusted and predicted R^2 values is less than 0.2. Based on this, the second order regression model shown in Equation (2) in coded form was selected.

Table 3 Statistical Analysis and Modeling Summary of Statistics

Source	Standard deviation	R^2	Adjusted R^2	Predicted R^2
Linear	3.05	0.9101	0.8921	0.8435
2FI	3.05	0.9101	0.8921	0.7988
Second order model	1.68	0.9810	0.9675	0.8662

$$\theta = 70.52 + 2.95A + 12.18\ B - 1.52AB - 4.09A^2 - 0.79B^2 \quad (2)$$

Table 4 presents the ANOVA of selected response model which was used for the establishment of the adequacy of the chosen second order regression model. From Table 4, the F and P value were 72.34 and $\prec 0.0001$ respectively. This indicates that the selected second order regression model is significant as the probability that the F – value of this nature will happen is less than 0.01 percent. The P values of the model terms A, B, AB, A^2 and B^2 were $\prec 0.0001$, $\prec 0.0035$, $\prec 0.0001$, 0.1124 and 0.4595 respectively. The P – value of less than 0.05 is a pointer that the model terms are significant while a P – value greater than 0.1 indicates the model terms are not significant. Therefore the model terms A, B and A^2 were taken to be significant while AB and B^2 were taken to be insignificant. In the case of presence of insignificant terms in a selected model, model reduction is necessary by jettisoning the insignificant terms as this improves the model in question. Hence the model terms AB and B^2 in Equation (2) were ignored to obtain the model shown in Equation (3).

$$\theta = 70.52 + 2.95A + 12.18\ B - 4.09A^2 \quad (3)$$

The adequate precision value of the second order regression model presented in Equation (3) was 28.92 as shown in Table 4. Adequate precision is a measurement of the signal to model ratio and a ratio greater than 0.4 is desirable [16 – 17]. This shows that the second order regression model in Equation (3) can be adopted to navigate the design space and for the process of optimization of Solous dumpsite leachate treatment.

From Table 4, it can be inferred that contact time and adsorbent dosage influence the removal of TDS from Soluos leachate dumpsite as the P – value were 0.0035 and less than 0.0035 respectively, which are less than 0.05. The F value of contact time and dosage were 18.57 and 316.99 respectively which indicated that the dosage with a higher F value has more influence on the removal of TDS from Soluos dumpsite leachate. The closer the R^2 value to unity, the better the model predicts the experimental data [19 – 22]. In this work, the R^2 value of 0.9810 revealed the adopted model in Equation (3) predicted and fited the experimental data up to 98.10 percent confidence level.

Table 4 ANOVA of selected response model

Source	Sum of Squares	df	Mean Square	F value	P value (Prob $\succ$ F)
Model	1014.83	5	202.97	72.34	$\prec$0.0001
A	52.10	1	52.10	18.57	0.0035
B	889.38	1	889.38	316.99	$\prec$0.0001
AB	9.24	1	9.24	3.29	0.1124
A^2	46.29	1	46.29	16.50	0.0048
B^2	1.72	1	1.72	0.61	0.4595
Standard deviation	1.68		R^2	0.9810	
Mean	68.27		Adjusted R^2	0.9675	
CV (%)	2.45		Predicted R^2	0.8662	
			Adequate Precision	28.92	

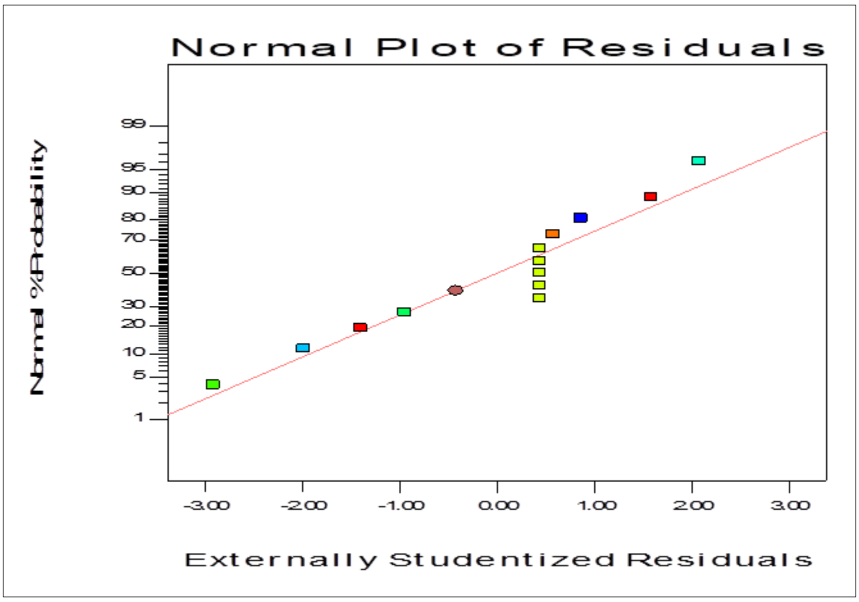

Figure 1 A graph of normal % probability against externally studentized residuals for removal od TDS in Soluos dumpsite leachate

Figure 1 depicts a graph of normal % probability against externally studentized residual for removal of TDS from Soluos dumpsite leachate. This further validates that the adopted model in this work is a true representation of Souluos dumpsite leachate treatment process and can be used to navigate the design space as well as optimization of the process. Figure 2 shows the 2 D contour plot of dosage against contact time. From Figure 2, increase in contact time, keeping dosage constant led to increase in the percentage removal of TDS. For instance, at dosage of 0.1 g/100 mL, the percentages removals of TDS were 49.67, 55.57 and 59.24 at contact time of 30, 75 and 120 mins respectively. Furthermore, increase in dosage, keeping contact time constant also resulted to increase in the percentage removals of TDS. For example, at contact time of 75 mins, the percentage removals of TDS were 55.57, 71.23 and 80.34 at dosage of 0.1, 0.55 and 1 g/100 mL respectively. This also supports the ANOVA result identifying dosage and contact time as significant terms.

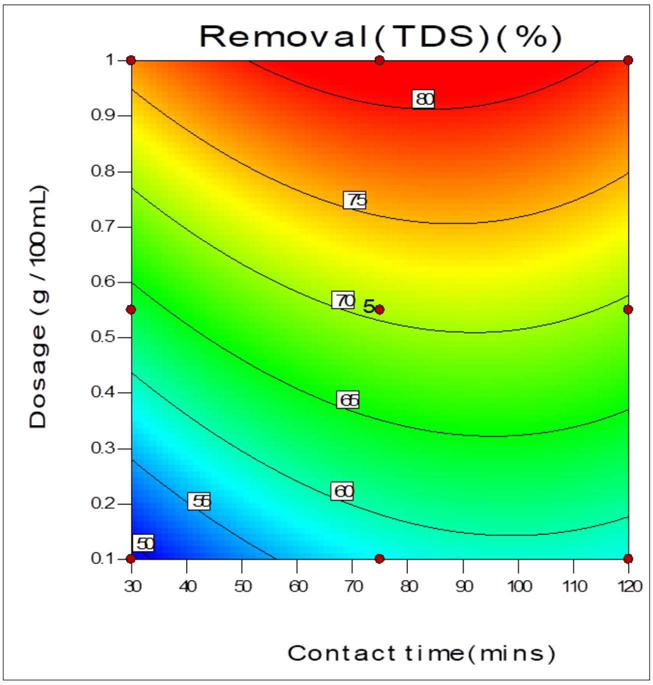

Figure 2 D contour plot of dosage againt contact time

Figure 3 reveals the 3 D plot of percentage removal of TDS against dosage and contact time. It clear that the dosage and contact time influence the percentage removal of TDS. From Figure 3, 79.17 percent removal of TDS can be achieved at contact time of 59 mins and dosage of 0.98 g/100 mlL.

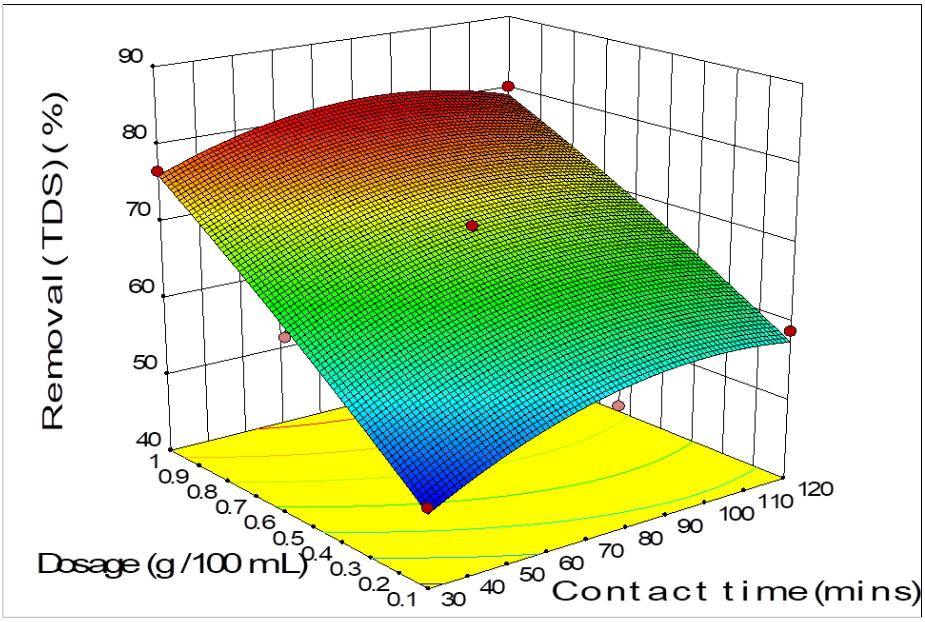

Figure 3 D plot of % removal of TDS against dosage and contact time

3.2. Numerical Optimisation of Percentage Removal of TDS

Numerical optimization component of RSM was designed mainly to replace experimental response with predictive response after studying the different effects of parameters which will result optimum response [23]. Numerical optimization was achieved with the aid of design expert version 10.0.3 software to obtain the desirability of the removal of TDS from Solous dumpsite leachate. The solution of different optimal values and the desirability of the response which varies between zero and unity is provided by the RSM software. The desirability function optimization method is a very important and attractive technique for process optimization particularly in the process industries [16, 24]. The desirability value of zero means not in agreement while the desirability value of unity indicates ideal [13 – 14]. In this work, optimization was carried out with the goal of achieving maximum percentage removal of TDS from Soluos dumpsite leachate in the range of contact time between 30 and 120 mins and dosage range between 0.1 and 1.0 g/100 mL.

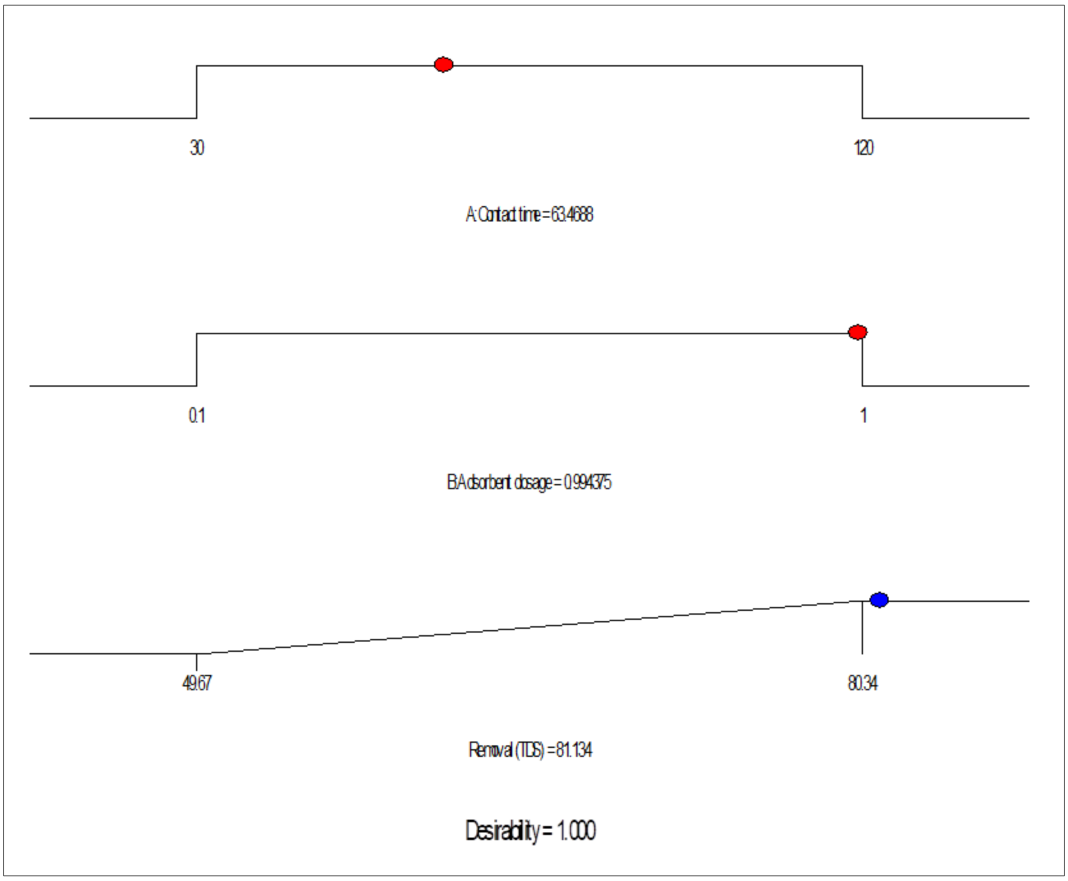

Figure 4 Ramp view desirabilty of percentage removal of TDS

Table 5 shows the numerical solution for desirability analysis. The table presents different combination of contact time, dosage percentage and the corresponding desirability. The desirability value for all the various combinations was unity which indicated they all fitted well. However, the contact time of 63.469 mins, dosage of 0.994 g/100 mL and percentage removal of 81.134 was chosen as the best combination. This is because 81.134 percentage removal of TDS from Soluos dumpsite leachate was the highest among all percentage removal of TDS which was in line with the goal of maximizing the percentage removal of TDS. Moreover, 63.469 mins was selected being the least among the contact time which also agreed with the goal of minimizing contact time. The dosage of 0.994 g/mL was also selected although it is the highest among all dosages but it was given consideration because it was obtained from agricultural waste.

The ramp view of the treatment of Soluos dumpsite leachate carried out in this work is illustrated in Figure 4. The ramp view revealed that 81.134 percent removal of TDS can be achieved at contact time of 63.468 mins and at dosage of 0.994 g/ 100mL in the range shown in Table 1 which corroborates the choice of selected in Table 5.

From the experimental data shown in Table 2, the highest percentage removal of TDS was 80.34 at contact time of 120 mins and dosage of 1 g/100 mL. The desirability results shown in Table 5 revealed the highest percentage removal of TDS to be 81.134 at contact time of 63.469 mins and dosage of 0.994 g/100 mL. the percentage removal of TDS of 81.134 is preferred though it was obtained under simulation cindition. This is because the percentage removal of 81.134 requires 63.469 mins for process time while that of 80.34 percent removal of TDS requires 120 mins and process time was given preference over dosage as the dosage was from agricultural waste but process time come with a cost. Moreover, the difference between the dosage for the experimental and simulation work was just 0.006 g/100 mL which is insignificant. Hence the contact time of 63.469 mins, dosage of 0.994 g/100 mL and 81.134 percent removal of TDS was odopted as the optimum condition in this work.

Table 5 Numerical solution for desirability analysis

S/N	Contact time	Dosage	θ	Desirability
1	63.469	0.994	81.134	1.000
2	75.563	0.978	81.392	1.000
3	90.750	0.978	81.398	1.000
4	82.875	0.966	81.251	1.000
5	107.063	0.989	80.606	1.000
6	97.532	0.951	80.508	1.000
7	90.676	0.989	81.658	1.000
8	72.517	0.999	81.797	1.000
9	70.539	0.955	80.652	1.000
10	101.702	0.970	80.661	1.000

4. Conclusion

Response surface central composite design optimisation of Soluos dumpsite treatment using biowaste has been carried out. The developed second order regression model was adopted in this work in comparism with the linear, and two factor interaction models because of its highest value of R^2 and its establishment of its adequacy by ANOVA. The developed second order regression model was taken as the true representation of the treatment process of Soluos dumpsite leachate and can be used to navigate the design space and predict the percentage removal of TDS from Soluos dumpsite. The percentage removal of TDS achieved under experimental condition was 80.34 at contact time of 120 mins and at dosage of 1.0 g/100 mL whiel 81.134 percent was obtained at contact time of 63.469 mins and at dosage of 0.994 g/100 mL under simulation condition. Contact time was given a preference over dosage and therefore a contact time of 63.469 mins, dosage of 0.994 g/100 mL and percentage TDS removal of 81.134 were adopted as the optimum conditions for the treatment of Soluos dumpste leachate.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declared that there is no conflict of interest in this work.

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