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Optimization study on sewage sludge conditioning using *Moringa oleifera* seeds

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ABSTRACT

Disposal of sewage sludge is a main problem faced by local municipalities in Malaysia. Sludge conditioned with chemical polymer often termed as undesirable use for land application. However, using natural polymer will help to reduce the impact of this problem. In this study, optimization using *Moringa oleifera* seeds as a natural polymer in sewage sludge conditioning is highlighted. An earlier sludge conditioning using jar test apparatus was conducted using *Moringa oleifera* seeds in three different forms; dry powder, distilled water extracted and salt extracted (1 N NaCl). Results from the study indicate that *Moringa oleifera* in distilled water extracted form shows the most optimum reduction in Capillary Suction Time (CST) value. Optimization of three important factors namely mixing speed, mixing duration and *Moringa oleifera* dosage for distilled water extracted form was done using Design of Experiments (DOE). Optimum values for the selected factors were obtained using Box-Behnken design, Response Surface Design Method (RSM). There was a total of seven set of optimized solutions produced. The best solution generated showed lowest CST and Specific Resistance to Filtration (SRF) was obtained at 4.5 s and 1.22×10^{11} m/kg respectively. These values were obtained under the optimum conditions of mixing speed at 100 rpm, mixing duration of 1 min and *Moringa oleifera* dosage of 4695 mg/L. The desirability index for the optimized solution was 1.000.

Keywords: Optimization; Response surface design methods; *Moringa oleifera*; Natural polymer; Sludge conditioning

1. Introduction

Domestic wastewater sludge disposal is an area of growing concern. Domestic wastewater has been identified as one of the major contributors of pollution to the environment in Malaysia [1]. With the rapid growth of Malaysia's population particularly in the urban areas, contributed largely by migration will incur higher requirement for wastewater treatment system. Sludge production in Malaysia is very dependant on the population increase and urbanization. Treatment and disposal of domestic sludge is a major consideration in a treatment process [2]. According to Bradley and Dhanagunan [3], about 9.74 million population equivalent (PE) or estimated to be 8 million people in Peninsular Malaysia were connected to a central sewage treatment

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system managed by IWK at the end of year 2001. When the population outside the IWK concession area is also taken into account, the total quantity of domestic sewage sludge produced in whole Malaysia is estimated to be 6 million m^3/year in year 2000 (total resident population of 22.2 million in year 2000).

Of the quantity of sludge collected in the year 2000, 60% is transported to existing sewage treatment facilities and discharged into the process units, 30% is disposed to drying beds and lagoons while only 10% is recycled through trenching for forestry and horticulture use. Ultimate disposal point for dried sludge from treatment facilities, drying bed and lagoons is sanitary landfill but become less attractive in the recent years as a result of scarcity of landfill capacity and the increasing cost [3].

Sludge management normally involves processes such as conditioning, dewatering, and disposal of sludge to the environment. In the total sludge treatment process from thickening to controlled dumping, sludge dewatering is one of the most important steps in reducing sludge volume and has a very big impact on total sludge treatment costs. Sludge is usually chemically conditioned to increase and improve the efficiency of dewatering. Common conditioners such as alum, ferric chloride and synthetic polymers; acrylamide or polyacrylamide based polymers have been used and studied. The cost of production of these chemicals is not only high but addition of this chemical affect the public health and detrimental to environment. Disposal of alum sludge after treatment is also believed to cause damage to the environment in Uganda [4]. Usage of acrylamide based polymers (polyacrylamide) in sludge conditioning was reported to produce trimethylamine (TMA) in limed sludges during sludge degradation [5].

Due to these disadvantages, *Moringa oleifera* as a natural polymer that is affordable and environmentally friendly has great potential to be used as conditioner for sludge conditioning and dewatering. *Moringa oleifera* seed contain water-soluble, positively charged proteins that act as an effective and excellent coagulant for treating water and wastewater [6]. Few researches had been reported on its use as a sludge conditioner [7, 8]. Ademiluyi [7] in his study compared the performance of powdered *Moringa oleifera*, ferric chloride and aluminium sulphate in sewage sludge conditioning. It was reported that the powdered *Moringa oleifera* produced comparable results with respect to cake solids concentration. Another study conducted by Muyibi *et al* [8] showed that *Moringa oleifera* seed powder performed the same as *Moringa oleifera* in water solution form but both forms performed better than oil extracted *Moringa oleifera* in gravity settling for waste activated sludge. The optimum dosages ranged from 4750 to 6000 mg/L. It was noted that optimum dosage of 4000 mg/L *Moringa oleifera* produced specific cake resistance of 2.5×10^{12} m/kg from initial of around 4.5×10^{12} m/kg.

However, previous studies on the performance of *Moringa oleifera* in sewage sludge conditioning has been limited to fixed experimental conditions; mixing speed and mixing duration. This conventional experimental method is hardly can be used to establish reliable relationships among the experimental input factors and the output responses. As a solution, design of experiment (DOE) can be applied efficiently to study the effect of factors (operating conditions) and their responses with minimum number of experiments. Under design of experiment, response surface methods (RSM) particularly Box-Behnken Design and Central Composite Design (CCD) are few of the popular method employed to find factor settings that optimize the responses (optimization process) [9,10]. RSM which is a technique for designing experiment assists researchers in building models, evaluate the effects of several factors (operating conditions) and thus achieve the optimum conditions for desirable responses [10].

The present study investigates the efficiency of *Moringa oleifera* in different forms on its sludge dewaterability after conditioning. The best form of *Moringa oleifera,* obtained from the jar test is then chosen to be tested using RSM (Box-Behnken Design) for optimization in term of optimum dosage, mixing speed and mixing duration. Two responses; Capillary Suction Time (CST) and Specific Resistance to Filtration (SRF) are monitored based on the statistical design formed.

2. Materials and methods

The methodology used in the present study can be summarized by the flow chart shown in Fig. 1.

2.1. Collection of sludge samples

Sludge samples used in the present study was settled activated sludge after clarification process collected from sludge holding tank in Sewerage Treatment Plant, Taman Tun Dr. Ismail, Kuala Lumpur, Malaysia. Temperature of the sludge samples on-site were ranging from 29 to 31°C. The sludge samples were collected between 9 and 10 in the morning and stored in a 9 L plastic container. The sludge sample was then transported back to the laboratory within 1 h after sampling. The sludge samples used for the study were kept for not more than 24 h. This is to minimize changes of the sludge samples during storage at 4°C in the refrigerator. APHA standard methods of examination of water and wastewater were followed in the analysis of samples during the experimental study [11]. Characterization of sludge samples is presented in Table 1.

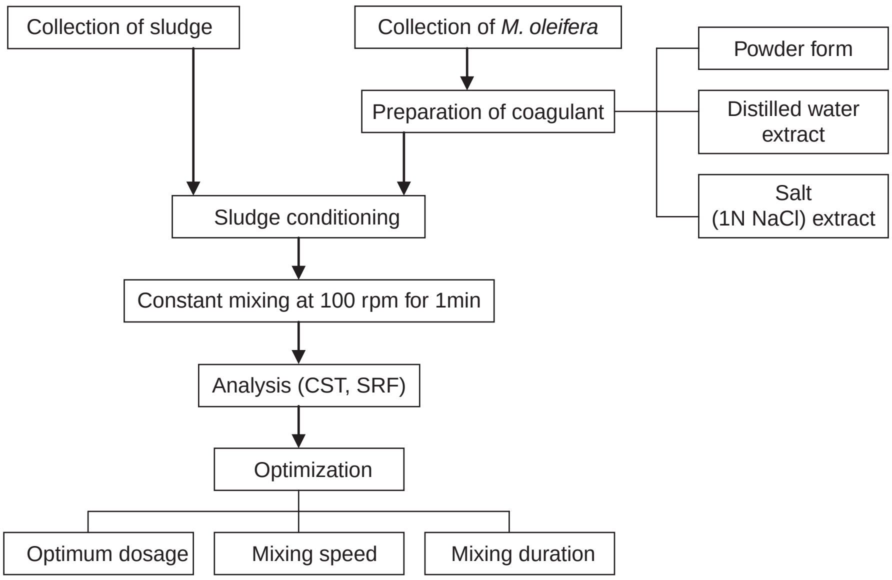

Fig. 1. Flow chart for the methodology of the present study.

2.2. Collection of *Moringa oleifera* seeds

The dry *Moringa oleifera* seeds used as a natural coagulant in this study were collected from area of Serdang, Selangor, Malaysia. Good quality seeds were selected and the seeds coat and wings were then removed manually and dried in the oven (Model Memmert ULE 400, Germany) for 24–48 hr at 45°C. After drying, the kernels were grounded to a fine powder using household electric blender (Model National MJ-C85 N). The fine powder was stored in different small glass containers with 10 g each. The containers were then capped and sealed before stored at 4°C for not more than 3 months.

2.3. Preparation of coagulant

In this study, *Moringa oleifera* seeds in three different forms; dry powder, distilled water extracted and salt extracted (1 N NaCl) were studied. Stock solution of the distilled water extracted *Moringa oleifera* at 50,000 mg/L (5%) was prepared by dissolving 10 g of the dry powder *Moringa oleifera* in 200 mL distilled water. The mixture was blended at max speed using household electric blender (Model National MJ-C85 N) for 1 min to extract active ingredients. The resulting suspension was then filtered through muslin cloth under vacuum filtration of 45 cm Hg. Collected filtrate was treated as coagulant. Stock solution of salt extracted (1 N NaCl) *Moringa oleifera* was prepared similar to the preparation of distilled water extracted *Moringa oleifera* for the exception of the distilled water was replaced with salt solution. Preparation of coagulant (*Moringa oleifera* in distilled water extracted and salt extracted) was done fresh before each sludge conditioning was carried out.

Table 1
Typical characteristic of settled activated sludge.

Parameters	Range	Mean value
pH	6.04–6.89	6.52
Temperature (°C)	27.7–29.5	28.7
TSS (mg/L)	3310–9080	5530
TDS (mg/L)	70–343	183
SSV (mL/L)	990–1000	996
SVI	110–300	196
Zeta Potential (mV)	–11.2 to –37.8	–15.3
CST (s)	5.2–9.3	6.9
SRF (m/kg)	2.000×10^{11} to 9.155×10^{11}	4.456×10^{11}

2.4. Sludge conditioning process

Settled activated sludge with 300 mL volume was used for each conditioning test. The sludge was mixed well each time before pouring out from the container. The jar test apparatus (Model Stuart Scientific, Flocculator SW1) was used to enable the mixing of polymer with sludge samples. Mixing speed and duration of the conditioning process were set at 100 rpm and 1 min respectively. *Moringa oleifera* dosage was varied from 1000 to 10,000 mg/L for the three different forms; dry powder, distilled water extracted and salt extracted (1 N NaCl). After the conditioning process was terminated, the conditioned sludge was then tested for Capillary Suction Time (CST) and Specific Resistance to Filtration (SRF).

The conditioning process was conducted at temperature between 28 and 30°C.

2.5. Parameter analysis

The pH and temperature of the settled sludge sample was determined with the help of pH meter, model Cyberscan 500. The measurements were obtained at 1 cm below the sludge surface with mixing. Total suspended solids (TSS), total dissolved solids (TDS), SSV and SVI (Sludge Volume Index) were determined according to APHA standard methods of examination of water and wastewater (1999). Drying of sludge for TSS and its filtrate after filtration for TDS were conducted in the oven (Memmert, Model ULE 400). To obtain zeta potential value for the sludge, the conditioned sludge was centrifuged at a speed of 4000 rpm for 10 min. The resulted supernatant was then collected for zeta potential measurement.

The Capillary Suction Time (CST) test determines rate of water released from sludge. It provides a quantitative measure, reported in seconds, of how readily sludge releases its water. In the present study, CST meter Model Triton Type 319 Multi-purpose CST was used. Well-mixed conditioned sludge with a volume of 6.4 mL was placed in a small cylinder on a sheet of chromatography paper. The paper extracts liquid from the sludge by capillary action. The time required for the liquid to travel a specified distance is recorded automatically by monitoring the conductivity change occurring at the two contact points appropriately spaced and in contact with the chromatography paper. The elapse time is indicative of the water drainage rate.

According to the APHA [11], SRF is performed using a standard Buchner funnel apparatus (90 mm diameter) with Whatman No.1 filter paper. In the present study, 60 mL of the conditioned sludge was sampled from beaker and subjected to a range of suction pressure at 32 ± 5 cm Hg for sludge conditioning using *Moringa oleifera* in dry powder form, 29 ± 9 cm Hg for sludge conditioned with distilled water extracted *Moringa oleifera* and 21 ± 3 cm Hg for salt (1 N NaCl) extracted *Moringa oleifera*. The time required for the first 40 mL of the filtrate collected in a graduated measuring cylinder was recorded. The sludge cake formed on the filter was dried in the oven (Memmert, Model ULE 400) at 105°C for 24 h before weighed to find the amount of the dry sludge cake. Viscosity of the conditioned sludge was determined using viscometer, model Brookfield DV2+ at surrounding temperature of 24–25°C. The SRF for each conditioned sludge was determined by plotting the elapsed filtration time per corrected filtrate volume (t/V) versus the corrected filtrate volume at designated vacuum pressure (Eq. 1). The slope of the line is the constant b in which is used to calculate the Specific Resistance to Filtration (SRF) value [12]:

$$r = \frac{2PA^2b}{\mu W} \tag{1}$$

where
b = slope of elapsed filtrate time vs. filtrate volume (s/m^6)
P = filtration pressure (N/m^2)
μ = viscosity ($N\ s/m^2$)
W = density of dry solids (kg/m^3)
r = specific resistance to filtration (m/kg)
A = area of the filter paper (m^2).

2.6. Experimental design and models

Statistical design of experiments and data analysis was done using Design-Expert software (Version 6.0.4, Stat-Ease, Inc., Minneapolis, USA). In the present study, Box-Behnken Design under category of Response Surface Methods (RSM) was applied to optimize the three most important operating conditions; coagulant dosage, mixing speed and mixing duration. Two important responses; CST and SRF were used to obtain optimum values for the stated operating conditions. Optimization was done on the best form of *Moringa oleifera* selected earlier from the conditioning process (most efficient and economic approach). The range of the tested coagulant dosage, mixing speed and mixing duration was 4500–5500 mg/L, 40–100 rpm and 1–5 min respectively. For better visualization of relationship between the operating conditions (factors) and the responses, contour plots were generated from the model. The optimum values of the operating conditions were then obtained from the plots.

3. Results and discussion

3.1. Variation of CST with polymer dosage during sludge conditioning

Fig. 2 shows the variation of CST with different dosages of *Moringa oleifera* in dry powder, distilled water extracted and salt (1 N NaCl) extracted forms. Addition of *Moringa oleifera* during sludge conditioning generally reduced the initial CST of the sludge. However, *Moringa oleifera* in dry powder and distilled water extracted form have larger reduction compared to *Moringa oleifera* in salt (1 N NaCl) extracted form. This phenomenon was due to a high concentration of monovalent cations, especially sodium, known to be detrimental to the floc stability [13, 14]. Past studies showed that sludge that received additional sodium deteriorated in settling and/or dewatering properties. It is theorized that monovalent cations displace divalent cations within the cation bridged floc structure by ion exchange, making flocs weak and sensitive to any

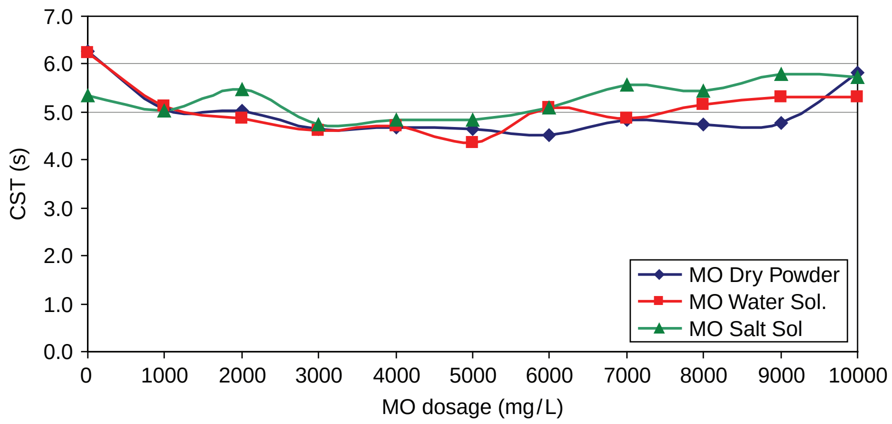

Fig. 2. Effect of *Moringa oleifera* dosage in different forms on CST of the conditioned sludge.

physiochemical changes on the floc structure. Optimum dosage for *Moringa oleifera* in all forms was found to be in the range of 1000–5000 mg/L. The result obtained was in agreement with findings reported by Ademiluyi [7] which reported 2750 mg/L dry powder *Moringa* as optimum dosage in conditioning digested domestic sludge and Muyibi *et al* [8] found that 4750 mg/L *Moringa oleifera* in water solution form and 6000 mg/L dry powder *Moringa oleifera* were the optimum dosage in activated sludge conditioning. It was believed that higher molecular weight cationic polyelectrolyte could increase rigidity of the flocs through bridging effect [15]. It was noted that academically, *Moringa oleifera* in distilled water extracted form was the most suitable form among the three forms in reducing the CST with optimum dosage of 5000 mg/L. From economic approach however, optimum dosage of 1000 mg/L *Moringa oleifera* in distilled water form was the most practical.

3.2. Variation of SRF with polymer dosage during sludge conditioning

Fig. 3 shows the variation of SRF with different dosages of *Moringa oleifera* in dry powder, distilled water extracted and salt (1 N NaCl) extracted forms. Generally, higher dosages of polymer led to lower SRF values. Steeper reduction in SRF was observed at 1000 mg/L for *Moringa oleifera* in all forms. Significant reduction in SRF with reduction of 6 and 15 times in magnitude was observed at 5000 mg/L *Moringa oleifera* salt extracted and dry powder forms respectively. *Moringa oleifera* in distilled water extracted form showed

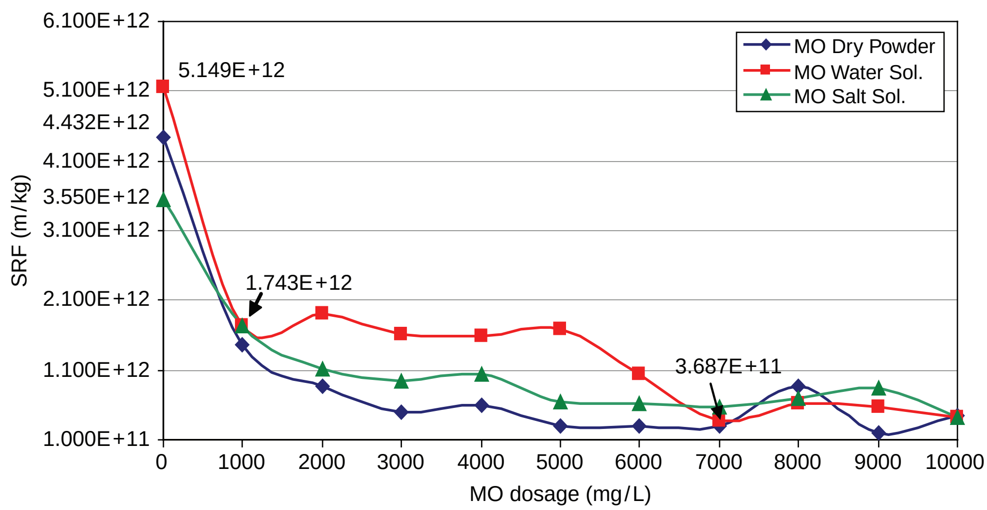

Fig. 3. Effect of *Moringa oleifera* dosage in different forms on SRF of the conditioned sludge.

reduction of 14 times in magnitude in SRF but at higher dosage of 7000 mg/L.

3.3. Experimental design

Relationship between operating conditions (coagulant dosage, mixing speed and mixing duration) with responses (CST and SRF) was studied using response surface methods. Range of operating conditions with their respective levels and responses investigated in the present study are highlighted in Table 2. These operating conditions range (mixing speed and mixing duration) were obtained from available literature review. The best performance of *Moringa oleifera* form (low CST and SRF at optimum dosage) was distilled water extracted form at 5000 mg/L. The range of coagulant dosage was set between 4500 and 5500 mg/L. Although dry powder *Moringa oleifera* showed lower SRF at less dosage, it is not practical for real application due to addition of solids content in treated sludge. Additional in sludge mass will translate into higher sludge volume produced and this incurs more cost. Moreover, sludge treated with dry powder *Moringa oleifera* will have their viscosity increased and this makes the sludge transportation through pipe difficult.

A total of 17 runs were produced using response surface methods (Box-Behnken Design) with 12 cube points and 5 center points. These points were needed to construct effectively up to second order of polynomial model. Runs numbered 5, 7, 9, 10 and 15 were the center points and repeated randomly in the below design table in order to obtain experimental error. Using multiple regression analysis, interaction between the three operating conditions and the two responses were studied and correlated.

3.4. Proposed models

Using multiple regression analysis, responses comprised of CST and SRF were correlated with the three operating conditions (coagulant dosage, mixing speed and mixing duration) using second order polynomial. The coefficients of the model equation and their statistical significance were evaluated using Design Expert 6.0.4 software. The quadratic regression model for the CST and SRF of the conditioned sludge in terms of coded factors are represented by Eqs. (2) and (3) respectively.

$$\text{CST (s)} = +\,22.138 - 0.080A + 0.183B - 5.780\text{E-}003\,C + 2.573\text{E-}004\,A^2 + 5.263\text{E-}007C^2 - 8.333\text{E-}004AB + 6.667\text{E-}006\,AC \quad (2)$$

$$\text{SRF (m/kg)} = -1.188\text{E+}012 - 1.529\text{E+}009A - 1.604\text{E+}010B + 5.820\,\text{E+}008C + 4.196\text{E+}006A^2 - 5.969\text{E+}004\,C^2 + 5.100\text{E+}006BC \quad (3)$$

Expression of the coded factors of A, B and C are as stated in Table 2. The coefficient with one operating con-

Table 2
Operating conditions with their levels and responses.

Run no.	Operating conditions			Responses	
	A: Mixing speed (rpm) (Coded)	B: Mixing duration (mins)(Coded)	C: Dosage (mg/L) (Coded)	CST (s)	SRF (m/kg)
1	100 (1)	3 (0)	4500 (0)	**4.6**	**1.299E+011**
2	40 (–1)	5 (1)	5000 (0)	**5.7**	**2.260E+011**
3	70 (0)	1 ((1)	4500 ((1)	**4.7**	**1.464E+011**
4	70 (0)	5 (1)	5500 (1)	**5.1**	**1.800E+011**
5	70 (0)	3 (0)	5000 (0)	**4.7**	**1.671E+011**
6	100 (1)	3 (0)	5500 (1)	**4.8**	**1.383E+011**
7	70 (0)	3 (0)	5000 (0)	**4.7**	**1.733E+011**
8	40 (–1)	1 (–1)	5000 (0)	**5.1**	**1.891E+011**
9	70 (0)	3 (0)	5000 (0)	**4.7**	**1.709E+011**
10	70 (0)	3 (0)	5000 (0)	**4.8**	**1.713E+011**
11	70 (0)	1 (–1)	5500 (1)	**4.6**	**1.323E+011**
12	70 (0)	5 (1)	5500 (1)	**5.2**	**1.737E+011**
13	100 (1)	1 (–1)	5000 (0)	**4.4**	**1.263E+011**
14	100 (1)	5 (1)	5000 (0)	**4.8**	**1.658E+011**
15	70 (0)	3 (0)	5000 (0)	**4.8**	**1.734E+011**
16	40 (–1)	3 (0)	5500 (1)	**5.4**	**1.860E+011**
17	40 (–1)	3 (0)	4500 (–1)	**5.6**	**1.852E+011**

dition (factor) represents effect of the particular single factor while coefficients with two factors and those with second order terms represent the interaction between the two factors and quadratic effect respectively. Presence of positive sign in front of the term indicates synergistic effect while negative sign indicates antagonistic effect [9].

Statistical analysis produced by the software indicated the quadratic model was the best represented, ignoring the aliased model. The selection of the model was based on low standard deviation and high R^2 values. The R^2 values for CST and SRF were 0.9821 and 0.9780 respectively which showed that the prediction of the experimental data was satisfactory.

3.5. Effects of operating conditions

The contour plot in Fig. 4 shows the effect of mixing speed and duration for CST of the conditioned sludge with *Moringa oleifera* in distilled water extracted form. It is apparent that increasing the mixing speed to 100 rpm and decreasing the mixing duration to 1–2 min with the *Moringa oleifera* dosage fixed at 5000 mg/L (center point), reduced the CST value. Lower CST resulted in improvement of sludge permeability; the water is easily separated from the sludge particles. According to Schwartz [16], the seed kernels of *Moringa oleifera* contain significant quantities of low molecular weight, water soluble proteins which carry a positive charge. When the crushed seeds are added to water, the proteins produce positive charges acting like magnets and attracting the predominantly negatively charged particles. The flocculation occurs when the proteins bind to the negatively charged particles forming flocs through aggregation. Study by Langer and Klute [17] shown that flocculation behaviour of waste activated sludge is less sensitive to rapid mixing and mixing becomes important only at low polymer dosage. Proper rapid mixing is more important when the affinity of the sludge particles and the polymer is stronger. Experiments with low cationic polymer (25% cation activity and at least 5 million molecular weight) dosed on the sludge exhibited low sensitivity to high mixing intensity above rotational speed of 500 rpm compared to highly cationic polymer (45% cation activity and 5 million molecular weight).

Fig. 5 shows the effect of mixing speed and duration on SRF in contour plot. The plot shows that higher mixing speed up to 100 rpm and lower mixing duration between 1 and 2 min reduced the SRF value of the conditioned sludge. This result confirmed earlier the reduction of CST value of the conditioned sludge under the similar operating conditions. It was also observed that lower magnitude of reduction in SRF value was obtained during sludge conditioning with high dosage of *Moringa oleifera*. Study by Ndabigengesere *et al* [18] indicated active agents in coagulation with *Moringa* are

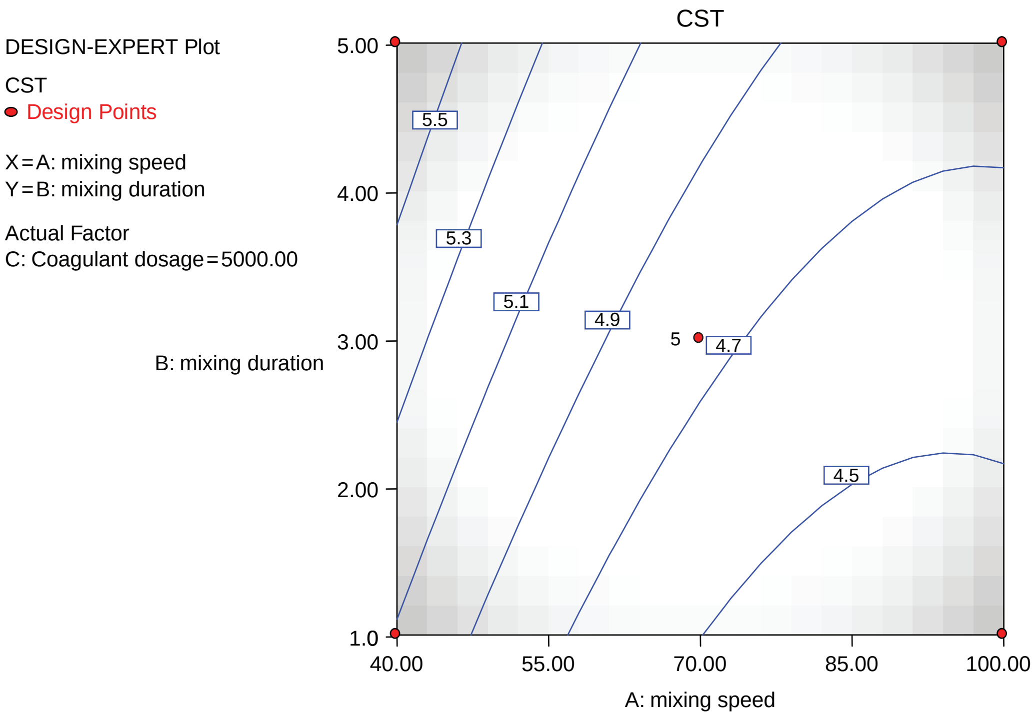

Fig. 4. Effect of mixing speed and duration on CST; contour plot.

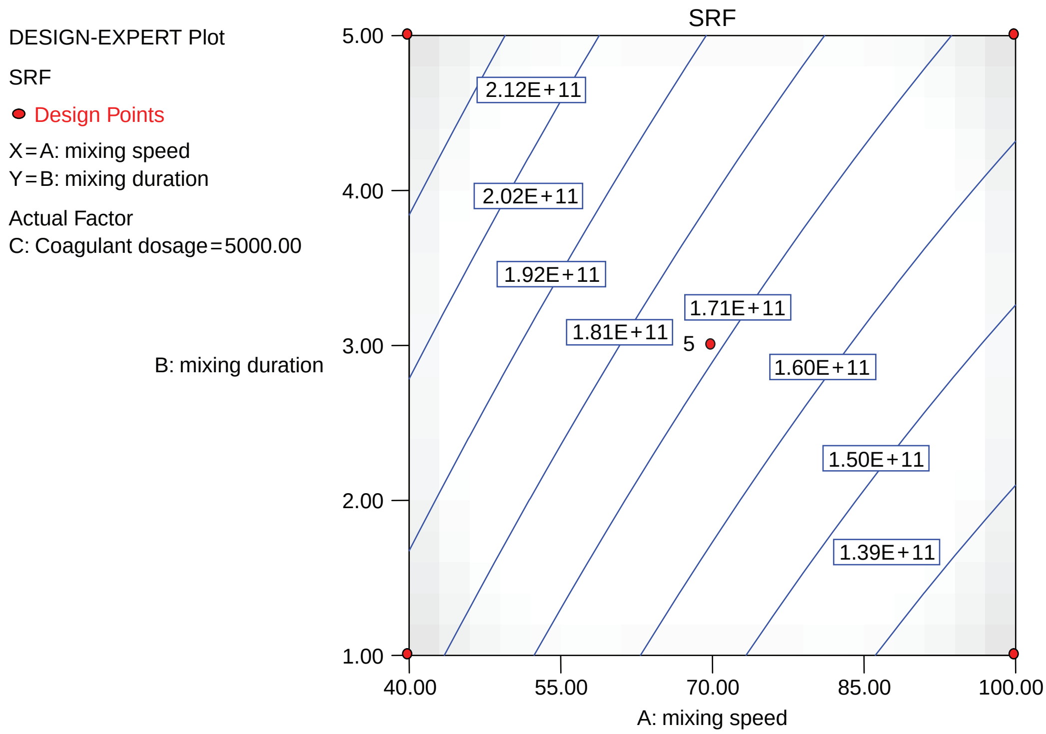

Fig. 5. Effect of mixing speed and duration on SRF; contour plot.

water soluble dimeric cationic proteins of 13 kDa with subunits (monomer) of about 6.5 kDa.. Zeta potential of a 5% solution of non-shelled *Moringa* seeds was found to be +6 mV. Low charge density cationic polymer flocculate with a bridging mechanism and give flocs with a flexible structure but less good filtration properties [19]. This explanation agrees well with sludge conditioned with *Moringa oleifera* compared to existing chemical polymer which the charge density and molecular weight can be manipulated to obtain higher efficiency of sludge conditioning.

3.6. Optimization

Using the numerical optimization of the Design Expert software on the proposed model, a set of seven solutions was generated in order to predict the optimum conditions of the process (Refer to Table 3). The minimum values of CST and SRF values were selected as criteria for optimum values. Two additional experiments were conducted, applying the best two optimum conditions (based on desirability) to confirm the agreement of the results achieved from the proposed model. As shown in Table 3, results obtained from the experiment agreed well with the predicted values from the model for both responses. Therefore, the optimum operating conditions for sludge conditioning using *Moringa oleifera* in distilled water extracted form were mixing speed,100 rpm; mixing duration, 1 min and *Moringa oleifera* dosage, 4695 mg/L.

4. Conclusions

Results from the study indicate that *Moringa oleifera* in distilled water extracted form shows the most optimum reduction in Capillary Suction Time (CST) value. Although dry powder *Moringa oleifera* was more effective in reducing SRF value, significant increased in solid content in the conditioned sludge was a huge setback. Optimization of three important factors namely mixing speed, mixing duration and *Moringa oleifera* dosage for distilled water extracted form was done using Design of Experiments (DOE). Optimum values for the selected operating conditions (factors) were obtained using Box-Behnken design, Response Surface Design Methods (RSM). There was a total of seven set of optimized solutions produced. The best solution generated showed lowest CST and Specific Resistance to Filtration (SRF) was obtained at 4.5 s and 1.22×10^{11} m/kg respectively. These values were obtained under the optimum conditions of mixing speed at 100 rpm, mixing duration of 1 min and *Moringa oleifera* dosage of 4695 mg/L. The desirability index for the optimized solution was 1.000.

Table 3
Optimized solutions.

Run	Mixing speed (rpm)	Mixing duration (min)	MO dosage (mg/L)	Mean CST (s)		Mean SRF (m/kg)		Desirability
				Predicted	Experiment	Predicted	Experiment	
1	99.97	1.00	4695	4.4	**4.5**	1.26E+011	**1.22E+011**	1.000
2	99.99	1.01	4674	4.4	**4.5**	1.26E+011	**1.22E+011**	1.000
3	98.11	1.02	4635	4.4	**4.6**	1.26E+011	**1.25E+011**	1.000
4	99.98	1.00	4634	4.4	**4.4**	1.26E+011	**1.30E+011**	1.000
5	96.34	1.00	4620	4.4	**4.6**	1.26E+011	**1.31E+011**	0.999
6	100	1.00	5131	4.4	**4.5**	1.26E+011	**1.26E+011**	0.996
7	99.99	1.00	4521	4.4	**4.5**	1.26E+011	**1.28E+011**	0.989

Values of Mean CST and SRF are of triplicates.

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