

Optimization And Parametric Kinetics Of Coag-Flocculation Of Aluminum Sulphate In Pharmaceutical Industry Effluent Medium Via Response Surface Methodology

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Abstract—Optimization and Parametric Kinetics of Coag-flocculation of alum-pharmaceutical effluent medium by Response surface methodology has been carried at room temperature. This is aimed at minimizing total dissolved and suspended solids (TDSS) inherent in the effluent system. Treatment optimization to serve these purposes were performed using jar tests and applying a response surface methodology (RSM) to the results. A 2³ full factorial central composite design was employed to explain the effects and interaction of three factors: coagulant dosage, settling time and pH. Kinetic data generated were presented with specified kinetic models for evaluation of functional kinetic parameters. The optimal values of pH, dosage and settling time were determined at 10, 0.1mg/l and 40min respectively. The results of kinetic parameters recorded are 2, 1.34E-05 l/mg.min and 0.14min for order of reaction (α), coag-flocculation reaction rate constant (k) and coagulation period; ($\tau_{1/2}$) respectively. At optimum, the TDSS was reduced from 1144.8mg/l to 93.26 mg/l, representing 91.85% removal efficiency. The results recorded in this work has shown that RSM is suitable for the optimization of the coa-flocculation operation by statistical determination.

Keywords—Optimization, Coag-flocculation, Pharmaceutical effluent, Alum, Response surface methodology.

1.0 INTRODUCTION

In the last few decades, industrial waste water treatment gained much importance. This may be connected with increased concern over the environmental quality [1].

The preference of contaminants in some water bodies used for domestic and industrial processes and coupled with the strict national and international regulations on water pollution necessitated that wastewater should be treated prior to discharge to the host communities [1].

Heightened awareness of the deleterious effects of industrial effluents on the environment, particularly water bodies has resulted in an intensive research effort to identify efficient methods of treatment so as to minimize the impacts [1].

Generally, the techniques employed for water and wastewater treatments includes, precipitation, coagulation and flocculation, lime softening, ion exchange, reverse osmosis or electro dialysis etc. Though all these techniques afford moderate to efficient industrial pollutants removal. Coagulation/ flocculation is preferred because of high efficiency, easy handling, availability and cost effectiveness [3]; [2].

Coag-flocculation technique is one of the most common methods for removing colloidal and suspended solid particles in water and wastewater [7].

Coagulation is the process of decreasing or neutralizing the electric charge on dissolved and suspended particles or Zeta potential on addition of chemical agent [2]. This allows the vander waals force of attraction to initiate aggregation of colloidal and fine suspended materials to form micro-flocs.

Flocculation is actually the conglomeration of these micro-flocs into larger aggregates so that they can be separated under gravity from the wastewater easily [5]; [4]; [6]. Readily coag-flocculation is optimized for the removal of inorganic colloids, dissolved natural organic loads, microbes and color which are typical composition of pharmaceutical industry effluent (PIE) [8]; [9].

Inorganic salts such as ferrous sulphate, Ferric chloride, lime, aluminum sulphate etc are generally employed for coag-flocculation operations. Among these inorganic coagulants aluminum sulphate is most widely used in this regard having proven to be very effective and efficient for water and wastewater treatment operations. In support of this assertion, on one of their conventional experiments with aluminum sulphate, [14], reported that aluminum sulphate optimally removed 85-95% of total dissolved and suspended solids (TDSS) from pharmaceutical industry effluent (PIE).

Previous research from similar works were mainly based on the conventional method (ie. One factor at a time, OFAT), usually applied in the search for the process optimal variables. Though acceptable but the disadvantage there is the individual optimization of variables, which are cumbersome, time consuming and incapable of producing very reliable results because true optimum may not be reached as interaction among variables is not considered [10]; [11]; [12]. To avert this, statistical method of response surface methodology (RSM) is employed to take care of the effects of individual factors and their interactive effects as well.

In this study RSM combined with central composite design (CCD) was used to design the experiment, build models and determine the optimum conditions. It investigates the effects of process parameter variations, such as coagulation pH, alum dosage and settling time on total dissolved and suspended solids TDSS

(as response) also measurement of coag-flocculation efficiency is determined.

2. Materials and Methods

2.1 Effluent Sampling and Characterization.

Effluent sample was taken from pharmaceutical company in Anambra State, Nigeria. Sample collection and characterization were done based on the standard method for the examination of water American Water Works Association [7]. Characterization was carried out immediately after sample arrived in the laboratory.

2.2 Coag-Flocculation Experiment

The sample of aluminum sulphate (analytical grade) which has been homogenized to fine powder was sourced from bridge head market, Onitsha, Anambra State, Nigeria. The jar test experiment was carried out based on standard bench scale nephelometric method. Appropriate dose of alum in the range of 0.1 – 0.7mg/l was added to 250ml of PIE sample in each case. the coag-flocculation pH was adjusted to 1,3, 5,7, 10 and 13 using 10M HCL or 10M NaOH before dosing of the coagulant. The samples were subjected to 2mins of rapid mixing (120rpm), 20mins of slow mixing (10rpm), followed by 40mins of settling. During settling, samples were withdrawn using pipette from 2cm depth and analyzed for optimization purposes with TDSS (mg/l) removal as a response parameter.

3.0 Theory

3.1 Experimental Design and Data Analysis

The three-level, three factorial experimental design was employed to optimize TDSS removal (as response) from PIE. The

design was composed of three levels (low, medium and high, being coded as -1, 0 and +1) and a total of 17 runs were carried out in duplicate to optimize the level of chosen variable such as pH, coagulant dosage and settling time. For the purpose of statistical computation, the three independent variables were designated as X_1 , X_2 and X_3 , respectively. According to the preliminary experiments, the range and levels used in the experiments are selected and listed in Table 1

The experimental design matrix and response result for the experimental variables are tabulated in Table 2. The results were analyzed by applying the coefficient of determination (R^2), response plots and analysis of variance (ANOVA). For RSM, the most commonly used second-order polynomial equation developed to fit the experimental data and determine the relevant model terms can be written as

$$Y = b_0 + \sum_{j=1}^m b_j X_j + \sum_{k,j} b_{kj} X_k X_j + \sum_{j=1}^m b_{jj} X_j^2 + \Sigma \quad (1)$$

With respect to this study, equation 1 is transformed to generic equation 2 for the $2^3 -$ CCD of the system under consideration.

were tested by G-test and CS1 - test, respectively.

3.2 Theoretical Background and Model Development.

For a homogeneous aggregating particles (i, j) in equilibrium state with negligible influence of gravitational, buoyancy, drag, vander waals and repulsive forces: [19];[21];[22].

$$\mu_i = U_i \frac{\partial(nu)}{\partial ni} \quad nS, nV, n_j \quad (1)$$

Also

$$\mu_i = G_i = \left[\frac{\partial(nG)}{\partial ni} \right] \quad p, T, n_j = \text{a constant} \quad (2)$$

$$\text{Thus } \mu_i = G_i = 0 \quad (3)$$

For a homogeneous phase solutions

$$\mu_i = \mu_i + RT \ln C_i \quad (4)$$

In a case where drag force (f_d) predominant there is a shift from the equilibrium state

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 \quad (2)$$

Where Y is the predicted response, b_0 , b_j and b_{ij} are constants coefficients; X_i and X_j are the coded independent factors; Σ is the random error [15]. The polynomial coefficients are determined by the following relationships below.

$$b_0 = a \sum_{u=1}^N Y_u + p \sum_{j=1}^m \sum_{u=1}^N X_{ju}^2 \quad (3)$$

$$b_i = e \sum_{u=1}^N X_{iu} Y_u \quad (4)$$

$$b_{ij} = g \sum_{u=1}^N X_{iu} X_{ju} Y_u \quad (5)$$

$$b_{ii} = c \sum_{u=1}^N X_{iu}^2 Y_u + d \sum_{j=1}^m \sum_{u=1}^N X_{ju}^2 + \rho \sum_{u=1}^N Y_u \quad (6)$$

The model terms were evaluated by the P-value (probability) with 95% confidence level. Homogeneity of the variance and significance of the polynomial coefficients

$$\text{Thus } f_d = - \frac{d\mu}{dx} \quad (5)$$

Note that Boltzman Constant (K_B) = Molar gas constant per particle i.e.

$$K_B = \frac{R}{n}$$

For a single particle component say i, $n = 1$,

$$K_B = R \quad (6)$$

Substituting equation 6 into 4, yields

$$\mu_i = \mu_i + K_B T \ln C_i \quad (7)$$

Where:

μ_i is chemical potential of component i

U_i is internal energy of component i

G_i is Gibb's free energy of component i.

n_i is the number of moles of component i

n_j is the number of moles of component j, indicating that

all moles numbers are held

constant except the i^{th} .

n is the number of particles

T is absolute temperature

C_i is concentration of particle component i

X is diffusion distance

f_d is viscous drag force

R is molar gas constant

K_B is Boltzman constant (molar gas constant per particle)

Substituting equation 7 into 5, gives

$$f_d = - \frac{d}{dx} (\mu_i^o + K_B T \ln C_i) \quad (8)$$

$$f_d = - \frac{K_B T}{dx} \frac{dC_i}{C_i} \quad (9)$$

But from ficks law

$$D^1 = - \frac{f_d}{B} \frac{C}{dc/dx} \quad (10)$$

Where D^1 is diffusion coefficient

B is friction factor

Comparing equations 9 and 10 yields Einstein's equation

$$D^1 = \frac{K_B T}{B} \quad (11)$$

The general model for microkinetic coagulation-flocculation of mono dispersed particle under the influence of Brownian motion is given by [18].

$$r_k = \frac{dN_k}{dt} = \frac{1}{2} \sum_{i=1}^k \alpha \beta (v_i, v_j) n_i n_j - \sum_{i=1}^k \alpha \beta (v_i, v_j) n_i n_j \quad (12)$$

Where $r_k = \frac{dN_k}{dt}$ is the rate of change of concentration of particle size K (Conc/time)

α is the fraction of collisions that result in particle attachment.

β is a function of coagulation-flocculation transport for Brownian, Shear and differential sedimentation mechanisms

The value of β for transport mechanism is given as [18].

$$\beta_{BR} = \frac{8}{3} \varepsilon_p \frac{K_B T}{\eta} \quad (13)$$

Where ε_p is collision efficiency

η is the viscosity of effluent medium

K_B is boltzman's constant (J/K)

T is absolute temperature (K)

The general equation representing aggregation rate of particles is obtained by solving the combination of equation 12 and 13 to yield

$$- \frac{dN_t}{dt} = KN_t^\alpha \quad (14)$$

Where N_t is total particle concentration at time t ,

$N_t = \sum n_t$ (Mass/volume)

K is the α^{th} order coagulation-flocculation constant

α is the order of coagulation-flocculation

And $k = \frac{1}{2} \beta_{BR}$ (15)

Also $\beta_{BR} = 2 \varepsilon_p K_R$ (16)

Combining equations 14, 15 and 16 yields

$$- \frac{dN_t}{dt} = \varepsilon_p K_R N_t^\alpha \quad (17)$$

Where K_R is the Von Smoluchowski rate constant for rapid coagulation [20].

But $K_R = 8R\pi D^1$ (18)

$R_p = 2a$ (19)

Where a is particle radius.

Recall, from Einstein's equation: $D^1 = \frac{K_B T}{B}$

Where B is the friction factor.

From stokes equation:

$$B = 6\pi\eta a \quad (20)$$

Where η is viscosity of coagulating and flocculating medium.

Combing equations 17 to 20 produce:

$$- \frac{dN_t}{dt} = \frac{4}{3} \varepsilon_p \frac{K_B T}{\eta} N_t^\alpha \quad (21)$$

Comparing equations 14 and 21 show that

$$K = \frac{4}{3} \varepsilon_p \frac{K_B T}{\eta} \quad (22)$$

For microkinetic aggregation, α theoretically equals 2 [20];[22].

From fick's law

$$J_f = D^1 4\pi R_p^2 \frac{dN_t}{dR} \quad (23)$$

Where J_f is flux – number of particles per unit surface entering a sphere with radius r

Re-arranging and integrating equation 23 at initial conditions $N_t = 0, R_p = 2a$.

$$J_f \frac{dR_p}{R_p^2} = \int_{N_o}^{N_t} dt \quad (24)$$

Therefore, $J_f = 8\pi D^1 a N_o$ (25)

In general, for particle of same size under the influence of Brownian motion, the initial rate of rapid coagulation – flocculation is

$$-\frac{dN_t}{dt} = J_f \cdot \epsilon_p \cdot N_o \quad (26)$$

On substitution of equations 11, 20 and 25 into 26 produce:

$$-\frac{dN_t}{dt} = 8\pi a \frac{K_B T N_o \epsilon_p}{6\pi\eta a} \quad (27)$$

$$\text{Thus } -\frac{dN_t}{dt} = \frac{4}{3} \epsilon_p \frac{K_B T N_o^2}{\eta} \quad (28)$$

Similarly at $t > 0$

$$-\frac{dN_t}{dt} = \frac{4}{3} \epsilon_p \frac{K_B T N_t^2}{\eta} \quad (29)$$

Hence, equation 29 has confirmed $\alpha = 2$, equation 7 transpose to

$$\frac{dN_t}{dt} = -KN_t^2 \quad (30)$$

Re-arranging and integrating equation 30 yields

$$= \int_{N_o}^{N_t} \frac{dN_t}{N_t^2} = -K \int_0^t dt \quad (31)$$

$$\text{Thus } \frac{1}{N_t} = Kt + \frac{1}{N_o} \quad (32)$$

Plot of $\left(\frac{1}{N_t}\right)$ Vs t produces a slope of K and intercept of $\frac{1}{N_o}$

From equation 32, making N_t the subject matter yield a relation for the evaluation of coagulation period ($\tau_{1/2}$)

$$N_t = \frac{N_o}{1 + N_o Kt} \quad (33)$$

$$\text{Similarly } N_t = \frac{N_o}{1 + \frac{t}{N_o K}} \quad (34)$$

$$\text{Where } \tau = \left(\frac{1}{N_o K} \right) \quad (35)$$

Putting equation 34 into 35, produce

$$N_t = \frac{N_o}{1 + \frac{t}{\tau}} \quad (36)$$

When $t = \tau$, equation 36, yields

$$N_t = \frac{N_o}{2} \quad (37)$$

Therefore as $N_o \rightarrow 0.5$; $\tau \rightarrow \tau_{1/2}$.

$$\text{Hence } \tau_{1/2} = \frac{1}{0.5N_o K} \quad (38)$$

For microkinetic aggregation of singlets, doublets and triplets under the influence of Brownian transport mechanism as a function of time ($t \leq 40$ mins) at early stages can be obtained by solving equation 1 exactly, resulting in general expression m^{th} order.

$$\frac{N_m(t)}{N_o} = \left\{ \frac{t}{2 \left(\frac{1}{N_o K} \right)} \right\}^{m-1} \left\{ \frac{1 + \frac{t}{\tau^1}}{2 \left(\frac{1}{N_o K} \right)} \right\}^{m+1} \quad (39)$$

$$\text{Similarly } \frac{N_m(t)}{N_o} = \frac{\left(\frac{t}{\tau^1} \right)^{m-1}}{\left(1 + \frac{t}{\tau^1} \right)^{m+1}} \quad (40)$$

Where $\tau^1 = 2\tau$

Hence for singlets ($m = 1$)

$$N_1(t) = N_o \left\{ \frac{1}{\left(1 + \frac{t}{\tau^1} \right)} \right\} \quad (41)$$

For doublets ($m = 2$)

$$N_2(t) = N_o \left\{ \frac{\left(\frac{t}{\tau^1} \right)}{\left(1 + \frac{t}{\tau^1} \right)^2} \right\} \quad (42)$$

For triplets ($m = 3$)

$$N_3(t) = N_o \frac{\left(\frac{t}{\tau^1} \right)^2}{\left(1 + \frac{t}{\tau^1} \right)^3} \quad (43)$$

Evaluation of coagulation-flocculation efficiency is given as:

$$E(\%) = \left(\frac{N_o - N_t}{N_o} \right) \times 100 \quad (44)$$

3.3 Statistical Analysis

The coag-flocculation experiments showing the relationship between the three variables (pH, dosage and settling time) and the process

response (TDSS removal) was analysed using RSM.

Table 1: Experimental Range and levels of Independent process variable.

Independent Variable	Lower Limit(-1)	Base Level (0)	Upper Limit (+1)
PH(X_1)	1	7	13
Dosage (X_2)	0.1g/l	0.4g/l	0.7g/l
Settling Time (X_3)	2 mins	21mins	40mins

Table 2: Process design matrix and response.

S/No	X_1	X_2	X_3	Y_1	Y_2	\bar{Y}
1	0	0	0	804	806	805
2.	-1	-1	-1	736	735	737.5
3.	1	-1	-1	662	664	663
4.	-1	1	-1	684	687	685.5
5.	1	1	-1	682	683	682.5
6.	0	0	0	804	805	804.5
7.	-1	-1	1	652	650	651
8.	1	-1	1	506	503	504.5
9.	-1	1	1	548	550	549
10	1	1	1	592	595	593.5
11.	0	0	0	804	801	802.5
12.	-1	0	0	592	594	593
13.	1	0	0	462	465	463.5
14.	0	-1	0	472	474	473
15.	0	1	0	1392	1390	1391
16.	0	0	-1	1098	1097	1097.5
17.	0	0	1	806	808	807

Table 3 Anova for response surface quadratic Model

Variables	Coefficient	Se	tstat	Pval	Fstat
Constant	842.6338	98.62	8.5442	5.9735×10^{-6}	$Sse = 3.7183 \times 10^6$
X_1	-30.7000	72.882	-0.42123	0.68622	
X_2	87.4500	72.882	1.1999	0.26922	dfc = 7
X_3	-75.9000	72.882	-1.0414	0.33231	
X_1X_2	32.5625	81.465	0.39961	0.70135	dfr = 9
X_1X_3	-3.3128	81.485	-0.040652	0.96871	ssr = 4.949×10^6
X_2X_3	2.1875	81.485	0.026845	0.97933	
X_1^2	-343.3592	140.8	-2.4386	0.044854	F = 1.0352
X_2^2	60.3908	140.8	0.4289	0.68089	
X_3^2	80.6408	140.8	0.57271	0.58476	Pval = 0.49328
	$R^2 = 0.5710$	Adj $R^2 = 0.0194$	Mst = 5.3118×10^4		

4.0 Results Discussion

4.1 Optimization Studies

The optimization of the coag-flocculation experiments were planned and carried out via 2^3 – Central Composite Design (CCD). The focus was to find out how the dependence of process response total dissolved and suspended solids (TDSS) is affected by independent factors pharmaceutical Industry effluent (PIE) pH, (X_1), coag-flocculant Dosage (X_2) and settling Time (X_3). The pH range studied was between 1 and 13, dosage varied between 0.1 and 0.7mg/l and settling time in the range of 2 to 40mins as shown in Table 1. To study the combined effects of these factors, experiment were carried out of different combinations of the physical parameters using statistically designed experiment shown in process design matrix shown in Tables 2 and 3. The main effect of the parameters and response behavior of the system was described by equation (45) as shown below

$$\bar{Y} = 842.6338 - 30.7000X_1 + 87.4500X_2 - 75.9000X_3 + 32.5625X_1X_2 - 3.3128X_1X_3 + 2.1875X_2X_3 - 343.3592X_1^2 + 60.3908X_2^2 + 80.6408X_3^2 \quad (45)$$

The optimization results obtained from equation (45) as interpreted by MATLAB 7.0 are presented in Table 4. This is aimed at minimizing TDSS, the optimal medium pH,

dosage and settling time were recorded at 10, 0.1mg/l and 40 min respectively. It can be observed that at optimal operation, the TDSS was reduced from 1144.8mg/l to 93.26mg/l.

On evaluation of this by employing equation (44) translates to 91.85% TDSS removal from the PIE. The corresponding optimized interactive surface response plots are presented in figures 1 – 3. Figure 1 shows the interaction effects of pH and dosage on the TDSS removal. Whereas figures 2 and 3 shows the interaction effects of pH and settling time; dosage and settling time on the removal of TDSS respectively. In figure 1, TDSS removal increases with decrease in dosage and at relatively increase in pH at the optimal value of 450g/l. In respect of figure 2, shows that TDSS removal increases with settling time and pH at optimal value of 450mg/l. While figure 3, shows that TDSS removal increases with increase in settling time and decrease in coagulant dosage at optimal value of 800 mg/l. The results of analysis of variance (ANOVA) for TDSS removal are shown in Table 3. The test for the significance of the coefficient at 95% confidence level ($P < 0.05$), indicated that second order effect of pH (X_1^2) is the significant model term. Other model terms are not significant. The fit of the model was checked by the determination coefficient (R^2). In this case the value of the determination coefficient ($R^2 =$

0.5710), indicates, that 42.90% of the total variation is not explained by the model. The value of the adjusted

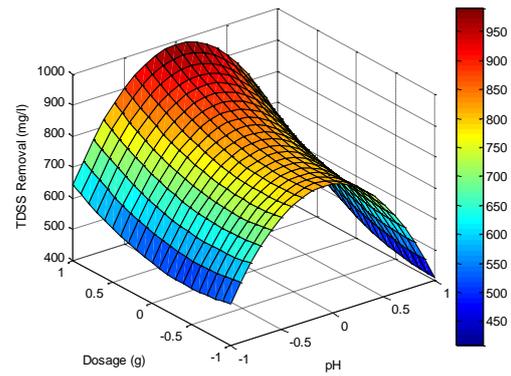


Figure 1. Coag-flocculation surface plots of alum in PIE showing interaction effects of pH and dosage.

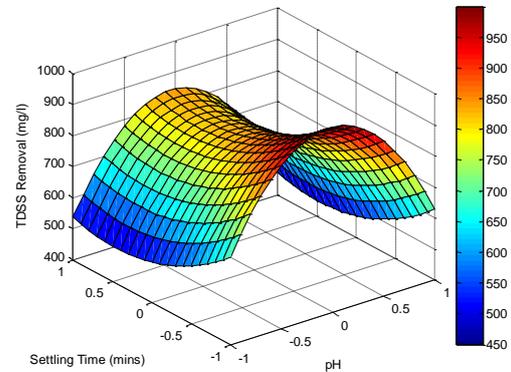


Figure 2. Coag-flocculation surface plots of alum in PIE showing interaction effects of pH and settling time.

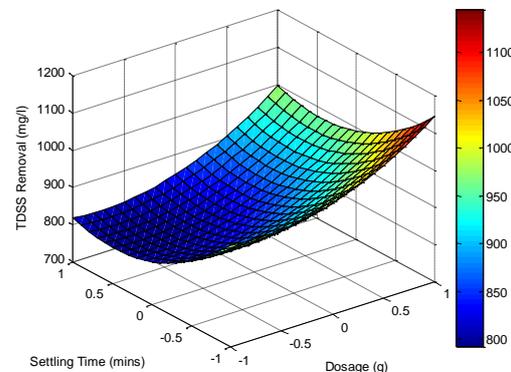


Figure 3. Coag-flocculation surface plots of alum in PIE showing interaction effects of dosage and settling time.

determination coefficient (adjusted $R^2 = 0.0194$ is low, hence could not provide adequate, explanation for the relationship between the independent variables and the corresponding response (Kuehl, 2000).

Coag-flocculation efficiency $E(\%)$ calculated from equation (44) is represented graphically as figure 4. It shows how settling time influences TDSS removal at constant dosage and optimum pH 10. Result shows that maximum efficiency was obtained at settling time of 40min. It could be observed that at 40mins for constant dosage of 0.1mg/l and pH 10 had achieved up to 86 – 93.26% efficiency. This supports the existing assertion that alum is an efficient coag-flocculant that can be employed for large scale wastewater treatment [14].

Table 4 Optimization results of PIE coag-flocculation based on 2 CCD.

Sample	X ₁ (pH)		X ₂ (Dosage)		X ₃ (Settling time)		Y _{TDSS removal} mg/l
	CV*	RV**	CV*	RV** (g/l)	CV*	RV** (min)	
Alum	0.0075	0.4023	1.0000	0.7000	-1.0000	0.1000	1144.8

* Coded Value

** Real value

4.2 Coag-flocculation Kinetic parameters.

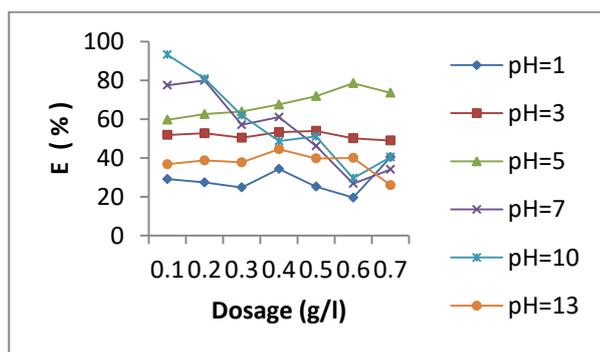


Fig. 4 Plot of $E(\%)$ VS Dosage at 40mins for varying pH.

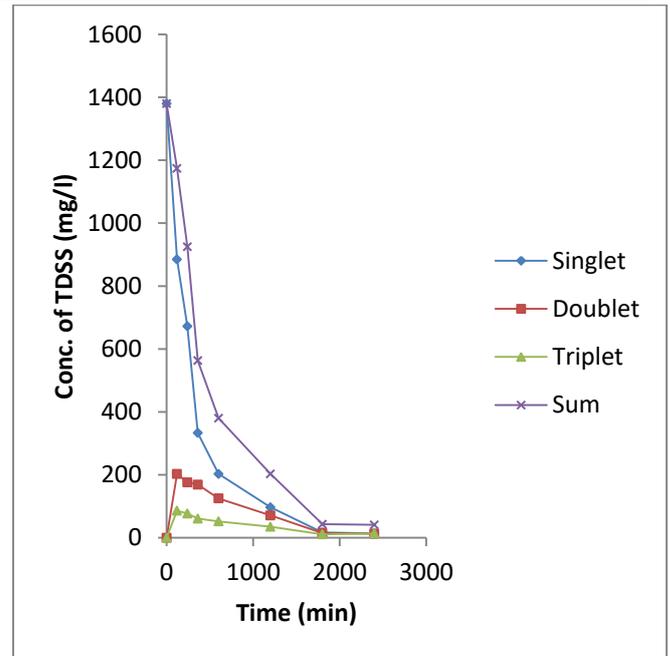


Fig. 5: Particles distribution plot for alum at half life of 0.14min.

This shows the functional activities of i and j particles in coag-flocculation system as aluminum sulphate coagulant is added onto the system under the influence of gravitational, buoyancy, drag, Vander waals and repulsive forces. This is imminently described by equations 1 to 44 and the summary of the coag-flocculation functional parameters at optimum conditions as determined by this work is shown in Table 5 for optimum dosage. Squared Linear regression coefficient (R^2) was employed in evaluation of level of accuracy of fit of experimental data on equation 32.

Table 5, indicates that R^2 ranges from 0.51 to 0.91 were significantly described by linearised form of equation 32. K is determined from the slope of the linearised form of equation 32 on plotting $1/N$ vs time. The result presented in table 5, indicate that K and β_{BR} has maximum values at the pH 10. This is an indication that more primary particles disappears from the system leading to formation of macro-flocs (Vonsmoluchowski, 1917). K is associated to energy barrier (KT) between two potential coag-flocculating particles (i and j) and also K is related to B_{BR} as seen in equation (15) i.e $K = \frac{1}{2} \beta_{BR}$ or $2k = \beta_{BR}$, indicating that increased

agitation under the influence of shear and differential sedimentation mechanisms doubles the effect of the rate per particle concentration and agglomeration at minimal coag-flocculation period ($\tau_{1/2}$). Observations from Table 5, there minimal variation of $K_R = f_n(\tau, \eta)$ as a result of negligible changes in the values of temperature and viscosity of the effluent medium. This is expected because the η is constant while temperature is varying minimally. At approximately invariant of K_R , ϵ_p relates directly to $2k = \beta_{BR}$. Thus ϵ_p is associated with kinetic energy required by the potential colliding particles. The resultant effect is that high ϵ_p requires high kinetic energy to overcome the repulsive forces. The coagulant period, ($\tau_{1/2}$) is determined from equation (38) i.e $\tau_{1/2} = f_n(No)$. Low $\tau_{1/2}$ is a requirement for higher No. this attributes to high settling rate associated with high values of TDSS. Also low values of $\tau_{1/2}$ corresponds to high value of K from Table 5, the rate equation

(-r) or $-(dN_t/dt)$, accounts for the rate of depletion of TDSS in effluent medium. Coag-flocculation operation is determined from equation (14). The result obtained show that (-r) is a function of K and $\tau_{1/2}$. The deductions from this phenomenon is that high rate of TDSS depletion is as a result of high K [17]. Equation (40) describes the time evolution of particle aggregation for monomer, dimmers, trimmers, denoted as $m = 1, 2, 3$ respectively. The particle cluster distribution profile as a function of time is depicted in figure 5. The monomers and total number of particles are seen decrease linearly more rapidly. This accounts for high rate of coag-flocculant brought by low $\tau_{1/2}$ and process being controlled by charge neutralization, and sweep-floc mechanism. Due to negligible repulsive forces in the system, the alum, is observed fuse the class of particles into one particle kernel and sweeps them away from the PIE medium [17].

Table 5: Coag-flocculation kinetic parameters and linear regression coefficient of ALUM in PIE at varying pH and 0.1mg/l dosage.

Parameters	pH = 1	pH = 3	pH = 5	
α	2.000	2.000	2.000	
R^2	0.511	0.835	0.849	
K l/mg.min	4.0E-06	7.0E-06	7.0E-06	
B_{BR} l/min)	1.5366E-19	1.5453E-19	1.5872E-19	K_R
l/min)	8.0E-06	1.4-05	1.4E-05	
ϵ_p l/mg	5.2063 E+13	9. 0597E+13	8.8821E+13	
$\tau_{1/2}$ (min)	543.48	207.04	207.04	
(-r)	4.0E-06 N_t^2	7.0E-06 N_t^2	7.0E-06 N_t^2	
N_0 (mg/l)	707.2136	794.9126	645.9948	

Parameters	pH = 7	pH = 10	pH = 13
α	2.000	2.000	2.000
R^2	0.714	0.646	0.906
Kl/mg.min	1.0E-05	1.34E-05	1. 2E-05
B_{BR} l/min)	1.5571E-19	1.5647E-19	1.5673E-19
KR l/min)	2.0E-04	2.68E-04	2.4E-05
ϵ_p l/mg	1.2844E+15	1.7128E+14	1.53130E+14
$\tau_{1/2}$ (min)	96.02	8.11	362.32
(-r)	1.0E-05 N_t^2	1.34E-04 N_t^2	1.2E-05 N_t^2
N_0 (mg/l)	548.5464	271.0762	637.3486

5.1 CONCLUSIONS

The application of RSM in finding optimal conditions for alum as an effective coag-flocculant in the treatment of turbid PIE effluent has been established. To get a better insight of the chosen factors for optimal coag-flocculation performance, the model was depicted as 3D response surface graphs. Statistical analysis showed that pH of the coagulating medium, have significant effect on the coagulation operation. The quadratic interactions of pH played a dominant role. The study reveal that the optimal conditions for minimum TDSS were pH Medium 10, coagulant dosage of 0.1mg/l, settling time of 40mins and removal efficiency of 93.26%.

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