Factorial Optimization and Peri-kinetics of Pharmaceutical Effluent Coag-flocculation by Pleurotus Tuberregium Sclerotium Tuber

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ABSTRACT - *Optimization and peri-kinetics of pharmaceutical industry effluent (PIE) Cosg-flocculation by pleurotus tuberregium sclerotium tuber has been undertaken at room temperature. This was investigated following standard method of bench scale Jar test. Pleurotus tuberregium sclerotium tuber (PTSC) was produced based on the work reported by Gunaratna, et al. A 2^3 full factorial central composite design was adopted for the experimental design and analysis of optimization results. The interactive effects of pH, dosage and settling time on the total dissolved and suspended solid (TDSS) particles removal were studied via response surface methodology. Peri-kinetic data generated were fitted in appropriate kinetic model for the evaluation of functional parameters. The optimal values of pH, dosage and settling time were recorded at 13, 0.3gll and 40minutes respectively. The maximum kinetics parameters recorded are 2.491E-04l/g.min and 7E-02 min for coag-flocculation aggregation rate constant (K) and coagulation period ($\tau_{1/2}$), respectively. The maximum TDSS removal efficiency of 98.68% was recorded after 40mins, thus re-affirming that PTSC is an efficient coag-flocculant at the condition of the experiment.*

Keywords: Pleurotus Tuberregium Sclerotium Tuber, Effluent, Coa-flocculation, Optmization

1.1 INTRODUCTION

Pharmaceutical industry effluent (PIE), a major waste product from drugs manufacturing and personal care products, is a notorious pollutant deleterious to the aquifers of pharmaceutical industry bearing communities in Nigeria. The characteristics of the pharmaceutical industry effluent is a major determinant for employing, the most suitable technique or remedial options available for the treatment [1]; [2]. Depending on the product manufactured, materials used and the processing details, the quality and the characteristics of PIE fluctuate significantly [3]. Pharmaceutical industry effluent may contain organic solvents, catalysts, additives, reactants, intermediates, raw materials and active pharmaceutical ingredients [2], which makes them difficult to treat. The presence of toxic or recalcitrant substances in such effluent results in lower chemical oxygen demand (COD) removal efficiencies [4]. It has been estimated that up to half of the pharmaceutical waste produced worldwide is released without any treatment [5]; [6]. Typically, untreated PIE contains suspended solids (100 – 226 mg/l), turbidity (500 – 1256 NTU), chemical oxygen demand (250 – 880 mg/l) and biochemical oxygen demand (200 – 620 mg/l).

[7]. Coag-flocculation treatment process is relatively simple, common and economical waste water treatment method [7].

Coag-flocculation techniques are very important in wastewater treatment operations. The removal mechanisms of this process mainly consists of charge neutralization of negatively charged colloids by cationic hydrolysis product, followed by incorporation of impurities in an amorphous hydroxide precipitate via flocculation. The aggregated particles form visible flocs that settle out under gravity [8]: [9]; [10].

The two primary coagulants (inorganic salts) – the salts of iron and alum are generally used in wastewater treatment via coag-flocculation process. Among these inorganic coagulants, alum is most widely used in Nigeria. However, studies have shown several drawbacks associated with using, aluminum salt, such as Alzheimer's disease and production of large sludge volume, impact on the pH value of water etc. [11].

In order to amileriote the prevailing challenges, approaches should be directed sustainable water treatment that are low in cost, eco-friendly, reliable and require minimal maintenance and operational skills. Pleurotus tuberregium sclerotium among other natural materials such as Telfoiria Occidentalis, corchorus olitorus, mucuna prurient posses these qualities and provide remedy for the identifiable deficiencies associated with non-conventional materials [10]; [12].

Pleurotus tuberregium is a tropical sclerotial mushroom, which can be quite large up to 30cm [13]. The tuber contains positively charged water soluble proteins that can attract the predominately negatively charged particle (total dissolved and suspended solids TDSS) inherent in the effluent to form settleable flocs [13]; [7].

Recently, researchers have shown interest in using natural coag-flocculants in treating, wastewater. However, pleurotus tuberregium sclerotium has not been used extensively in this regard.

The study is aimed at providing kinetic data, the mathematical relationship that predicts the interaction of the studied variables and the optimal values can be applied to similar situations in order to improve quality of wastewater being discharged to the environment.

2. Materials and Method

2.1.1 Pharmaceutical Industry Effluent

The effluent used in this study was taken from pharmaceutical industry located in Anambra State, Nigeria. The physicochemical and biological characteristics of the effluent presented in Table 1 were determined based on a standard method [14].

Table 1 Characteristics of pharmaceutical industry effluent.

Parameters	Values
pH	3.87
Temperature (^{0}C)	28.00
Electrical conductivity (m/m^2)	8.17
Phenol (mg/.l)	nil
Total Hardness	6000.00
Ca Hardness (mg/.l)	3344.00
Mg Hardness (mg/.l)	2656.00
Chloride CL^- (mg/.l)	100.00
Dissolved oxygen (mg/.l)	20.00
Turbidity (NTU)	1256.00
Iron Fe^{2+} (mg/.l)	nil
Nitrate No_3^{2-} (mg/.l)	nil
Total acidity (mg/.l)	250.00
TDS (mg/.l)	57.25
TSS (mg/.l)	225.50
COD (mg/.l)	880
BOD (mg/.l)	620
Oil and grease (mg/.l)	nil
Total viable count (cfu/ml)	90.00
Total coliform count (cfu/ml)	10.00
Pseudomonas aeruginosa (MPN/ML)	nil

2.1.2 Pleurotus Tuberregium Sclerotium (PTS) Sample

The tuber of pleurotus tuberregium sclerotium plant (precursor to PTSC) was sourced from Nkwo market, Enugwu-Ukwu, Anambra State. The analysis of PTSC tuber powder were performed following a standard method [15] and characteristics result presented in Table 2.

Table 2. Characteristics of PTSC precursor

Parameters	Values
Moisture content (%)	10.00
Ash Content (%)	6.00
Lipid content (%)	9.00
Crude protein (%)	43.70
Carbohydrate (%)	5.51
Crude fibre (%)	11.00

2.2 Coag-flocculation Experiment

Experiment were carried out in a jar test apparatus equipped with a six-unit multiple stirrer system. Appropriate dosage of PTSC in the range of 0.1 – 0.7g/l was added to 250ml of PIE. The suspension, tuned to pH range of 1,3,5,7,10 and 13 using 10M solution sulphuric acid and sodium hydroxide. The samples were subjected to 2 minutes of rapid mixing (120rpm), 20 minutes of slow mixing (10rpm), followed by 40minutes of settling.

During settling, samples were withdrawn using pipette from 2cm depth and analyzed for turbidity (NTU) (which was later converted to TDSS in mg/l) in changes with a view to determining the optimal conditions (pH, dosage, settling time through 2^3 central composite design (CCD) and kinetics parameters. The whole experiment was repeated using Alum. Independent variables range and levels for the coag-flocculation process optimization are presented in table 3 while table 4 shows the full 2^{3-} CCD factorial design matrix with output response. The experimental results of the 23-CCD were studied and interpreted by software, MATLAB 7.0 to estimate the response of the dependent variable. The kinetics of coag-flocculation and extent of aggregation were monitored at optimal conditions at room temperature for 2,4,6,10,20,30 and 40min. the result generated were fitted in appropriate kinetic model.

Table 3: Experimental range and levels of independent process variables

Independent variable	Lower Limit (-1)	Base Level (0)	Upper Limit (+1)
pH	1.0000	7.0000	13.0000
Dosage	0.1000	0.4000	0.7000
Settling time	2.0000	21.0000	40.0000

3.0 THEORETICAL PRINCIPLES

3.1 COAG-FLOCCULATION MODEL DEVELOPMENT

For a homogeneous aggregating particles (i, j) in equilibrium state with negligible influence of gravitational, buoyancy, drag, van der Waals and repulsive forces [16]; [17]; [18]

$$\mu_i = U_i \frac{\delta(n_w)}{\delta(n_i)} \quad nS, nV, n_j \qquad (1)$$

Also

$$\mu_i = t_i = \frac{\delta(n_c)}{\delta((n_i)} \quad p, T, n_j = \text{a constant} \qquad (2)$$

(3)

For a homogeneous phase solutions

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

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

Thus $f_d = -\frac{K_B T}{C_i}\frac{dC_i}{dx}\frac{dx}{dx}$ (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

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

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

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 [19] .

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

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.

ß is a function of coagulation-flocculation transport for Brownian, Shear and

differential sedimentation mechanisms

The value of for transport mechanism is given as [19].

$$ß_{BR} = \frac{8}{3}\frac{£_p K_B T}{n} \quad (13)$$

Where $_p$ is collision efficiency

? is the viscousity of effluent

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

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

Where N_t is total particle concentration at time t, $N_t = \Sigma n_t$ (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 $_{BR} = 2 £_p K_R$ (16)

Combining equations (14), (15) and (16) yields

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

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

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

Where R_o is particle radius

D^1 is diffusion coefficient for intending flocculating particles i and j

$$= R_i + R_j \quad (19)$$

Where R_p is relative particle radius for R_i and R_j

Putting $R_i = R_o$ and $R_j = R_o$

Equation (19) transposes to $R_p = 2R_o$ (20)

Recall from equation (11)

$$D^1 = \frac{K_B T}{B}$$

And from stokes equation $B = f$

$$V = \frac{K_B T}{f} \quad (21)$$

Where K_B – is Boltzman's constant (J/K)

T – is absolute temperature (K)

V – is the velocity acquired by potential aggregating particles under the influence of stiochastic force (as result of heat and stirring of the system).

But for a solid sphere of radius R_o, the stokes equation gives

$B = 6 p? R_o$

Where ? is viscosity of coagulating and flocculating medium.

Combing equations (17) to (22) produce:

$$\frac{dN_t}{dt} = \frac{4}{3} \frac{£_p K_B T N_t^{a}}{n} \quad (23)$$

Comparing equations (14) and (23) show that

$$K = \frac{4}{3} \frac{£_p K_B T}{n} \quad (24)$$

For peri-kinetic aggregation, *a* theoretically equals 2 [17]; [18]

From fick's law

$$J_f = D^1 4? R_p^2 \frac{dN_?}{dR}^{?} \quad (25)$$

Where J_f is flux

Re-arranging and integrating equation (25) at initial conditions $N_t = 0$, $R = 2R_o$

$$\frac{Jt}{4\pi} \frac{dRp}{R_p^2} \int_o^{Rp} dRp = \int_{N_o}^{N_t} d N_t$$

Thus $J_f = 8pD^1 R_o N_o$

Generally, for particle of same size under the influence of Brownian motion. The initial rate of coag-flocculation is

$$-\frac{dN_t}{dt} = Jt\ \pounds p\ N_o \qquad (28)$$

Substituting equations (21), (22) and (27) into (28) yields

$$-\frac{dN_t}{dt} = \frac{4}{3}\ \pounds p\ \frac{K_B T}{n}\ N_0^2 \qquad (29)$$

Similarly

$$-\frac{dN_t}{dt} = \frac{4}{3}\ \pounds p\ \frac{K_B T}{n}\ N_0^2 \quad att > 0$$

Hence equation (29) has confirmed $a = 2$

For $a = 2$ equation (14) transposed to

$$\frac{dN_t}{dt} = KN_t^a \qquad (30)$$

Re-arranging and integrating equation (3(yields Integrating

$$\int_{N_O}^{N_t} \frac{dN_t}{N_t} = -K\int_o^t dt \qquad (31)$$

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

Plot of $\frac{1}{N}$ vs t gives a slope of K and intercept of $\frac{1}{N_o}$

On evaluation of equation (32), $_{1/2}$ (Coagulation period) can be determined.

$$N_t = \frac{N_o}{1 + \left\{\frac{t}{\frac{1}{Nok}}\right\}} \qquad (33)$$

$$\text{Where} = \left\{\frac{1}{Nok}\right\} \qquad (34)$$

Substituting equation (34) into (33) yields

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

As t = t equation (34) transpose to;

$$N_t = \frac{N_o}{2}$$

Similarly

$$tN_t = 0.5\ N_o$$

As N_o fi $0.5N_o$; t fi $\frac{t}{2}$,

Hence equation (33) becomes

$$\frac{t}{2} = (0.5N_oK)^{-1} \qquad (37)$$

For a coagulation period, where total number of concentration N_t is halves, solving equation (12) results in the general expression for particle of m^{th} order.

$$\frac{N_m}{N_o}(t) = \left[\frac{KN_o t}{2}\right]^{m-1} \Big/ [1 + \frac{KN_o t}{2}]^{m+1} \qquad (38)$$

Recall; $\frac{t}{2} = \frac{N_o K}{2}$ or $(0.5N_o K)^{-1}$

For single particle (m = 1)

$$\frac{N_1 t}{N_o} = \frac{1}{\left(1 + \frac{KN_o t}{2}\right)^2} \quad (39)$$

$$\therefore N_1 t = N_o \frac{1}{\left(1 + \frac{KN_o t}{2}\right)^2} \quad (40)$$

For double particles (m = 2)

$$\frac{N_2 t}{N_o} = \frac{\left[\frac{KN_o t}{2}\right]^2}{\left[1 + \left[\frac{KN_o t}{2}\right]^3\right]} \quad (41)$$

$$\therefore N_2 t = N_o \frac{\left[\frac{KN_o t}{2}\right]^2}{\left[1 + \left[\frac{KN_o t}{2}\right]^3\right]} \quad (42)$$

For triple particles (m = 3

$$\frac{N_3 t}{N_o} = \frac{\left[\frac{KN_o t}{2}\right]^3}{\left[1 + \left[\frac{KN_o t}{2}\right]^4\right]} \quad (43)$$

$$\therefore N_3 t = N_o \frac{\left[\frac{KN_o t}{2}\right]^3}{\left[1 + \left[\frac{KN_o t}{2}\right]^4\right]} \quad (44)$$

Finally, the evaluation of coag-flocculation efficiency or coag-flocculant performance of the process was obtained by applying the relation below.)

$$E_{i,j}(\%) = \left[\frac{N_o - N_t}{N_o}\right] \times 100$$

3.2 Coag-flocculation Optimization

Optimization was studied by central composite design (CCD). The parameters: pH, dosage and settling time were chosen as independent variables at two levels while particle (TDSS) uptake is the output response (dependent variable). A 2^3 full factorial experimental designs with three centre points, six star points and seventeen runs experiments was employed in this study. The centre points emphasizes the changes in the middle of the plan and measures the degree of precision property, while star points verify the non linear suspected curvature. The behavior of the systems is explained by the multivariable polynomial equation presented below.

$$\mathbf{Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{12}X_{13}X_1X_3 + b_{23}X_2X_3 + b_{11}X^2_1 + b_{22}X^2_2 + b_{33}X^2_3} \quad (46)$$

X_1 is pH, X_2 is dosage, X_3 is settling time.

The polynomial coefficients (b_0, b_1, b_{22} etc) in equation (46) is determined using the following expression below.

$$b_o = \alpha \sum_{u=i}^{N} Yu + p\sum_{j=i}^{m} \Sigma_{u=}^{N} X^2 j \quad (47)$$

$$b_i = e\Sigma_{u=i}^{N} X_{iu} + Y_u \quad (48)$$

$$b_{ij} = g\sum_{u=1}^{n} X_{ui} X_{ju} Y_u \quad (49)$$

$$b_{ij} = C\sum_{u=1}^{N} X_{ju}^2 Y_u + d\sum_{j=1}^{m}\sum_{u=1}^{N} X^2 ju + p\sum_{u=1}^{N} Y_u \quad (50)$$

Table 4: Process design matrix and output response

S/N	X_1	X_2	X_3	Y_1	Y_2
1	0	0	0	326	328
2	-1	-1	-1	564	565
3	1	-1	-1	830	827
4	-1	1	-1	1060	1063
5	1	1	-1	1526	1529
6	0	0	0	326	322
7	-1	-1	1	196	194
8	1	-1	1	132	136
9	-1	1	1	380	383
10	1	1	1	112	115
11	0	0	0	326	327
12	-1	0	0	760	762
13	1	0	0	122	125
14	0	-1	0	414	416
15	0	1	0	438	435
16	0	0	-1	584	586
17	0	0	1	292	294

Where: X_1- pH; X_2- dosage; X_3- Settling time; Y- process response

RESULTS AND DISCUSSION

4.1 Optimization studies

The optimization of the coag-flocculation process with respect to pH, dosage and setting time was achieved by response surface methodology through 2^3-CCD. The trust is on how the dependent output variable –TDSS uptake is influenced by independent variables: PIE pH(X_1), coag-flocculant dosage (X_2) and settling time (X_3) the pH considered were 1,3,5,7,10 and 13 varied dosage of range between 0.1 and 0.7g/l and settling time of 2,4,8,10,20,30 and 40 as shown in table… Experiments were performed at different combinations of the physical parameters using statistically designed experiments as shown in Table 4. The results obtained were used to study the effects of these factors on the TDSS uptake. The main effects of the parameter and response behavior of the system is explained by equation 51.

$$Y_u = 338.1338 - 345.0000 X_3 \quad (51)$$

The optimization results obtained from equation as interpreted by MATLAB 7.0 are presented in Table 5, with the motive of minimizing TDSS. The optimal pH, dosage and settling time were recorded at 13, 0.3g/l and 40 mins, respectively. It is observed that at optimal operation, the TDSS is reduced from 2637.6000 to 34.7827mg/l. The corresponding optimized interactive surface response plots are presented in figures 1-3. Figure 1 shows the interaction effects of dosage and pH on the TDSS removal.

For figure 2, the interaction effect of settling time and dosage. It is worthy to note that the value of the output response is a function of colour intensity of the three dimensional plots (3-D plots). In that regard the TDSS residual values recorded for figures 1 – 3 are 300,100 and 100mg/l respectively. In general, 3-D plots aids to observe the surface area of curve within which the process can perform at optimal level as a result of the effects of interaction of the variables. This will go further to show the figures where the interaction effects of these variables has greatest impact on the output response. Based on the residual values recorded, it can be observed that figure 2 and 3 recorded the least. On evaluation of equation (45) ie:

$$E_{I,j}(\%) = \frac{N_o - N_t}{N_o} \times 100$$

Where No – initial turbidity value (TDSS) ; N_t – final turbidity value (TDSS residue)

gives the efficiency of the process i.e percentage of TDSS removed at the end of the process which translate to output response.

Coag-flocculation efficiency E% obtained on evaluation of equation 45, is graphically presented in figure 4. It shows minimal variation of TDSS removal at varying dosage and optimum pH 13 and 40 minutes settling time. It can be observed from figure 4 that at 8 minutes, all the dosage had recorded up to 80% TDSS removal efficiency. The implication is that any quantity in dosage range considered can be used to achieve good PTSC performance. However, the dosage with best performance is 0.3g/l at E(%) > 98%. This is in agreement with Table 5.

Furthermore, the performance of PTSC was compared with that of Alum as shown in figure 5 at optimal pH and settling time. PTSC performed better than alum for all the dosages considered. This amplify's the effectiveness of PTSC as an organic aggregating agent that are biodegradable and eco-friendly [7].

Table 5: Optimization results of Coag-flocculation based on 2^3CCD.

Sample	X_1(pH)		X_2(Dosage)		X_3settling time		Y(TDSS removal mg/l)
	CV*	RV**	CV*	RV**(mg/l)	CV*	RV**(mg/l)	
PTSC	-1.0000	0.10000	1.0000	0.7000	-1.0000	0.1000	34.7827

*coded value

**Real value

4.2 Coag-flocculation Kinetics

This sub-section analyses the coag-flocculation functional parameters obtained at optimum conditions in this work, posted in table 6 for varying dosages.

Coefficient of determination (R^2) was employed in ascertaining the level of accuracy of fit of the experimental data on the coag-flocculation process main model denoted as (equation 32). Table 6 show that majority of R^2 are greater than 0.75. hence it can be concluded that experimental data were adequately described by equation 32. K which is coag-flocculation constant (or aggregation constant) is evaluated from the slope of equation (32) on plotting 1/N vs time, 1/No is the intercept. K and B_{BR} values has minimal influence of the varying dosage of PTSC.

This phenomenon is a result of the near same efficiency value achieved by the varying PTSC dosages as illustrated in figure 4.

Overview of table 6, show that Von Smoluchowski rate constant K_R = fn (t, μ) variation is minimal, due to insignificant changes in the values of temperature and viscousity of the effluent medium. At the vicinity near unit of K_R , particle collision efficiency (εp) relates directly to 2k = B_{BR}. apparently high εp result in kinetic energy to overcome repulsive forces. It is pertinent to note that from table 6, high $\tau_{1/2}$ corresponds to low εp and K, indicating presence of repulsive forces in the system. From theoretical consideration,$\tau_{1/2}$ and K_R are understood to be prerequisite factors for coagulation efficiency prior to flocculation. Equation (38) is the generalized relation for time evolution of m-particle aggregation (singlets, doublets and triplets; where m = 1,2, 3 respectively) at microscopic level. The behavioural activity of the class of the particles are depicted in figure 6. The general trend obtainable in figure 6, show existence of minimal repulsive forces at low $\tau_{1/2}$ causing relatively high bridging between the class of particle leading to high coag-flocculation. This accounts for high percentage of TDSS being sweeps away from PIE by PTSC [7].

Table 6: Coag-flocculation kinetic parameters and linear regression coefficient of PTSC at varying dosage and pH of 13.

Parameters	0.1g/l	0.2g/l	0.3g/l	0.4g/l	0.5g/	0.6g/l	0.7g/l
Y	1.46E-04 X+1.46E-03	2.04E-04 X+1.175E-03	2.491E -04 X+2.4337E-03	2.005E-04 X+3.2039E-03	1.51E-04 X+3.3286E-03	1.959E-05 X+1.9558E-03	2.03E-04 X+1.961E-03
α	2.000	2.000	2.000	2.000	2.000	2.000	2.000
R^2	0.945	0 .967	0.877	0.762	0.608	0.639	0.780
K(l/g.min)	1.46E-04	2.04E-04	2.491E -04	2.005E-04	1.51E-04	1.959E-05	2.03E-04
K_R(l/min)	1.5801E-19	1.5801E-19	1.5801E-19	1.5826E-19	1.5826E-19	1.5826E-19	1.5826E-19
β_{BR}(l/g.min)	2.92E-04	4.08E-04	4.982E-04	4.01E-04	3.02E-04	3.918E-04	4.06E-04
$\varepsilon_p(g^{-1})$	18480E+15	2.5821E+15	3.1530E+15	2.5378E+15	1.9083E+15	2.4757E+15	2.5654E+15
$\tau_{1/2}$ (min)	0.12	0.09	0.07	0.09	0.12	0.09	0.09
(-r)	1.46E-04N_t^2	2.04E -4N_t^2	2.491E -04N_t^2	2.005E -04N_t^2	1.51E -04N_t^2	1.959E -04N_t^2	2.03E -04N_t^2
N_A(g/l)	684.9315	851.0638	697.4960	32.1196	300.4266	511.2997	509.9439

Note :Y- Process response; φ - Order of reaction; R^2 – Coefficient of determination ; K- Coag-flocculation coβ – Collision factor for Brownian transport; ε- Collision efficiency; $T_{1\backslash 2}$ – Coagulation period \half life ; -r – Rate equation; instant; K_R –Von Smoluchowski rate constant

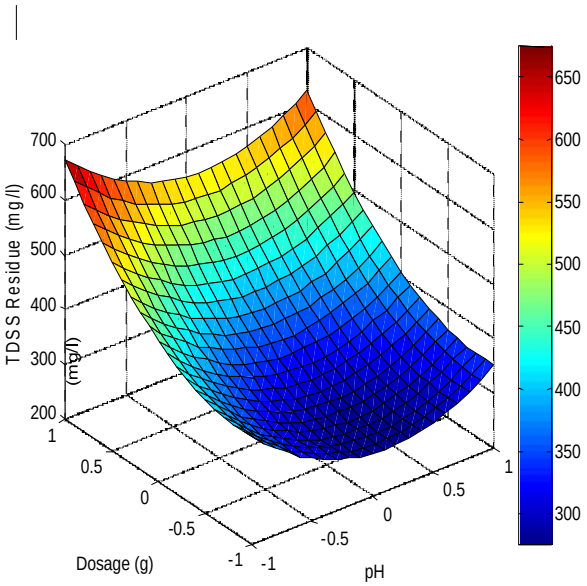

Fig.1:Coag.flocculation surface plots of ptsc showing interaction of dosage and pH

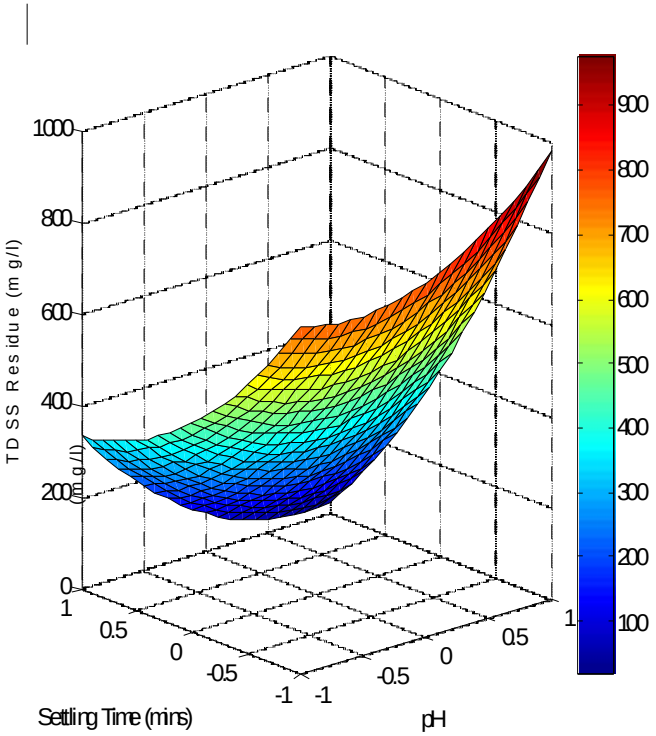

Fig.2:Coag.flocculation surface plots of ptsc showing interaction of settling time and pH

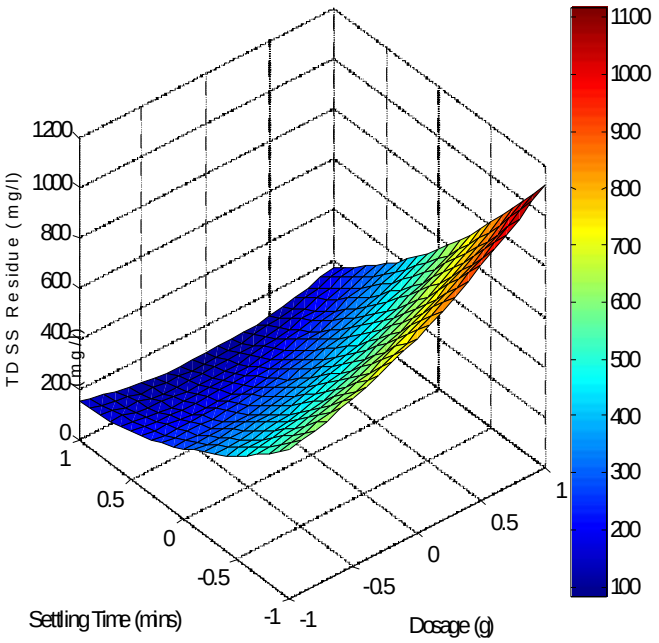

Fig.3:Coag.flocculation surface plots of ptsc showing interaction of settling time and dosage

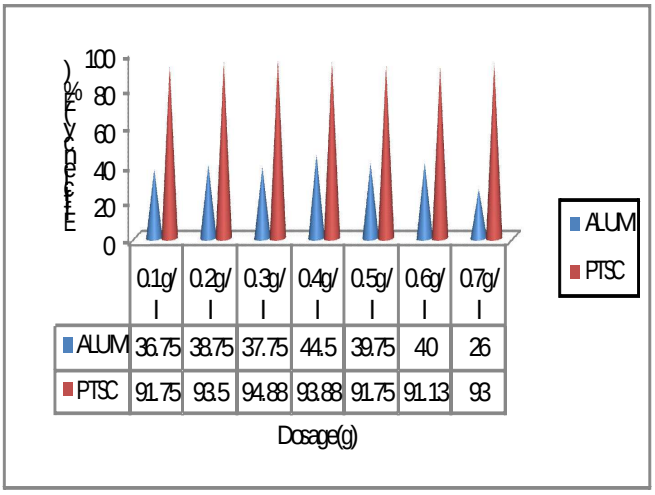

Fig.5: Comparative coag-flocculation performance at 40mins for varying ptsc and alum

dosages at pH of 13

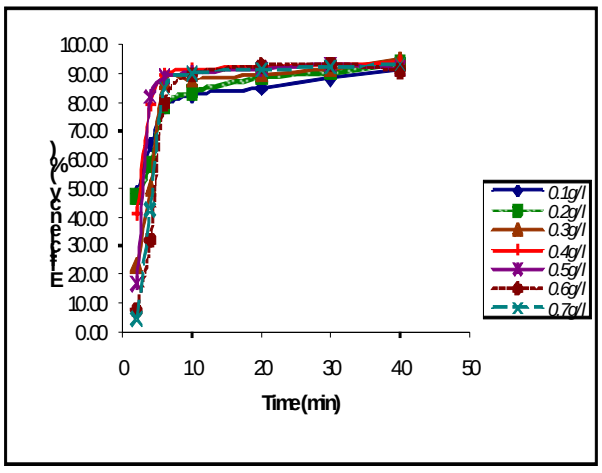

Fig.4: Removal efficiency as a function of time and **ptsc** dosage for PIE at pH 13

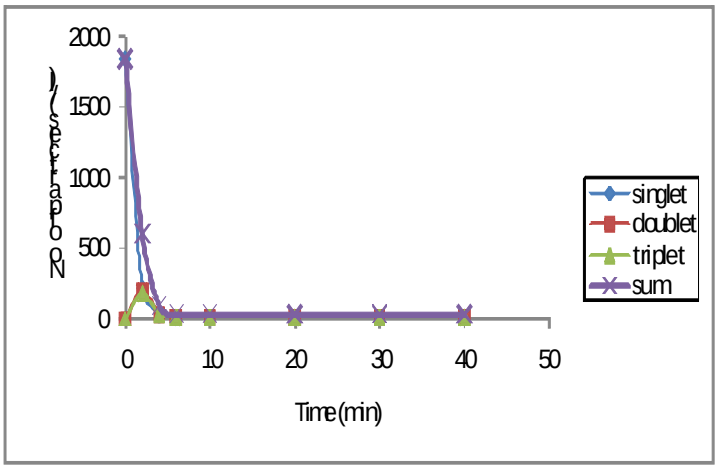

Fig.6: Particle distribution plot for ptsc at minimum half life 0.07min

CONCLUSION

The use of PTSC as an effective coag-flocculant for the remediation of high turbid water like PIE has been established. The removal of 98.68% TDSS after 40minutes of the treatment period gave credence to the fact that PTSC is good coag-flocculant for scaleable wide applications for waste water and water treatments. The system can operate optimally at pH 13, 0.3g/l dosage and 40minutes settling time.

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