Nature and Science, 2009;7(6), ISSN 1545-0740, http://www.sciencepub.net, naturesciencej@gmail.com

Coag-flocculation kinetics and functional parameters response of Periwinkle shell coagulant (PSC) to pH variation in organic rich coal effluent medium

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ABSTRACT

The coag-flocculation performance of PSC as affected by pH variation in coal washery effluent has been investigated at room temperature using various dosages of unblended PSC. In addition, coag-flocculation parameters such as α, K, β_{BR}, K_R, ε_p and $\tau_{1/2}$ are determined. Turbidity measurement was employed using the nephelometric (turbidimetric) standard method while PSC preparation was adapted from the works of Fernandez-Kim. The maximum PSC performance is recorded at α of 2, K of $1.6667\text{x}10^{-3}\text{m}^3/$ kg.s, dosage of 0.4 kg/m^3, pH of 6 and $\tau_{1/2}$ of 8.0s while the minimum performance is recorded at α of 2, K of $8.833\text{x}10^{-5}\text{m}^3/$ kg.s, dosage of 0.5kg/m^3, pH of 10 and $\tau_{1/2}$ of 218s.The minimum value of coagulation efficiency, E (%) recorded is > 95% .In general, the computed parameters lie within range of previous works .The results obtained confirmed that the theory of fast coag-flocculation holds for coag-flocculation of the coal washery effluent using the coagulant investigated and at the conditions of the experiment. [Nature and Science. 2009;7(6):1-18]. (ISSN: 1545-0740).

Keywords: Coag-flocculation,Kinetics,CoalEffluent,Periwinkle shell,coagulation

INTRODUCTION

Traditionally ,coag-floculation is aimed at the removal of suspended colloidal particles when the stabilized colloids are aided to overcome their repulsive forces leading to the aggregation of the particles into flocs.(Ma et al ,2001;Di Terrlizzi, 1994;Edzwald,1987;O'meila, 1978)
Among the factors that affect the process are raw effluent quality, temperature, pH, chemical and bacteriological parameters etc(jin,2005).

Coag-flocculation may be achieved by any of the common coagulants such as alum, lime etc. The coagulation behaviors of these common coagulants have been well investigated with little or no attention given to the coag-flocculation potential of many animal and plant derivatives. To this end, a focus is hereby given to the study on periwinkle shell as potential source of coagulant derivative. Periwinkle shell is a natural carbohydrate biopolymer derived by deacetylation of chitin, a major component of the shells of crustacean. (Fernadez-Kin, 2004).

PSC is a non-toxic, biodegradable and biocompatible polymer. Previous results obtained from the study on crustacean derived coagulants highlight promise of renewable polymeric materials with extensive application in removal of colloidal particles in wide range of effluent media (Fernandez-Kin, 2004)

However, in spite of the abundance of periwinkle in our local communities in Nigeria, little or no comprehensive work has been reported. Against this backdrop, this work endeavors to explore and generate interest in the utilization of periwinkle shell as coagulants. As a step in this direction, this work focuses on coagulation performance and kinetics of PSC under varying pH of coal washery effluent, a typical medium for this kind of study. Thus, if well developed, PSC can serve as a suitable replacement either in total or in part for the inorganic coagulants.

THEORETICAL PRINCIPLES AND MODEL DEVELOPMENT

The rate of successful collisions between particles of sizes i and j to form particle of size *k* is (Thomas *et al*, 1999; Jin, 2005):

$$N_{ij} = \varepsilon_p \beta (i,j) n_i n_j \qquad \ldots 1$$

where N_{ij} = the rate of collisions between particles of size i and j(mass concentration / time)
ε_p = collision efficiency
$\beta(i,j)$ = collision factor between particles of size i and j
$n_i n_j$ = particle concentration for particles of size i and j, respectively.
Assuming monodisperse, no break up and bi particle collision , the general model for perikinetic coag-flocculation is given as (Swift and Friedlander 1964 ; Jin, 2005)

$$\frac{dn_k}{dt} = \frac{1}{2}\sum_{i+j=k}\beta(i,j)n_i n_j - \sum_{i=1}^{\infty}\beta(i,k)n_i n_k \qquad \ldots 2$$

where $\frac{dn_k}{dt}$ is the rate of change of concentration of particle of size k (concentration / time). β is a function of the coag-flocculation transport mechanism .The appropriate value of β for Brownian transport is given by Von Smoluchowski (1917):

$$\beta_{BR} = \frac{8}{3}\varepsilon_p \frac{k_B T}{\eta} \qquad \ldots 3$$

where k_B is Boltzmann's constant (J/K)

T is Absolute temperature (K)

The generic aggregation rate of particles (during coagulation / flocculation) can be derived by the combination of equations 2 and 3 to yield:

$$-\frac{dN_t}{dt} = KN_t^{\alpha} \qquad \ldots 4$$

where N_t is total particle concentration at time t, $N_t = \sum n_k$ (mass / volume)

K is the α^{th} order coag-floculation constant

α is the order of coag-floculation process

And $K = \frac{1}{2}\beta_{BR}$ …5

where β_{BR} is collision factor for Brownian transport

Also, $\beta_{BR} = \varepsilon_p K_R$ …6

combining equations 4,5 and 6 produce:

$$-\frac{dN_t}{dt} = \frac{1}{2}\beta_{BR}N_t^{\alpha} \qquad \ldots.7$$

$$= \frac{1}{2}\varepsilon_p .K_R N_t^{\alpha} \qquad \ldots 8$$

where K_R is the Von smoluchowski rate constant for rapid coagulation (Van Zanten, *et al* 1992)

However $K_R = 8\pi R_p D'$ ….9

$R_p = 2a$ ….10

where D' is particle diffusion coefficient

a is particle radius.

From Einstein's equation: $D' = K_B \, T/B$ …11

From Stoke's equation : $B = 6\pi\eta a$ ….12

where B is the friction factor

η is the viscosity of the fluid

combining equations 9 and 11 give:

$$K_R = \frac{8\pi R_p K_B T}{B} \qquad \ldots 13$$

combining equation 12 and 13 give:

$$K_R = \frac{8\pi R_p K_B T}{6\pi\eta a} \qquad \ldots 14$$

Putting equation 10 in 14 yields:

$$K_R = \frac{8}{3}\frac{K_B T}{\eta} \qquad \ldots 15$$

combining equations 8 and 15 give:

$$-\frac{dN_t}{dt} = \frac{1}{2}\varepsilon_p\left(\frac{8}{3}\frac{K_B T}{\eta}\right)N_t^{\alpha}$$

$$= \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} N_t^{\alpha} \qquad \ldots 16$$

Comparing equations 4 and 16 show:

$$K = \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} \qquad \ldots 17$$

For perikinetic aggregation, α theoretically equals 2 as would shown below (Fridrikhsberg, 1984; Hunter, 1993):

From Fick's law,

$$J_f = D' 4\pi R_p^{\ 2} \frac{dN_t}{dR_p} \qquad ..18$$

Integrating equation 18 at initial conditions $N_t = 0$, $R = 2a$:

$$\frac{J_f}{D' 4\pi}\int_0^{R_p} \frac{dR_p}{R_p^{\ 2}} = \int_{N_0}^{N_t} dN_t \qquad ...19$$

Therefore $N_t = N_0 - \frac{J_f}{4\pi D' R_p}$ …20

It implies,

$$0 = N_0 - \frac{J}{4\pi D'(2a)} \qquad ...21$$

Therefore $J_f = 8\pi D' a N_0$ …22

$$= \frac{1}{2}\cdot K_R \cdot N_0 \qquad ...23$$

For central particle of same size undergoing Brownian motion, the initial rate of rapid coag-flocculation is:

$$-\frac{dN_t}{dt} = J_f \cdot \varepsilon_p \cdot N_0 \qquad \ldots 24$$

$$= \frac{1}{2}\cdot K_R \cdot \varepsilon_p \cdot N_0 N_0$$

$$= \frac{1}{2}\cdot K_R \cdot \varepsilon_p \cdot N_0^2$$

$$= \frac{1}{2}\cdot \varepsilon_p \cdot \frac{8}{3}\frac{K_B T}{\eta}\cdot N_0^2$$

$$= \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} \cdot N_0^2 \qquad \text{...25}$$

$$\equiv \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} N_t^2 \text{ at } t > 0$$

Hence, from equation 25, $\alpha = 2$

However in real practice, empirical evidence shows that in general $1 \le \alpha \le 2$ (WST, 2003; Menkiti, 2007).Based on this , what is required to evaluate *K* is to determine the line of better fit between $\alpha = 1$ and 2 while the experimental data are fitted into linearised form of equation 4.

Hence, for $\alpha = 1$,equivalence of equation 4 yields:

$$\frac{dN}{dt} = - KN \qquad \text{...26}$$

Integrating within the limits, produces

$$\int_{N_0}^{N} \frac{dN}{N} = -\int_0^t Kdt \qquad \text{...27}$$

Equation 27 yields:

$$\ln N = \ln N_0 - Kt \qquad \text{...28}$$

$$\ln\left(1\Big/\left[1/N \right] \right) = \ln N_0 - Kt$$

$$\ln\left(1/N \right) = Kt - \ln N_0 \qquad \text{...29}$$

Plot of $\ln\left(1/N \right)$ vs. t gives a slope of *K* and intercept of $(-\ln N_0)$.

For $\alpha = 2$; equivalence of equation 4 yields:

$$\frac{dN}{dt} = -KN^2 \qquad \text{...30}$$

Hence:

$$\int_{N_0}^{N} \frac{dN}{N^2} = -K\int_0^t dt \qquad \text{...31}$$

$$\frac{1}{N} = Kt + 1/N_0 \qquad \text{...32}$$

Plot of $\ln\left(1/N \right)$ Vs t produces a slope of *K* and intercept of $1/N_0$.

For the evaluation of coagulation period ($\tau_{1/2}$), from Equation 32:

$$N = \frac{N_0}{1 + N_0 K t} \qquad \text{....33}$$

$$= \frac{N_0}{\left[1 + \dfrac{t}{\left(1/N_0 K \right)} \right]} \qquad \text{...34}$$

let $\tau = \left[{}^{1}\!/_{N_0 K} \right]$ ...35

Hence:

$$N = \frac{N_0}{1 + (t/\tau)} \qquad \text{…36}$$

When $t = \tau$, equation 36 becomes

$$N = {}^{N_0}\!/_{2} \qquad \text{…37}$$

Therefore as $N_0 \to 0.5N_0 ; \tau \to \tau_{1/2}$

Hence $\tau_{1/2} = {}^{1}\!/_{(0.5 N_0 K)}$ ...38

For Brownian aggregation at early stages (t≤30 minutes), equation 2 can be solved exactly, resulting in the expression (Holthof *et al*, 1996):

$$\frac{N_{m(t)}}{N_0} = \frac{\left[{}^{t}\!/_{2} \left(\frac{1}{KN_0} \right) \right]^{m-1}}{\left[1 + \frac{t}{2\left(\frac{1}{KN_0} \right)} \right]^{m+1}} \qquad \text{….39}$$

Where $\tau = \left(\frac{1}{N_0 K} \right)$

Therefore $\frac{N_{m(t)}}{N_0} = \frac{\left[{}^{t}\!/_{2\tau} \right]^{m-1}}{\left[1 + {}^{t}\!/_{2\tau} \right]^{m+1}}$ 40

Let $2\tau = \tau'$

Therefore $\frac{N_{m(t)}}{N_0} = \frac{\left[{}^{t}\!/_{\tau'} \right]^{m-1}}{\left[1 + {}^{t}\!/_{\tau'} \right]^{m+1}}$ ...41

Equation 41 gives a generic expression for particle of *m-th* order .Hence,

For singlets *(m=1)*

$$N_1 = N_0 \left[\frac{1}{\left(1 + {}^{t}\!/_{\tau'} \right)^2} \right] \qquad \text{...42}$$

For doublets *(m=2)*

$$N_2 = N_0 \left[\frac{\left({}^{t}\!/_{\tau'} \right)}{\left(1 + {}^{t}\!/_{\tau'} \right)^3} \right] \qquad \text{….43}$$

For triplets *(m=3)*

$$N_3 = N_0\left[\frac{\left(t/\tau'\right)^2}{\left(1+t/\tau'\right)^4}\right] \qquad ....44$$

Conversion of Turbidity (NTU) to TSS *(mg/l)* yields (Metcalf and Eddy,2003):

$$\text{TSS } (mg/l) = (\text{TSS}_f).\text{T} \qquad ...45$$

Where T = turbidity (NTU)

(TSS_f) =Conversion factor to TSS

EXPERIMENTAL METHODS

The procedure for processing of the periwinkle shell to coagulant is adapted from the work of Ferdinandez-Kin (2004).The jar test were conducted based on standard Bench Scale Nephlometric Method for the Examination of water and waste water.(WST,2003;AWWA, 1985)

RESULTS AND DISCUSSION

The values of coag-flocculation reaction parameters are presented in tables 1 to 5.For the case of $\alpha = 1$, it is a shift from theoretical expectation but in line with empirical evidence (WST,2003).Generally, the value of α affects that of K inversely .Since K is rate per concentration and K is associated with energy barrier (KT) , it is understandable that for higher α to be obtained , a lower K is a necessary condition for such phenomenon (Fridkisberg,1984) .The K and α values are to a large extent consistent with previous works on Brownian coagulation (Van Zanten and Elimelechi,1992). $K(=0.5\beta_{BR})$ values appreciably is less sensitive to a given pH as the dosage of PSC changes from 0.1kg/m^3 to 0.5kg/m^3.Variation in K_R is generally minimal as presented in the tables 1 to 5 .This is because K_R is a function of viscosity and room temperature both of which did not vary considerably during the study.

The discrepancies in α, K and K_R are explained by the unattainable assumption that mixing of particles and coagulant throughout the dispersion is 100 % efficient before any aggregation occurs. The effect of this limitation will be local increases in particle ratios during the mixing phase given uneven distribution of particles / coagulant complexes. The complexity of this system makes it hard to have all the values of $\alpha = 2$.(Yates *et al* , 2001).Another account is the interplay between the van der waal forces and the hydrodynamic interactions which typically reduces the theoretically predicted K by a factor of 2.However, since K also depends on the type of counter ion, additional short range forces represent the most likely explanation for any other remaining discrepancies (Holthof *et al* ,1997;Holthof *et al* ,1996).

At nearly invariant values of K_R ,ε_p directly relates to $2K= \beta_{BR.}$ The consequence is that high ε_p results in high kinetic energy to overcome the zeta potential.The implication is that the double layer is either reduced or the colloids destabilized to actualize low $\tau_{1/2}$ in favour of high rate of coagulation. The results show that high values $\tau_{1/2}$ corresponds to low ε_p and K, and indication of repulsion in the system.$\tau_{1/2}$ values lie within the range of previous works where milliseconds had been obtained. (Hunter, 1993).

TSS (Kg/m^3) VS TIME PLOTS.

The TSS Vs time plots are presented in Figs 1 to 5.As single particles flocculate into large aggregates ,the turbidity of the dispersion decreases and the transmission intensity increases. This behavior simply reflects the complex dependence of turbidity on particle number (dropping) and particle size (increasing) over time (Yates *et a*l, 2001).The consequence of this is the highest rate of coagulation usually recorded at the early time of the coag-flocculation process. This is supported by $\tau_{1/2}$ that lies within seconds' .Fig 1 to 5 indicate that the best coagulation was obtained at pH of 6.

EFFICIENCY, E (%) VS TIME

Plots of E (%) Vs time are presented in Figs 6 to 10 .The E illustrates the effectiveness of the PSC to remove turbidity from the effluent .The plots show that the least E > 95% ;supports the low values of $\tau_{1/2}$ .This justifies the theory of fast coagulation (Von Smoluchowski , 1917)which validates the real life application of coagulation in which 90% of particle removal is usually achieved within the first five minutes of coag-flocculation .With the exception of Fig 8 ,the highest and lowest E were recorded for pH of 6 and pH of 10 respectively.

PLOT OF E (%) VS pH

This is presented in Fig 11.It indicates the performance of various doses of the PSC at varying pH. Interestingly, all the doses have a similar trend having their maxima at pH = 6 and minima at pH = 10.All the doses have the same E at pH of 2, indicating that the doses do not affect the efficiency at pH = 2.However, the optimum doses at pH = 6 is 0.4kg/m^3 PSC.

PLOT OF E (%) VS DOSAGE (kg/m^3)

This is presented in Fig 12.It confirms the observation made in Fig 11.The optimum dose is 0.4kg/m^3 at pH = 6.However,it should be noted that between 0.1kg/m^3 to 0.3kg/m^3 PSC, pH = 2 gives a better performance .As already observed, pH = 10 gives a poor performance for all doses.

PARTICLE DISTRIBUTION PLOTS:

These are presented in Fig 13 to 17; one for each of the tables 1 to 5 for the optimum *K* .The trend is similar for all the curves. The particle distributions expected in a typical coag-flocculation process are shown in these figures. It is notable that the curves N_i *Vs t*, beginning with twins (doublets), passes through a maximum because they are absent at the initial instant $(t = 0, N_2 = 0)$ and at the end of coag-flocculation process $(t = \infty, N_2=0)$. The number of primary particles (singlets) can be seen to decrease more rapidly than the total number of particles. For all consolidated particles, the curves pass through maxima whose height lowers with an increase consolidation.

The curves are expected in coag-flocculation where there is absence of excessive colloidal entrapment and high shear resistance. Mainly, the dominant mechanism in these graphs are charge neutralization combined with low bridging to ensure moderate speed of coag-flocculation as represented in Figs 13 to 17.The discrete nature of formation of $N_{1,}N_2$ and N_3 is associated with moderate energy barrier..

Table 1:Coag-flocculation Functional Parameters for varying pH and constant dosage of 0.1kg/m^3 PSC

Parameter	pH =2	pH = 4	pH = 6	pH = 8	pH = 10
A	1	2	2	1	2
R^2	0.9607	0.987	0.9931	0.9856	0.7777
K	$1.4483x10^{-3}s^{-1}$	$3.3333x10^{-4}m^3/kg.s$	$6.6667x10^{-4}m^2/kg.s$	$3.9167x10^{-4}s^{-1}$	$1.3333x10^{-4}m^3/kg.s$
β_{BR}	$2.8967x10^{-3}s^{-1}$	$6.6666x10^{-4}m^3/kg.s$	$1.3333x10^{-3}m^3/kg.s$	$7.8334x10^{-4}s^{-1}$	$2.6667x10^{-4}m^3/kg.s$
K_R	$1.4869x10^{-17}m^3/s$	$1.4182x10^{-17}m^3/s$	$1.5640x10^{-17}m^3/s$	$1.4250x10^{-17}m^3/s$	$1.3726x10^{-17}m^3/s$
ε_p	$1.9480x10^{14}m^3$	$4.7007x10^{13}kg^{-1}$	$8.5249x10^{13}kg^{-1}$	$5.4971x10^{13}m^{-3}$	$1.9426x10^{13}kg^{-1}$
$T_{1/2}$ (sec)	4.0 sec	39.2 sec	20.1 sec	49.60 sec	136.1 sec
-r	$1.4483x10^{-3}C$	$3.3333x10^{-4}C^2$	$6.6667x10^{-4}C^2$	$3.9167x10^{-4}C$	$1.3333x10^{-4}C$

Table 2:Coag-flocculation Functional Parameters for varying pH and constant dosage of 0.2kg/m^3 PSC

Parameter	pH =2	pH = 4	pH = 6	pH = 8	pH = 10
A	1	1	1	2	2
R^2	0.9888	0.9896	0.967	0.9790	0.6623
K	$1.4933x10^{-3}s^{-1}$	$1.0217x10^{-3}s^{-1}$	$3.100x10^{-4}s^{-1}$	$1.6667x10^{-4}m^3/kg.s$	$1.3333x10^{-4}m^3/kg.s$
β_{BR}	$2.9866x10^{-3}s^{-1}$	$2.0434x10^{-3}s^{-1}$	$6.2x10^{-4}s^{-1}$	$3.3334x10^{-4}m^3/kg.s$	$2.6666x10^{-4}m^3/kg.s$
K_R	$1.431x10^{-17}m^3/s$	$1.4150x10^{-17}m^3/s$	$1.5463x10^{-17}m^3/s$	$1.3880x10^{-1}7m^3/s$	$1.3763x10^{-17}m^3/s$
ε_p	$2.086x10^{14}m^{-3}$	$1.4440x10^{14}m^{-3}$	$4.0094x10^{13}m^{-3}$	$2.4001x10^{13}kg^{-1}$	$1.9374x10^{13}kg^{-1}$
$T_{1/2}$ (sec)	4.0	13	43	117	136.0
-r	$1.4933x10^{-3}$ C	$1.0217x10^{-3}$ C	$3.100x10^{-4}$ C	$1.6667x10^{-4}$ C^2	$1.3333x10^{-4}$ C^2

Table 3:Coag-flocculation Functional Parameters for varying pH and constant dosage of 0.3kg/m^3 PSC

Parameter	pH =2	pH = 4	pH = 6	pH = 8	pH = 10
A	1	2	1	2	2
R^2	0.8977	0.7815	0.9927	0.9627	0.7198
K	$1.4667x10^{-3}s^{-1}$	$3.3333x10^{-4}m^3/kg.s$	$5.6333x10^{-4}s^{-1}$	$1.6667x10^{-4}m^3/kg.s$	$1.3333x10^{-4}m^3/kg.s$
β_{BR}	$2.9334x10^{-3}s^{-1}$	$6.6666x10^{-4}m^3/kg.s$	$1.1267x10^{-3}s^{-1}$	$3.3334x10-4m^3/kg.s$	$2.6667x10^{-4}m^3/kg.s$
K_R	$1.7659x10^{-17}m^3/s$	$1.7173x10^{-17}m^3/s$	$1.7357x10^{-17}m^3/s$	$1.4786x10^{-17}m^3/s$	$1.4148x10^{-17}m^3/s$
ε_p	$1.6611x10^{14}m^{-3}$	$3.8819x10^{13}kg^{-1}$	$6.4911x10^{13}m^{-3}$	$2.2543x10^{13}kg^{-1}$	$1.8848x10^{13}kg^{-1}$
$T_{1/2}$ (sec)	4.0	39	24.0	117	136
-r	$1.46667x10^{-3}$ C	$3.3333x10^{-4}$ C^2	$5.6334x10^{-4}$ C	$1.6667x10^{-4}$ C^2	$1.3333x10^{-4}$ C^2

Table 4 :Coag-flocculation Functional Parameters for varying pH and constant dosage of 0.4kg/m^3 PSC

Parameter	pH =2	pH = 4	pH = 6	pH = 8	pH = 10
α	1	2	2	2	2
R^2	0.9662	0.947	0.9714	0.983	0.6616
K	$8.5517x10^{-4}s^{-}1$	$3.3333x10^{-4}m_3/kg.s$	$1.6667x10^{-3}m^3/kg.s$	$1.6667x10^{-4}m^3/kg.s$	$1.3333x10^{-4}m^3/kg.s$
β_{BR}	$1.7103x10^{-3}s^{-1}$	$6.6666x10^{-4}m^3/kg.s$	$3.3334x10^{-3}m^3/kg.s$	$3.3334x10^{-4}m^3/kg.s$	$2.6666x10^{-4}m^3/kg.s$
K_R	$1.424x10^{-17}m_3/s$	$1.3844x10^{-17}m^3/s$	$1.3861x10^{-17}m^3/s$	$1.2905x10^{-17}m^3/s$	$1.1373x10^{-17}m^3/s$
ε_p	$1.2058x10^{14}m^{-3}$	$4.8154x10^{13}kg^{-1}$	$2.4047x10^{-14}kg^{-1}$	$2.5829x10^{13}kg^{-1}$	$2.3445x10^{13}kg^{-1}$
$T_{1/2}$ (sec)	6.7	39.0	8.0	117.0	136.0
-r	8.5517x10-4 C	$3.3333x10^{-4}$ C^2	$1.6667x10^{-3}$ C^2	$1.6667x10^{-4}$ C^2	1.3333x10+ C^2

Table 5:Coag-flocculation Functional Parameters for varying pH and constant dosage of 0.5kg/m^3 PSC

Parameter	pH =2	pH = 4	pH = 6	pH = 8	pH = 10
A	2	2	2	2	2
R^2	0.928	0.9464	0.9744	0.9697	0.444
K	$5x10^{-4}m^3kg^{-1}s^{-1}$	$3.3333x10^{-4}m3/kg.s$	$6.6667x10^{-4}m^3/kg.s$	$1.6667x10^{-4}m^3/kg.s$	$8.3333x10^{-5}m^3/kg.s$
β_{BR}	$1x10^{-3}m^3/kg.s$	$6.6667x10^{-4}m^3/kg.s$	$1.3333x10^{-3}m^3/kg.s$	$3.3333x10^{-4}m^3/kg.s$	$1.6667x10^{-4}m^3/kg.s$
K_R	$1.4200x10^{-17}m^3/s$	$1.6622x10^{-17}m^3/s$	$1.7182x10^{-17}m^3/s$	$1.4924x10^{-17}m^3/s$	$1.4280x10^{-17}m^3/s$
ε_p	$7.0418x10^{13}kg^{-1}$	$4.0107x10^{13}kg^{-1}$	$7.759x10^{13}kg^{-1}$	$2.2334x10^{13}kg^{-1}$	$1.1671x10_{13}kg^{-1}$
$T_{1/2}$ (sec)	12	39.2	20	117	218
-r	$5x10^{-4}$ C^2	$3.3333x10^{-4}$ C^2	$6.6667x10^{-4}$ C^2	$1.6667x10^{-4}$ C^2	$8.3333x10^{-5}$ C^2

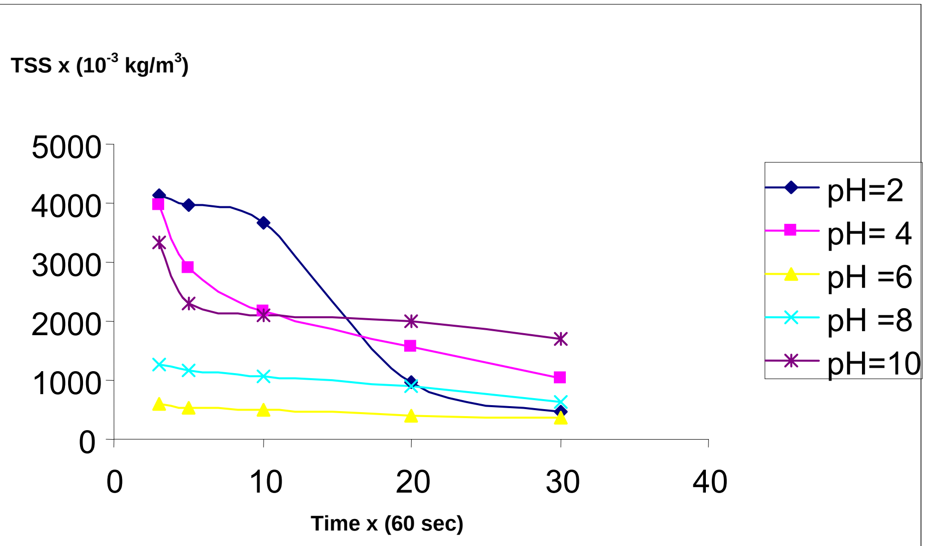

Fig 1:Plot of TSS Vs Coag-floccualtion Time for 0.1kg/m^3 PSC at varying pH

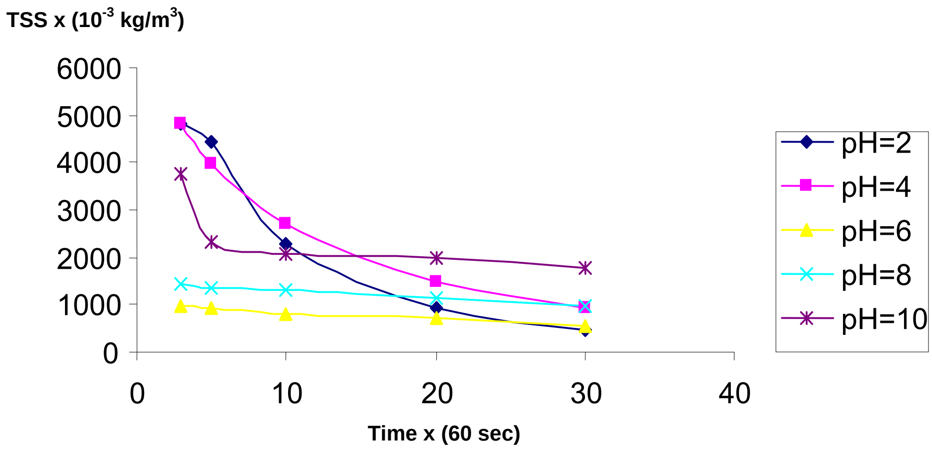

Fig 2:Plot of TSS vs Coag-flocculation Time for 0.2 kg /m^3 PSC at varying pH

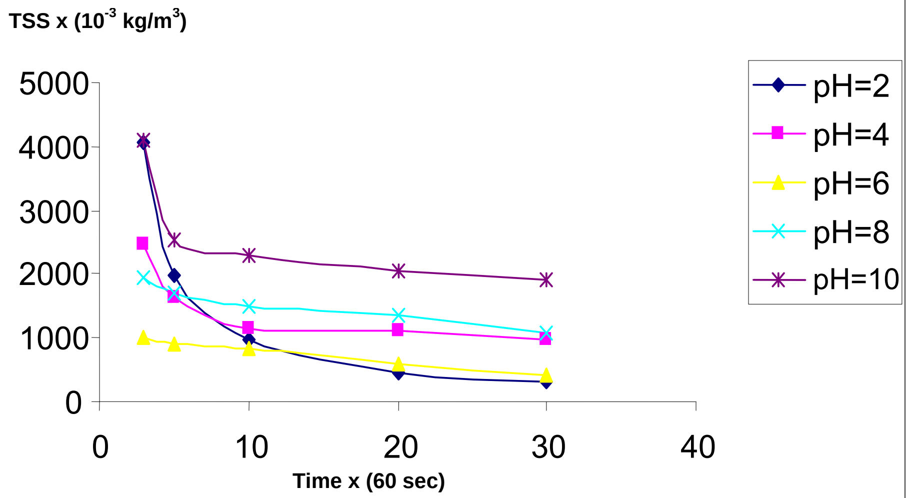

Fig 3:plot of TSS vs Coag-flocculation Time for 0.3kg/m^3 PSC at varying pH

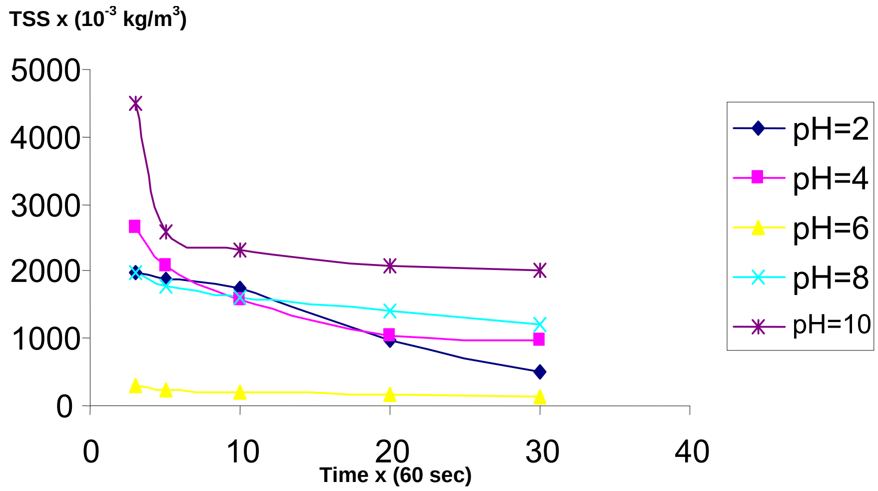

fig4: Plot of TSS vs Coag-flocculation Time for 0.4kg/m^3 PSC at varying pH

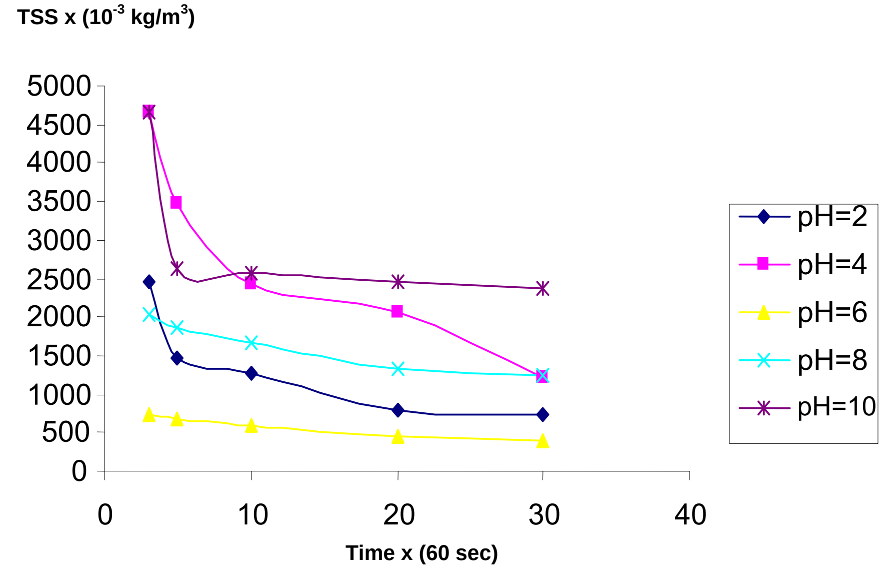

Fig5:plot of TSS vs Coag- flocculation Time for 0.5kg/m^3 PSc at varying pH

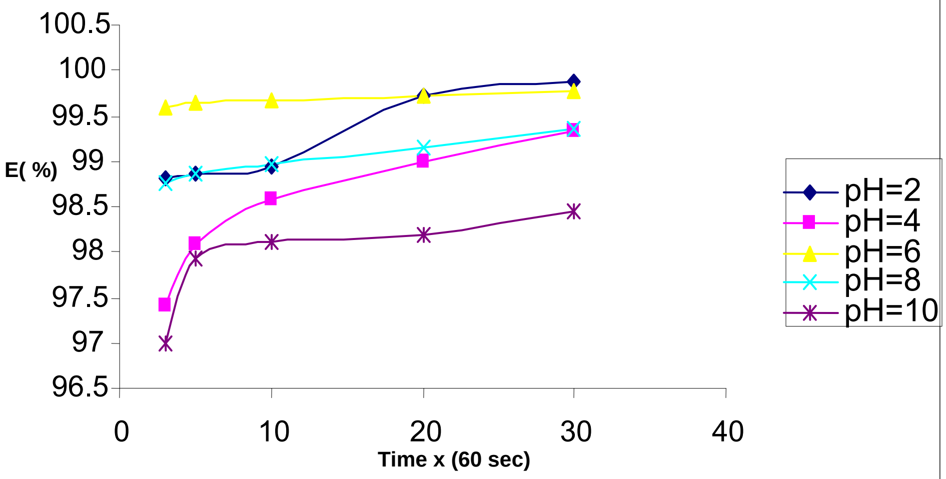

fig 6:Plot of E vs time at varying pH and constant dosage of 0.1kg/m^3 PSC

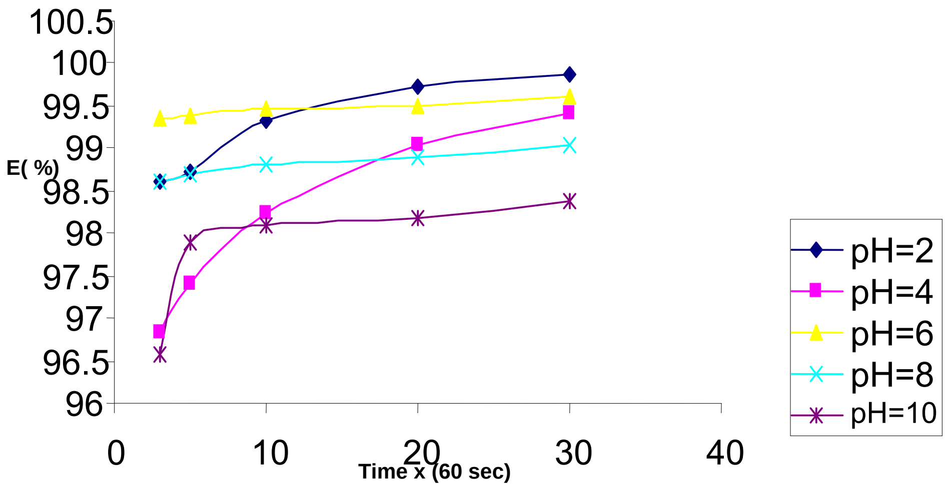

fig7:plot of E vs time at varying pH & constant dosage of 0.2kg/m^3 PSC

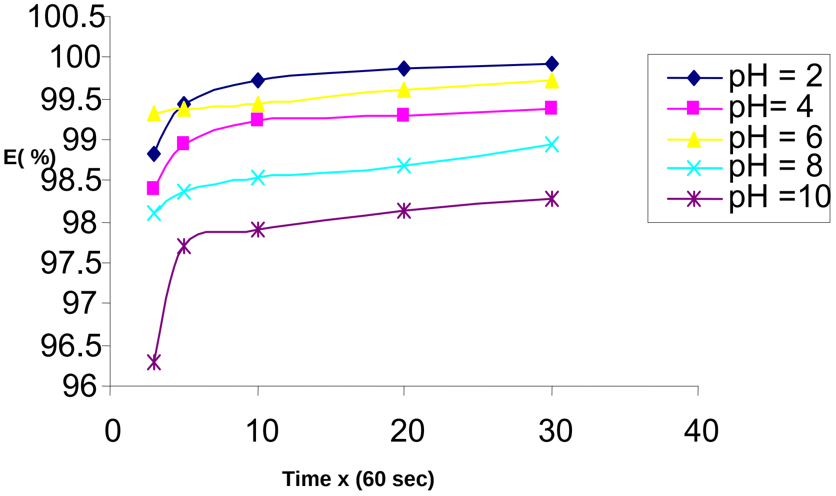

fig8:plot of E vs time at varying pH & constant dosage of 0.3kg/m^3 PSC

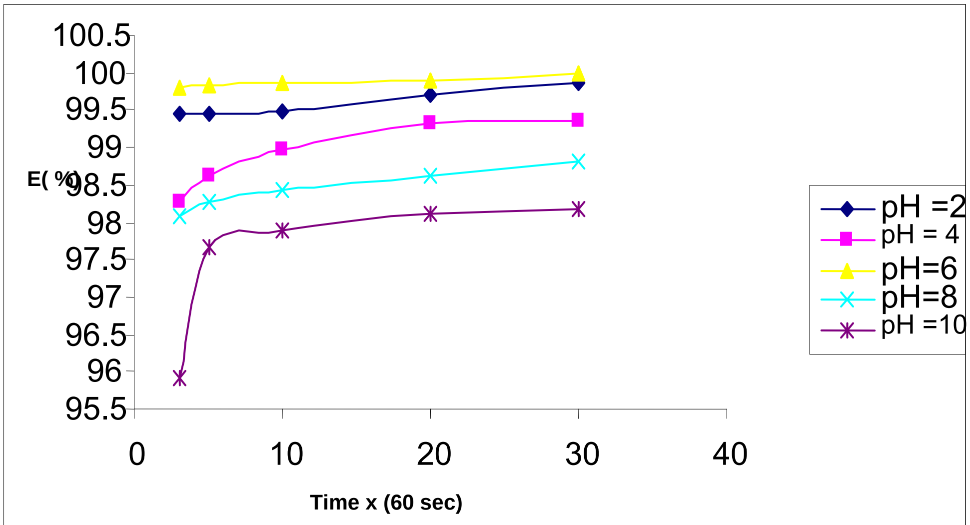

fig9:plot of E vs time at varying pH at constant dosage of 0.4kg/m^3 PSC

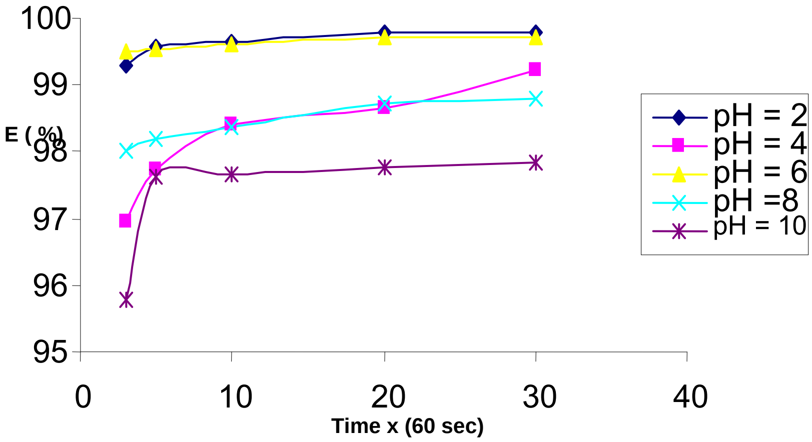

fig10:Plot of E vs time at varying pH & constant dosage of 0.5kg/m^3 PSC

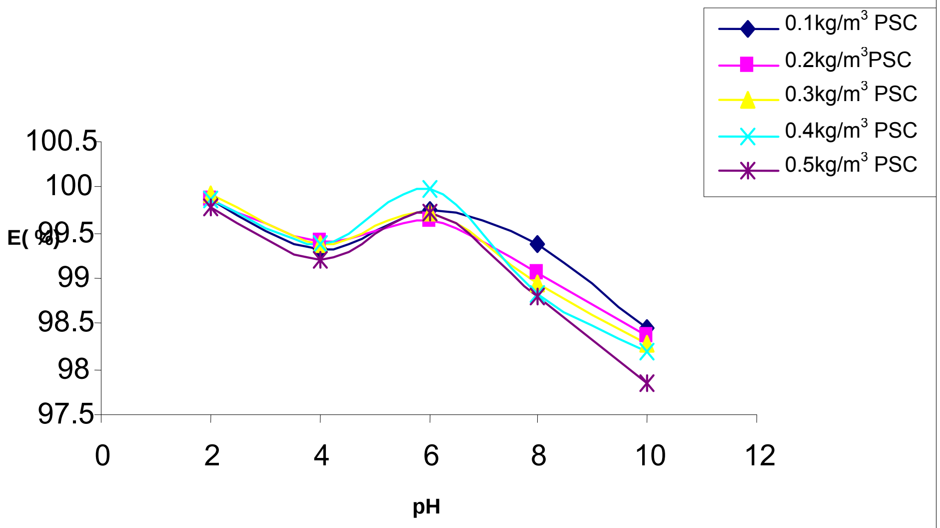

fig11:plot of Coag-flocculation efficiency Vs pH at 30 mins for varying dosages

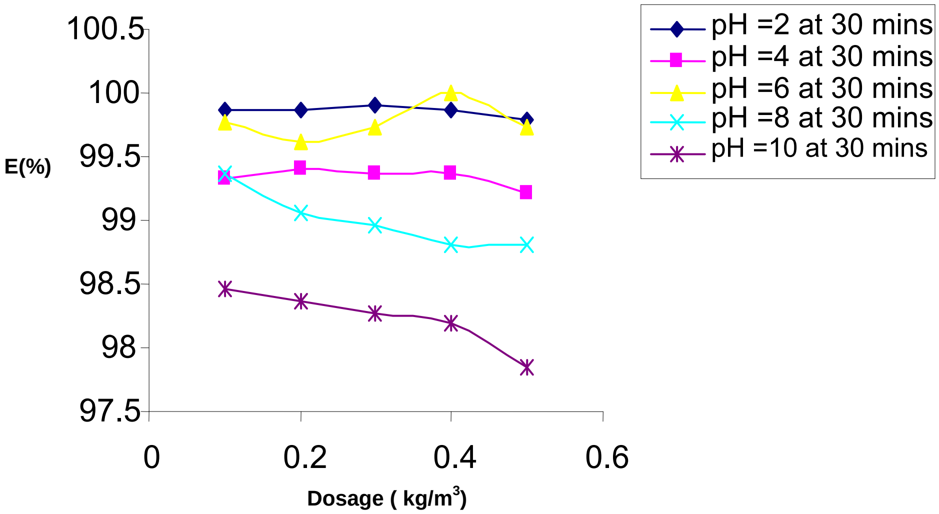

Fig 12:plot of Efficiency vs Dosage at varying pH & constant time

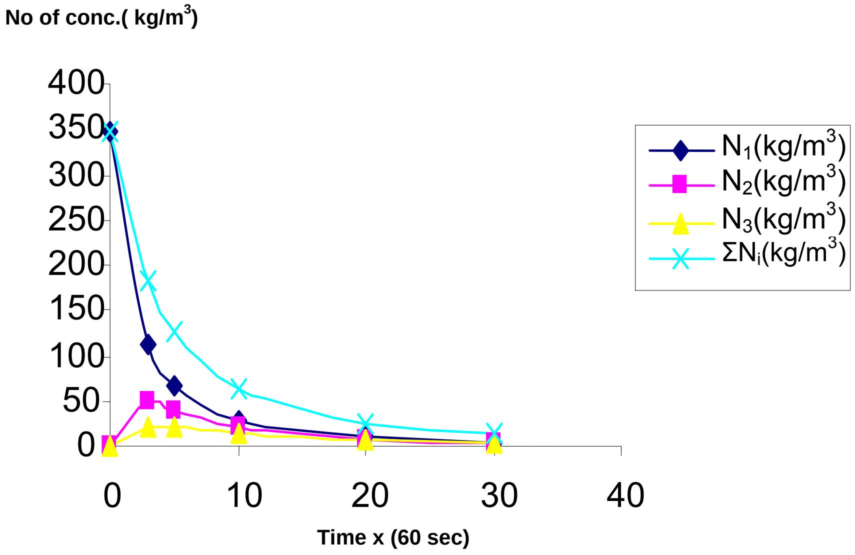

Fig 13:Particle distribution plot for 0.1kg/m^3 PSC at pH of 2

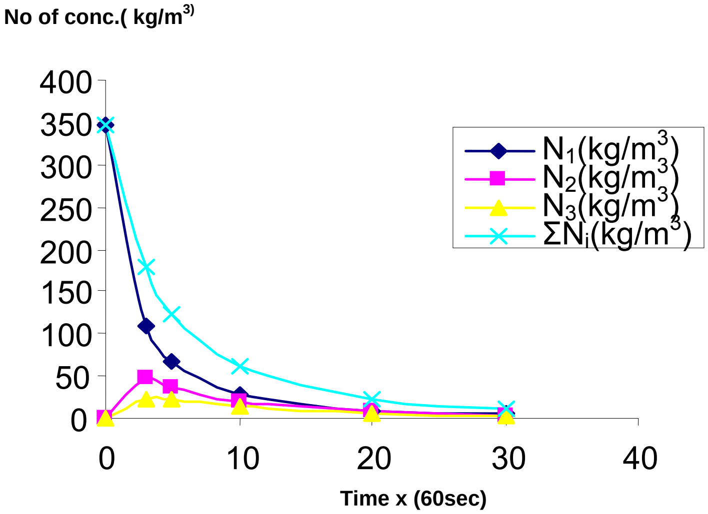

Fig 14:Particle distribution plot for 0.2kg/m^3 PSC at pH of 2

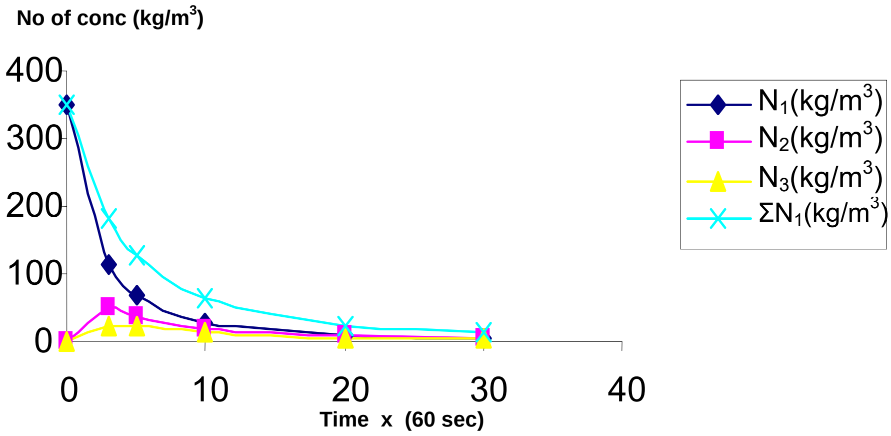

Fig 15: particle distribution plot for 0.3kg/m^3 PSC at pH of 2

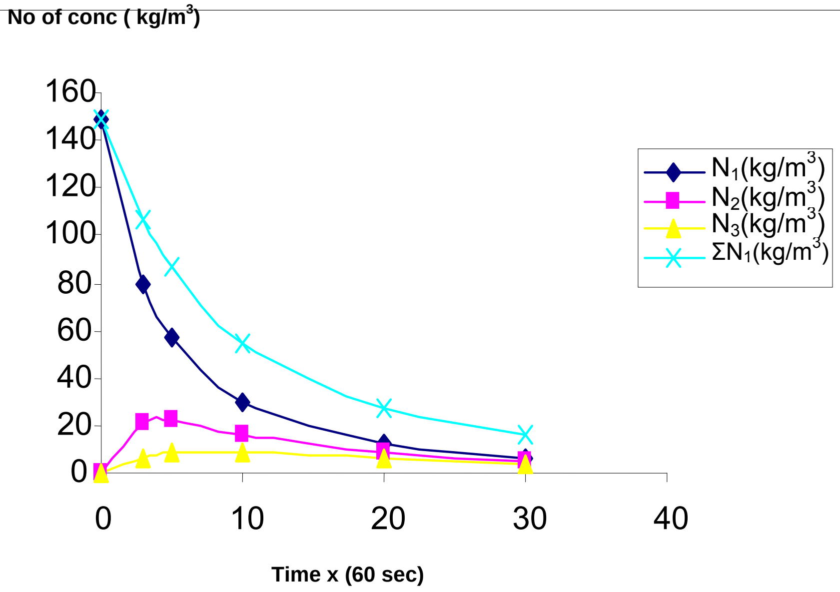

Fig 16: Particle plot distribution plot for 0.4kg/m^3 PSC at pH of 6

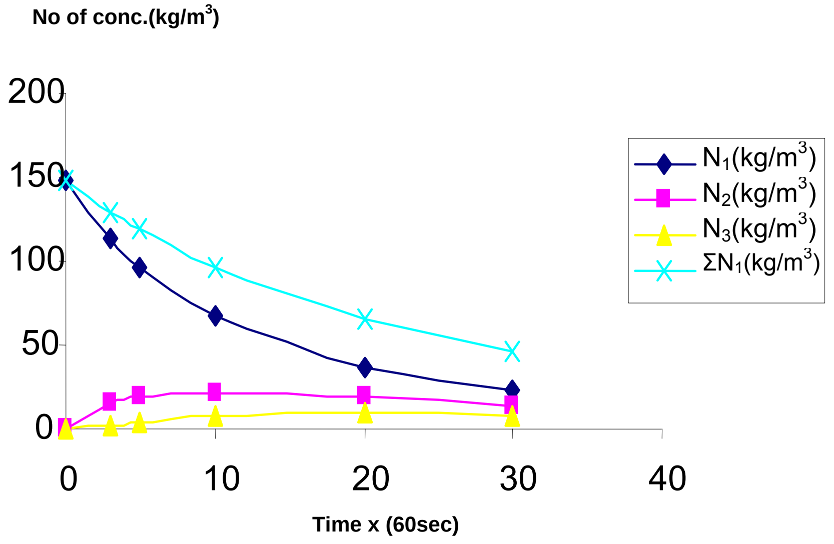

Fig 17:Particle plot distribution plot for 0.5 kg/m^3 PSC at pH of 6

CONCLUSION

The reduction of TSS recorded within the first 5 minutes and high level of E (%) presents the potential of PSC as Chitin derived coagulant that can be utilized in large scale water treatment.

The experimental results with respect to functional parameters highly agree with similar previous works (Jin;2005,Van Zanten and Elimelechi;1992,Holthof *et al* 1996)

NOMENCLATURE:

K :α^{th} order coag-flocculation constant
β_{BR}:Collision factor for Brownian Transport
ε_p:Collision Efficiency
$\tau_{1/2}$:Coagulation Period / Half life
E: Coag-floculation Efficiency
R^2: Coefficient of Determination
α: Coag-flocculation reaction order
$-r$: Coag-flocculation reaction rate

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4/1/2009