Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.3, pp.279-298, 2011
jmmce.org Printed in the USA.

Coag-Flocculation Studies of *Afzelia Bella* Coagulant (ABC) in Coal Effluent Using Single and Simulated Multi Angle Nephelometry

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ABSTRACT

Following the need for the use of environmentally friendly, renewable resource in industrial processes, this work explores the potential of an effective application in pilot scale of Afzelia bella seed as a coag-flocculant. The study evaluates the coag-flocculation efficiency and functional kinetic parameter response to varying pH and dosage of coal washery effluent and ABC respectively. The maximum coag-flocculation performance is recorded at rate constant, K of 3.3333 x $10^{-3}m^3$/kg.s, dosage of (0.3 and 0.2kg/m^3); pH of 2 and coagulation period, $\tau_{1/2}$ of 28.1216 s while the minimum is recorded at K of 1.6667 x $10^{-4}m^3$/kg.s, dosage of 0.2kg/m^3, pH of 10 and $\tau_{1/2}$ of 562.365 s. The least value of coag-flocculation efficiency, E (%)>89.00. Simulated and unsimulated values of rate constants K_s and K respectively are in close agreement, validating the concept of perikinetics. The potential of ABC as an effective organic coag-flocculant has been established. The results confirm that theory of rapid coag-flocculation holds for the aggregation of coal washery effluent using ABC and at the conditions of the experiment.

Keywords: *Afzelia bella; coag-flocculation; coal effluent; kinetics; nephelometry.*

1. INTRODUCTION

1.1 Background

In waste water treatment operations, the process of coag-flocculation (coagulation / flocculation) is employed to separate suspended solids from waste effluent; via floc formation [1, 2, 3, 4,]. Among the factors that can affect the formation of the flocs are temperature, pH, effluent quality e.t.c. [5].

Coag-flocculation can be achieved by the use of inorganic substances (alum, $FeCl_3$ e.t.c) and natural organic derivatives. However, the caog-flocculation behaviors of these inorganic aggregates agents are well documented with little or no attention given to the study of the animal and plant material as a potential source of organic derived coagulant. To this end, focus is hereby given to the study of a plant material, *Afzelia bella* bean, as a potential source of coagulant derivative. *Afzelia bella* is a leguminous plant, rich in protein, fat and starch. It is a native to tropical climate such as Eastern Nigeria [6].

Afzelia bella is an edible, non-toxic and biodegradable substance. Previous results obtained in its thickening properties highlight promise of renewable material with extensive application in water treatment technology.

However, in spite of the abundance of *Afzelia bella* in our local communities in Nigeria, little or no comprehensive work has been reported on its coag-flocculating application. Against this backdrop, this work endeavors to explore and generate interest in the utilization of *Afzelia bella* as a coagulant. In line with this, the work focuses on coag-flocculation performance and kinetics of ABC under varying pH of coal washery effluent (a typical medium for this kind of study) using single and simulated multi angle light scattering techniques. Thus if well harnessed and developed, ABC can be an alternative to or be used in conjunction with the inorganic coagulant. Ultimately, post usage handling and health challenges posed by the inorganic coagulant can be reduced.

1.2 Theoretical Principles and Model Development

For a uniformly coag-flocculating equilibrium phase with negligible influence of external forces [7]:

$$\mu_i = \overline{G}_i = \left[\frac{\partial G}{\partial n_i}\right]_{P,T,n} = \text{a constant} \qquad \ldots.1$$

And

$$-f_d = \frac{K_B T}{C_i}\frac{dC_i}{dx} \qquad \ldots 2$$

Where G is the total Gibbs free energy

n_i is the number of moles of component i

μ_i *is* chemical potential

C_i is concentration

x is diffusion distance

f_d is viscous drag force.

K_B is Boltzmann's constant (J/K)

T is Absolute temperature (K)

But from Ficks law

$$D' = \frac{-f_d}{B}\frac{C_i}{\left(dC_i/dx\right)} \qquad \ldots 3$$

Where D' is diffusion coefficient

B is friction factor

Comparing equation 2 and 3 generates Einstein's equation:

$$D' = \frac{K_B T}{B} \qquad \ldots 4$$

For similar phase, the rate of successful collision between particles sizes i and j (mass concentration/time) to form particle of size k is [8, 5]:

$$N_{ij} = \varepsilon_p \beta(i,j) n_i n_j \qquad \ldots 5$$

where

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 [9, 5]:

$$\frac{dn_k}{dt} = \frac{1}{2}\sum_{i+j=k}\beta(i,j)n_i n_j - \sum_{i=1}^{\infty}\beta(i,k)n_i n_k \qquad \ldots 6$$

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 [10]:

$$\beta_{BR} = \frac{8}{3}\varepsilon_p \frac{K_B T}{\eta} \qquad \ldots 7$$

The generic aggregation rate of particles (during coagulation / flocculation) can be derived by the combination of equations 6 and 7 to yield:

$$-\frac{dN_t}{dt} = KN_t^{\alpha} \qquad \ldots 8$$

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

K is the Menkonu coag-flocculation rate constant for α^{th} order.

α is the order of coag-flocculation process .

Meanwhile $K = \frac{1}{2}\beta_{BR}$ …9

Also, $\beta_{BR} = 2\varepsilon_p K_R$ …10

Combining equations 8,9 and 10 produce:

$$-\frac{dN_t}{dt} = \varepsilon_p K_R N_t^{\alpha} \qquad \ldots .11$$

Where K_R is the Von smoluchowski rate constant for rapid coagulation [11].

However $K_R = 8\pi a D'$ 12

$R_p = 2a$ 13

Where a is particle radius.

From Einstein's equation: $D' = K_B T/B$

From Stoke's equation : $B = 6\pi\eta a$ 14

where η is the viscosity of the coag-flocculating fluid

Combining equations 11 to14 gives:

$$-\frac{dN_t}{dt} = \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} N_t^{\alpha} \quad \text{...15}$$

Comparing equations 8 and 15 show:

$$K = \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} \quad \text{...16}$$

For perikinetic aggregation, α theoretically equals 2 as would be shown below [12, 7]:

From Fick's law,

$$J_f = D' 4\pi R_p^{\ 2} \frac{dN_t}{dR} \quad \text{..17}$$

Integrating equation 17 at initial conditions $N_t = 0$, $R = 2a$:

$$\frac{J_f}{D' 4\pi}\int_0^{R_p} \frac{dR_p}{R_p^{\ 2}} = \int_{N_0}^{N_t} dN_t \quad \text{...18}$$

Thus $J_f = 8\pi D' a N_0$ ...19

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

$$-\frac{dN_t}{dt} = J_f \cdot \varepsilon_p \cdot N_0 \quad \text{...20}$$

$$= \frac{4}{3}\varepsilon_p \frac{K_B T}{\eta} \cdot N_0^2 \quad \text{...21}$$

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

Hence, from equation 21, $\alpha = 2$

For $\alpha = 2$; equivalence of equation 8 yields:

$$\frac{dN}{dt} = -KN^2$$

Hence:

$$\int_{N_0}^{N} \frac{dN}{N^2} = -K\int_0^t dt \quad \text{...22}$$

Thus $\frac{1}{N} = Kt + 1/N_0$ ...23

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

For the evaluation of coagulation period ($\tau_{1/2}$), from Equation 23:

$$N = \frac{N_0}{\left[1 + \frac{t}{\left(1/N_0 K\right)}\right]} \qquad ...24$$

Where $\tau = \left[1/N_0 K\right]$ …25

Hence:

$$N = \frac{N_0}{1 + (t/\tau)} \qquad …26$$

When $t = \tau$, equation 26 becomes

$$N = N_0/2 \qquad …27$$

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

Hence $\tau_{1/2} = 1/(0.5 N_0 K)$ ...28

For Brownian (perikinetic) aggregation at early stages (t≤30 minutes), equation 6 can be solved exactly, resulting in the generic expression

$$\frac{N_{m(t)}}{N_0} = \frac{\left[t/\tau'\right]^{m-1}}{\left[1 + t/\tau'\right]^{m+1}} \qquad ...29$$

Where $\tau' = 2\tau$

Hence, for singlets *(m=1)*

$$N_1 = N_0 \left[\frac{1}{\left(1 + t/\tau'\right)^2}\right] \qquad ...30$$

For doublets *(m=2)*

$$N_2 = N_0 \left[\frac{\left(t/\tau'\right)}{\left(1 + t/\tau'\right)^3}\right] \qquad ...31$$

For triplets *(m=3)*

$$N_3 = N_0 \left[\frac{\left(t/\tau'\right)^2}{\left(1 + t/\tau'\right)^4}\right] \qquad ….32$$

Also for the coagulating phase, the intensity of light scattered from suspension of monodispersed phase is described as [11]:

$$I(q, \mathrm{T}_d) = I(q,0)\left[1 + 2 \sum_{m=2}^{\infty} C_m(\mathrm{T}_d) A_m(q)\right] \qquad ....33$$

Where I(q, T_d) is the intensity of light scattered by the initially unaggregated suspension ;
$\mathrm{T}_d = t / \tau'$ (dimensionless time)

q is the scattering wave vector

$$q = \left(\frac{4\pi}{\lambda_0}\right) n_0 \sin(0.5\theta) \qquad \ldots 34$$

where λ_0 is the wave length of the laser incident light in Vacuum, *($\lambda_0 = 2\pi a / 6$)*
n_0 is the refractive index of the suspending medium
θ is the scattering angle
A_m is the form factor for an aggregate consisting of m primary particles.
a is radius of particles sphere.

If the coagulating medium obeys the Rayleigh-Gans-Debye (RGD) approximations, then

$$A_m(q) = \sum_{i}^{m} \sum_{j>1}^{m} \frac{\sin qr_i}{qr_{ij}} \qquad \ldots 35$$

Where r_{ij} is the centre-to-centre separation of primary particles i and j in the given m-fold aggregate. The summation accounts for all pairs of particle centers in the aggregate.

The expression for the scattered intensity in view of many possible configurations arising from larger aggregates is:

$$I(q, \mathrm{T}_d) = I(q,0)\left[1 + 2\frac{\sin qd_0}{qd_0}\frac{\mathrm{T}_d}{(1+\mathrm{T}_d)^3} + 2\sum_{m=3}^{\infty} C_m(\mathrm{T}_d) A_m(q)\right] \qquad \ldots 36$$

The form factors are given by an average of all contributing structures where d_0 is hard core interaction diameter of singlets.Differentiating equation 36 as t→0, yields:

$$\frac{I}{I(q,0)}\left(\frac{dI(q,t)}{dt}\right)_{t\to 0} = \frac{d}{dt}\left[1 + 2\frac{\sin qd_0}{qd_0}\frac{\mathrm{T}_d}{(1+\mathrm{T}_d)^3} + 2\sum_{m=3}^{\infty} C_m(\mathrm{T}_d) A_m(q)\right] \qquad \ldots 37$$

$$\frac{I}{I(q,0)}\left(\frac{dI(q,t)}{dt}\right)_{t\to 0} = \left[\beta_{BR} N_0 \frac{\sin qd_0}{qd_0}\right] \qquad \ldots 38$$

Using simulated version of equation 38, K_S (simulated K) can easily be determined at several scattering angles. A plot of $\frac{I}{I(q,0)}\left(\frac{dI(q,t)}{dt}\right)_{t\to 0}$ Vs $\frac{\sin qd_0}{qd_0}$ gives a slope of $N_0\beta_{BR}$ from where $(K_S)_{t\to 0}$ could be determined.

2. MATERIALS AND METHODS.

The sample of *Afzelia bella* was sourced from Nsugbe,Anambra State, Nigeria and processed to ABC based on the work reported by Adebowale and Adebowale [13].

The jar test was conducted based on standard Bench scale Nephelometric method (single angle procedure) for the examination of water and waste water [14, 15] using model WZS-185 MC Turbidimeter, APPNo 688644A Gulenhamp magnetic stirrer and mettler Toledo Delta 320 pH meter.

For the simulation, excel package was used while d_0 = 1μm [16, 7] and n_o [17] were generated from literature and simple experiment respectively.

3. RESULTS AND DISCUSSION

3.1 Coag-flocculation Parameters

The values of caog-flocculation reaction parameters are presented in Tables 1 to 6. For all cases of dosages and pH, the value of α is 2, though with the exception of few, the corresponding value of R^2 is generally >0.9. This result actually emphasizes its consistency with Von Smoluchowski theory of coagulation. Meanwhile, it should be noted that α relates with *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, lower *K* is a necessary condition for such phenomenon [12]. $K\ (=0.5\beta_{BR})$ values appreciably are less sensitive to a given pH as the dosage of ABC changes from 0.1kg/m^3 to 0.5kg/m^3 .This may be as a result of situation where same or similar coag-flocculation mechanism is controlling the process. Also, the variation in K_R is generally minimal; following insignificant changes in values of temperature and viscosity of the coag-flocculation medium.

At nearly invariant values of K_R ,ε_P relates directly 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 favor of high rate of coagulation. The results show that high values of $\tau_{1/2}$ 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 reported [7].

Table1: Coag-flocculation Functional parameters for varying pH and constant dosage of 0.1kg/m^3 ABC

Parameter	pH=2	pH=4	pH=6	pH=8	pH=10
α	2	2	2	2	2
R^2	0.976	0.907	0.989	0.944	0.937
K (m^3/kg.s)	1.667 x 10^{-3}	3.333 x 10^{-4}	1 x 10^{-3}	3.333 x 10^{-4}	1.667 x 10^{-4}
β_{Br} (m^3/kg.s)	3.333 x 10^{-3}	6.667x10^{-4}	2x10^{-3}	6.667x10^{-4}	3.333x10^{-4}
K_R (m^3/s)	1.273x10^{-17}	1.470x10^{-17}	1.274x10^{-16}	1.470x10^{-16}	1.470x10^{-16}
ε_p (kg^{-1})	2.618x10^{14}	4.535x10^{12}	1.570x10^{13}	4.535x10^{12}	2.268x10^{12}
$\tau_{1/2}(s)$	56.237	281.19	93.748	281.191	562.365
$(SP)_0^c$ (kg/m^3)	0.417	1.25	0.526	1	1.667
$(N_p)_0^c$ (m-^{3})	2.5 x 10^{26}	7.5 x 10^{26}	3.1694 x 10^{26}	6.0221 x 10^{26}	10.0371 x 10^{26}
$-r$ *(kg/m^3.s)*	1.667x10^{-3} c^2	3.333x10^{-3} c^2	1x10^{-3} c^2	3.333x10^{-4} c	1.667x10^{-4} c

Table2: Coag-flocculation Functional parameters for varying pH and constant dosage of 0.2kg/m^3 ABC

Parameter	pH=2	pH=4	pH=6	pH=8	pH=10
α	2	2	2	2	2
R^2	0.977	0.866	0.991	0.982	0.893
K (m^3/kg.s)	3.333 x 10^{-3}	3.333 x 10^{-4}	1.167 x 10^{-3}	3.333 x 10^{-4}	1.667 x 10^{-4}
β_{Br} (m^3/kg.s)	6.667 x 10^{-3}	6.667x10^{-4}	3.333x10^{-3}	6.667x10^{-4}	3.333x10^{-4}
K_R (m^3/s)	1.639x10^{-17}	1.6250x10^{-16}	1.639x10^{-16}	1.625x10^{-16}	1.625x10^{-16}
ε_p (kg^{-1})	4.072x10^{14}	4.102x10^{12}	2.034x10^{13}	4.102x10^{12}	2.051x10^{12}
$\tau_{1/2}(s)$	28.122	281.191	80.337	281.19	562.366
$(SP)_0^c$ (kg/m^3)	0.526	1.25	0.526	1	1.667
$(N_p)_0^c$ (m-^{3})	3.167x 10^{26}	7.528 x 10^{26}	3.346 x 10^{26}	0.675E-4	0.675E-4
$-r$ *(kg/m^3.s)*	3.333 x 10^{-3}c^2	3.333x10^{-4}c^2	1.167x10^{-3} c^2	3.333x10^{-4} c^2	1.667x10^{-4} c^2

Table3: Coag-flocculation Functional parameters for varying pH and constant dosage of 0.3kg/m^3 ABC

Parameter	pH=2	pH=4	pH=6	pH=8	pH=10
α	2	2	2	2	2
R^2	0.983	0.620	0.968	0.996	0.9347
K (m^3/kg.s)	3.333 x 10^{-3}	3.333 x 10^{-4}	1.167 x 10^{-3}	1.500 x 10^{-3}	1.667 x 10^{-4}
β_{Br} (m^3/kg.s)	6.667 x 10^{-3}	6.667x10^{-4}	3.333x10^{-3}	3x10^{-3}	3.333x10^{-4}
K_R (m^3/s)	1.303x10^{-16}	1.315x10^{-16}	1.307x10^{-16}	1.333x10^{-16}	1.242x10^{-16}
ε_p (kg^{-1})	5.117x10^{13}	5.069x10^{12}	2.551x10^{13}	2.251x10^{13}	2.684x10^{12}
$\tau_{1/2}(s)$	28.122	281.191	80.337	62.486	562.365
$(SP)_0^c$ (kg/m^3)	0.434	1.429	0.526	0.526	1.667
$(N_p)_0^c$ (m-^{3})	2.614x 10^{26}	8.603 x 10^{26}	3.168 x 10^{26}	3.168 x 10^{26}	10.037x10^{26}
$-r$ *(kg/m^3.s)*	3.333 x 10^{-3}c^2	3.333x10^{-4}c^2	1.167x10^{-3} c^2	3.333x10^{-4} c^2	1.667x10^{-4} c^2

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

Parameter	pH=2	pH=4	pH=6	pH=8	pH=10
α	2	2	2	2	2
R^2	0.922	0.403	0.851	0.979	0.934
K (m^3/kg.s)	3.333 x 10^{-3}	1.667 x 10^{-4}	3.333 x 10^{-4}	1.667 x 10^{-3}	1.667 x 10^{-4}
β_{Br} (m^3/kg.s)	6.667 x 10^{-3}	3.333x10^{-4}	6.667x10^{-3}	3.333x10^{-3}	3.333x10^{-4}
K_R (m^3/s)	1.130x10^{-16}	1.231x10^{-16}	1.130x10^{-16}	1.242x10^{-16}	1.243x10^{-16}
ε_p (kg^{-1})	5.902x10^{13}	2.708x10^{12}	5.902x10^{13}	2.684x10^{13}	2.683x10^{12}
$\tau_{1/2}(s)$	28.122	562.366	281.193	56.237	562.237
$(SP)_0^c$ (kg/m^3)	0.100	1.429	1.111	0.556	1.429
$(N_p)_0^c$ (m-^{3})	0.602x 10^{26}	8.603 x 10^{26}	6.891 x 10^{26}	3.346 x 10^{26}	8.603x10^{26}
$-r$ *(kg/m^3.s)*	3.333 x $10^{-3}c^2$	1.667 x $10^{-4}c^2$	3.333 x $10^{-4}c^2$	1.667 x $10^{-3}c^2$	1.667x10^{-4} c^2

Table 5: Coag-flocculation Functional parameters for varying pH and constant dosage of 0.5kg/m^{3}ABC

Parameter	pH=2	pH=4	pH=6	pH=8	pH=10
α	2	2	2	2	2
R^2	0.921	0.549	0.986	0.979	0.934
K (m^3/kg.s)	3.333 x 10^{-3}	3.333 x 10^{-4}	5.000 x 10^{-4}	1.667 x 10^{-3}	1.667 x 10^{-4}
β_{Br} (m^3/kg.s)	6.667 x 10^{-3}	6.667 x 10^{-4}	10.000x10^{-4}	3.333x10^{-3}	3.333x10^{-4}
K_R (m^3/s)	1.587x10^{-16}	1.408x10^{-16}	1.587x10^{-16}	1.408x10^{-16}	1.121x10^{-16}
ε_p (kg^{-1})	4.200x10^{13}	4.735x10^{12}	3.151x10^{12}	2.367x10^{13}	2.974x10^{12}
$\tau_{1/2}(s)$	28.119	281.191	187.459	56.237	562.366
$(SP)_0^c$ (kg/m^3)	0.769	1.429	1.111	0.323	1.429
$(N_p)_0^c$ (m-^{3})	0.602x 10^{26}	8.603 x 10^{26}	6.891 x 10^{26}	3.346 x 10^{26}	8.603x10^{26}
$-r$ *(kg/m^3.s)*	3.333 x $10^{-3}c^2$	3.333 x $10^{-4}c^2$	5.000 x $10^{-4}c^2$	1.667 x $10^{-3}c^2$	1.667x10^{-4} c^2

Table 6: Representative values of K (Experimental) and K_s (Simulated) at varying dosage and pH

pH	Dosage(kg/m^3)	N_0(Particles / m^3)	d_0(μm)	K(m^3/kg.s)	K_S(m^3/kg.s)
2	0.1	2.509 x 10^{26}	1.0	1.667 x 10^{-3}	1.594 x 10^{-3}
4	0.1	7.528 x 10^{26}	1.0	3.333 x 10^{-4}	3.321 x 10^{-4}
6	0.1	3.169 x 10^{26}	1.0	1x 10^{-3}	9.466 x 10^{-4}
8	0.1	6.022 x 10^{26}	1.0	3.333 x 10^{-4}	3.321 x 10^{-4}
10	0.1	1.004 x 10^{27}	1.0	1.667 x 10^{-4}	1.494 x 10^{-4}
2	0.1	2.509 x 10^{26}	1.0	1.667 x 10^{-3}	1.594 x 10^{-3}
2	0.2	3.169 x 10^{26}	1.0	3.333 x 10^{-3}	3.155 x 10^{-3}
2	0.3	8.603 x 10^{26}	1.0	3.333 x 10^{-3}	3.487 x 10^{-3}
2	0.4	0.602 x 10^{26}	1.0	3.333 x 10^{-3}	3.321 x 10^{-3}
2	0.5	4.631 x 10^{26}	1.0	3.333 x 10^{-3}	3.240 x 10^{-3}

Meanwhile, the values of K (now K_S) from equation 38 determined from the simulated light scattering model are in strong agreement with K (from equation 23) determined from experimental jar test. These results underscore the concept of Brownian (rapid) coag-flocculation at early time even in situation where independent procedures were employed in the determination of the parameters. The representative's plots for the determination of K and K_S (simulated K) are presented in Figs 1 to 4.

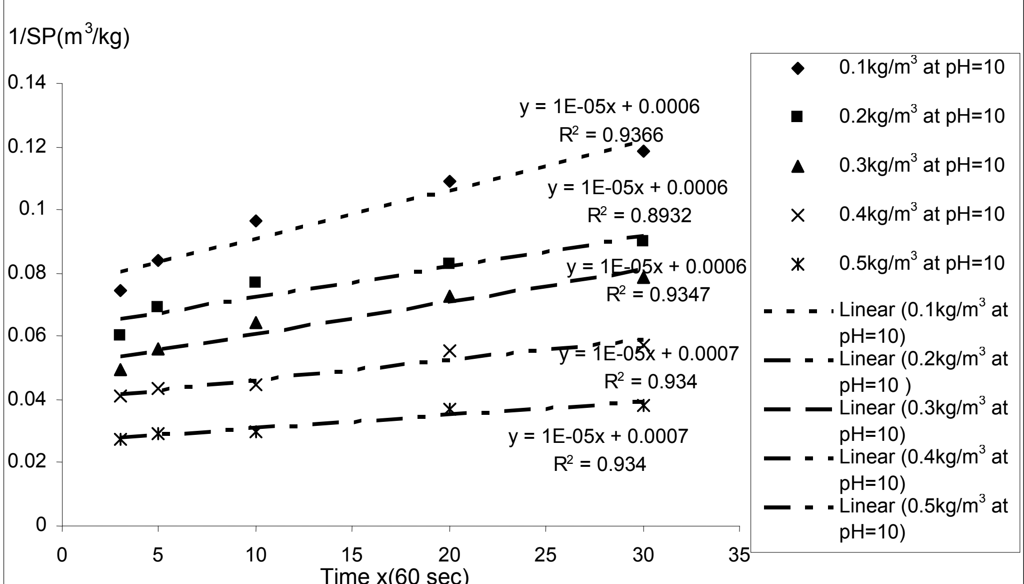

Fig 1: Selected representative plots of 1/SP Vs time based on minimum $\tau_{1/2}$

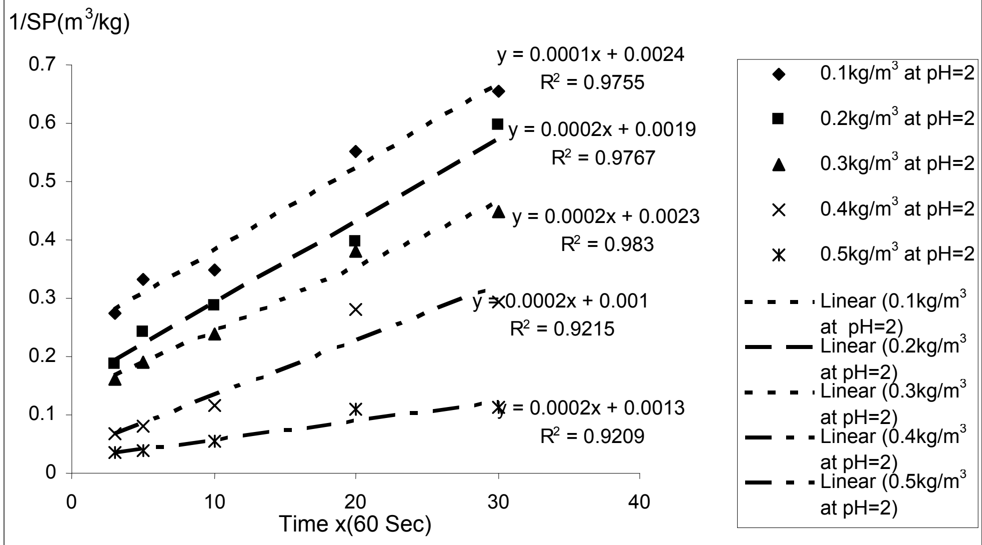

Fig 2: Selected representative plots of 1/SP Vs Time based on maximum $\tau_{1/2}$

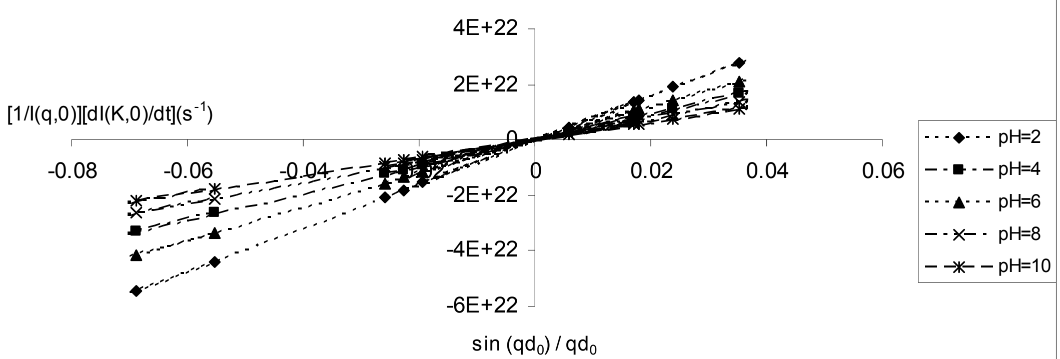

Fig 3: Initial intensity changes Vs. interference factor at 0.1kg/m^3 ABC

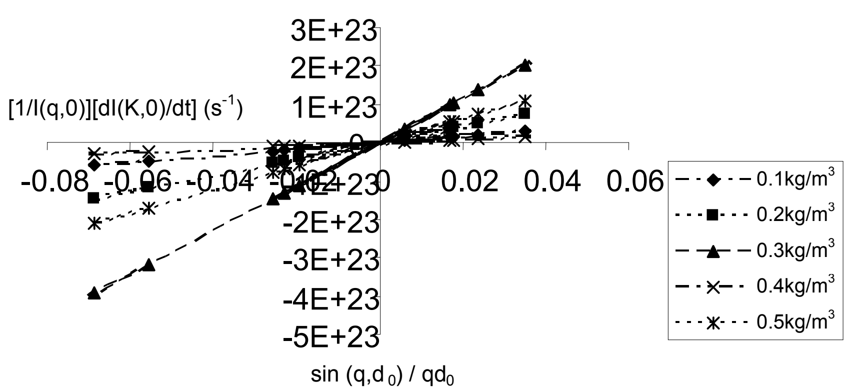

Fig 4: Initial intensity change Vs. interference factor for ABC at pH of 2

The discrepancies in K, K_R and $(SP)_0^c$ are explained by the unattainable assumption that mixing of particles and ABC throughout the dispersion is 100% efficient before any aggregation occurs. The effect of this limitation will be local increase in particle ratios during the mixing phase given uneven distribution of particles / ABC complexes [18]. Another account is the interplay between the Vander Waal forces and the hydrodynamic interactions which typically alters the theoretically predicted parameter values by a factor of ±2.However, other additional short range forces may represent the most likely explanation for any other remaining discrepancies [19, 20].

3.2 SP (kg/m^3) Vs Time plots

The SP Vs Time plots are presented in Figs 5 to 9. The common trend is that SP reduces with time. This is because as single particles flocculate into large aggregates and settle, the turbidity of the dispersion decreases and the transmission intensity increases. This behavior reflects the complex dependence of turbidity (hence coag-flocculation) on particle number (dropping) and particle size (increasing) over time [18]. The rapid settling of the flocculated particle is shown in Figs 5 to 9 where 90% of the initial SP concentration of 21204.72mg/l were removed at the 3rd minute. This is supported strongly by the values of $\tau_{1/2}$ recorded in Tables 1 to 5 where the highest and least coag-flocculation were achieved at pH of 2 and 10 respectively.

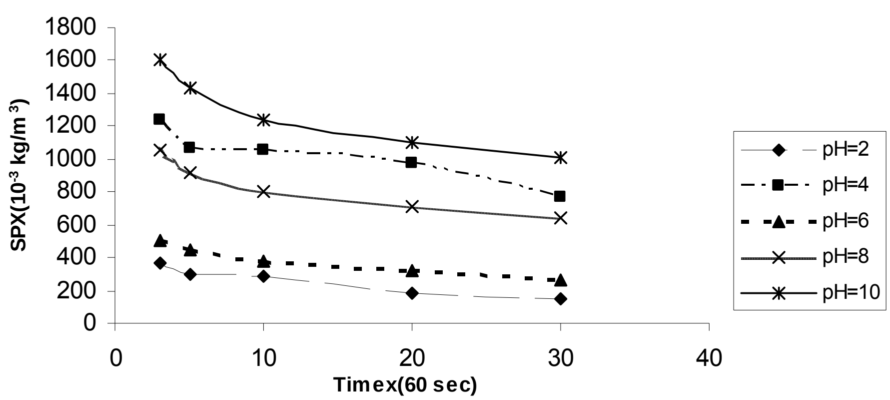

Fig 5:Plot of SP vs Coag-flocculation Time at varying pH and constant dosage of 0.1kg/m^3

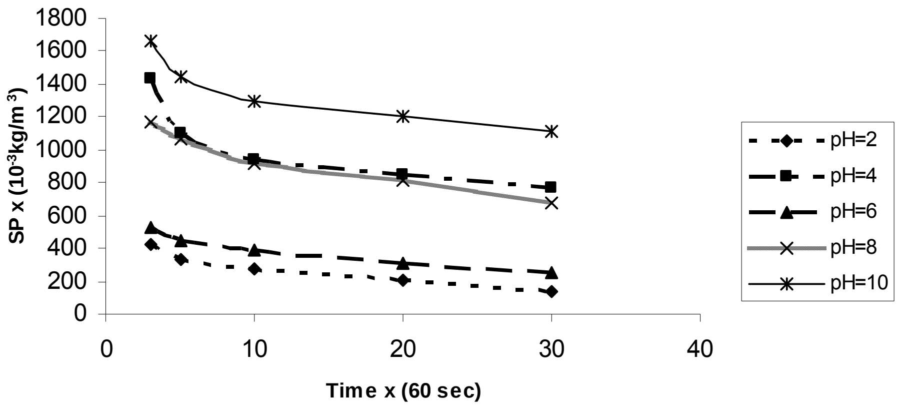

Fig 6:plot of SP Vs Coag-flocculation Time at varying pH and constant dosage of 0.2kg/m³

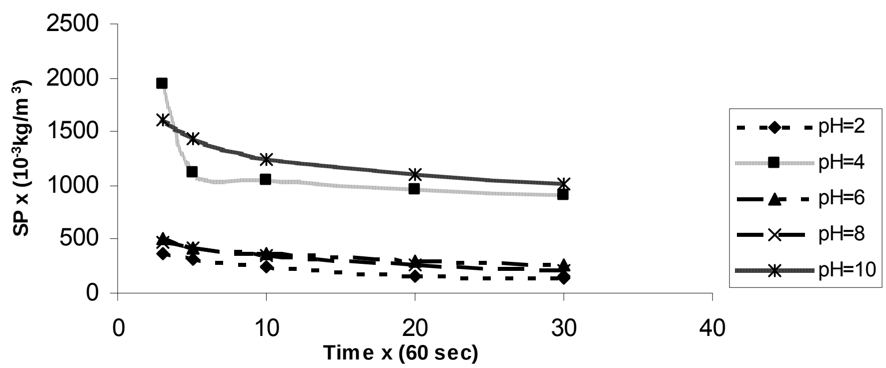

Fig 7:plot of SP Vs Coag-flocculation Time at varying pH and constant dosage of 0.3kg/m³

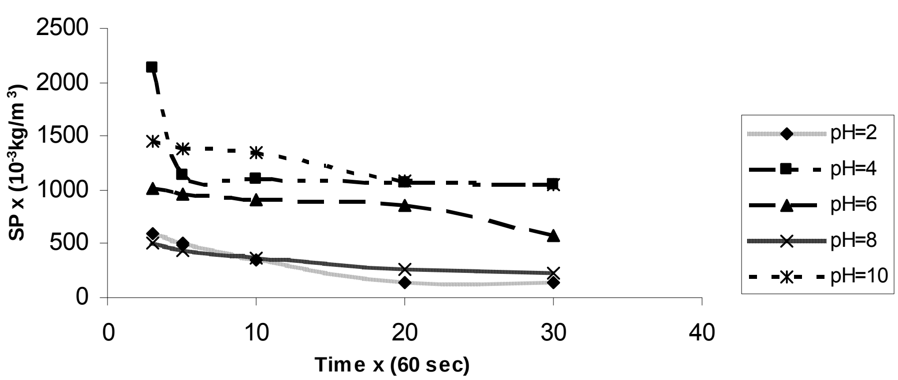

Fig 8:Plot of SP Vs Coag-flocculation Time at varying pH and constant dosage of 0.4kg/m³

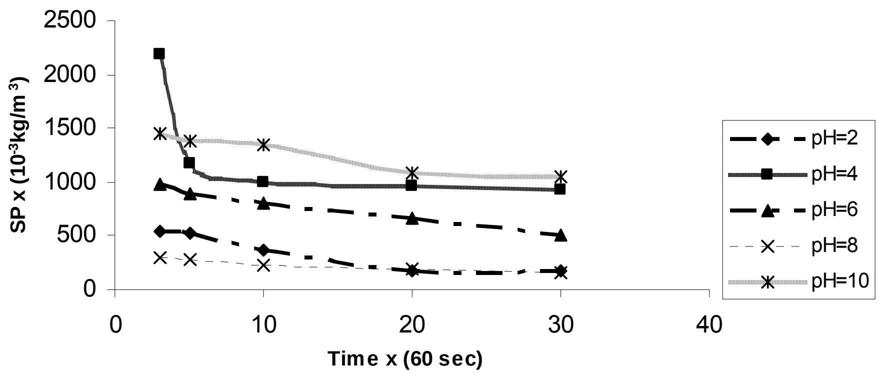

Fig 9:Plot of SP Vs Coag-flocculation Time at varying pH and constant dosage of 0.5kg/m³

3.3 Efficiency E (%) vs. time

Plots of E (%) Vs time are presented in Figs 10 to 14. The E (%) indicates the effectiveness of ABC to remove suspended particle (turbidity) form the effluent. The plots show that the least E > 89.00 justifies the effectiveness of ABC. This collaborates with the values of $\tau_{1/2}$ and real life application of coag-flocculation in which 90% of the particle removal is usually achieved within the first five minutes of the process. Observation shows that the best coag-flocculation was achieved at pH of 2 followed by 6 and 8.

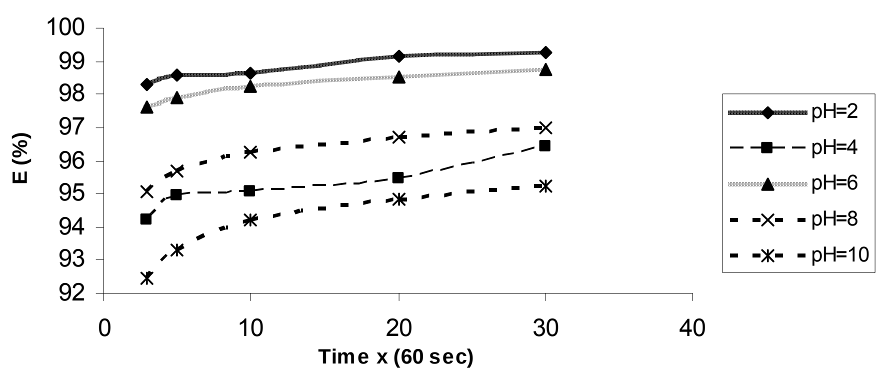

Fig 10:Plot of E(%) Vs Coag-flocculation Timeat varying pH and constant dosage of 0.1kg/m³

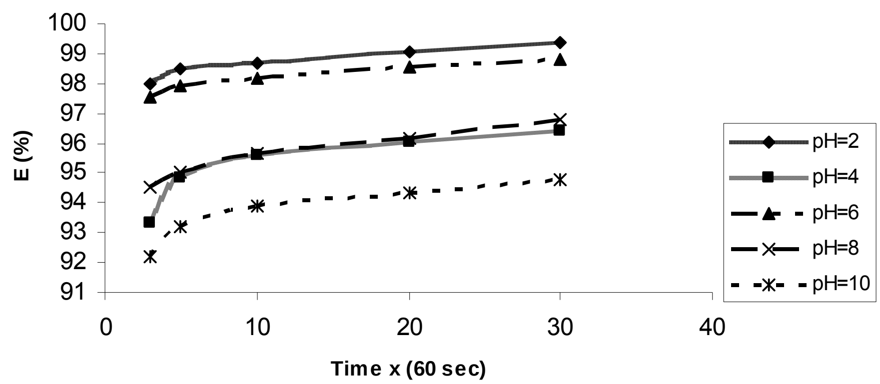

Fig 11:Plot of E(%) Vs Coag-flocculation Time at varying pH and constant dosage of $0.2kg/m^3$

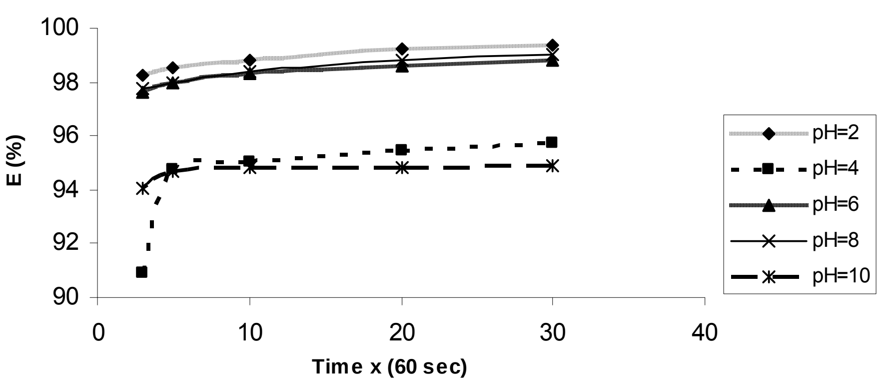

Fig 12:Plot of E Vs Coag-flocculation Time at varying pH and constant dosage of $0.3kg/m^3$

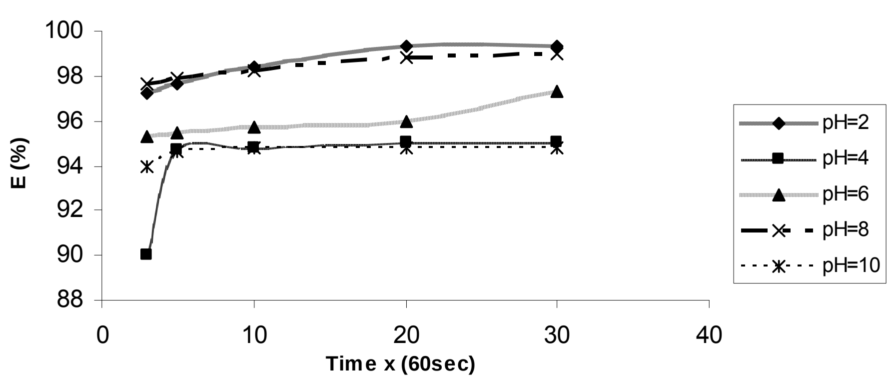

Fig 13:Plot of E Vs Coag-flocculation Time at varying pH and constant dosage of $0.4kg/m^3$

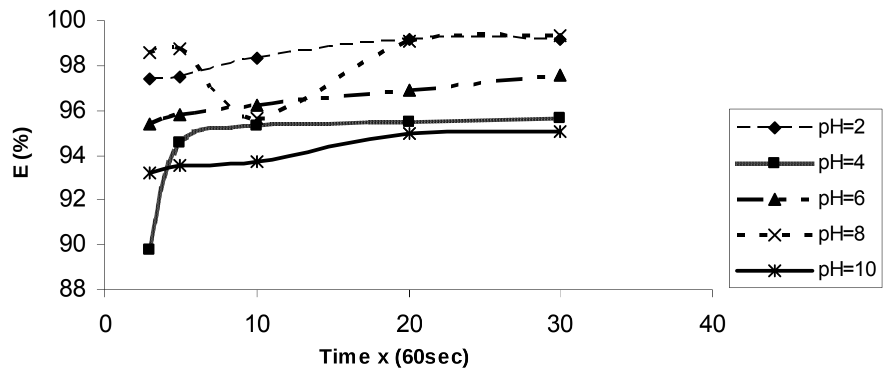

Fig 14:Plot of E vs Coag-flocculation Time at varying pH and constant dosage of 0.5kg/m^3

3.4 E (%) vs. pH

This is presented in Fig 15. It indicates the performance of various doses of ABC at varying pH. Interestingly, all the doses have a similar trend having their maxima at pH=2 and minima at pH=10.All doses have the same E at pH of 2,indicating that dose does not affect the E(%) at pH of 2.

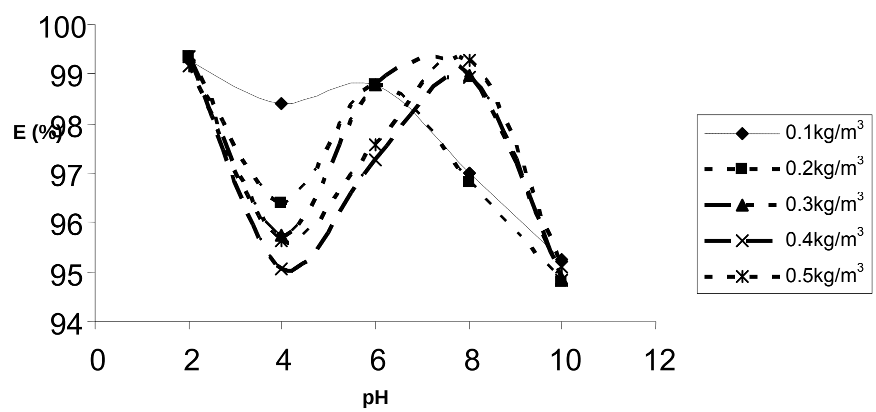

Fig 15: Plot of E(%) Vs pH at 30 min for varying dosages

3.5 E (%) vs. Dosage (kg/m^3)

This is presented in Fig 16. The optimum dosages are 0.1kg/m^3 and 0.3kg/m^3 at E = 99.3722% and pH =2.It confirms the observation made in fig 15.pH of 10 has the least E(%) for all the dosages.

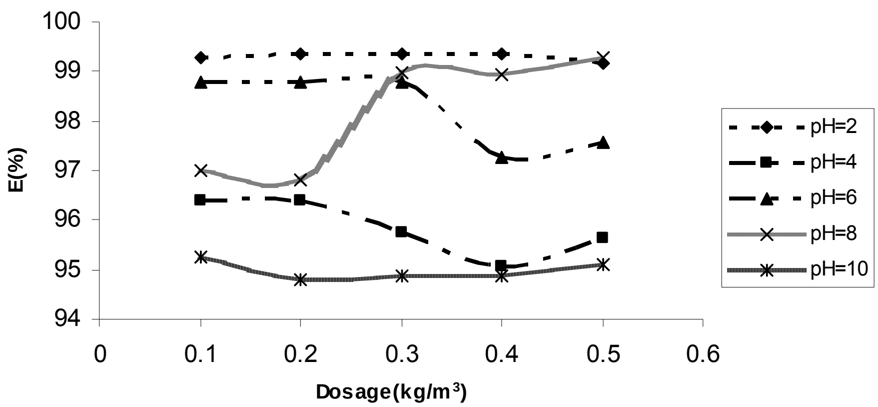

Fig 16:Plot of E(%) Vs Dosages at varying pH and constant Time

3.6 Time Evolution of the Cluster Size Distribution

The representative plots (here N_i given in particles / m^3) are presented in Figs 17 and 18. The discussion is presented in two cases as follows:

Case I: Consider Fig 17. The particle distributions expected in a typical coag-flocculation process is shown here. The curves N_i Vs. t, beginning with twins (doublets) passes through a maxima because they are absent at the initial instant (t=0, N_2=0) and at the end of coag-flocculation process (t=∞, 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. The discrete nature of formation of N_1, N_2, and N_3 is associated with moderate energy barrier.

Case II: Consider Fig 18.This is the case in which the values of N_3 and $\sum N_i$ are close such that their variation with time is near same. Also, similar trend with respect to N_2 and N_i is obtained. The plot indicates that there exists a wide margin of difference in concentration values between the pair of (N_3 and $\sum N_i$) and (N_2 and N_i).The implication is the existence of high shear force and resistance to collision. This is clearly demonstrated by the value of $\tau_{1/2}$ which is the highest recorded. This is an indication of high zeta potential associated with the process.

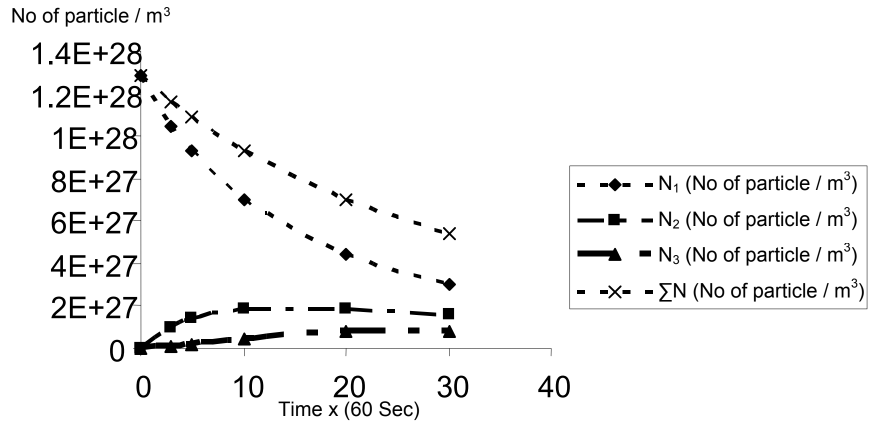

Fig 17: Time evolution of the cluster size distribution for $\tau_{1/2}$ = 28.1216

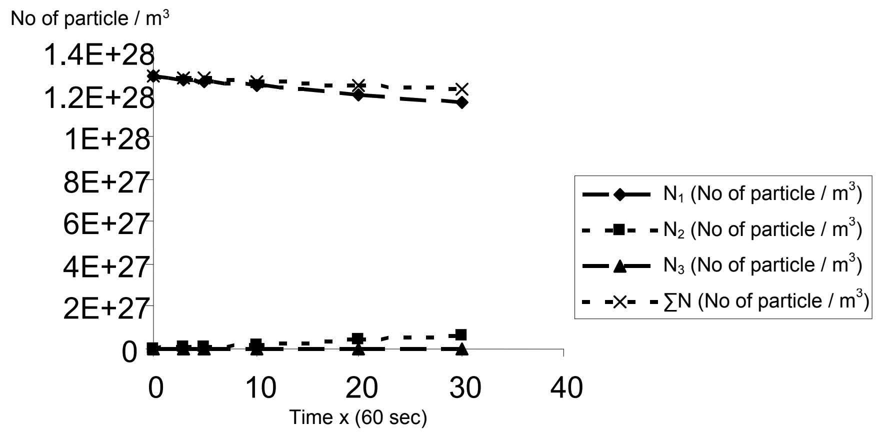

Fig 18: Time evolution of the cluster size distribution for $\tau_{1/2}$ = 562.365

4. CONCLUSION

The efficiency of ABC recorded presents it as a potential source of organic derived coagulant that can be applied in large scale water treatment .The optimum dosages , pH and $\tau_{1/2}$ for the coag-flocculation are (0.3kg/m^3 and 0.2kg/m^3) , 2 and 28 seconds respectively. The obtained results are generally in agreement with previous works [5, 11, 20, 21] and in conformity with perikinetic theory.

NOMENCLATURE

K :Menkonu coag-flocculation reaction rate constant
β_{BR}: Collision factor for Brownian Transport
ε_p: Collision Efficiency
$\tau_{1/2}$: Coagulation Period / Half life
E: Coag-flocculation Efficiency

R^2*:* Coefficient of Determination
α: Coag-flocculation reaction order
-r: Coag-flocculation reaction rate
$(SP)_0^c$: Computed initial suspended particle (kg/m^3)
J_f *:*Flux
f_d*:* Drag force
K_S : *K* value obtained from simulation.
ABC: *Afzelia bella* coagulant
d_o : Hard core interaction diameter of the primary particle.
a: Radius of the primary particle

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