

Coag-flocculation method for removal of turbidity from brewery effluent using okra (*Hibiscus esculentus* L) seed extract as a natural coagulant.

Abstract

This work investigated the potential for an effective use of Okra seed extract as an efficient bio coagulant for treatment of brewery effluent. The study was carried out using nephelometric jar test. The perikinetetic data generated were fitted to specific models for the determination of reaction order, rate constant, period etc. The maximum coag-flocculation performance is recorded at rate constant, K_m of $3.6 \times 10^{-3} \text{ L(mg.min)}^{-1}$, dosage of 100 mg L^{-1} , pH of 6 and coagulation period of 0.38min while the minimum is recorded at K_m of $2.95 \times 10^{-5} \text{ L(mg.min)}^{-1}$, dosage of 500 mg L^{-1} , pH of 10 and period of 93min. The optimum efficiency recorded at 88.31% for 30min shows that the system is perikinetetic controlled. The results indicate that okra extract can serve as a potential coagulant for the treatment of brewery effluent.

Keywords: Okra seed, Brewery Effluent, Coag-flocculation, turbidity, Perikinetics

1 INTRODUCTION

There has been an increasing demand of water usage in brewery industry, as a result, a large volume of wastewater is being generated. In brewery industry, the main section that consumes much water is the brew house, cellars and packaging [1].

The large quantity of wastewater produced from brewery industry contains significant amount of pollutants that usually pose serious risk to human beings, environment, and aquatic life if not properly treated prior to disposal. There are several ways to treat this wastewater. Coagulation-flocculation process is widely used for the treatment of water and wastewater (coagulation and flocculation are two different processes first of all. Second, they do not remove anything from water or wastewater, requiring following clarification steps, as sedimentation, flotation, filtration, etc). In this process, three important steps are considered: coagulant formation, colloid particles destabilization and inter particle collision and aggregation [2,3,4,5].

The coagulation/flocculation process involves the addition of inorganic/organic coagulants such as Aluminum sulphate, polyamine and *Xanthosomaspp* etc. When added in wastewater, they neutralize the negative charges in the dispersed non-settleable solids, resulting in the formation of micro flocs (this is one of the coagulation mechanisms, but there are others) [6,7].

Since Alzheimer disease is associated with Aluminum (better mention only aluminum), coupled with significant generation of recalcitrant sludge, there is a need to create a platform for the use of natural coagulants which are eco-friendly and locally abundant [8]. Natural coagulants are promising and have attracted the attention of many researchers because of their abundance, low price and biodegradability [19, 20].

Okra is a perennial shrub plant, which can reach three meters in height. It belongs to the family of Malvaceae, and is given the scientific name of *Hibiscus esculatus* L. It is a crop of fast vegetative cycle and high yield [15]. Okra seed is mainly composed of oligomeric catechins (2.5 mg g⁻¹ of seeds) and flavonol derivative (3.4 mg g⁻¹ of seeds), while the mesocarp is mainly composed of hydroxycinnamic and quercetin derivatives (0.2 and 0.3 mg g⁻¹ of skins). Pods and seeds are rich in phenolic compounds with important biological properties like quercetin derivatives, caechin oligomers and hydroxycinnamic derivatives [16, 17]. Okra powder being rich in proteins, fat and polysaccharides shows a promising flocculation properties, an indication of the availability of active sites capable of adsorbing colloids during coagulation-flocculation process [18, 19].

The objective of the current work is to investigate the natural coagulant (okra seed extract) using coagulation-flocculation processes on the removal of turbidity from brewery effluent for a range of parameters (pH, doses, time).

2 COAGULATION THEORY AND MODEL DEVELOPMENT

2.1 The theory of rapid coagulation

For an aqueous coagulating suspension, where Brownian particle collision is in force, the number of collision occurring per unit time per unit volume, K_{ij} , for two species of particles of volumes v_i and v_j is expressed as [7, 9, 10]

$$K_{ij} = \beta_{BR}(v_i v_j) n_i n_j \quad 1$$

Where $\beta_{BR}(v_i v_j)$ is collision frequency

$n_i n_j$ is the number of concentration of particles

The formation rate r_f of particles of volume V_k , resulting from collisions of volumes V_i and V_j is given by [9]:

$$r_f = \frac{1}{2} \sum_{i+j=k} K_{ij} \quad 2$$

The summation of $i+j$ implies an overall collision for which

$$V_k = V_i + V_j \quad 3$$

Conversely, the rate of particle loss by collision is

$$r_l = \sum_{i=1}^{\infty} K_{ik} \quad 4$$

Hence the rate of change due to Brownian motion in the fluid medium is :

$$\frac{dn_k}{dt} = \frac{1}{2} \sum_{i+j=k} K_{ij} - \sum_{i=1}^{\infty} K_{ik} \quad 5$$

Putting equation 1 into equation 5, yields

$$\frac{dn_k}{dt} = \frac{1}{2} \sum_{i+j} \beta_{BR} (V_i V_j) n_i n_j - n_k \sum_{i=1}^{\infty} \beta_{BR} (V_i V_k) n_i \quad 6$$

For kernel like particles,

$$K_{ij} = 4\pi(D_i + D_j)(a_i + a_j) \quad 7$$

$$\text{Also, } K_{ij} = \frac{2}{3} \left(\frac{K_B T}{\eta} \right) \quad 8$$

Combining equations 7 and 8 yields

$$(D_i + D_j) = \frac{K_B T}{6\pi\eta} \left(\frac{1}{a_i} + \frac{1}{a_j} \right) \quad 9$$

Putting $(D_i + D_j)$ of equation 9 into equation 7 yields

$$K_{ij} = \frac{2}{3} \frac{K_B T}{\eta} \frac{(a_i + a_j)^2}{a_i a_j} \quad 10$$

For particles of difference radius with dimmer formation of an initially monodispersed suspension:

$$\frac{(a_i + a_j)^2}{a_i a_j} = \begin{cases} 4 & \text{for } a_i = a_j \\ >4 & \text{for } a_i \neq a_j \end{cases} \quad 11$$

Hence, for the case of $a_i = a_j$, equation 10 becomes :

$$K_{11} = \frac{8}{3} \frac{K_B T}{\eta} \quad 12$$

Where K_{11} is the Smoluchowski coagulation rate constant.

If $K_{ij} \rightarrow K_{11} = \beta_{BR}(v_i v_j) n_i n_j$, equation 6 solves exactly to yield:

$$\frac{N_t}{N_o} = \frac{(K_{11} N_o t/2)^{n-1}}{(1 + K_{11} N_o t/2)^{n+1}} \quad 13$$

It has been established that for aggregating system at $n=1$; extending into flocculation regime, such that

$K_{11} \approx K_m$ [10]equation 13, transforms to equation 14:

$$\frac{1}{\sqrt{N_L}} = \left(\frac{K_m N_o}{2\sqrt{N_o}} \right) t + \frac{1}{\sqrt{N_o}} \quad 14$$

Where $K_m = \frac{1}{2} \beta_{BR}$

$$= \frac{2}{3} \varepsilon_p \frac{K_B T}{\eta}$$

K_m is defined as Menkonucoag-flocculation rate constant accounting for Brownian coag-flocculation transport of destabilized particle at α^{th} order

88 ϵ_p is collision efficiency

89 From equation 13, coag-flocculation period is obtained as

90
$$\tau_{1/2} = \frac{1}{(0.5K_M N_o)} \quad 15$$

91 There is, however, a reasonable relationship between Turbidity and total suspended solid for the settled
92 effluent. The general form of the relationship is as follows:

93
$$\text{TSS (mg L}^{-1}\text{)} = \text{TSS}_f \times (T) \quad (\text{reference? This depend on size and particle size distribution, among others})$$

94 where TSS is total suspended solid, mg L⁻¹

95 $\text{TSS}_f = 2.3$ is a factor used to convert turbidity reading to total suspended solids [11]

96 T is turbidity (NTU)

97 The concentration of singlets, doublets and triplets during coagulation can be evaluated by solving
98 equation 13.

99 Hence, for singlets (n=1)

100
$$N_1 = N_o \left[\frac{1}{1 + t/\tau'} \right] \quad 17$$

101 For doublets (n=2)

102
$$N_2 = N_o \left[\frac{t/\tau'}{(1 + t/\tau')^3} \right] \quad 18$$

103 For triplets (n=3)

104
$$N_3 = N_o \left[\frac{(t/\tau')^2}{(1 + t/\tau')^4} \right] \quad 19$$

105 Where $\tau' = 2\tau$

106

107 Evaluation of coagulation –flocculation efficiency is given as

108
$$E(\%) = \left[\frac{N_o - N_t}{N_o} \right] \times 100 \quad 20$$

109

110 **3 Materials and Method**

3.1 Material Sampling, Preparation and Characterization

3.1.1 Brewery Effluent

The effluent was collected from brewery plant located in Enugu, Enugu State Nigeria. The characterization of the effluent and the analysis presented in Table 1 were determined based on standard method (WST, 2005; AWWA 2005).

3.1.2 Okra Seed Sample

The Okra seed pods were bought from Ogbete market, Enugu State Nigeria. The Okra seed pods were prepared according procedure reported by Agarwal et al [12]. The characteristics of okra seed was on the basis of AOAC [13] standard method and presented in Table 2. Tables 1 and 2 were not attached.

3.2 Coagulation- flocculation Experiment

Experiments were conducted using conventional jar test apparatus. Desired dosages of Okra coagulant between 100-500mg L⁻¹ were directly dosed into 300mL of Brewery Effluent contained in standard 1000mL beaker (G.C17). The suspension, tuned to pH 2-10 using H₂SO₄/NaOH, was subsequently subjected to 2 minutes (it is a long time for rapid mixing!) of rapid mixing (200rpm), 20 minutes of slow mixing (30rpm) using a magnetic stirrer. After agitation, the suspended solution was transferred into a cylinder (JayTec.Uk) of height 33.5cm at an angle so that the flocs will not break (this is a big methodological mistake. We cannot transfer (split) flocculated water). During settling, 10mL of the supernatant was withdrawn from 2cm depth and changes in total turbidity particles (mg L⁻¹; turbidity in mg/L?) measured at 3, 5, 10, 15, 20, 25 and 30 min (which settling velocity?).

4 Results and discussion

4.1 Plot of Efficiency E % vs Time, pH and dosage

The removal efficiency E(%) with time, pH and dosage is obtained based on the evaluation of equation 20. This is presented in figures 1-7. This was obtained at 100, 200, 300, 400 and 500mg L⁻¹ dosage for pH 2, 4, 6, 8 and 10. From figures 1-7, it can be shown that efficiency increases with time (as expected), but its magnitude varies for different pH and dosage. The efficiency at first 3 minutes were generally between 59-70% at pH 2 and 4, respectively. This justified the theory of fast coagulation [9]. Also at 30 min, the efficiency was between 85 and 92.6% at pH 2 and 200mg L⁻¹. The implication is that at least 80 and 90% of initial solid dissolved particles load were removed at 3 and 30 min (30 min settling is too much time. In practice it would conduct to a huge settling basin), respectively [10]. Figure 6 shows that the performance of Okra seed coagulant (OSC) in removing total dissolved solid particles from brewery effluent is not significantly affected by the dosage. All the doses have a similar behavior having their maxima at pH=2 and minima at pH=10. The performance of the coagulant reached the optimum value at pH 2 and 4. The poor performance at high doses (especially 500mg L⁻¹) could be attributed to the phenomenon of excess coagulant being adsorbed on the colloidal surface and producing restabilized colloids. (take care with this; with sweep coagulation this is not expected)

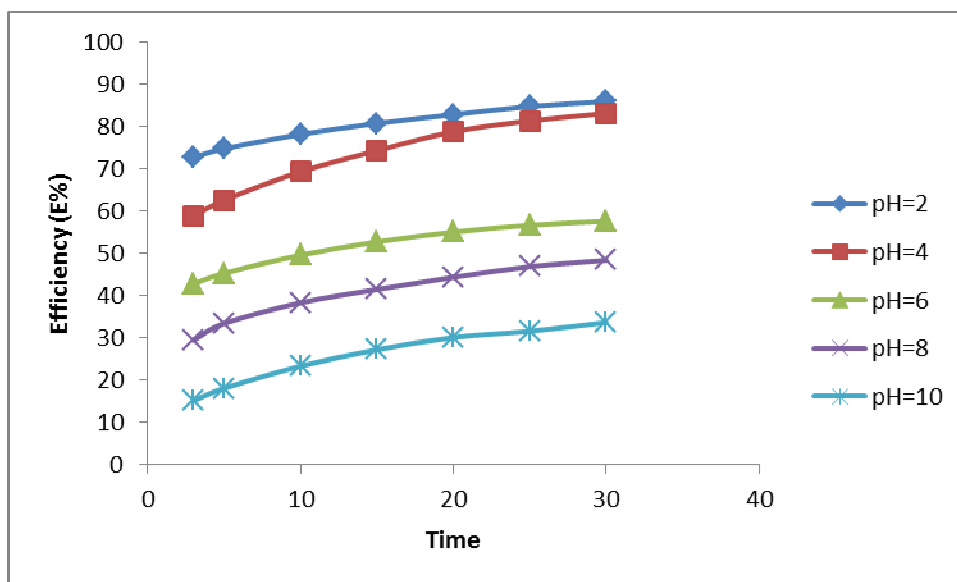


Figure 1: Plot of Efficiency (E %) vs coag-flocculation time for 100mg L⁻¹ Okra at varying pH

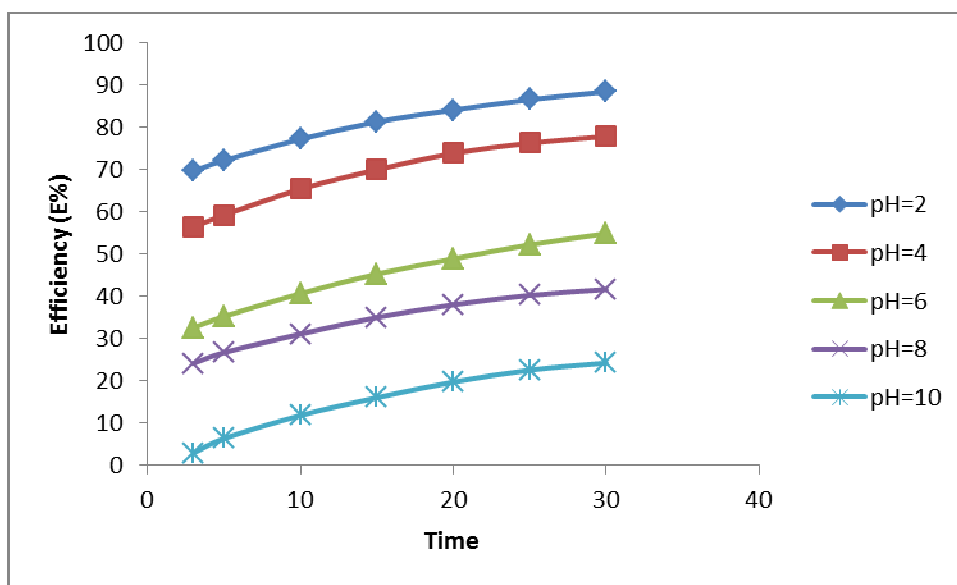


Figure 2: Plot of Efficiency (E %) vs coag-flocculation time for 200mg L⁻¹ Okra at varying pH

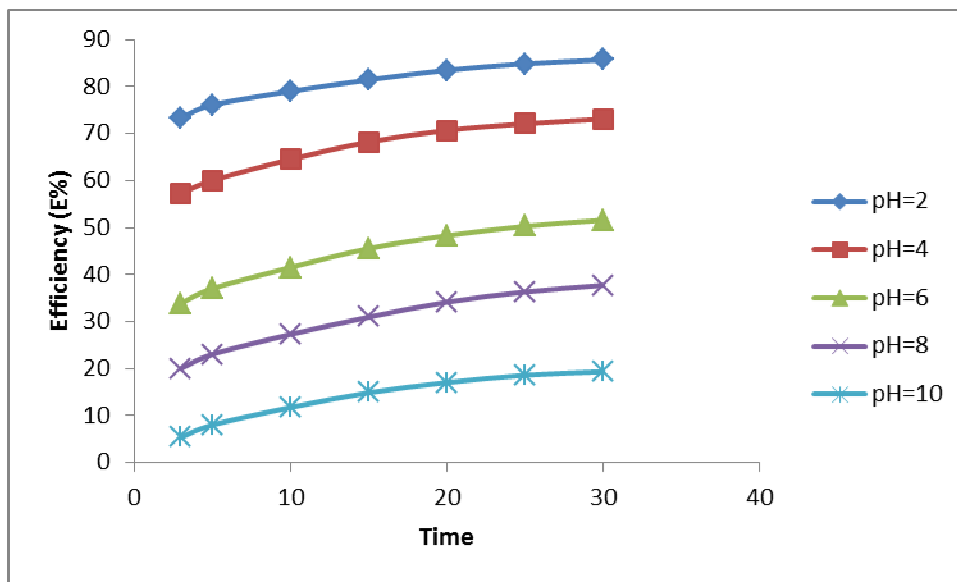


Figure 3 : plot of Efficiency (E%) vs coag-flocculation time for 300mg L⁻¹ Okra at varying pH

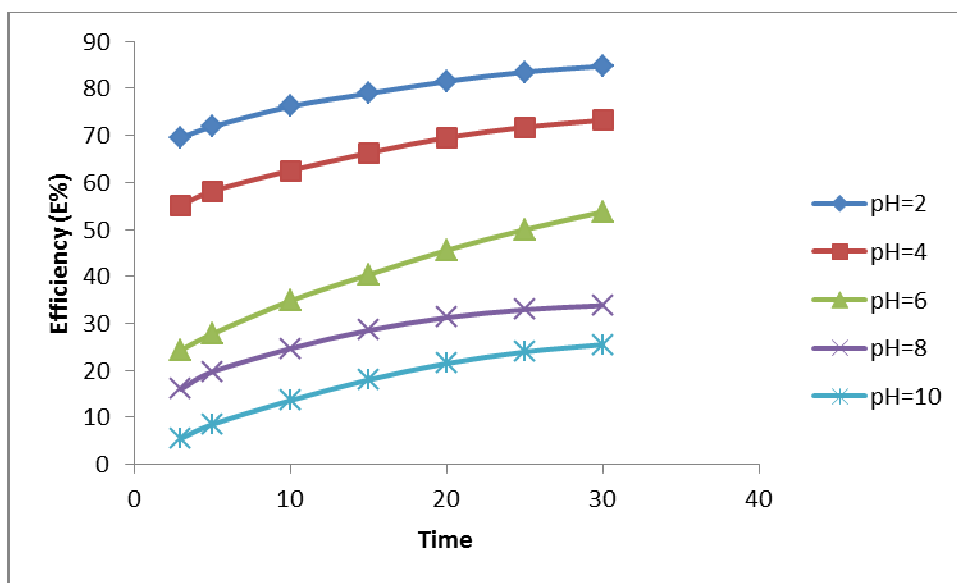


Figure 4: Plot of Efficiency (E %) vs coag-flocculation time for 400mg L⁻¹ Okra at varying pH

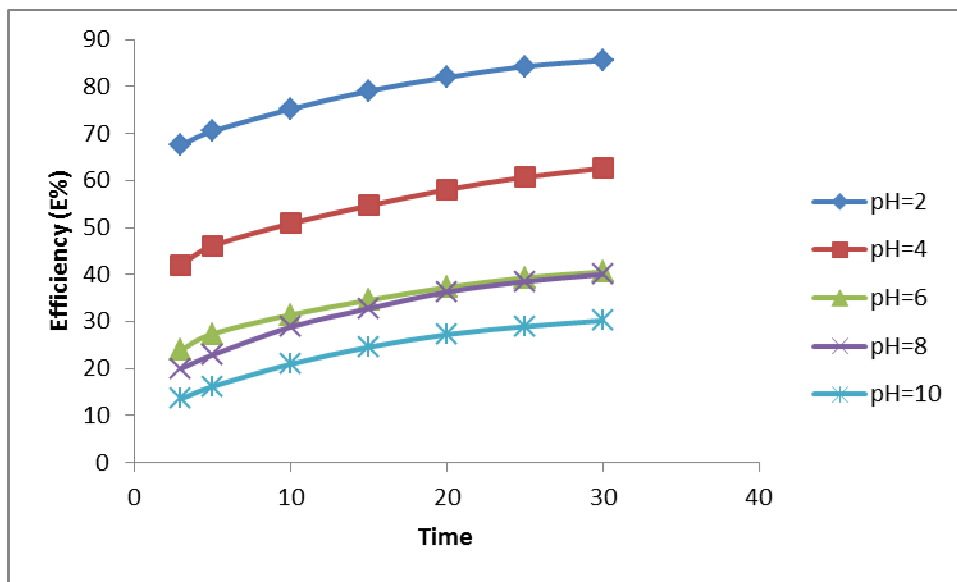


Figure 5: Plot of Efficiency (E%) vs coag-flocculation time for 500mg L⁻¹ Okra at varying pH

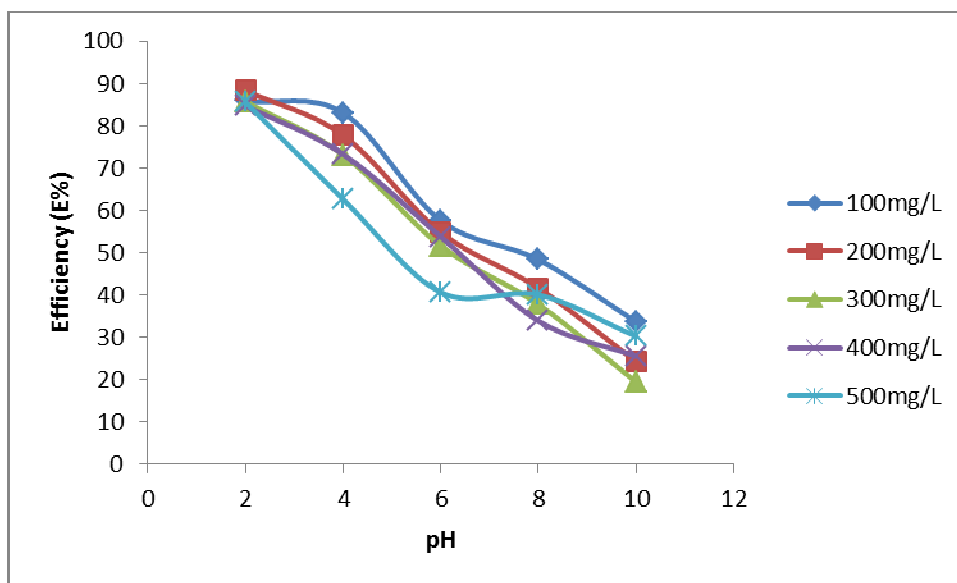


Figure 6: Plot of Efficiency (E%) vs pH at varying Okra dosage

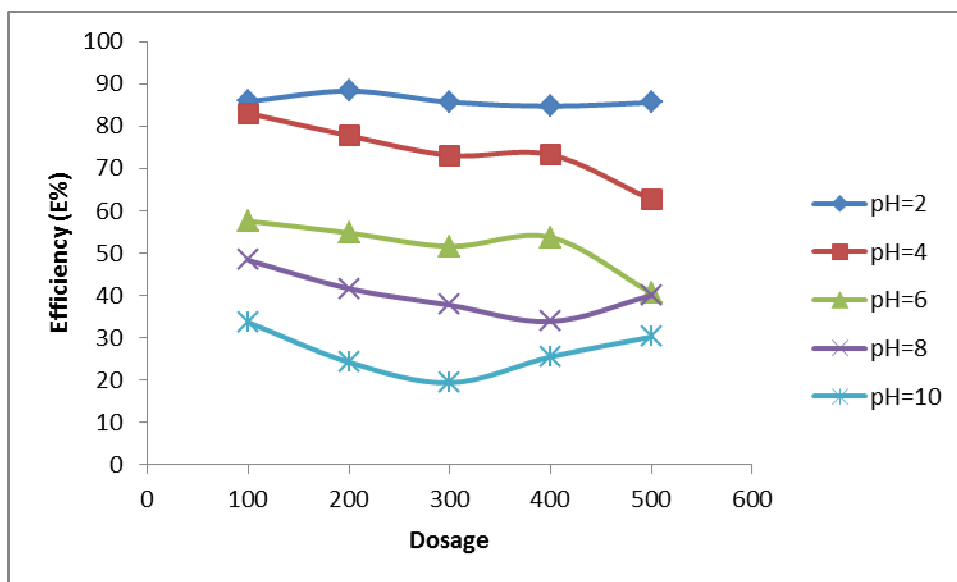


Figure 7: Plot of Efficiency (E%) vs dosage at varying pH

4.2 Nephelometric Kinetic Result

This test was performed for a sample of BRE with an initial SDP of 137.66mg L⁻¹ for 100-500mg L⁻¹ dosage of OSC dosage and pH 2-10 range, respectively.

Assuming perikinetic aggregation condition, where $\alpha=2$, solving equation 13, gives equation 14, which is presented in the selected linear plots in figure 8. The plots of $\frac{1}{\sqrt{N_t}}$ Vs t yields, K_m and $\frac{1}{\sqrt{N_o}}$, as the slope and intercept, respectively. The results presented in tables 3-7, show that majority of R^2 values are high, which shows that the reaction is a second order.

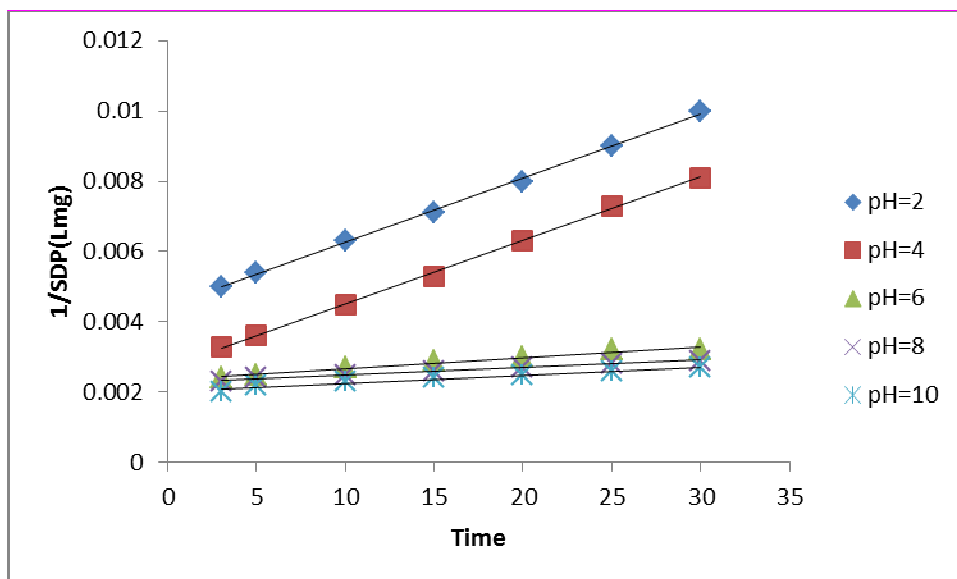


Figure 8: Representative kinetic plot of 1/SDP as a function of time for 100mg L⁻¹ Okra dosage

Meanwhile, the value of $K_m = 0.5\beta_{BR}$ can be obtained from equation 15. However, the highest value of K_m of $3.6 \times 10^{-3} L(mg.min)^{-1}$ for the process is recorded at pH of 6 and $100mg L^{-1}$ OSC. The least of K_m of $2.95 \times 10^{-5} L(mg.min)^{-1}$ is recorded at pH of 10 and $500mg L^{-1}$. In this study, the lowest $\tau_{1/2}$ (0.38 min) is recorded at high K_m of $3.6 \times 10^{-3} L(mg.min)^{-1}$ which favors fast coag-flocculation process[9]. Generally, K_m values were obtained from equation 14 and the representative kinetic plot presented in figure 8. In the tables 3-7, the variation of K_R is minimal, following insignificant changes in values of temperature and viscosity of the effluent medium. Using equation 14, the values of β_{BR} , and ε_p were calculated. The coag-flocculation period, $\tau_{1/2}$ which indicates the time taken for the initial concentration of turbidity particles to reduce by half, is calculated from equation 15.

Table 1: Characterization of Brewery Effluent (for all this table, take care with significant digits)

Parameters	Values
Temperature	27
pH	7.68
Turbidity (NTU)	316.63
Electrical Conductivity (μ/cm)	5290.0
Total hardness ($mg L^{-1}$)	41.0
Ca hardness ($mg L^{-1}$)	36.0
Mg hardness ($mg L^{-1}$)	14.0
Ca^{2+} ($mg L^{-1}$)	15.6
Mg^{2+} (mg^{-1})	0.6
Fe^{2+} ($mg L^{-1}$)	0.178
SO_4^{2-} ($mg L^{-1}$)	46.224
NO_3^{2-} ($mg L^{-1}$)	0.178
Cl^- ($mg L^{-1}$)	80.826
TDS ($mg L^{-1}$)	3438.5
TSS ($mg L^{-1}$)	30.406
E. Coil	Nil???
BOD ₅ ($mg L^{-1}$)	640

Table 2: Characterization of Okra seed (and the most important, as molecular weight, charge density, etc?)

Parameters	% values
Protein	23.0
Moisture content	12.0
Crude fiber	13.5
Fat content	11.0
Ash content	7.2
Carbohydrate	33.3

Table 3: Coag-flocculation kinetic parameter of Okra in BRE at varying pH and 100mg L⁻¹ dosages

Parameters	pH=2	pH=4	pH=6	pH=8	pH=10
A	2	2	2	2	2
R^2	0.9977	0.9938	0.969	0.9864	0.9601
K(L/mg.min)	5.09×10^{-3}	4.04×10^{-3}	3.6×10^{-3}	3.23×10^{-3}	2.89×10^{-3}
β_{BR} (L/mg.min)	1.0×10^{-2}	8.16×10^{-3}	7.2×10^{-3}	6.46×10^{-3}	5.78×10^{-3}
K_r (L/min)	7.3×10^{-19}	7.65×10^{-19}	7.45×10^{-19}	7.45×10^{-19}	7.45×10^{-19}
ε_p (mg ⁻¹)	1.37×10^{16}	1.08×10^{16}	9.67×10^{15}	8.67×10^{15}	7.76×10^{15}
$\tau_{1/2}$ (min)	0.54	0.68	0.38	0.85	0.95
τ' (min)	1.08	1.36	0.76	1.7	1.9
(-r)mg/min	5.09 $\times 10^{-3} N_t^2$	4.04 $\times 10^{-3} N_t^2$	$3.6 \times 10^{-3} N_t^2$	3.23 $\times 10^{-3} N_t^2$	2.89 $\times 10^{-3} N_t^2$

Table 4: Coag- flocculation kinetic parameter of Okra in BRE at varying pH and 200mg L⁻¹ dosage

Parameters	pH=2	pH=4	pH=6	pH=8	pH=10
A	2	2	2	2	2
R^2	0.997	0.9911	0.9896	0.9498	0.9671
K(L/mg.min)	4.61×10^{-3}	4.05×10^{-3}	3.27×10^{-3}	3.15×10^{-3}	2.78×10^{-3}
β_{BR} (L/mg.min)	9.22×10^{-3}	8.1×10^{-3}	6.54×10^{-3}	6.3×10^{-3}	5.56×10^{-3}
K_r (L/min)	7.44×10^{-19}	7.43×10^{-19}	7.45×10^{-19}	7.45×10^{-19}	7.5×10^{-19}
ε_p (mg ⁻¹)	1.24×10^{16}	1.09×10^{16}	8.78×10^{15}	8.46×10^{15}	7.4×10^{15}
$\tau_{1/2}$ (min)	0.59	0.68	0.84	0.87	0.98
τ' (min)	1.18	1.36	1.68	1.74	1.98
(-r)mg/min	4.61 $\times 10^{-3} N_t^2$	4.05 $\times 10^{-3} N_t^2$	3.27 $\times 10^{-3} N_t^2$	3.15 $\times 10^{-3} N_t^2$	$2.78 \times 10^{-3} N_t^2$

Table 5: Coag-flocculation kinetic parameter of Okra in BRE at varying pH and 300mg L⁻¹ dosage

Parameters	pH=2	pH=4	pH=6	pH=8	pH=10
A	2	2	2	2	2
R^2	0.9873	0.9639	0.9574	0.9407	0.881
K(L/mg.min)	5.22×10^{-3}	4.2×10^{-3}	3.37×10^{-3}	3.03×10^{-3}	2.82×10^{-3}
β_{BR} (L/mg.min)	1.04×10^{-2}	8.4×10^{-3}	6.74×10^{-3}	6.06×10^{-3}	5.64×10^{-3}
K_r (L/mg.min)	7.43×10^{-19}	7.43×10^{-19}	7.6×10^{-19}	7.45×10^{-19}	7.4×10^{-19}
ε_p (mg ⁻¹)	1.4×10^{16}	1.13×10^{16}	8.86×10^{15}	8.14×10^{15}	7.57×10^{15}
$\tau_{1/2}$ (min)	0.53	0.65	0.83	0.91	0.97
τ' (min)	1.06	1.3	1.66	1.82	1.95
(-r)mg/min	5.22 $\times 10^{-2}N_t^2$	$4.2 \times 10^{-3}N_t^2$	3.37 $\times 10^{-3}N_t^2$	3.03 $\times 10^{-3}N_t^2$	2.82 $\times 10^{-3}N_t^2$

220

221 Table6: Coag-flocculation kinetic parameter of Okra in BRE at varying pH and 400mg L⁻¹ dosage

Parameters	pH=2	pH=4	pH=6	pH=8	pH=10
A	2	2	2	2	2
R^2	0.9977	0.9941	0.9998	0.9167	0.9514
K(L/mg.min)	4.78×10^{-3}	3.97×10^{-3}	3.1×10^{-3}	2.98×10^{-3}	2.82×10^{-3}
β_{BR} (L/mg.min)	9.4×10^{-3}	7.94×10^{-3}	6.2×10^{-3}	5.96×10^{-3}	5.64×10^{-3}
K_r (L/mg.min)	7.34×10^{-19}	7.45×10^{-19}	7.45×10^{-19}	7.45×10^{-19}	7.46×10^{-19}
ε_p (mg ⁻¹)	1.28×10^{16}	1.06×10^{16}	8.32×10^{15}	8.0×10^{15}	7.56×10^{15}
$\tau_{1/2}$ (min)	0.57	0.69	0.88	0.92	0.97
τ' (min)	1.14	138	1.76	1.84	1.95
(-r)mg/min	4.78 $\times 10^{-3}N_t^2$	3.97 $\times 10^{-3}N_t^2$	$3.1 \times 10^{-3}N_t^2$	2.98 $\times 10^{-3}N_t^2$	2.82 $\times 10^{-3}N_t^2$

222 Table 7: Coag-flocculation kinetic parameter of Okra in BRE at varying pH and 500mg L⁻¹dosage

Parameters	pH=2	pH=4	pH=6	pH=8	pH=10
A	2	2	2	2	2
R^2	0.9981	0.9836	0.9719	0.9719	0.8947
K(L/mg.min)	4.58×10^{-3}	3.58×10^{-3}	3.03×10^{-3}	3.03×10^{-3}	2.95×10^{-5}
β_{BR} (L/mg.min)	9.0×10^{-3}	7.16×10^{-3}	6.06×10^{-3}	6.06×10^{-3}	5.9×10^{-5}
K_r (L/mg.min)	7.32×10^{-19}	7.45×10^{-19}	7.45×10^{-19}	7.45×10^{-19}	7.45×10^{-19}
ε_p (mg ⁻¹)	1.23×10^{16}	9.61×10^{15}	8.14×10^{15}	8.14×10^{15}	7.92×10^{13}
$\tau_{1/2}$ (min)	0.6	0.76	0.91	0.91	9.3
τ' (min)	1.2	1.52	1.82	1.82	186
(-r)mg/min	4.58 $\times 10^{-3}N_t^2$	3.58 $\times 10^{-3}N_t^2$	3.03 $\times 10^{-3}N_t^2$	3.03 $\times 10^{-3}N_t^2$	2.95 $\times 10^{-5}N_t^2$

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224 **4.3 Particles Distribution Plots**

The particle distribution plots are presented in figures 9 and 10 for $\tau_{1/2}=0.38\text{min}$ and $\tau_{1/2}=9.3\text{min}$ respectively. By substituting $\tau_{1/2}$ from equation 15 into 17, 18, 19, the microscopic particles aggregation can be graphically illustrated. In figure 9, the number of singlet particle decreases more rapidly than the sum particles. This indicate that early stage of this coag-flocculation is affected by colloidal destabilization and rapid sweep [10, 14]

In figure 10, the plot exhibits opposing profile to that of figure 9. Here there is decrease in rapidity of flocculation resulting from destabilization inertia. The curve clearly demonstrates that there is slow colloidal destabilization, resulting to low particle entrapment and low bridging mechanism.

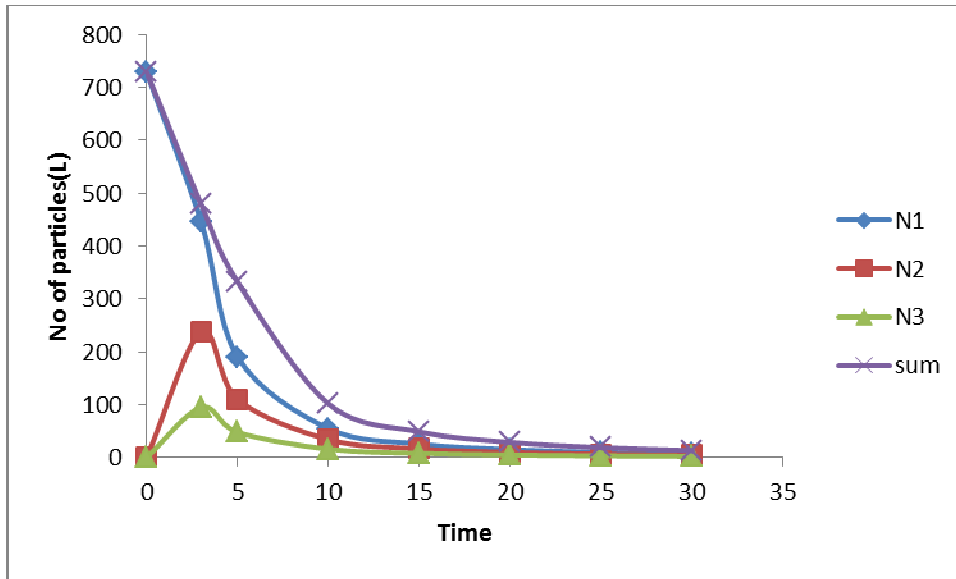


Figure 9 : Particles distribution behavior for half life of 0.38min

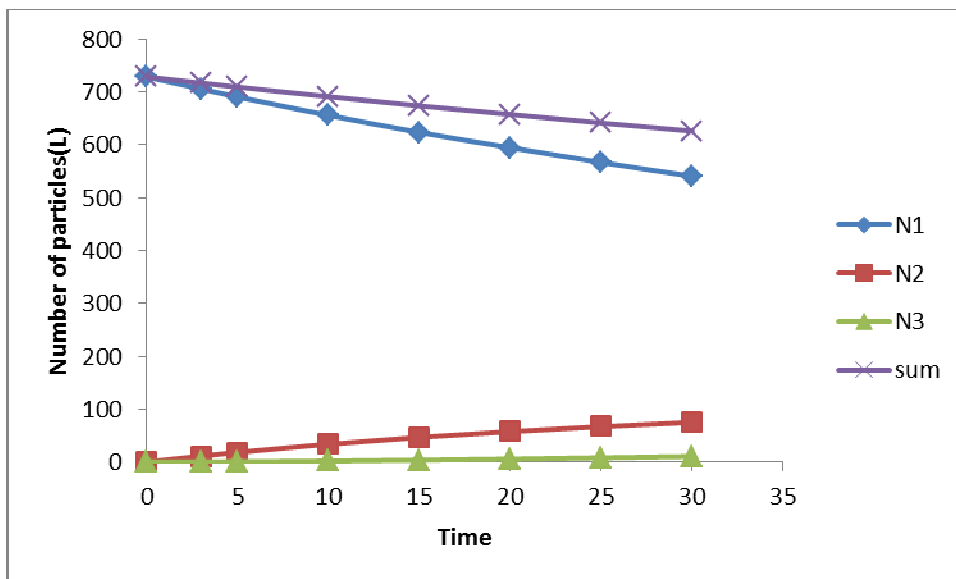


Figure 10 : Particles distribution behavior for half-life of 9.3min

5.0 Conclusion

The potential application of Okra seed extract as an effective plant coag-flocculation has been established. The process effectively removed 88.5% turbidity from the effluent. However, the jar test conducted was sensitive to pH and dosage (as expected). 200mg L^{-1} dose of Okra seed coagulant and pH 2 were found to be optimal conditions for the effluent treatment. It could be inferred at the experimental conditions that coag-flocculation process using okra seed was feasible for the treatment of brewery effluent.

Nomenclature

K_m : Menkonu coag-flocculation rate constant

K: Coagulation-flocculation reaction rate constant

K_R : Smoluchowski coag-flocculation 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

OSC: Okra Seed Coagulant

BRE: Brewery effluent

TDSP: Total Dissolved Solid Particles

SDP: Solid Dissolved Particles

N_0 : Concentration of SDP at time $t=0$

N_t : Concentration of SDP at time, t

References

264 [1] Van der Merwe, A., Friend, J.F.C. Water management at a malted barley brewery. Water SA., 2002.
265 28(3), 313-318.

266 [2] Ndabigengesere, A., Narasiah, K.S., Quality of water treated by coagulation using moringa oleifera
267 seeds. Water Research 2009:32, 781-791.

268 [3] Peary, H.S., Rowe, D.R., Tchobanoglous, G., Environmental Engineering. McGraw-Hill,
269 Inc., New York 1985.

270 [4] Crawford, H.B., Margolies, R.T. The NALCO water handbook. McGraw-Hill Book Company, New
271 York 1988.

272 [5] Fillandeau, L., Blanpain-Avet, P., Danfin, G. Water, wastewater and wastewater management in
273 brewery industries. Journal of cleaner production, 2006: 14, 463-471

274 [6] WST., About coagulation and flocculation: Information Bulletin USA, 2005.

275 [7] B.I. Okolo, P.C. Nnaji, M.C. Menkiti, V.I. Ugonabo, O.D. Onukwuli, Parametric Response Evaluation for
276 Xanthosoma spp. Induced Coag-Flocculation of Brewery Effluent, Green and Sustainable Chemistry,
277 2014, 4, 7-14
278

279 [8] Ghebremichael K., Moringa seed and pumice as alternative natural materials for drinking water
280 treatment. TRITALIWR PHD 1013 Ph.D Thesis, KTH Land and Water Resources Engineering (2004).

281 [9] Von Smoluchowski, M., 1917; Versuche einer Mathematischen Theorie der Koagulationskinetik
282 Kolloider Lösungen, Z. Phys. Chem. 92: Pp 129-168.

283 [10] Menkiti M.C., Onukwuli, O.D. Coag-flocculation of Mucuna seed Coag-flocculant (MSC) in Coal
284 washery effluent (CWE) using light Scattering effects; AIChE journal, 2012: 56(4), 303-1307.

285 [11] Metcalf and Eddy Physical Unit Process, Wastewater Engineering Treatment and Reuse. 4th Ed.
286 Tat. Graw-Hill, New York 2003.

287 [12] Agarwal M., Rajani S., Mishra A., RaS J.P. i, Utilization of Okra gum for Treatment of Tannery Effluent,
288 Int. J. Polymeric materials, 2003: 52, 1049-1057

289 [13] AOAC, Official Methods of Analysis, Association of Official Analytical Chemists, 14th ed. USA. (1993).

290 [14] Holthof, H., Egelhaaf, S. U., Borkovec, M., Schurtenberger, P., and Sticher, H., 1996; "Coagulation
291 Rate Measurement of Colloidal Particles by Simultaneous Static and Dynamic Light Scattering."
292 Langmuir vol 12, Pp 5541.

293 [15] Edilson de Jesus, Paulo Victor Cruz, Jose Adair Pacifico, Antonio Santos Silva, Removal of turbidity,
294 suspended solids and ions of Fe from aqueous solution using okra powder by coagulation-flocculation
295 process. American journal of water resources, 2013 vol. 1 No. 3 20-24.

- 296 [16] Sanjeet Kumar, SokonaDagnoko, Adamou Haougui, Alain Ratnadass, Dov Pasternak and Christophe
297 Kouame. Okra (*Abelmoschus* spp.) in West and central African: Potentials and progress on its
298 improvement. *African journal of Agriculture Research* vol. 5(25), Pp 3590-3598, 2010.
- 299 [17] Arapitsas P. Identification and quantification of polphenolic compounds from okra seeds and skins.
300 *Food chem.* 110: 2008; 1041-1045.
- 301 [18] Agarwal M., Srinivasan R., Mishira A. "Study on flocculation efficiency of okra gum in sewage
302 wastewater." *Macromol Mater and Eng.* 286: 560-3, 2001.
- 303 [19] Muyibi, S.A., C.A Okuofu, Coagulation of low turbidity surface water with *Moringaoleifera* seed.
304 *International journal of Environmental studies*, 48: (1995) 263-273.
- 305 [20] Menkiti, M.C., Nnaji, P.C., Nwoye, C.I., Onukwuli, O.D., Coagulation –flocculation kinetics and
306 functional parameters response of *Mucuna* seed coagulant to pH variation in organic rich coal effluent
307 medium. *Journal of minerals and material characterization and Enginerring*, vol 9, no 2(2010) Pp 89-103.