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Sustainable Treatment of Domestic Sullage through Utilization of *Garcinia mangostana* pericarp extract as Natural Coagulant

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Key words: Biological oxygen demand, Natural coagulant, Optimum dosage, Total suspended solids

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Abstract

This paper presented the potential of *Garcinia mangostana* as a natural coagulant in the removal of selected water quality parameters, namely: turbidity, total suspended solids, and biochemical oxygen demand from domestic sullage generated by the University of Science and Technology of Southern Philippines. The jar test method is used in the optimization of the coagulants and lab analysis uses the gravimetric method, dilution technique, and digital meter for the measurements of the parameters. Characterization of *Garcinia mangostana* revealed a possible functional group that influences coagulation activity. Optimization of pure *Garcinia mangostana* using the jar test method showed the highest efficiency removal for the selected water parameters at 50 mg/L and pH9. Using the optimum dosage of 50 mg/L, the optimum settling time was 90 minutes for the treatments of A100, M100, $A_{50}M_{50}$, $A_{25}M_{75}$ & $A_{75}M_{25}$. The highest removal percentage was at pH9 for turbidity at 93.25% ($A_{50}M_{50}$), TSS removal was 93.32% at $A_{50}M_{50}$, whilst percent BOD removal was 92.12% ($A_{75}M_{25}$). Statistical evidence showed significant differences in the measured values among treatment designs with optimum doses. To investigate the influence of mixing intensity, settling rate, contact time, and other variables are suggested for future studies to help improve removal efficiency.

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Introduction

Water is a vital substance and of great importance in all-natural and anthropogenic activities. In the past, it has been considered an infinite goods; current misuse, coupled with growing demand, has made reserves of fresh and clean water decrease (Telles and Costa, 2010). The rapid increase in the production and consumption processes generates as well as rejects solid materials regularly from various sectors – agricultural, commercial, domestic, industrial, and institutional. The expansion of the urban population and increased coverage of domestic water supply and sewerage give rise to greater quantities of municipal wastewater (Kilobe *et al.*, 2013). Municipal wastewater is a combination of different types of wastewater originating from a sanitary system of commercial housing, industrial facilities, and institutions, in addition to any groundwater, surface water, and stormwater that may be present (Ismail *et al.,* 2012). If left untreated, wastewater release or those carried by runoff into bodies of water can lead to several environmental ramifications. Wastewater treatment is employed as an action to protect the quality of limited freshwater resources and therefore make it more acceptable for beneficial reuse (Shon *et al.,* 2006). Various traditional and advanced technologies have been utilized to remove the colloidal particles from wastewater, such as ion exchange, membrane filtration, precipitation, flotation, solvent extraction, adsorption, coagulation, flocculation, biological and electrolytic methods (Radoiu *et al.,* 2004). Among those methods, coagulation/flocculation is one of the most widely usedsolid–liquid separation processes for the removal of suspended and dissolved solids, colloids, and organic matter present in industrial wastewater (Renault *et al.,* 2009). Coagulation/flocculation is a commonly used process in water and wastewater treatment in which compounds such as aluminum sulfate, ferric chloride, and/or polymer are added to the wastewater in order to destabilize the colloidal materials and cause the small particles to agglomerate into larger settleable flocs (Amuda and Amoo, 2006). Alum (aluminum sulfate) has been the most popular for the treatment of water and is widely used in treatment plants (Ugwu *et al.,* 2017), but it has been found to pose some health, economic and environmental problems upon usage, among which are neurological diseases such as percentile dementia and induction of Alzheimer's disease (Ferreira *et al.,* 2008; Martyn *et al.,* 1989). The use of synthetic flocculants like alum and iron can cause health hazards. Alzheimer's disease and dementia are associated with the use of aluminum ions in treated waters (Anastasakis *et al.,* 2009). As a result, several studies have explored the use of natural coagulants as an alternative or an aid to chemical coagulants to eliminate or, if not lessen, their harmful effects. Natural coagulants (plant materials) are considered a good substitute. Several studies have shown the great potential of natural coagulants as an alternative or replacement as coagulants or coagulant aids in treating wastewater from industries. Natural coagulants answer the investigation is carried out with real water, rather than simulated water, in order to obtain the most reproducible results possible for surface water treatment as possible. On the other hand, improvements in the extraction process are included for the evaluation of parameters such as pH or agitation speed inside the usual working ranges in water treatment. Thus, an approach to reducing chemical dosage using natural coagulants must be investigated to develop a sustainable treatment of domestic wastewater. Presently, there is no study about *Garcinia mangostana's* potential as a natural coagulant in optimizing the coagulation-flocculation process for the treatment of domestic wastewater. Specifically, the study sought to i.) characterize *Garcinia mangostana* pericarp powdered extract; ii.) optimize the pure *Garcinia mangostana* (M100) pericarp extract and alum (A100) using various coagulant dosages (50 mg/L, 100 mg/L, 150 mg/L), and settling time (30 min, 60 min & 90 min) at pH5, pH7, & pH9; iii.) Determine the removal efficiency of turbidity, TSS and BOD at various treatment combination.

Materials and methods

The methods used in this study are descriptive and experimental. One-way Analysis of variance (ANOVA) using Microsoft excel version 2016 at a 5% level of significance is used to determine the significant difference between the different treatments.

Research setting

Fig. 1 shows the study area. The wastewater sample is collected at the sump pit of the University of Science and Technology of Southern Philippines, Cagayan de Oro Campus, and brought to the laboratory for coagulation treatment.

Collection of water sample

A wastewater sample is collected from the sump pit of the University of Science and Technology of Southern Philippines, Cagayan de Oro Campus. It is characterized as grey water, which is generated from the buildings of the school campus. The sample water is taken and brought to the school laboratory for its Analysis using the coagulation process.

Preparation & Characterization of Garcinia mangostana

C1. Powder preparation

The Mangosteen pericarp sample was collected from the wet market and was pre-treated by washing it in DI water. Fig. 2 below shows the powder preparation. Mangosteen peel was cut into small pieces and boiled in a water bath at 70 ^{o}C until the supernatant produced was colorless for complete removal of the Mangosteen pericarp and dye color. After which, it was ground by using an electric grinder machine with a siever to a size between 90 µm – 125 µm. The sediments of Mangosteen pericarp were dried in an oven at 40 ˚C for 1 hour and kept in a tight container ready for use. The other coagulation agent was aluminum sulfate [$Al_2(SO_4)_3$] extra pure, Merck].

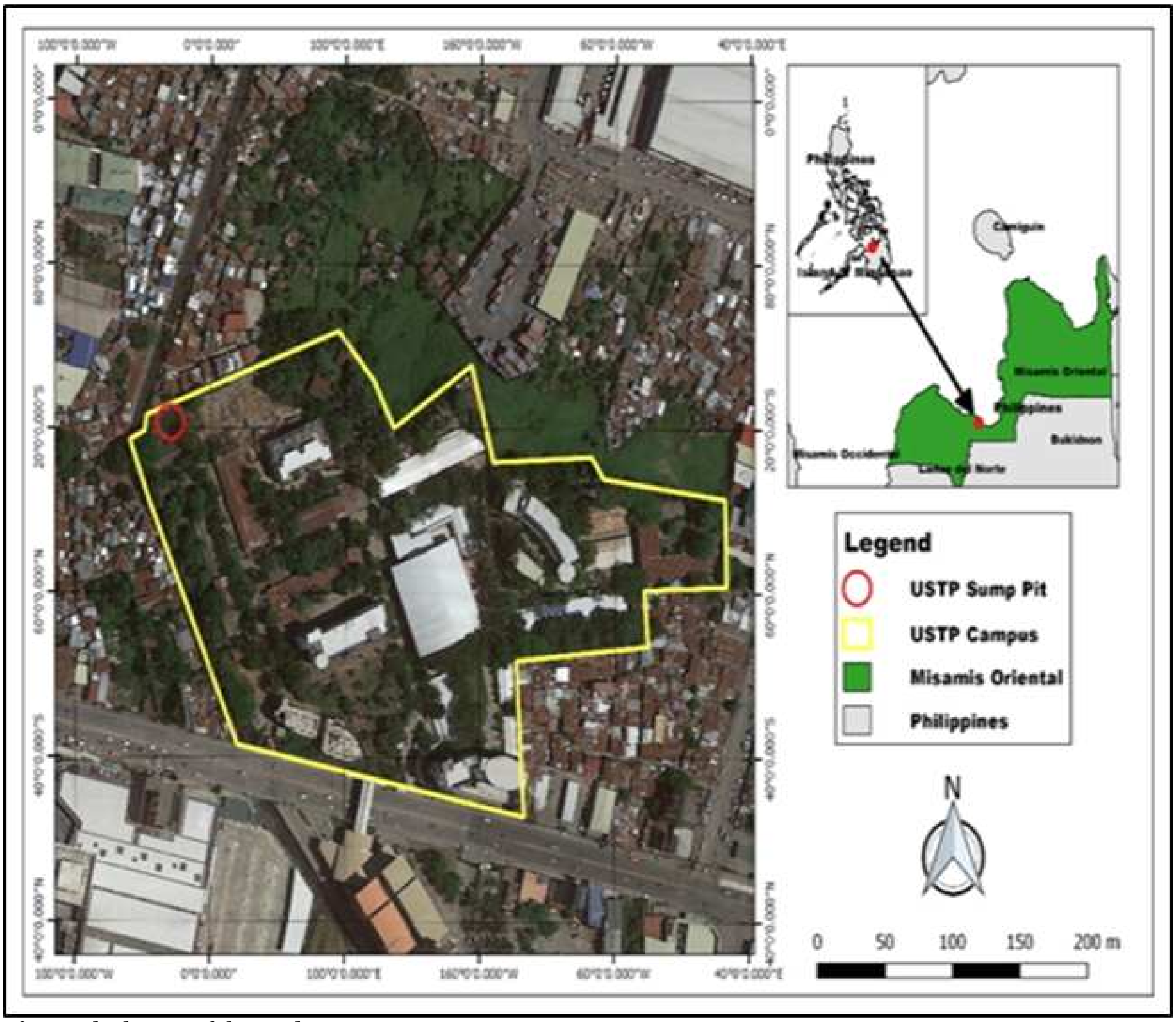

Fig. 1. The layout of the study area.

$$\text{Yield of mangosteen rind (\%)} = \frac{\text{Weight of mangosteen rind (g)}}{\text{Weight of raw material (g)}} \times 100 \quad (1)$$

C2. Characterization of Garcinia mangostana pericarp extract

The physical characteristics of mangosteen pericarp powder are measured according to its powder diameter in microns, color, odor, texture, percent moisture content, and solubility. Fourier –transform infrared spectroscopy analysis (FTIR) was used to determine the functional group or possible compounds present in the sample of mangosteen pericarp powder. FTIR is an analytical technique used to identify organic or inorganic materials.

The method of Analysis involving FTIR used infrared light to scan test samples and observe chemical properties. The FTIR instrument sends infrared radiation of about 10,000 cm^{-1} to 100 cm^{-1}. Some radiation was absorbed and some passed through, which absorbed radiation is converted into vibrational energy by the sample molecules (Kellner *et al.,* 1988; Wathoni *et al.,* 2019; Sriyanti *et al.,* 2018). The resulting signal presents a spectrum that represents the molecular fingerprint of the sample. This technique is useful in analyzing the chemical composition of substances. In this study, a powder sample of *Garcinia mangostana* pericarp extract was subjected to FTIR analysis to determine a functional group of this substance which have influenced the coagulation property.

A. Jar Test & Optimization of Coagulants

Analysis of the optimum dosage of synthetic and natural coagulants was done using a jar test. Fig. 3 shows the flow chart diagram of the jar test design with different treatment combinations using the natural coagulant *Garcinia mangostana* and synthetic coagulant aluminum sulfate (Alum).

The purpose of the jar test is to determine the optimum dosage/concentration of each coagulant to be used for the treatment design, as shown in Table 1. The jar test for each coagulant (Alum and *Garcinia mangostana*) was done separately. Each coagulant dose varies at 50 mg/l, 100 mg/l, and 150 mg/l, while stirring speed was also varied at 550 rpm at 3 minutes contact time followed by 200 rpm at 7 minutes for each dose. After the jar test, the optimum dose for each coagulant was used in the treatment design experiment using the same volume of wastewater sample. The aluminum salt and mangosteen pericarp extract were treated separately at various pH conditions, namely: pH =5, pH =7, and pH =9, with varying contact times and varying stirring speeds. It was then allowed to settle separately at different settling times, between 30 minutes, 60 minutes, and 90 minutes. The same process was applied during the actual treatment (Table 1) using different percent coagulant mix and to the control. After sedimentation, following various settling times, the supernatant liquid was collected by decantation and analyzed for turbidity, TSS, and BOD. The coagulant dose that gives the best results in the reduction of the selected water quality parameters was the optimum dose. All experiments were performed at room temperature (22±1 °C) and the pH of the samples was tested before and after the addition of the coagulant to adjust it to its desired pH. After the jar test, the optimum dose for each coagulant was used to conduct the experiment applying the described treatment design as shown in Table 1.

B. Analysis of Treated Effluent

All treated water samples were analyzed to determine the values of turbidity, total suspended solids, and biological oxygen demand. Turbidity was measured using a digital turbidity meter which was calibrated prior to the test. Total suspended solids were analyzed by the use of the gravimetric method. Filtration of the treated effluent with TSS filtration apparatus followed by a series of heating and weighing until the constant mass is achieved.

Results and discussion

Characterization of Garcinia mangostana

Garcinia mangostana is characterized according to its physical and chemical characteristics. Chemical characteristics involve the FTIR analysis in determining the possible functional group which is the reason for its coagulative property.

Table 1. Field layout of various coagulant optimum doses.

Treatment #	Description	% Coagulant added
1	Control	0
2	M100	100% Mangostana
3	A100	100% Alum
4	$M_{75}A_{25}$	75% Mangostana & 25% Alum
5	$M_{50}A_{50}$	50% Mangostana & 50% Alum
6	$M_{25}A_{75}$	25% Mangostana & 75% Alum

A1. Physical Characteristics of Garcinia mangostana pericarp extract

Table 2 shows the results of the physical characteristics of *Garcinia mangostana* peel powder.

Mangosteen has been selected in this research because a large number of mangosteen pericarp are generated every year (Chen *et al.*, 2012). On the other hand, carcinogenic risk related to chemical coagulants can be reduced since mangosteen pericarp have toxic free (Pedraza-chaverri *et al.*, 2008) and anti-cancer properties (Huang *et al.*, 2014; Theodoro *et al.*, 2013). The coagulation mechanisms work based on different principles and one or more mechanisms could be employed for more effective particle destabilizations (Malakoutian & Fatehizadeh 2010).

The coagulation mechanism, in this case, could be due to double–layer compression or charge neutralization.

Table 2. Physical characteristics of mangosteen peel powder.

Color	Brownish
Texture	gummy
Solubility	Soluble in water
Size	100 microns
odor	odorless
Moisture content	9.60%

Table 3. Percent removal efficiency of turbidity.

Treatment	pH5	pH7	pH9
A100	97.81	98.14	98.31
M100	75.04	79.26	81.45
$A_{50}M_{50}$	88.7	91.4	93.25
$A_{25}M_{75}$	86.17	88.87	90.73
$A_{75}M_{25}$	87.02	90.22	92.07

A2. FTIR Analysis of Garcinia mangostana pericarp extract

In the case of mangosteen powder, the mechanism that is used here is charge neutralization, where the minute powder of mangosteen acts as the proton while the colloidal particles in water are negatively charged. The union of the two oppositely charged ions resulted in the formation of flocs making heavier density and ultimately removed by gravity settling or filtration. Fig. 4 shows the graphical presentation of FTIR spectra of mangosteen powder. FTIR result on mangosteen powder in Fig. 4 indicates a broad medium peak between 3550 cm^{-1} to 3050 cm^{-1} indicative of O-H or C-H stretching. Its fingerprint region has a weak peak between 1550 cm^{-1} to 1050 cm^{-1}.

This broad medium peak which is observed between 3550-3050 cm^{-1} is indicative of the hydroxyl compound group (-OH).

Table 4. Percent removal efficiency of TSS.

Treatment	pH5	pH7	pH9
A100	95.9	96.8	98.4
M100	73.8	75.94	79.14
$A_{50}M_{50}$	91.71	92.51	93.32
$A_{25}M_{75}$	89.84	89.3	90.64
$A_{75}M_{25}$	90.64	91.98	92.51

This is maybe due to the presence of pectin in mangosteen pericarp (Wathoni *et al.*, 2019). The carbonyl group is present in the fatty acids and protein structures. As shown in the graph, peaks between 1600 cm^{-1} to 1000 cm^{-1} were weak but sharp. It was supported by previous studies that the spectrum between 1600 cm^{-1} and 1400 cm^{-1} can increase the adsorption of the flocs to aggregate (Zhang *et al.*, 2012). The presence of carbohydrates and protein has influenced the coagulation activity of mangosteen peel powder (Choy *et al.*, 2015). Manurakchinakorn, 2014).

Table 5. Percent removal efficiency of BOD.

Treatment	pH5	pH7	pH9
A100	94.89	95.62	97.81
M100	76.64	78.98	79.71
$A_{50}M_{50}$	89.34	91.09	91.53
$A_{25}M_{75}$	85.4	89.78	89.93
$A_{75}M_{25}$	88.61	90.36	92.12

The presence of high organic matter in water with a greater surface charge has been found to dominate the coagulation process (Kim *et al.*, 2006; Suttirak & The presence of mangosteen peel powder acts as a positive charge which attracts the negatively charged colloidal particles in water, reducing the residual turbidity (Okuda *et al.*, 2001).

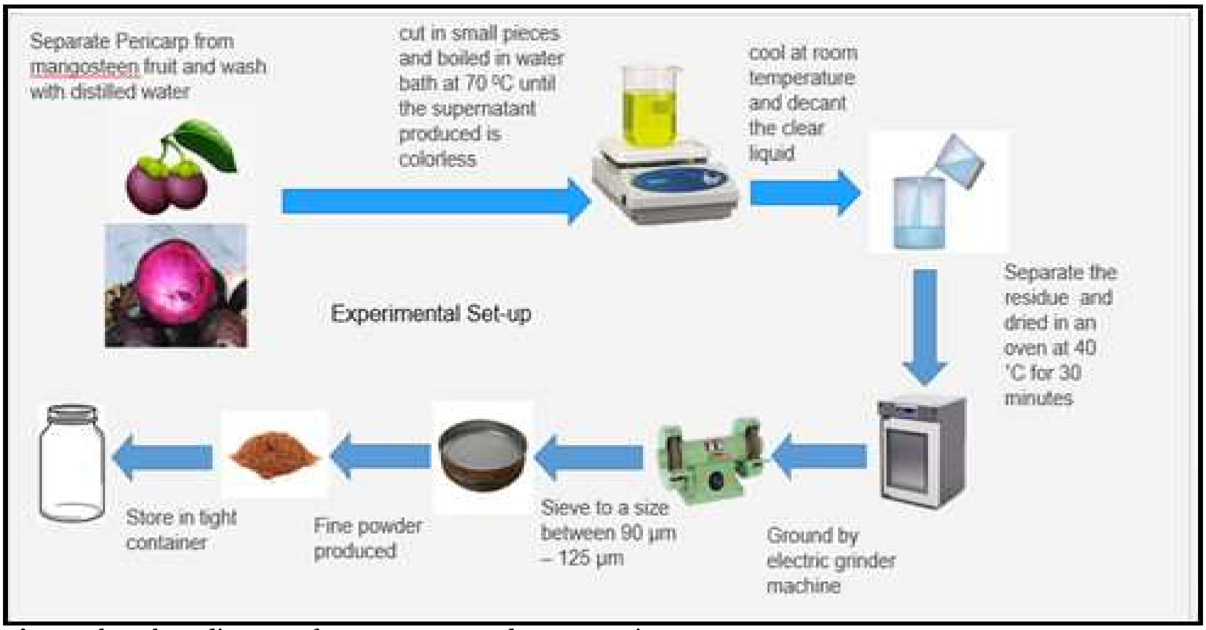

Fig. 2. Flow chart diagram of mangosteen powder preparation.

A. Optimization of Alum (A100)

Fig.5, Fig.6 and Fig.7 showed the optimization results using alum as a coagulant. Three (3) parameters were tested for its removal efficiency at variable coagulant dosage, settling time, and pH. A volume of 50mL wastewater sample was taken and treated with a similar ratio of 100% alum stock solution (A_{100}) at different alum dosages of 50 mg/L, 100 mg/L and 150 mg/L, respectively.

As shown in Fig. 5, the percentage removal of turbidity during alum optimization was shown to be the highest at a lower coagulant dosage of 50 mg/L as compared to the other coagulant dosages. Results showed better removal at a higher settling time of 90 minutes as compared to the other settling time of 60 min. and 30 min. At 150 mg/L and 90 minutes, the removal efficiency of turbidity was 93.31%, 93.92%, and 93.0% for pH 5, pH 7, and pH 9; while at 100 mg/L of coagulant dosage and 90 minutes settling time, turbidity removal was 94.22%, 95.14% and 95.44% for pH5, pH7, and pH9.

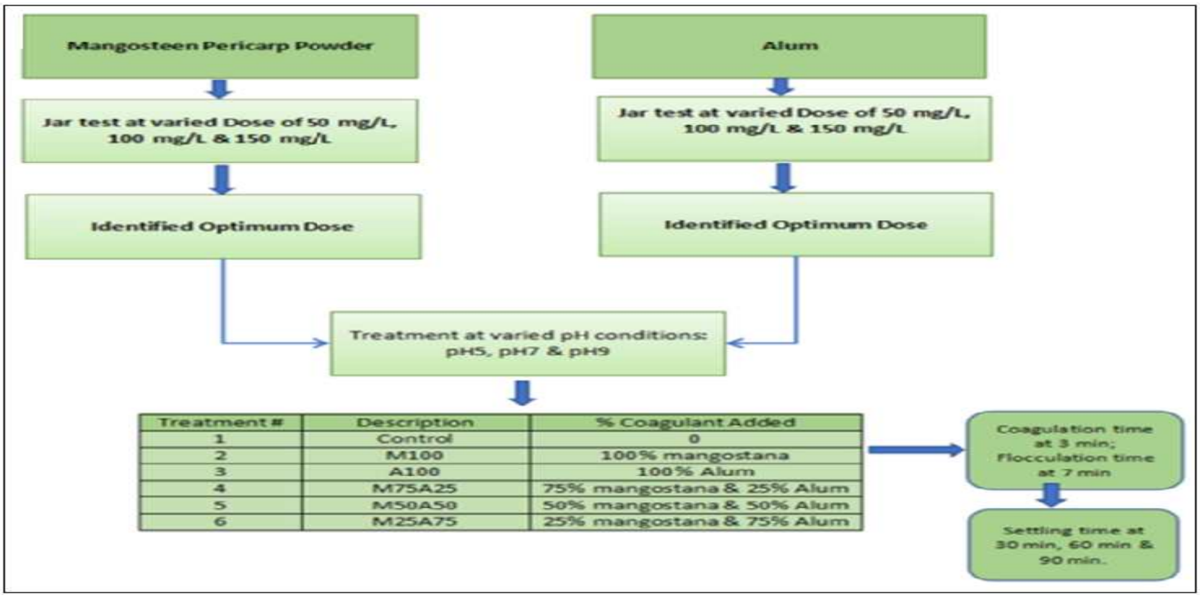

Fig. 3. Flowchart diagram of Jar test and treatment process.

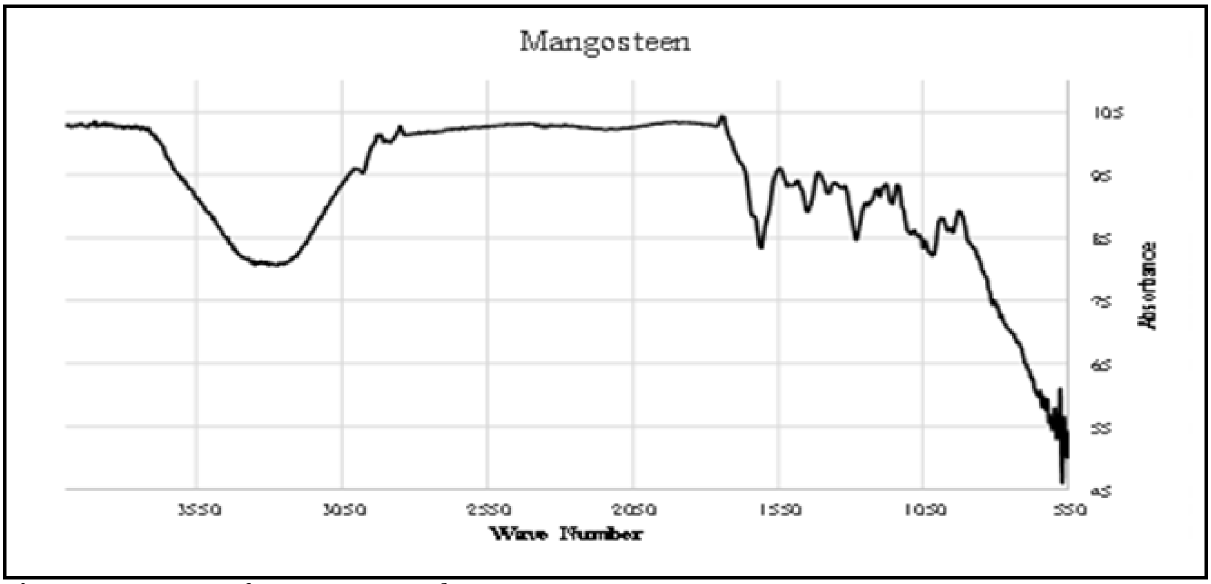

Fig. 4. FTIR spectra of Mangosteen powder.

The maximum amount of turbidity percentage removal obtained for turbidity at optimum settling time was 96.35%, 98.18%, and 98.48% at pH 5, pH 7, and pH 9, respectively. Fig. 6. below shows the optimization of coagulant alum using TSS as a measuring parameter. At 50 mg/L of dosage, the graph showed the highest removal at 90 minutes with a value of 96.6% (pH5), 97.05% (pH7), and 98.27% (pH9). On the other hand, when the coagulant dosage was increased to 100 mg/L, the removal of TSS was again highest at 90 minutes with values of 93.65% (pH5), 95.13% (pH7), 96.15% (pH9) and further increase of coagulant dosage to 150 mg/L resulted to the removal of TSS at 92.05% (pH5), 94.42% (pH7), and 92.31% (pH9).Fig. 7. below shows the alum optimization result using biochemical oxygen demand (BOD) as the water quality parameter being measured when alum is used as the coagulant in the treatment procedure. According to the result presented in the bar graph, BOD removal at 50 mg/L at 30 minutes was 91.67% (pH5), 93.43% (pH7), and 94.31% (pH9); increasing the settling time to 60 minutes at the same alum dose resulted to the removal of BOD at 92.84% (pH5), 95.91% (pH7), and 91.18% (pH9). Further increase of settling time to 90 minutes at the same alum dose of 50 mg/L showed the highest removal which attained BOD removal efficiency of 94.74% (pH5), 96.78% (pH7), and 97.52% (pH9).

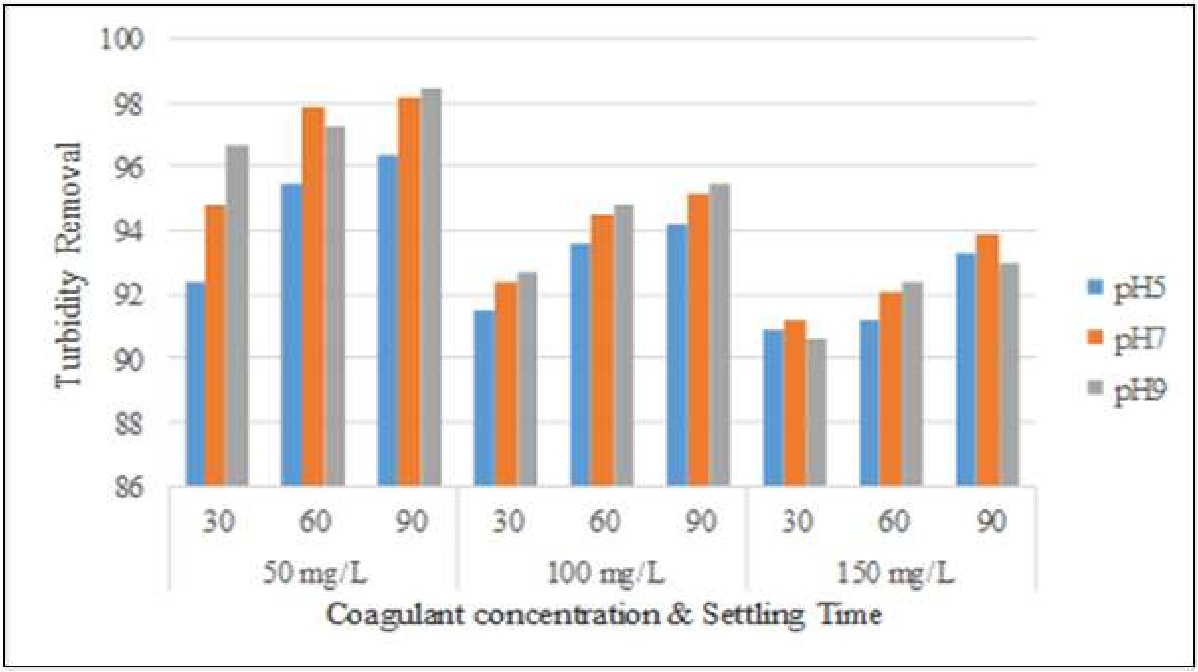

Fig. 5. Optimization of Coagulant Alum with Turbidity.

According to the result presented in the bar graph (Fig.7), BOD removal at 50 mg/L at 30 minutes was 91.67% (pH5), 93.43% (pH7), and 94.31% (pH9); increasing the settling time to 60 minutes at the same alum dose resulted to the removal of BOD at 92.84% (pH5), 95.91% (pH7), and 91.18% (pH9). Further increase of settling time to 90 minutes at the same alum dose of 50 mg/L showed higher removal which attained BOD removal efficiency of 94.74% (pH5), 96.78% (pH7), and 97.52% (pH9). When the alum dose was increased to 100 mg/L at 90 minutes, the results of BOD removal were 92.11% (pH5), 94.45% (pH7), and 93.72% (pH9); and further increase of alum dose to 150 mg/L resulted in removal efficiency of 90.65% (pH5), 91.53% (pH7), and 92.11% (pH9). It is apparent from figure 5.6 that a lower alum dose has higher BOD removal. Two–way Analysis of variance (ANOVA), see appendix, for all parameters showed a *p*-value (*p*-value <0.05) which signifies that measured values for the removal of turbidity, TSS, and BOD differ significantly with the means of observations between settling time (30 min, 60 min, 90 min) and coagulant dosage (50 mg/L, 100 mg/L, 150 mg/L). Results, as shown, indicated that removal percentage varies with coagulant dose and settling time. Percentage removal increases with an increase in settling time though the magnitude differs for a particular dosage and pH (Ugonabo *et al.*, 2012).

B. Optimization of Garcinia mangostana (M100)

In the optimization of *garcinia mangostana* (mangosteen) as a coagulant, the method is carried out, the same as the other coagulant. A 100% stock solution of *garcinia mangostana* was freshly prepared and dosages of 50 mg/L, 100 mg/L, and 150 mg/L were added with respective 50 mL wastewater samples in all setups. As shown in the figures 8, 9 and 10, it is evident that the measured values of the parameters significantly reduced as the settling time increased at a lower dosage of 50 mg/L when compared to the other two dosages of 100 mg/L and 150 mg/L in all pH conditions. Fig. 8 below shows the optimization of *Garcinia mangostana* using turbidity as the water quality parameter.

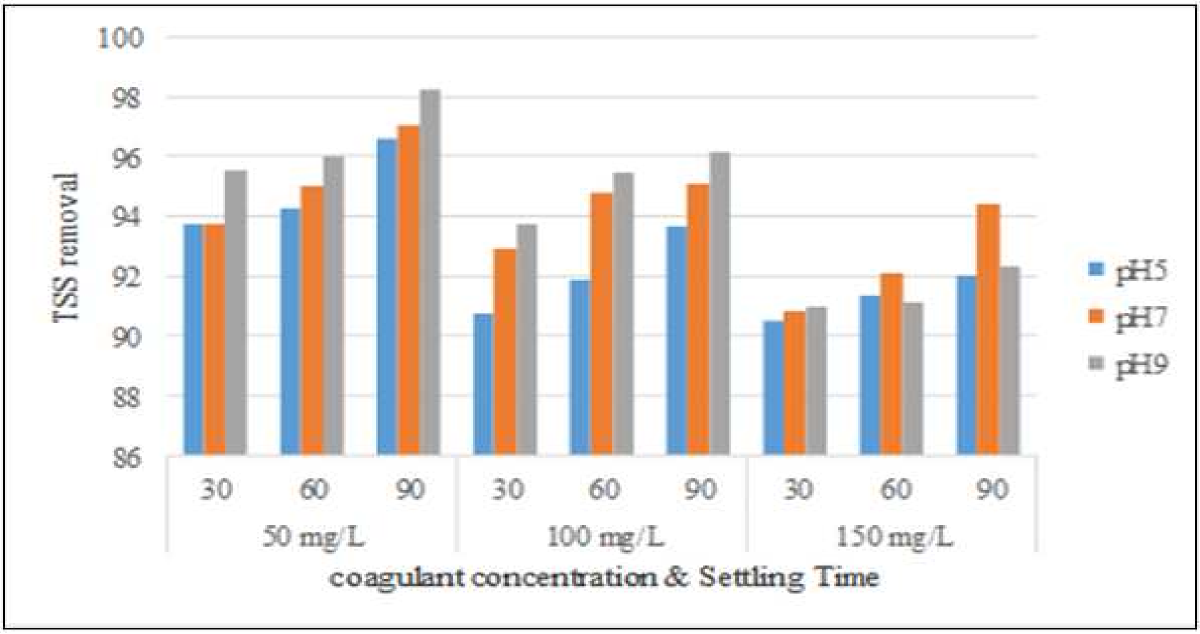

Fig. 6. Optimization of Coagulant Alum with TSS.

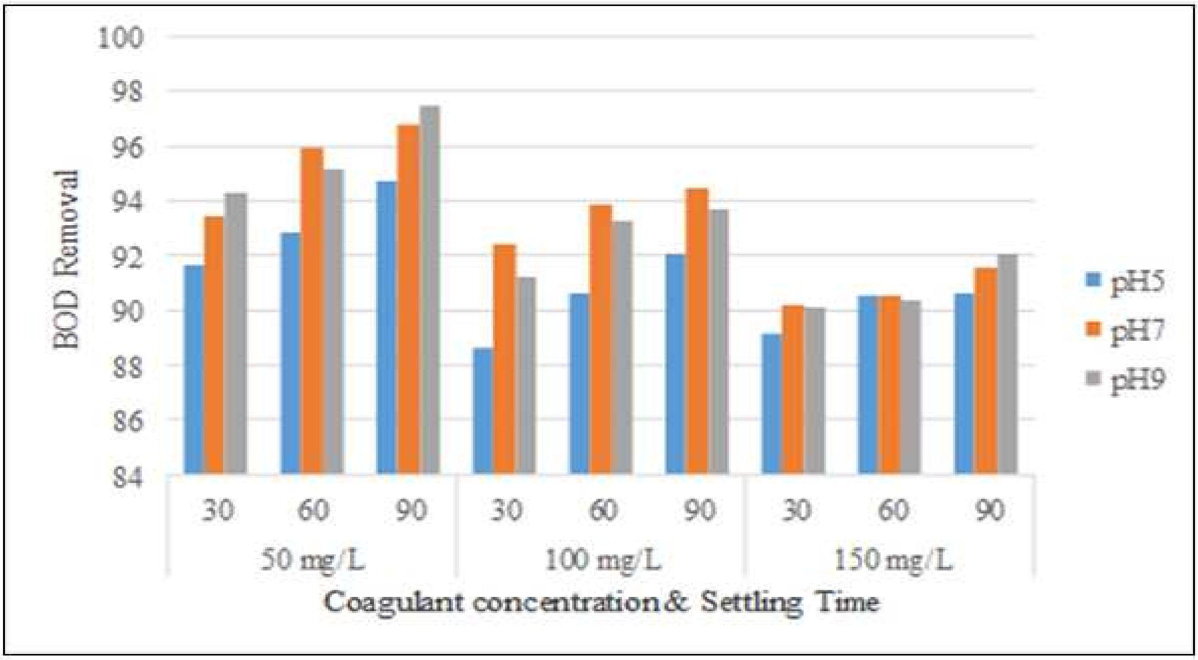

Fig. 7. Optimization of Coagulant Alum with BOD.

The fig. 8 revealed that a lower coagulant dose of 50 mg/L has the highest turbidity removal of 69.30% (pH5, 30 min), 70.21% (pH5, 60 min), 75.38% (pH5, 90 min), 75.68% (pH7, 30 min), 77.20% (pH7, 60 min), 79.33% (pH7, 90 min); 79.64% (pH9, 30 min), 80.24% (pH9, 60 min), and 82.37% (pH9, 90 min). Results of turbidity removal at 100 mg/L of coagulant dosage revealed turbidity removal of 60.18% (pH5, 30 min), 64.13% (pH5, 60 min), 68.37% (pH5, 90 min); 69.90% (pH7, 30 min), 74.77% (pH7, 60 min), 76.59% (pH7, 90 min); 72.34% (pH9, 30 min), 75.08% (pH9, 60 min), & 78.72% (pH9, 90 min).

Further increase of *Garcinia mangostana* coagulant dose to 150 mg/L reduced turbidity removal to 52.58% (pH5, 30 min), 58.97% (pH5, 60 min), 61.39% (pH5, 90 min); 68.09% (pH7, 30 min), 69.30% (pH7, 60 min), 71.43% (pH7, 90 min); 60.48% (pH9, 30 min), 66.26% (pH9, 60 min) & 69.60% (pH9, 90 min). It revealed that the optimum dose for *Garcinia mangostana* is 50 mg/L since it is the dosage with the highest turbidity removal. Fig. 9 shows the optimization of coagulant *Garcinia mangostana* with the water quality parameter TSS.

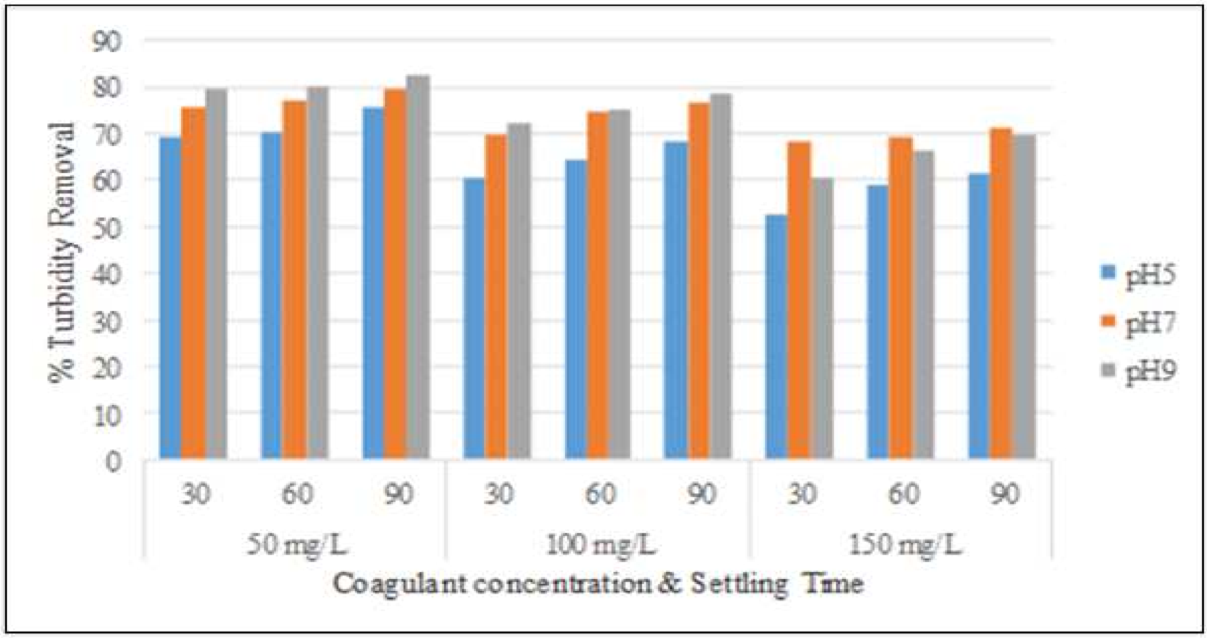

Fig. 8. Optimization of Coagulant *Garcinia mangostana* with Turbidity.

When *Garcinia mangostana* was optimized using total suspended solids (TSS) as the water quality parameter (Fig. 9), it revealed TSS removal of 73.08%, 75.64%, 79.48% at pH 5, pH7 & pH 9 at 90 minutes of settling time and 50 mg/L of coagulant dose. Lower removal was observed when settling time was reduced to 60 minutes with the same dosage of 50 mg/L at 71.79% (pH5), 73.08% (pH7), & 77.56% (pH9); while with 30 minutes settling time and 50 mg/L dose, removal of TSS were further reduced to 69.23% (pH5), 71.15% (pH7), & 76.28% (pH9).

When *Garcinia mangostana* as a coagulant dose was increased to 100 mg/L, results of TSS removal were 65.38% (pH5, 30 min), 68.59% (pH5, 60 min), 72.44% (pH5, 90 min); 70.51% (pH7, 30 min), 72.44% (pH7, 60 min), 74.36% (pH7, 90 min); 70.51% (pH9, 30 min), 72.43% (pH9, 60 min) and 73.07% (pH9, 90 min). Increasing the coagulant dose further to 150 mg/L resulted in TSS removal of 58.33% (pH5, 30 min), 61.54% (pH5, 60 min), 63.46% (pH5, 90 min); 60.26% (pH7, 30 min), 66.02% (pH7, 60 min), 69.87% (pH7, 90 min); 67.95% (pH9, 30 min), 68.58% (pH9, 60 min), and 71.79% (pH9, 90 min).

Lastly, the optimization of *Garcinia mangostana* as a coagulant using biochemical oxygen demand (BOD) (figure 10) as a water quality parameter is shown in fig. 10. At lower coagulant dose of 50 mg/L, BOD removal was 73.72% (pH5, 30 min), 74.74% (pH5, 60 min), 75.62% (pH5, 90 min); 75.04% (pH7, 30 min), 77.52% (pH7, 60 min), 78.25% (pH7, 90 min); 77.95% (pH9, 30 min), 78.24% (pH9, 60 min), & 79.56% (pH9, 90 min). At 100 mg/L of coagulant dose, BOD removal was reduced to 68.32% (pH5, 30 min), 70.80% (pH5, 60 min), 72.26% (pH5, 90 min); 70.36% (pH7, 30 min), 74.45% (pH7, 60 min), 76.64% (pH7, 90 min); 70.80% (pH9, 30 min), 74.16% (pH9, 60 min), and 76.64% (pH9, 90 min). Further increase of coagulant dose to 150 mg/L, resulted in BOD removal of 60.43% (pH5, 30 min), 65.26% (pH5, 60 min), 67.44% (pH5, 90 min); 65.26% (pH7, 30 min), 68.61% (pH7, 60 min), 70.80% (pH7, 90 min); 69.19% (pH9, 30 min), 73.43% (pH9, 60 min), and 73.72% (pH9, 90 min.). It has been observed that the optimum dosage for *Garcinia mangostana* using BOD as a parameter was 50 mg/L since it has the highest removal as compared to the two other dosages. The settling time optimum was at 90 minutes for all measured parameters. The trend of % removal for *Garcinia mangostana* changes with pH conditions, but the statistical result did not show significant results.

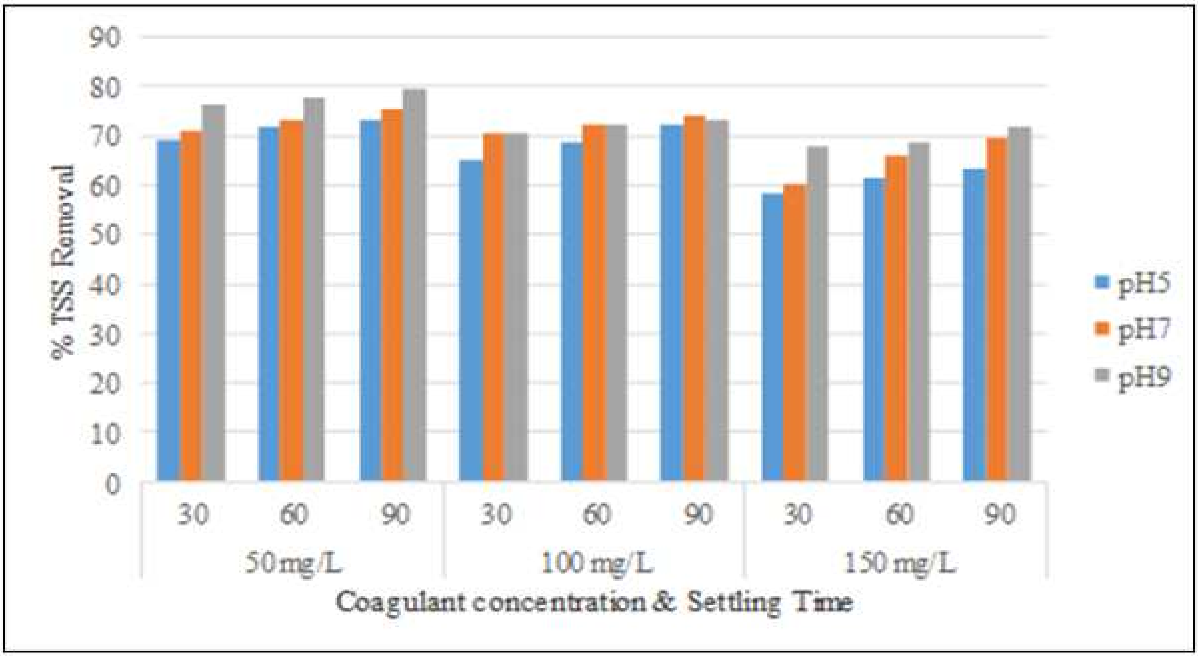

Fig. 9. Optimization of Coagulant *Garcinia mangostana* with TSS.

C. Removal Efficiency of Turbidity, TSS & BOD

D1. Turbidity

Data revealed that with the use of 100% alum (A100) solution, turbidity removal was highest at pH 9 with a removal percentage of 98.31%. A study by Zonoozi *et al.* (2008) is in agreement with this study where it reported that when Alum was used to treat wastewater containing Acid Red 398 dye solution by coagulation/flocculation process, it also removed 80% of turbidity at 140 mg/L of alum. Similar observations were also noted when the treatment used was *Garcinia mangostana* as the coagulant aid under an optimum dose of 50 mg/L and optimum settling time of 90 minutes, results revealed that 50% *mangostana* and 50% alum attained removal efficiency of 88.7%, 91.4% and 93.25% at pH 5, 7, and 9. Further, a 75% *mangostana* & 25% alum obtained removal efficiency of 86.17%, 88.87%, and 90.73%. Lastly, a 25% *mangostana* and 75% alum attained removal percentages of 87.02%, 90.22%, and 92.07%.

The trend in the removal efficiency showed that there is increasing removal of turbidity as pH increases. It showed that with *mangostana* as the coagulant aid highest removal was observed at $A_{50}M_{50}$ at pH 9 at 93.25%. This result was compared to a study conducted by Zhang *et al.*, 2006 where the optimum dosage of the natural coagulant of 60 mg/L reached the highest turbidity removal efficiency of 99%. Results, as shown, indicated that removal efficiency varies with treatment designs under optimum coagulant dose and settling time. The magnitude differs for a particular coagulant and pH conditions (Ugonabo *et al.*, 2012; Metcalf *et al.*, 2006). Bouladjoul *et al.* (2018) mentioned that other natural coagulants have minimal effect on changes in pH conditions.

D2. Total Suspended Solids

Table 4 presented results for the removal efficiency of total suspended solids after wastewater has been treated with coagulant and coagulant aids with different treatment designs. As shown in the results, a treatment combination containing Garcinia mangostana, 50% mangostana, and 50% alum ($A_{50}M_{50}$) under an optimum dosage of 50 mg/L and optimum settling time of 90 minutes resulted in removal efficiency of 91.7%, 92.5%, and 93.3% for pH5, pH7, and pH9. When the percent of mangostana was increased in the treatment mix containing 75% mangostana and 25% alum ($A_{25}M_{75}$), it achieved removal efficiency of 89.9, 89.3%, and 90.6%; while decreasing the percent mix of the coagulant aid into 25% mangostana and 75% alum ($A_{75}M_{25}$) attained TSS removal efficiency of 90.6%, 91.9% and 92.5% for the treatment under pH5, pH 7 and pH9 subsequently.

D3. Biochemical Oxygen Demand

Table 5 shows shown results of the removal efficiency of the biological water quality parameter, BOD, when wastewater was subjected to the coagulation-flocculation process using treatment designs.

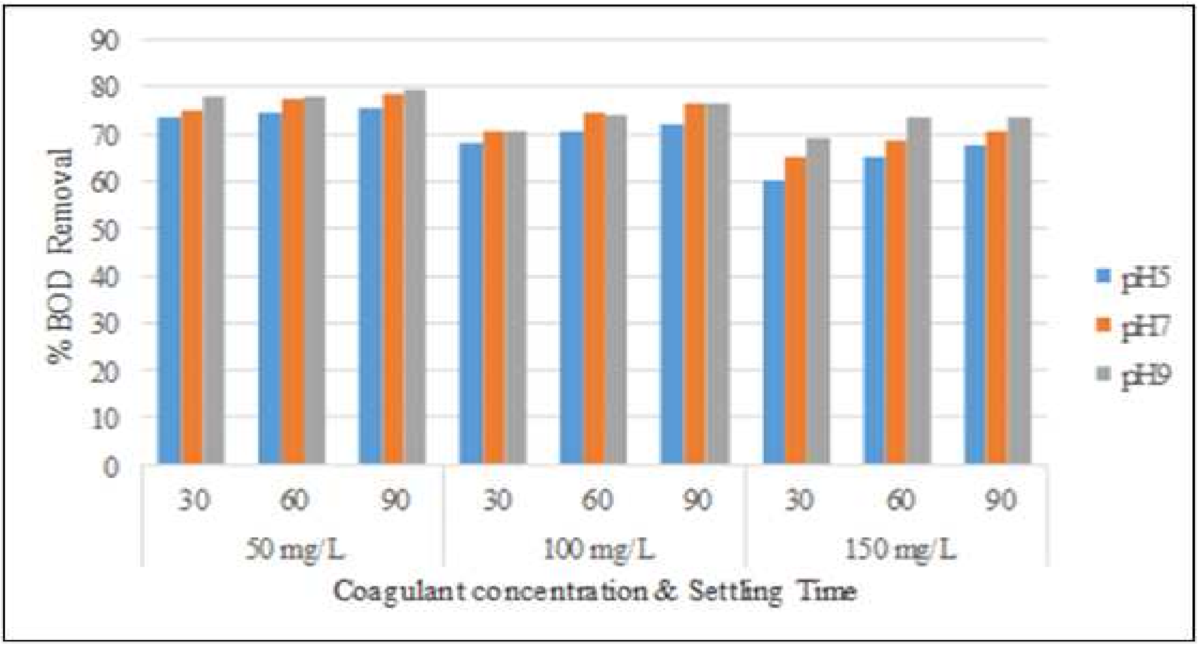

Fig. 10. ptimization of Coagulant *Garcinia mangostana* with BOD.

Using *Garcinia mangostana* as a coagulant aid with 25% *mangostana* ($A_{75}M_{25}$) resulted in a removal efficiency of 88.61% at pH 5, 90.36% at pH 7, and 92.12% at pH 9. When mangostana was increased to 50% ($A_{50}M_{50}$) in the treatment design, the removal efficiency of BOD was 89.34% (pH5), 91.09% (pH7) & 91.53% (pH9). Further, when the % mangostana was increased to 75% ($A_{25}M_{75}$), BOD removal efficiency was 85.4% (pH5), 89.78% (pH7) & 89.93% (pH9). Lastly, results also revealed that BOD removal efficiency increases with pH with *Garcinia mangostana* as a coagulant aid. Like any other natural coagulant, *Garcinia mangostana* showed potential in the removal of contaminants in water. A study by Folkard and Sutherland, 2001 showed that using natural coagulant, there was substantial removal of BOD at more than 50% as compared to the conventional treatment process (Jain *et al*., 2015).

Conclusion and recommendation

Results of the characterization of *Garcinia mangostana* pericarp extract showed that the presence of hydroxyl and carbonyl as a functional group may have influenced the coagulation activity during the wastewater treatment. Optimization results revealed that with pure alum (A100), turbidity removal was highest at 50 mg/L at 90 min at 96.35% (pH5), 98.18% (pH7), and 98.48%(pH9). TSS removal with a value of 96.6% (pH5), 97.05% (pH7), and 98.27% (pH9), and BOD removal of, on the other hand, optimization of pure *mangostana* (M100), showed maximum removal at 94.74% (pH5), 96.78% (pH7) and 97.52% (pH9). Results of the study proved that with a treatment design using *Garcinia mangostana* as a coagulant aid, the highest removal efficiency for turbidity was with a treatment combination of $A_{50}M_{50}$ with 93.25% at pH9, TSS removal efficiency was highest with a treatment mix of $A_{50}M_{50}$ with 93.32% at pH9, while BOD removal was highest at A75M25 at 92.12% at pH9. Further efforts could be made to improve the removal efficiency of the contaminants under study by enhancing other variables, such as mixing intensity and contact time between the water and coagulant, as well as other factors. It is also recommended to try this natural coagulant to remove other water pollutants like excessive nutrients and heavy metals from domestic wastewater. It is also suggested that future studies investigate other local plant materials for their possible potential in treating not only domestic wastewater but also industrial wastewater. This idea will reduce chemical residuals in many effluents, which is due to the excessive use of synthetic coagulants in many treatment industries. The use of bio-coagulants would definitely address sustainable development goals related to water and sanitation.

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