RESPONSE SURFACE OPTIMIZATION OF TREATED TURBID WATER USING BANANA STEM JUICE.

J. C. Agunwamba[1] M. I. Aho[2], M. B. Iorwua[3] and M. T.Tiza[4]

[1]Professor, Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria.
Email - nwambaagu@yahoo.com
[2]Senior Lecturer, Department of Civil Engineering, University of Agriculture, Makurdi, Nigeria.
Email - aho_ped@yahoo.com
[3]Post-Graduate student, Department of Civil Engineering, University of Agriculture, Makurdi, Nigeria.
Email - iorwuabemmichael@gmail.com
[4]Post-Graduate student Department of Civil Engineering, Career Point University, Kota, India.
Email - tizamichael@gmail.com

Abstract: The effectiveness of banana stem juice as a natural coagulant for treatment of turbid water was investigated. The main parameter studied was Turbidity. Coagulation experiments using jar test was performed with a flocculation system where the effects of Turbid Water pH, Retention time as well as Dosage of Banana Stem Juice on coagulation was examined. A Three Level Factorial Design in Response Surface Methodology (RSM) using Design Expert software was applied in the model analysis. Consequently, most of the actual and predicted values closely agreed with various regression coefficients. The characteristics of the Turbid water was determined with TSS at 222 mg/L, turbidity at 143 NTU and COD at 89.36 mg/L, BOD at 44.68 mg/L, DO_1 at 11.7 mg/L, DO_5 at 6.93 mg/L, pH at 7, Temperature at 27.3°C. Turbidity reduction using Banana Stem Juice was achieved at pH 6.5 with percentage removal of 88.54 % (16.39 NTU) after 60 minutes retention time with dosage of 8 ml. The Analysis of Variance (ANOVA) shows that the model was significant and R^2 for Turbidity, was 0.99. It could be concluded that Banana Stem Juice showed tremendous potential as a bio-coagulant for turbid water treatment purposes and could be applied in the pre-treatment stage prior to secondary treatment.

Key Words: Turbidity, Coagulation, Dosage, Retention Time, Response Surface Methodology.

1.0 INTRODUCTION:

Drinking water is a vital resource for all human beings and the access to safe and clean drinking water is a major concern throughout the world (WHO, 2007). Producing potable water from surface water or ground water usually involves one or several treatment steps for removing unwanted substances. When surface water is used as raw water, turbidity removal is often an essential part of the treatment process. In order to make clean water an available resource for as many people as possible, cheap, simple, robust and efficient process methods are necessary.

Developing countries are facing potable water supply challenges because of inadequate financial resources. The cost of water treatment is increasing and the quality of river is not stable due to suspended and colloidal particle load caused by land development, effluent disposal from agricultural and industrial production as well as high storm runoff during raining season.

About 1.2 million people still lack safe drinking water and more than 6 million children die from diarrhea in developing countries every year. In many parts of the world, river water with high turbidity is used for drinking purposes (Eman *et al*. 2010).

Surface water contains both dissolved and suspended particles, coagulation and flocculation processes are used to separate the suspended solids from the water.

The suspended particles vary considerably in source, composition, charge, particle size, shape and density. Correct application of coagulation and flocculation processes and selection of the coagulant depend upon understanding the interaction between these factors. The small particle such as clay and organic matter are destabilized (kept in suspension) by the action of physical forces on the particle themselves. One of the forces that play a dominant role in destabilization results from the surface charge present on the particles. Most solid suspended in water possess a negative charge, (Yongabi, 2010), and since they have the same type of surface charge, they repel each other when they come close in contact. Therefore, they will remain in suspension rather than clump together and settle out of the water.

Turbidity is a measure of cloudiness of water and has its origin from particles suspended in water. These particles are natural contaminants and most often mineral particle such as clay, silt or organic flocs. Turbidity is a major problem in drinking water treatment when the water source is surface water but can often be neglected in treatment of ground water (Cech, 2005), (Hammer and Hammer Jr, 2005).

World Health Organization (WHO) has set the standard value for the residual turbidity in drinking water at 5 (NTU). Higher turbidity levels are often associated with higher levels of disease causing microorganism such as viruses, parasites and some bacterial (Eman *et al.* 2010).

Native plants have traditionally been used to improve the quality of water in many countries in Africa and Latin America such as seeds of moringa used in guatemala, Peach and Bean Seeds, used in Bolivia. It has been reported that dried beans (*vicia fave*) and peach seeds (*Percial vulgaris*) have been used in Bolivia and other countries for water treatment. Similarly, *Schoenoplectus tatora,* an aquatic plants has been used in Bolivia and Peru for water quality treatment (Kebreab, 2004 and Miller *et al.* 2008).

The choice of natural plants also known as bio-coagulants over the chemical – based coagulants such as: aluminium sulphate, ferric chloride, polyaluminium chloride and synthesis polymers stem from the fact that they are cost effective, abundance in availability, environmentally friendly, biodegradable, medically potent, low sludge productivity and increased P^H (Mohd *et al*. 2013).

Recent studies by Ngabigengesere and Narasiah, (1998) and Katayon *et al.* (2006) indicated a number of serious drawbacks linked to the use of aluminium salts such as Alzheimer's disease associated with high aluminium residuals in treated water, excessive sludge production during water treatment and considerable changes in water chemistry due to reactions with the OH^- and alkalinity of water.

Research on natural coagulants have been focused on Moringa oleifera seeds (Olsen, 1987; Muyibi and Evison, 1995; Ndabigengesere *et al.* 1995) for the past 20 years but more researchers are studying the application of other natural coagulants such as Long Bean Extract, *Cactus opuntia*, *Jatropha caurcas* (*physis unit*), locust bean seeds, Garri flour. The most recent is a preliminary study of Banana Stem Juice for treatment of spent coolant wastewater (Habsah *et al.* 2013).

According to Namasivayan *et al.* (1993), waste banana pith can be used effectively as an adsorbent for the removal of 87 % Rhodamine B from textile wastewater at pH 4. Another research also on colour removal showed that the pith of banana stem can effectively remove the direct red colour and acid brilliant blue from aqueous solution through adsorption (Namasivayan *et al.* 1988). Other than that, banana pith also should be a useful biosorbent in the preliminary removal of cuprum from electroplating wastes (Low *et al.* 1995).

The use of banana stem juice as a bio-coagulant for turbidity removal in turbid water treatment, however is limited in publish literature. While the above cited researches focused on the use of banana pith in the treatment of waste water. This thesis reports on the potential of banana stem juice as a bio-coagulant for the coagulation of turbid water.

Banana is an herbaceous plant of the *genus Musa Spp.* of the family Musaceae. It is one of the most widely grown tropical fruits because of its high food value and an important addition to the diet. Banana plantation occupies large part of the land in tropical Nigeria. The stem from which the fruit bunches have been taken are usually cut off because it will never again grow fruit. The stems are therefore abandoned on the plantation to rot or be used as fertilizer. The abandoned stems sometimes ferment a fungal disease called Sigatoka (Black Leaf Streak) which destroys banana leaves and reduce crop yield by 40% (Habsah *et al.* 2013).

Also, naturally occurring coagulants like Banana Stem Juice are usually considered to be safe for human health as opposed to the chemical coagulants which have health risk in potable water treatment.

Water and sanitation facilities in sub Saharan Africa and Africa in general are appalling and for the most part absent. Poor waste disposal facilities, open field defecation, untreated cum poorly treated wastewater from factories constantly contaminate ground water sources. An average of 125litres of clean water is needed per person per day yet, in Africa in general, most people cannot boost of 25 litres of clean free water.

The situation is grave in most villages, resulting to heavy consequences on the entire nation or continent in that 70 % of Africans live in the rural area and practice subsistence agriculture. Apparently water borne disease constitutes 80 – 90 % of the disease burden on the continent with sharp rise in the morbidity and mortality rates. In an attempt to treat these infections, lack of adequate finances to purchase the necessary antibiotics has led to abuse and poor compliance to treatment, thus increasing the prevalence of antibiotic resistance strains of organism such as salmonellosis, ameobiasis, helicobacter pylori infections and many others thereby compounded the pathogenicity and epidemiological pattern.

Water purification technologies in Africa are quite cumbersome as most of the technologies are imported from western countries at exorbitant cost, making the final treated water products expensive to a highly impoverished population. Water is therefore decisive resources for socio- economic and environmental integration as well as inevitable tool for sustainable development. More than 80 % of disease burden in the low income earning countries are waterborne. In high-income earning countries, about 90 % of potable water is treated using unecological means (Yongabi, 2010).

Given the perceived environmental impact of dumped banana stem on banana plantations Vis a Vis the economic and medical disadvantages posed by the use of chemical coagulant. This study intends to turn our lemon to lemonade by utilizing the juice of discarded banana stem to coagulate turbid water.

2.0 MATERIALS AND METHODS:

2.1 Sample Collection

Matured Banana stems (*Musa acuminate)* were collected along the banks of river Benue in Makurdi, Benue state, Nigeria in March, 2015. The thorns were removed and the pith of the stems was then separated from the foliage. 100g of small pieces of the pith was mixed with 10 mL of distilled water using a mixer. The mixed pith was then filtered and the juice collected. The fresh juice of banana stem was stored in a refrigerator at 7 ^oC to ensure its freshness. To avoid any fermentation, the coagulation experiment using this banana stem juice as a bio coagulant was carried out on the same day. The turbid water used in the experiment was obtained from River Benue in air tight containers of 20 litres and taken to the Benue State Water Treatment Plant for laboratory analysis.

2.2 Statistical Analysis

Three Level Factorial design in the RSM software was applied in the jar test coagulation study. The variables selected were retention time (minutes) as X_1 and dosage of coagulants (mg/L) as X_2. The response observed was turbidity. A second degree quadratic polynomial equation was used in Equation (1).

$$Y = B_0 + B_1X_1 + B_2X_2 + B_{12}X_1X_2 + B_{11}{X_1}^2 + B_{22}{X_2}^2 \dots\dots\dots\dots\dots\dots \quad (1)$$

Where, Y is the predicted responses which is (Turbidity), B is the linear coefficients, X_1 and X_2 are input variables (namely retention time and dosage). The low, middle and high levels of each variable, namely retention time and dosage, were coded as −1, 0 and +1 respectively. Based on Equation (1), a total of 13 runs were necessary in order to optimize the turbidity removal that involved two independent variables, viz., retention time and dosage. The design of experiments was carried out using the software Design Expert (Courtesy: Stat-Ease Inc., Statistic Made Easy, Minneapolis, MN, USA. Version 7.0.6.2005).

2.3 Data Analysis

Data collected was processed, coded and analyzed to facilitate answering the research objectives. Inferential statistics was also used. The Inferential statistics tools such as analysis of variance

(ANOVA), regression analysis and a second order quadratic models were employed to test the significance of model obtained and to optimize the influence of retention time and dosage of Banana Stem Juice with turbidity, TSS and COD.

2.4 Determination of Dissolved Oxygen (DO)

The dissolve Oxygen Analyzer (model JPB -607 made by the HACH company) was used. The meter was switched on and the probe immersed into distilled water to rinse and adjust the value to zero reading. The probe was then immersed into the water sample and the reading recorded. The process was repeated for all samples.

2.5 Determination of Chemical Oxygen Demand (COD)

The COD test was measured using Spectrophotometer (Model-HACH, DR/2010). Chemical oxygen demand (COD) refers to the amount of oxygen required to oxidize the organic compounds in a water sample to carbon dioxide and water.

2.6 Determination of Biochemical Oxygen Demand (BOD)

The BOD after 5days incubation was determined based on the modified winkler azide's method.

2.7 Determination of Temperature

Temperature of water before and after the treatment was measured using EUTECH Instrument Company, model 700, digital thermometer.

2.8 Determination of Total Suspended Solids (TSS)

Direct reading Spectrophotometer (DR/2000) from HACH Company was used. The program number (630) for suspended solids was entered on the spectrophotometer and the wavelength was adjusted to 810 nm and the mg/l was displayed. A blank sample cell bottle of 25 ml was filled with deionized water sample was then placed in the cell holder. The light shied was closed. The zero key was pressed and the reading displayed as 0.00 mg/l. The blank was then removed, 25 ml of water sample was measured using the sample cell bottle and placed into the sample compartment, and then the light shield was closed. The read/enter key was pressed and the reading displayed in mg/l and recorded. This procedure was repeated for all water samples.

2.9 Determination of pH

The pH meter EUTECH instrument company, model 700, made from Singapore was used. It was powered by electricity which when switched on and the probe immersed into the water sample, the reading displayed and was recorded as it stabilized.

The turbid water was adjusted to different pHs using the lime powder and HCl. At each adjusted pH, the sample water was allowed to settle over a period of 225 minutes where aliquots of the aqueous solution were extracted for COD, TSS and turbidity measurement.

2.10 Determination of Turbidity

Turbidity test was measured using portable turbidimeter EUTECH Instrument Company, model TN - 100. The principle of the turbidity measurement is based on a comparison of the intensity of light scattered by the sample. The sample cell was placed into the turbidimeter and the turbidity value was shown in NTU unit. The total turbidity percentage removal was calculated as follows:

$$\text{Turbidity percentage removal} = (A - B)/C\ x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots (2)$$

where A is turbidity of turbid water sample (NTU), B is turbidity after treatment (NTU), and C is turbidity of turbid water sample (NTU).

2.11 Jar Test

The equipment used for jar tests was STUART SCIENTIFIC FLOCCULATOR (SW1) with 6 beakers of 1000 mL capacity each. Each beaker was filled with 500 mL of the sample water. Varying amounts of coagulant were added to the samples in the 6 beakers and stirred at 200 rpm for 2 minutes. The rapid mix stage helped to disperse the coagulant throughout each container. Then the stirring speed was reduced to 100 rpm and continued mixing for 10 minutes. This slower mixing speed helped in promoting floc formation by enhancing particle collisions which led to larger flocs. This speed was slow enough to prevent shearing of the floc due to turbulence caused by stirring too fast. The contents were allowed to settle for about 0, 10, 20, 30, 40, 50 and 60 minutes. After sedimentation, samples were collected for water quality assessment.

2.12 Turbid Water Characterization Study

The parameters determined were pH, temperature, total suspended solids TSS, BOD, COD and turbidity. The pH and turbidity values of the Turbid water was found to be pH 7 and 143 NTU respectively at an ambient temperature of 27.3 ^{o}C whereas the COD and TSS concentrations were found at 89.36 mg/L and 222 mg/L respectively. Furthermore, Dissolved Oxygen for day one (DO_1) was 11.7 mg/L and Dissolved Oxygen after five days (DO_5) was 6.93 mg/L. Bio-chemical Oxygen Demand (BOD) was 44.68 mg/L.

3.0 RESULTS AND DISCUSSION

Table 1: Characterization of Turbid Water.

Parameter	Concentration	Units
pH	7.0	-
Temperature	27.30	°C
Total Suspended Solids	222	Mg/l
Bio-chemical Oxygen Demand	44.68	Mg/l
Chemical Oxygen Demand	89.36	Mg/l
Turbidity	143	NTU
Dissolved Oxygen (DO_1)	11.7	Mg/l
Dissolved Oxygen (DO_5)	6.93	Mg/l

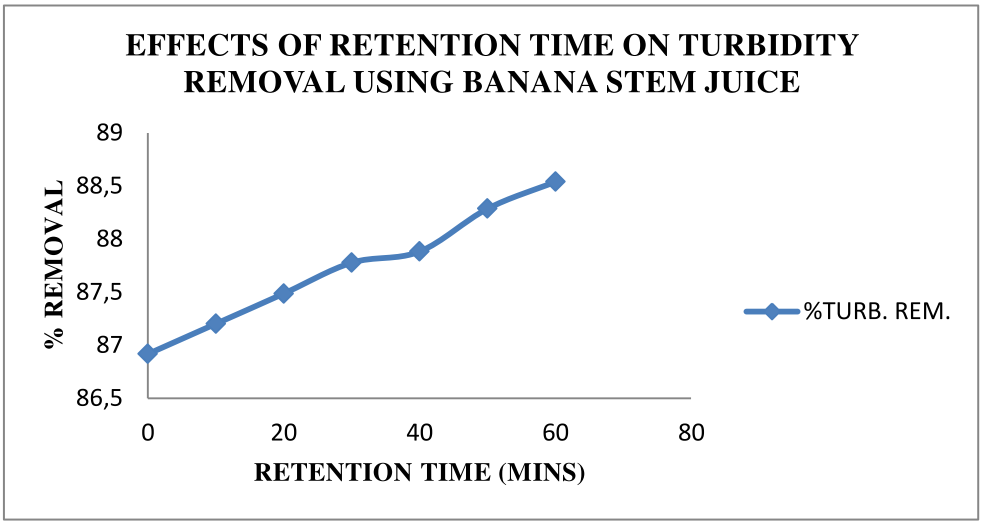

Figure 1: Effects of Retention Time on Turbid water Using Banana Stem Juice coagulant.

3.1 Effect of Retention Time on Banana Stem Juice.

The effect of retention time on the percentage removal of turbidity was investigated and displayed in Figure.1; Results indicated that at optimum retention time of 60 minutes, 88.5 %, removal in Turbidity was achieved. This retention time is lower than the retention time of conventional chemical treatment unit, where it is usually more than 3.5 hrs. Chances are that at prolonged retention time, coagulation using Banana stem juice can result in efficient removal for low as well as high turbidity. However, if used on industrial scale, increased retention time will lead to lower production of potable water or a need of investment in larger sedimentation basins, which is not always feasible. Flocs that do not settle during sedimentation will be removed during the following filtration. If a large fraction of the flocs pass through the sedimentation step without settling, it will lead to a high load on the filters, and increase in clogging. The filters will thus need to be backwashed more often, which also will have a negative impact on the drinking water production rate.

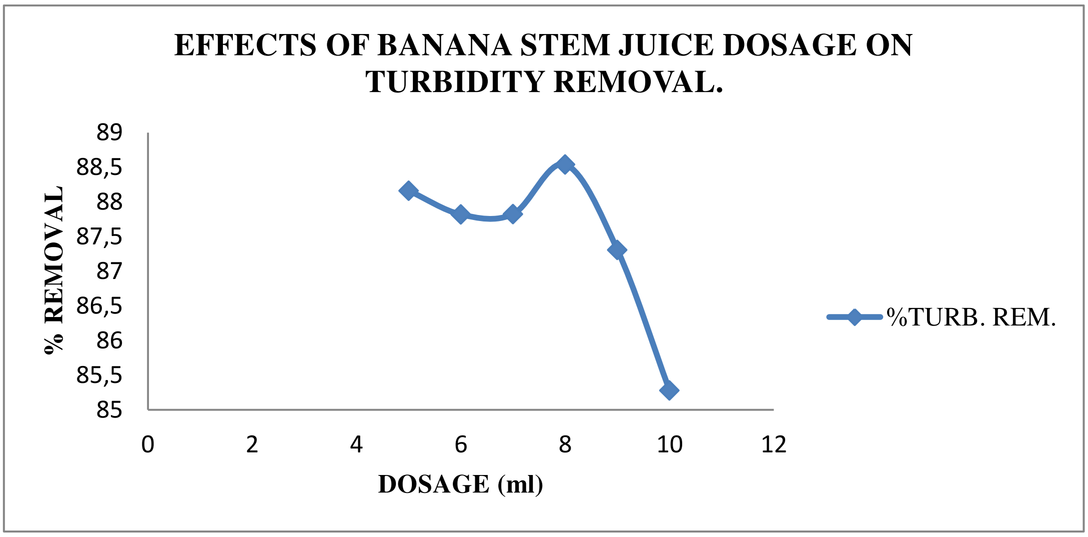

Figure 2: Effects of Banana Stem Juice Dosage on the Coagulation Process of Turbid Water.

3.2 Effect of Dosage on Banana Stem Juice

Figure 2 shows the effect of the dosage of banana stem juice as a bio-coagulant on flocculation effectiveness at optimum pH value 6.5 for banana stem juice. For banana stem juice, the dosages ranged from 5 to 10ml, and the volume of turbid water used was 300 mL. A turbidity removal percentage of about 88.54% was achieved at 8ml dosage.

Table 2 also analyses the compliance of turbidity concentrations of turbid water treated with banana stem juice with standard effluent discharge limits stipulated by the Environmental Protection Act, 2002. The pH value of treated turbid water complied with the pH range (6.0–8.5) stipulated by the Act. Although banana stem juice reduced the turbidity concentrations to 16.39 NTU (88.54 %), the values of 16.39 NTU for turbidity was higher than WHO standards. The result from this study indicates that banana stem juice is suitable as a natural coagulant in the pretreatment process of turbid water, and further treatment is needed before it can be consumed. Nevertheless, banana stem juice showed high potential as a natural coagulant for water treatment purposes.

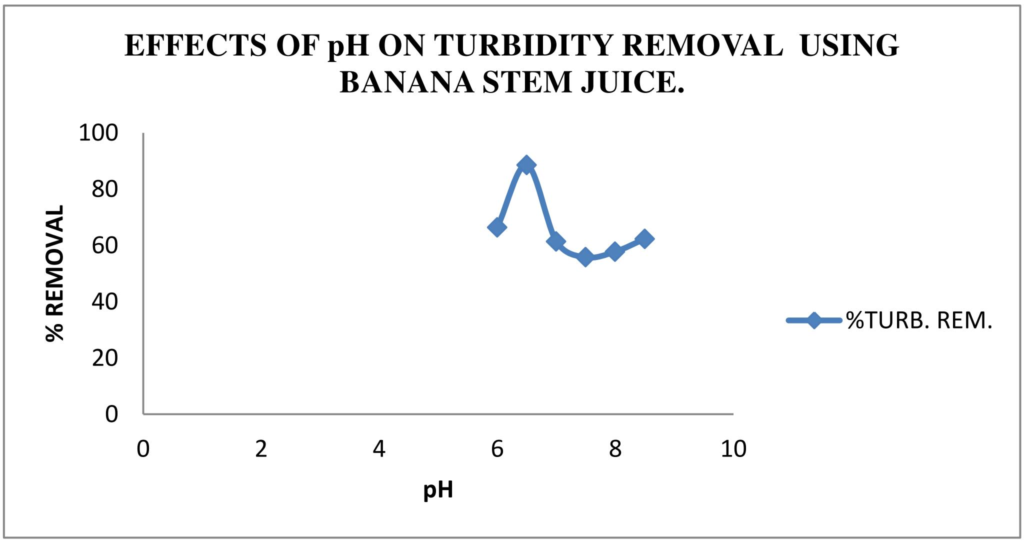

Figure 3: Effects of Turbid Water pH on Banana Stem Juice coagulant.

3.3 Effect of pH on Banana Stem Juice.

The chemistry of coagulants depends on the pH of any solution during the flocculation process. This can be seen when ferric salts undergo rapid, uncontrolled hydrolysis reactions upon their addition to water, forming a series of chemical products or complexes (Jiang and Graham 1998). Therefore, controlled pH of the turbid water determines the effectiveness of banana stem juice in the flocculation process, where it determines the maximum turbidity percentage removal. Figure 3 shows the effect of pH on the coagulation of the turbid water using banana stem juice as a natural coagulant. The volume of turbid water used was 300ml and the volume of banana stem juice used was 450 ml per test. From the graph, the highest recorded turbidity removal percentage was observed at pH of 6.5 to be 88.54 %. Generally, pH of 6.5 was found to be a good pH for efficient removal of turbidity by banana stem juice. This result indicated that at pH of 6.5, the maximum amount of coagulant is converted to solid phase flocs particles. At pH value higher and lower than this pH of minimum solubility, the charges produced by inulin as a natural polymer from banana stem juice for bridging and entrapping the microfloc to form larger floc was very low; thus, the adsorption on the surfaces of precipitated floc particles was very minimal. A similar observation was also seen from the findings by Habsah et al. (2013), in their studies using Banana Stem Juice as a Natural Coagulant in Spent Coolant Wastewater Treatment, where the highest turbidity removal percentages recorded using Banana stem juice was at pH 5.

Parameter	Unit	Maximum Permitted Levels
Colour	TCU	Unobjectionable
Temperature	0 Celsius	40
Turbidity	NTU	5
pH	-	5 – 9
COD	Mg/l	120
BOD_5	Mg/l	40
TSS	Mg/l	35

Table 2 : Physicochemical Parameters for Water Quality in Nigeria.

3.4 Surface Response on the Range of Banana Stem Juice Dosages and Retention Times on Turbidity Reduction.

3.4.1 Turbidity Removal

The turbidity reduction in the turbid water with different coagulant dosages and retention times is shown in figures 4, 5, and 6. The initial turbidity was 143 NTU. At low coagulant dosages with long Retention times, the turbidity concentration decreased significantly. However, the optimum turbidity reduction was about 88.54 % with a retention time of 60 minutes using 8 ml of Banana Stem juice at the pH of 6.5.

However, it was observed that with increasing dosages of Banana Stem juice, the turbidity reduction decreases. The optimum turbidity reduction was achieved at 8 ml and retention time of 60 minutes. The R^2 was 0. 99 and the model were described using a second order quadratic model on the reduction of turbidity can be represented by following equation:

$$Y_{Turbity} = 143 - 0.823X_1 - 32.8X_2 + 0.0778X_1X_2 + 0.00205{X_1}^2 + 2.21{X_2}^2 \ldots\ldots (3)$$

Figure 6 represents the close to fit in the experimental values with the predicted data on turbidity reduction in Turbid water. From Equation (3), the accuracy of prediction was 99%. The value of the turbidity could be predicted based on the actual values of the independent variables of dosage and retention time up to an accuracy of 99%. Table 3 shows the analysis of variance with the Model F-value of 1081.69 that implies the model was significant and according to the ANOVA interpretation. There was only 0.01% chance that a “Model F-value” this large could occur due to interference. Furthermore, the ANOVA interpretation, indicated that the “Prob > F” was 1.08E+003 and accordingly, values of “Prob > F” less than 0.05 indicate model terms X_1, X_2, X_1X_2 and ${X_2}^2$ are significant.

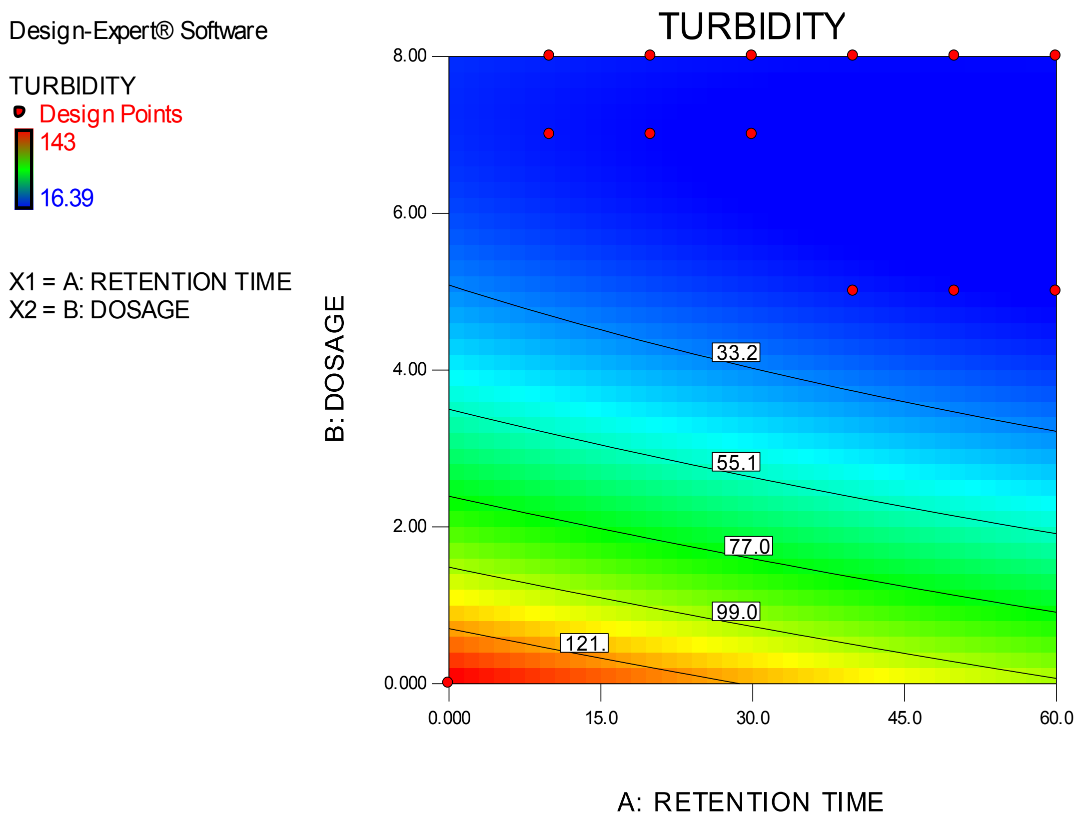

Figure 4: Surface Plot to Determine the Reduction of Turbidity in Turbid water Using Retention Time and Dosage of Banana Stem Juice.

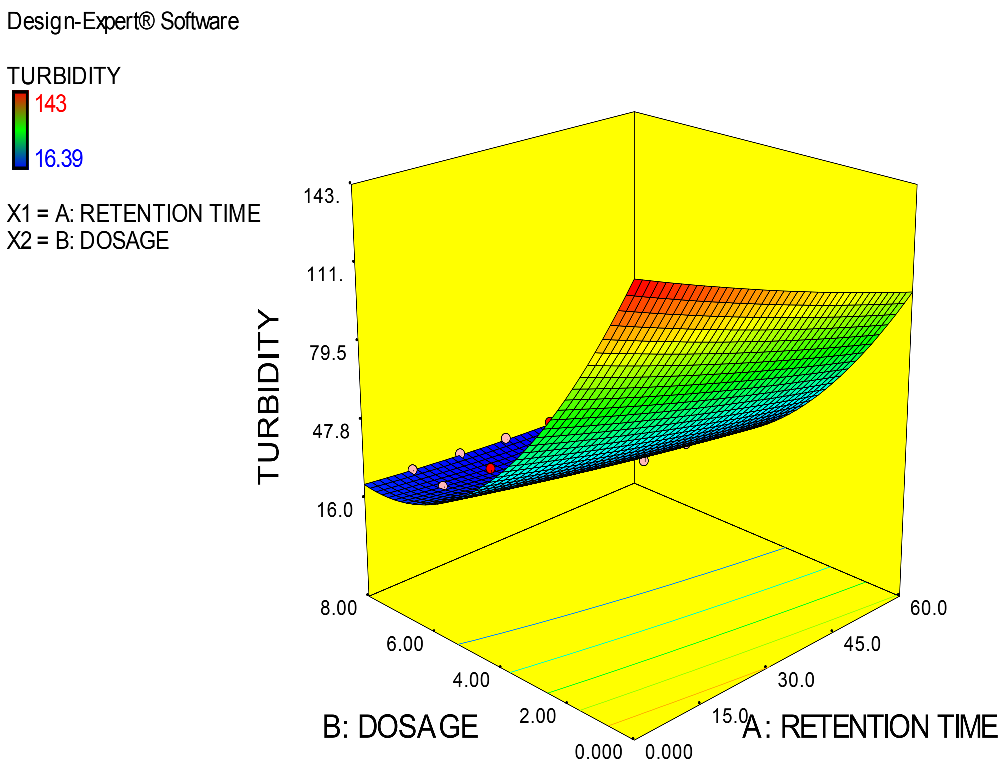

Figure 5: Contour Plot to Determine the Reduction of Turbidity in Turbid water Using Retention Time and Dosage of Banana Stem Juice.

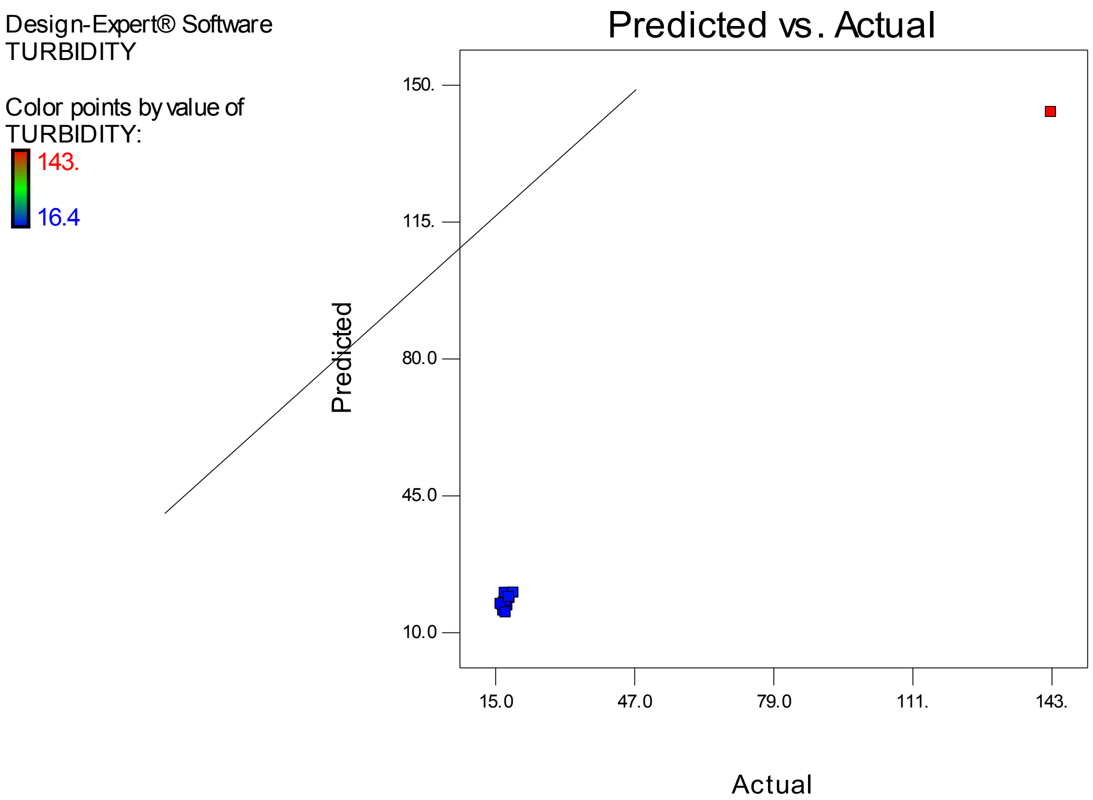

Figure 6: Predicted vs Actual Plots to Determine the Reduction of Turbidity in Turbid water Using Retention Time and Dosage of Banana Stem Juice.

Source	Sum of squares	DF	Mean square	F-value	P= Prob>F
Model	1.45E+004	5	2.90E+003	1.08E+003	<0.0001
Residual	18.8	7	2.68		
Cor Total	1.45E+004	12			

Table 3: Analysis of variance for Turbidity on Varying Retention Times with Dosage using Banana Stem Juice.

CONCLUSIONS:

Treatment of turbid water from a River Benue – Nigeria was investigated using banana stem juice as a natural coagulant. The characteristics of the Turbid water was determined with TSS at 222 mg/L, turbidity at 143 NTU, BOD at 44.68 mg/L, DO_1 at 11.7 mg/L, DO_5 at 6.93 mg/L, pH at 7, Temperature at 27.3°C and COD at 89.36 mg/L. Turbidity reduction using Banana Stem Juice was achieved at pH 6.5 with percentage removal of 88.54 after 60minutes retention time with dosage 8 ml. A Three Level Factorial Design in Response Surface Methodology (RSM) using Design Expert software was applied in the model analysis. The Analysis of Variance (ANOVA) show that the model was significant with R^2 for Turbidity, was 0.99.

Although the final result for Turbidity did not comply with the standard drinking water limits of 5 NTU however, with percentage removal of turbidity exceeding 80%, it is suggested that banana stem juice can be used in the pretreatment stage of turbid water prior to secondary treatment.

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