

Ground Water Sustainability by Carica papaya Seed Bio-coagulant Oriented Modeling and Optimization of Mechanic Village Seep Water

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Abstract— Treatment of seeped water from Nekede mechanic village by coagulation/flocculation using Carica papaya seed bio-coagulant was investigated in this study with the aim of removing turbidity and colour in the water sample. Bench-scale nephelometric jar tests were performed to remove the contaminants from the sample water collected in a shallow well located within the vicinity of the village. Process parameters were initially varied to investigate their effects on the reaction process adopting one-factor-at-a-time approach. Thereafter, the experiment was designed within a narrow region of search for optimality of the process variables. Response Surface Methodology (RSM) was employed in the design adopting the rotatable central composite design (CCD) option. Analysis of variance (ANOVA) results showed that the turbidity and colour removal efficiency models yielded p-values that were less than 0.001 at 5% significance levels, coefficient of determination R^2 of 0.916 and 0.9535, adjusted R^2 of 0.9231 and 0.9070, predicted R^2 of 0.7420 and 0.7670, adequate precision of 13.95 and 12.36dB, and coefficient of variation (CV) that were less than 10% respectively. Process optimization results had 7.48, 330mg/l, 30mins and 34°C as the optimal process parameters for P^H , coagulant dosage, setting time and temperature respectively. At these points, the optimal turbidity and colour removal efficiencies were 98.03 and 62.51% respectively. The treated water met the World health organization (WHO) and federal environmental protection agency (FEPA) standards for portable water and water disposal purposes respectively. It is therefore concluded that while Carica papaya coagulant is very effective in the removal of turbidity and colour from the ground water, the process at 34°C is described by a quadratic model.

Keywords— Bio-coagulant, Groundwater sustainability, Modeling, Optimization and Seep water.

I. INTRODUCTION

Environmental pollution has become the biggest problem to the human race on this planet. It is adding impurity to our environment and will hamper the core of existence of man and nature (WWW.biology.tutorvista.com). The growing human needs and ceaseless drive to satisfy them have led to the production of varying forms of harmful wastes that ultimately rest in our aqua system. Although industrialization is inevitable, various devastating ecological and human disasters which have continuously occurred over the last three decades or so implicate industries as major contributors to environmental degradation and pollution problems of various magnitudes (Babayemi et al., 2013). Mechanic village has been implicated as one of major sources of ground water

pollution (Nwachukwu et al., 2010). Pollution occurs when nature does not know how to decompose an element that has been brought to it in an unnatural way without creating harm or damage to itself (WWW.biology.tutorvista.com). The pollution menace can reach some disturbing proportions as crops on the land, aquatic and human lives are in serious danger. Pollution incident can damage corporate reputations and incur costly penalties (WWW.wpinternational.com). Industrial effluents if not treated adequately and properly controlled also pollute ground water. Drainage of industrial effluent without treatment and its use for irrigation purpose are possible ways of heavy metal accumulation in plant food chain (Leismana, 2009). Again, meeting environmental legislation on industrial effluent discharge is a challenge for a wide range of industrial manufacturing companies. As a result, both boreholes and rivers generally have poor quality water in the affected areas leading to such diseases as cholera, bilharzias, and diarrhea (Menkiti et al., 2011).

Water is very essential for human survival and existence. Among man's major survival needs, water is next to air in hierarchy. The availability of a water supply adequate in terms of both quantity and quality is essential to human existence (WWW.tropical.rainforest-animals.com). A high-quality water supply is central to the overall health of agricultural economy, the viability of the cities and rural communities. According to the 4th UN-UNESCO report on water, Africa remains the continent with limited access to quality resources despite its vast potential (Kabba, 2005). According to Emman et al., 2009, about 1.2billion people still lack safe drinking water and more than 6million children die from diarrhea in developing countries every year. It is therefore necessary that water conservation is given the proper attention it deserves.

Coagulation-flocculation is a widely used physiochemical process due to its simplicity and effectiveness in the primary purification of water and in industrial water treatment to restore the palatability and improve the elastic appearance of turbid water (Choy et al., 2013). It occurs in successive steps to overcome the force stabilizing the suspended particles during particle collision and growth of floc.

Water treatment is very expensive for developing countries and also requires the use of products which are not without impact on consumer's health (Altaher and Alhamadi 2011). Many developing countries cannot afford the high cost of

imported chemicals for water treatment. Also the chemical coagulants have several disadvantages such as relative high costs, harmful effects on human health, production of large sludge volumes as well as the fact that they considerably affect P^H of the treated water (Vijayaraghan et al., 2011). Attempts to confront these challenges highlight the persistent search for new substitutes to metal salts and the current drive to improve the efficiency of existing substitutes (Menkiti and Onukwuli, 2011).

A bio-coagulant is a natural material which initiate an aggregating process during water and wastewater treatment. When in solution, it furnishes ionic charges opposite to those of the colloidal turbid particles in water and thus neutralizes the repelling charges (Chong, 2012). In wastewater, it aggregates dissolved contaminants and tiny particles into larger ones so that filtration, clarification, or any other solid removal process may be used to remove them. The bio-coagulants have emerged to be promising alternative materials to replace the conventional ones. Compared with the conventional chemical types, they are safe and biodegradable polymers (eco-friendly), fairly shear stable, generally toxic free, easily available from reproducible agricultural resource lower cost, and produce no secondary pollution (Bolto and Gregory, 2007). Additionally, they also have been found to generate not only a much smaller sludge volume of up to five times lower but also with a higher nutritional sludge value. As such, sludge treatment and handling costs are lowered making them a more sustainable option. Since they also consume less alkalinity than their chemical counter parts like alum during coag-flocculation reaction, pH adjustments can be omitted and this provides extra cost savings. They are equally non-corrosive (Swati and Govinden, 2005) which eliminates concern of pipe corrosions.

Carica papaya is a small, sparsely branched tree, usually with a single stem growing from 5cm to 10m tall, with spirally arranged leaves confined to the top of the trunk. The leaves are large, 50 – 70cm in diameter, deeply palmately lobed, with seven lobes (www.en.u.wikipedia.org). The inside hollow of the papaya fruit is lined with numerous grew seeds as large as pepper coin and surrounded by a mucilaginous material derived from their arils. Papaya seed flour can be a source of protein (www.scialert.net).

Optimization is a process of finding an alternative with the most cost effective or highest achievable performance under the given constraint, by maximizing the desired factors and minimizing undesired ones (www.businessdictionary.com). The most common goals are to minimize cost and maximize throughput and/or efficiency. It is a fundamental and frequently applied task for most engineering activities. In industrial decision making, it is one of the major quantitative tools (www.en.wikipedia.org).

Modeling is the representation of a system or part of a system in physical or mathematical form that is suitable for demonstrating the behavior of the system (Dieter, 1991). A model is therefore an idealization of a real-world situation that aids in the analysis of a problem. A model may be either descriptive or predictive. While a descriptive model enables us to understand a real-world system or phenomenon, a

predictive one helps us to both understand and predict the performance of the system (Luben, 1990).

Ground water is the primary source of water used nationally, thus knowledge about its availability and sustainability are essential for the successful management and future development of this limited source (Dennehy et al., 2004). Ground water sustainability as defined by Alley et al., 1999, is the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences. It is therefore the effective and holistic management of water resources. It is the ability to meet the water needs of the present without compromising the ability of future generations to do the same (www.aquatechtrade.com>su...). Ground water sustainability concept is used when considering future water uses.

Mechanic village represents several acres of land mapped out for automobile mechanics, where automobile owners must go for repair and services of their motor vehicles (Nwachukwu et al., 2010). The concept has been described as a twenty first century strategy to improve upon environment quality in developing countries. If the village is well planned and built with collection and recycling of spent oil, and proper disposal of spent electrolytes, environment quality will improve. This will reduce soil pollution, bioavailability of toxic heavy metals and poor nutrients available to crops and vegetables, within and around the villages (Nwachukwu et al., 2010).

Mechanic village seeped water therefore constitutes the ground water reaching the earth's surface through the soil capillarities from an underground aquifer (www.thefreedictionary.com).

The study is therefore intended to carry out Carica papaya bio-coagulant oriented modeling and optimization of Nekede mechanic village seeped water for ground water sustainability. This is in view of the fact that striving towards a more sustainable and cleaner production is important from a competitive as well as in an environmental perspective as introduction of sustainability concept in water and wastewater treatment solves challenges of environmental pollution (Lundkvist et al., 2013). Since the desire to conserve and protect the aqua system is a global one, it becomes imperative following the limited availability of usable water to a significant number of human populations. The consequence is how to remove to a tolerable level, the pollution causative factor's loads from such raw water in order to produce usable water that is pure enough for its intended use (Ani et al., 2011).

II. MATERIALS AND METHODS

2.1 Water Sample

The raw water used in this study was collected from an uncemented shallow well up to 20cm deep within the vicinity of Nekede mechanic village along Aba Road, Owerri. The water comprises of rain and surface waters which infiltrate (seeped) into the well. Nekede mechanic village is located in Owerri West Local Government Area in Imo State of South Eastern Nigeria.

2.2 Carica Papaya Seeds Sample (CPS)

The seeds were obtained from various papaya fruits. The seeds were washed severally to remove dusts and the gummy substances attached to the seeds. They were then dried in the sun until they become very light in weight. The seeds were ground to fine powder using blender. The powder was sieved into 0.5mm particle and stored in an airtight container. The seed is a neglected waste material, non-edible, non-toxic and biodegradable.

2.3 Characterization of Effluent Sample

This is to ascertain the contaminants levels of the effluent. Effluent sample was collected from Nekede Mechanic village site using sterilized polyethylene can. The characterization was done in accordance with the standard method for the examination of water (Clesceri et al., 1999). The sample for heavy metal analysis was preserved by acidifying with conc H_2NO_3 (at 0.20ml/100ml effluent). This was intended to forestall the adsorption of elements on the container walls. The other sample was preserved with ice-block bearing cooler to forestall degradation at 3°C prior to analysis (Afuye and Mogaji, 2015).

2.4 Coagulation-flocculation

Jar tests were carried out based on standard bench-scale nephelometry (WST, 2003; AWWA, 2005). The dependent variables in the experiments were turbidity and colour removal efficiencies while pH, coagulant dosage, setting time and temperature were the independent variables. The coag-flocculation P^H was adjusted using 0.1M H_2SO_4 or 0.1M NaOH just before dosing of the coagulant. The experiments were conducted using a magnetic stirrer (Model CMS-01,M/s. Contech instruments Ltd) with two (2) minutes of rapid mixing (250 rpm), immediately followed by 20mins of slow mixing (40rpm) followed by 30mins of setting. During the setting, the yields were determined by withdrawing samples with pipette from 2cm dept after every 5 minute, till 50 minutes and analyzing same for turbidity and colour.

2.5 Determination of Turbidity

The turbidimeter, model no wzs-185, was calibrated with solution of known turbidity with minimum and maximum turbidities of 3NTU and 10,000NTU respectively selected for calibration. After calibration, a cleaned indexed sample curette was filled to within ½ of the top with the sample aliquot. The cap was placed on the curvette already coated on the outside with small amount of silicon oil to prevent condensation. The sample curvette was then placed into the well and aligned with the locator pin on the optical well and the NTU reading taken directly from the display.

2.5.1 Determination of turbidity removal efficiency

Percentage of turbidity removal efficiency (response variable or yield) was calculated using the formular:

Turbidity removal efficiency

$$y_1, (\%) = \frac{T_R - T_T}{T_R} \times 100 \quad (1)$$

Where T_R and T_T are turbidities of raw water and treated water respectively.

2.6 Determination of Colour

Commodity colorimeter model: BC 200H was used for this measurement. The sample vial was cleaned, dried and rinsed with the sample water gotten by diluting 10m/ of treated water sample with distil water to upto 100ml. The vial was then capped with the screw cap and gently inverted several times. The used sample water was discarded and the rinsing procedure repeated two more times. The vial was filled with the sample water, capped with the screw cap, and placed into the sample well after wiping the vial with a soft, lint-free cloth to ensure that the outside was dry, clean and free from indulges.

Vial was then aligned using the mark on it with the meter's index mark and read/enter key was pressed and the meter displayed the reading within 3 seconds.

2.6.1 Determination of colour removal efficiency

Percentage of colour removal efficiency was calculated from: colour removal efficiency,

$$Y_2(\%) = \frac{C_R - C_T}{C_R} \times 100 \quad (2)$$

Where C_R and C_T are the colours of raw water and treated water respectively.

2.7 Experimental Design and Data Analysis

Design expert software version 13 (Slate-Ease, Inc; U.S.A) was used to design the experiment. The rotatable central composite design (CCD) matrix was adopted for the Response surface methodology (RSM). The CCD, introduced by Box and Wilson in 1951, has stood the test of time in fitting quadratic surfaces, which normally works well for the process optimization (Montgomery, 1985). In the rotatable CCD, a total of 30 experiments-corresponding to 2^4 full factorial design at two factor level coded \pm /notation), eight axial points (star points) with coordinates $(+\alpha, 0, 0, 0)$, $(0, +\alpha, 0, 0)$, $(0, 0, +\alpha, 0)$, $(0, 0, 0, +\alpha)$, $(-\alpha, 0, 0, 0)$, $(0, -\alpha, 0, 0)$, $(0, 0, -\alpha, 0)$, $(0, 0, 0, -\alpha)$ and eight replicates at the centre point each with coordinate $(0, 0, 0, 0)$ super-imposed on one another-were conducted. While the star points verify the non-linear suspected cuvatives, the replicates at the centre point verify variations in the middle of the plan and serves as a tool for proper measurement of the degree of precision. The value of the α for rotatability is a function of the number of points in the factorial region of the design cubical in this case) and is given by equation:

$$\alpha = (N_F)^{1/4} \quad (3)$$

Where: N_F is the number of points in the cubical region of the design.

$$\text{Since } N_F = 2^m \quad (4)$$

Where m is the number of factors, equation 3 gives the value of α as $(2^4)^{1/4} = 2$, as indicated by the design expert software.

Choice of base level and variation interval for each factors are 7.0, 350mg/l, 35mins and 350°C respectively for pH, coagulant dosage, settling time and temperature. Their variation intervals are respectively 1.5, 50mg/l, 10mins and 10°C. The full factorial CCD matrix codes for the experiments are indicated in table 2 below, while table 1 shows the levels and range of variables tested in 2^4 -CCD.

III. RESULTS AND DISCUSSION

3.1 Physiochemical Characteristics of the MVSW

The physiochemical characteristics of MVSW were determined and presented in table 3 with the WHO and FEPA standards.

TABLE 1: Levels and Range of variables tested in 2^4 – CCD.

| Independent variable | Lower limit (-I) | Base level (0) | Upper limit (+I) |
|----------------------------|------------------|----------------|------------------|
| pH | 5.5 | 7.0 | 8.5 |
| Coagulant dosage (mg/l) | 300.0 | 350.0 | 400.0 |
| Setting time (min) | 25.0 | 35.0 | 45.0 |
| Temperature($^{\circ}$ C) | 25.0 | 35.0 | 45.0 |

TABLE 2: Full factorial 24 rotatable matrix codes for the experiments

| Run | F ₁ x ₁ | F ₂ x ₂ | F ₃ x ₃ | F ₄ x ₄ | F ₅ x ₁ x ₂ | F ₆ x ₁ x ₃ | F ₇ x ₁ x ₄ | F ₈ x ₂ x ₄ | F ₉ x ₂ x ₃ | F ₁₀ x ₃ x ₄ | F ₁₁ x ₁ x ₂ | F ₁₂ x ₂ ² | F ₁₃ x ₂ ³ | F ₁₄ x ₂ ⁴ | Y ₁ | Y ₂ |
|-----|----------------------------------|----------------------------------|----------------------------------|----------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|--------------------------------------------------|--------------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|----------------|----------------|
| 1. | -1 | +1 | -1 | -1 | +1 | -1 | -1 | +1 | -1 | +1 | +1 | +1 | +1 | +1 | | |
| 2. | -1 | +1 | +1 | +1 | +1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | | |
| 3. | +1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 4. | +1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 5. | +1 | -1 | -1 | -1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | | |
| 6. | -1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | | +1 |
| 7. | +1 | +1 | -1 | +1 | +1 | -1 | +1 | -1 | +1 | -1 | +1 | +1 | +1 | +1 | | +1 |
| 8. | +1 | +1 | -1 | -1 | +1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | | |
| 9. | +1 | -1 | +1 | -1 | -1 | +1 | -1 | -1 | +1 | -1 | +1 | +1 | +1 | +1 | | |
| 10. | -1 | -1 | -1 | +1 | +1 | +1 | -1 | +1 | -1 | +1 | +1 | +1 | +1 | +1 | | |
| 11. | +1 | -1 | +1 | +1 | -1 | +1 | +1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | | |
| 12. | -1 | +1 | -1 | -1 | -1 | +1 | +1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | | |
| 13. | +1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 14. | -1 | +1 | -1 | -1 | -1 | +1 | +1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | | |
| 15. | +1 | +1 | +1 | -1 | -1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | | |
| 16. | -1 | +1 | +1 | -1 | +1 | -1 | +1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | | |
| 17. | +1 | -1 | +1 | +1 | -1 | -1 | -1 | +1 | +1 | -1 | +1 | +1 | +1 | +1 | | |
| 18. | -1 | -1 | +1 | -1 | +1 | -1 | -1 | -1 | -1 | +1 | +1 | +1 | +1 | +1 | | |
| 19. | +1 | -1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | +1 | | |
| 20. | +1 | 0 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | +1 | 0 | | |
| 21. | +1 | 0 | -1 | -1 | 0 | -1 | 0 | 0 | 0 | -1 | +1 | 0 | +1 | +1 | | |
| 22. | +1 | +1 | 0 | 0 | +1 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | +1 | +1 | | |
| 23. | +1 | 0 | 0 | -1 | 0 | 0 | -1 | 0 | 0 | -1 | +1 | 0 | 0 | +1 | | |
| 24. | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 25. | +1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 26. | +1 | 0 | 0 | +1 | 0 | 0 | +1 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 27. | +1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 28. | +1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 29. | +1 | +1 | 0 | 0 | +1 | 0 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |
| 30. | +1 | 0 | +1 | 0 | 0 | +1 | 0 | 0 | 0 | 0 | +1 | 0 | 0 | 0 | | |

TABLE 3: Result of physiochemical characteristics of the MVSW and WHO and FEPA Standards.

| S/N | Parameter | A (MVSW) | WHO (2006, 2011) | FEPA (Ekanem et al., 2016) |
|-----|--------------------------------------|----------|------------------|----------------------------|
| 1. | Temperature ($^{\circ}$ C) | 30.1 | 25.0 | <40 |
| | pH | 7.3 | 6.5-8.5 | 6-9 |
| 2. | Conductivity (μ S/cm) | 4322.86 | 8-10,000 | 1000 |
| 3 | Turbidity (NTU) | 8.20 | <5.0 | 6.8 |
| 4 | Colour (CPU) | 31.10 | ≤ 15 | 7.0 |
| 5 | BOD (mg/l) | 39.60 | 5 | 30.0 |
| 6 | COD(mg/l) | 85.14 | 10 | 80 |
| 7 | SO ₄ ²⁻ (mg/l) | 0.111 | < 500 | 500 |
| 8 | PO ₄ ³⁻ (mg/l) | 0.128 | 6.5 | 5.0 |
| 9 | NO ₃ (mg/l) | 1.281 | 50 | 20 |
| 10 | TS (mg/l) | 2857.13 | 500 | 250 |
| 11 | TDS (mg/l) | 2809.86 | 300 | 2000 |
| 12 | TSS (mg/l) | 49.27 | 30 | 30 |
| 13 | Pb (mg/l) | 0.804 | 0.01(A,T) | <1 |
| 14 | C _u (mg/l) | 0.512 | 2 | 1.5 |
| 15 | M _n (mg/l) | 0.697 | 0.4 | 0.2 |
| 16 | C _r (mg/l) | 0.0321 | 0.05(P) | 0.05 |
| 17 | Zn (mg/l) | 0.351 | ≤ 3.0 | ≤ 1.0 |
| 18 | Fe (mg/l) | 1.077 | 0.3 | 20 |
| 19 | Ni(mg/l) | 0.0115 | 0.07 | 0.2 |
| 20 | C _d (mg/l) | 0.0394 | 0.003 | 0.01 |

Note: A: provisional guideline value because calculated guideline value is below the achievable quantification level; P: provisional guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

The table shows that turbidity and colour of the MVSW are high at 8.20NTU and 31.10CPU respectively. These physiochemical characteristic values found approximate to the ones obtained by Nwachukwu et al., (2010).

3.2 Contaminants Removal Efficiency Profiles

The contaminant removal efficiency profiles of some selected turbidity and colour contaminant for MVSW treated

with PPSC at various temperatures are shown in figures 1 to 6. These plots which were obtained from OFAT experiments show that the highest turbidity and colour removals were obtained at between the dosage of 200-400mg/l, pH of 6-10 after 50minutes setting time and temperature of 30-40°C. These results provide an insight to the narrower region for the optimal search. This is in line with previous researches such as Menkiti, 2010a; Menkiti and Onukwuli, 2010b; and Asia and Oladoja, 2003. Thus, in the designed experiment, the optimization target was set to search within these boundaries.

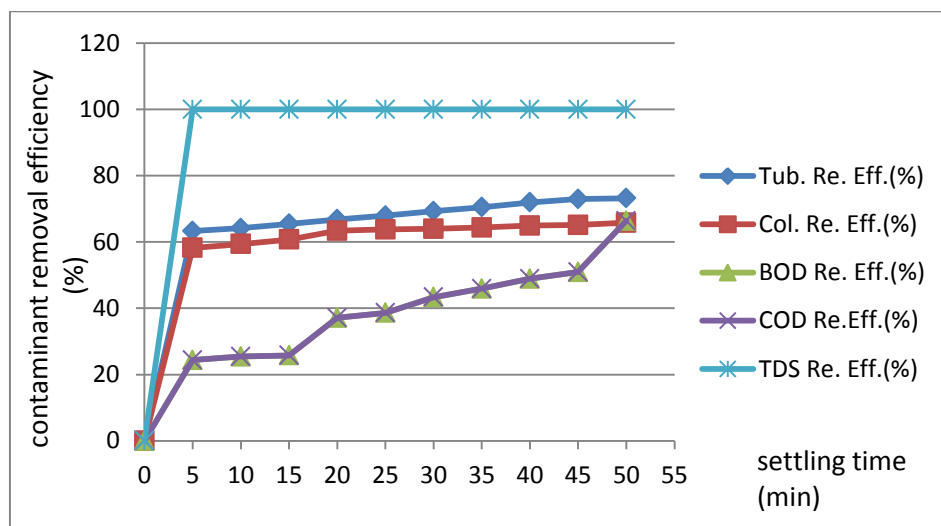


Figure 1: Contaminants removal efficiency vs settling time at pH of 6.0, for pawpaw seed dose of 400mg/l and temperature of 40oC for MVSW

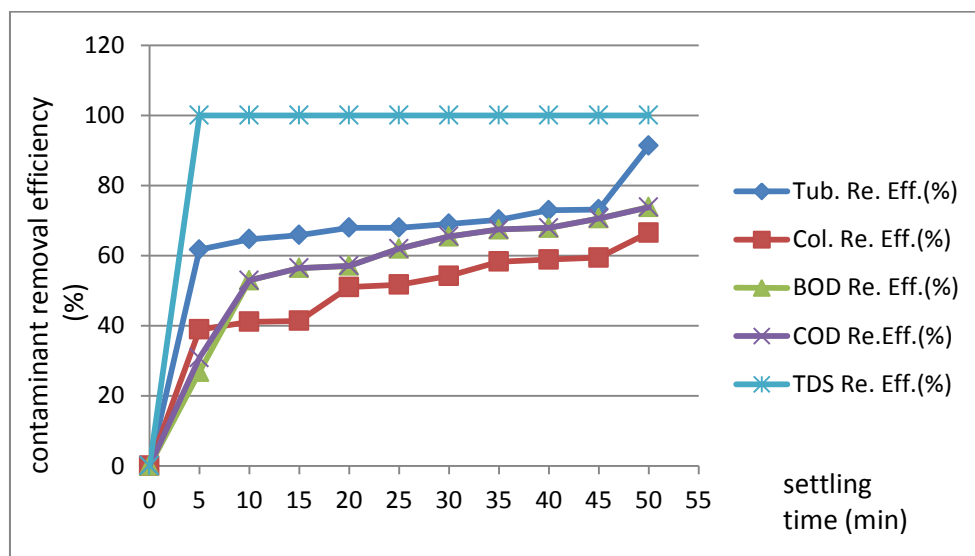


Figure 2: Contaminants removal efficiency vs settling time at pH of 8.0, for pawpaw seed dose of 400mg/l and temperature of 30°C for MVSW

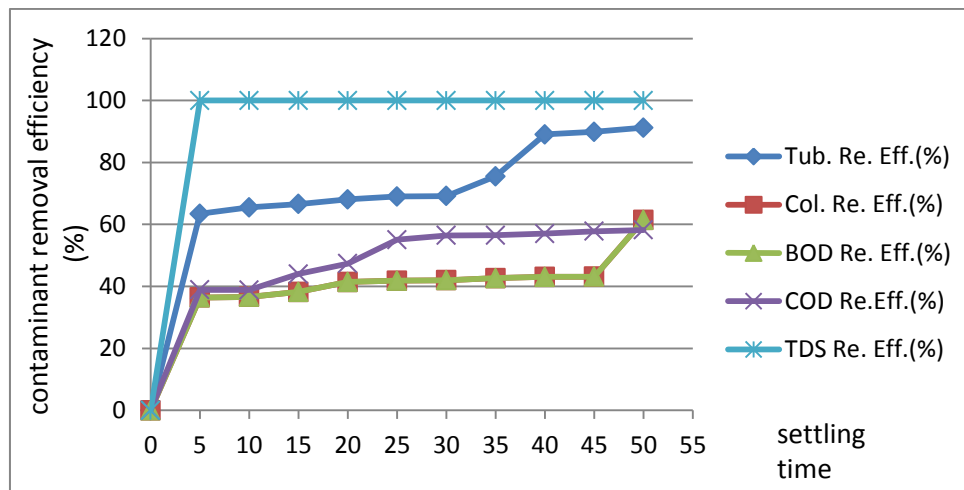


Figure 3: Contaminants removal efficiency vs settling time at pH of 8.0, for pawpaw seed dose of 400mg/l and temperature of 30°C for MVSW

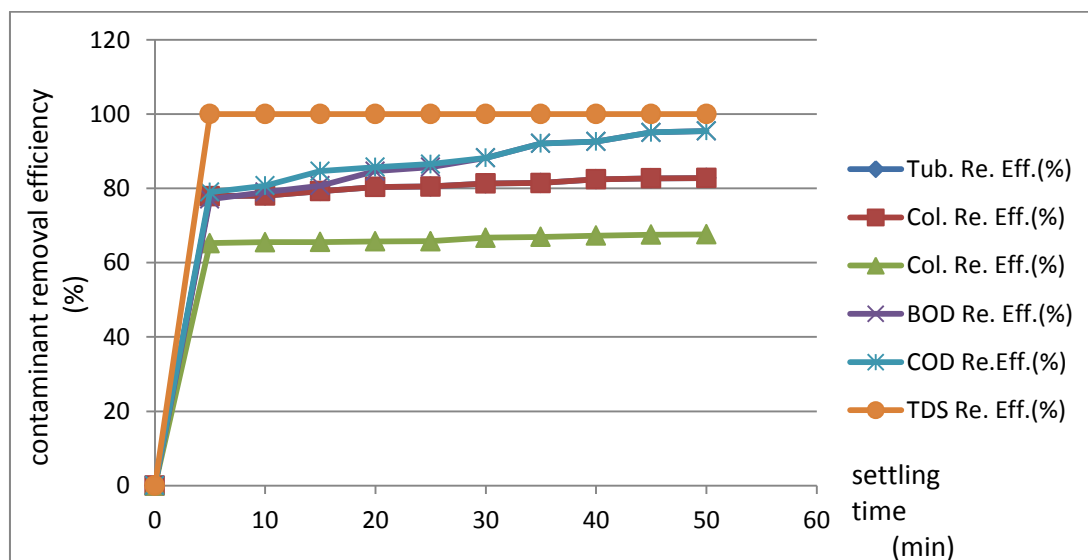


Figure 4: Contaminants removal efficiency vs settling time at pH of 6.0, for pawpaw seed dose of 400mg/l and temperature of 40°C for MVSW

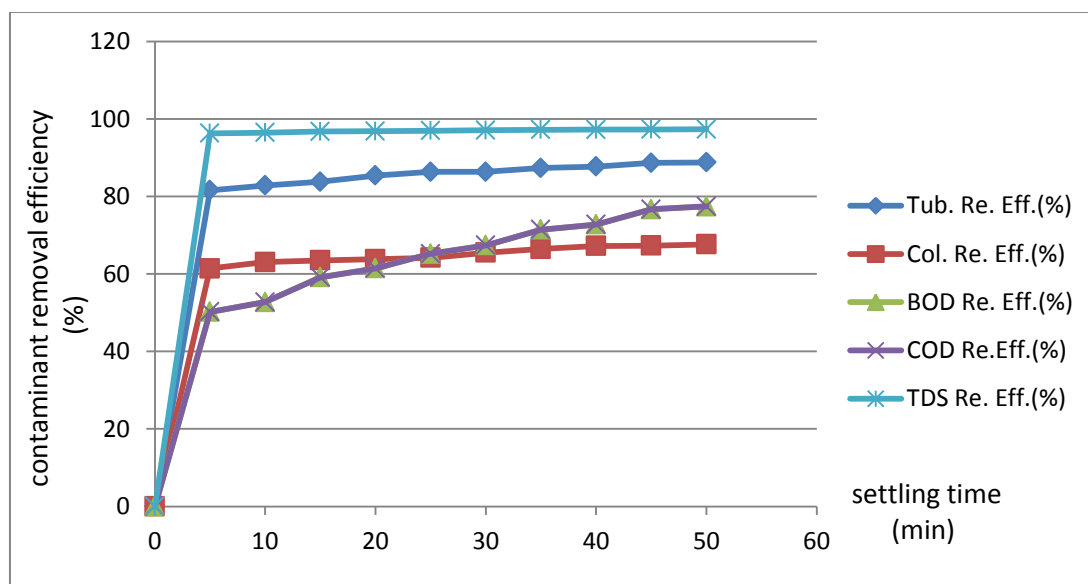


Figure 5: Contaminants removal efficiency vs settling time at pH of 8.0, for pawpaw seed dose of 400mg/l and temperature of 30°C for MVSW

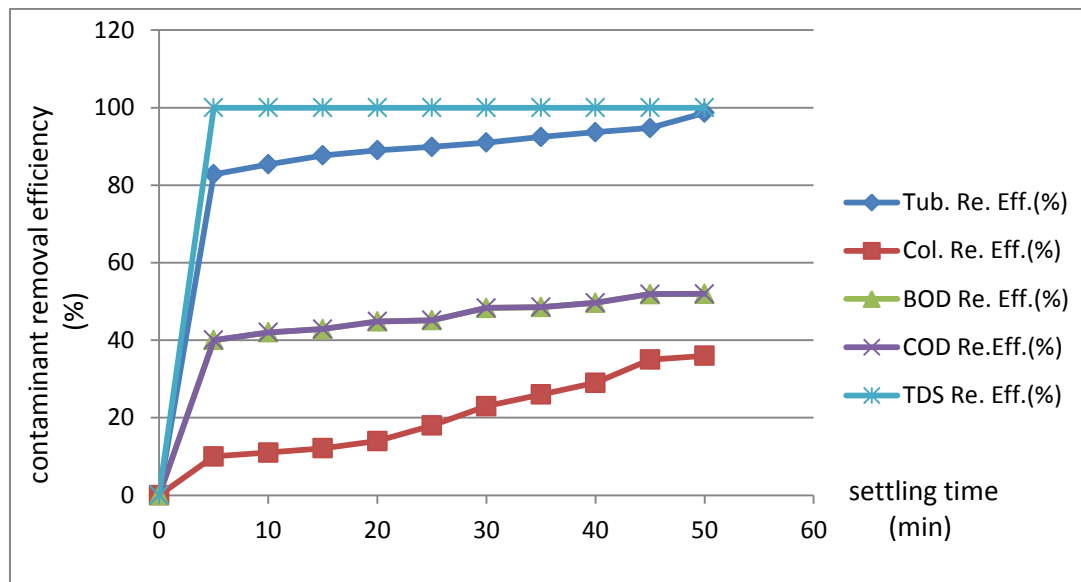


Figure 6: Contaminants removal efficiency vs settling time at pH of 6.0, for pawpaw seed dose of 400mg/l and temperature of 30°C for MVSW

3.3 Statistical Analysis

The ANOVA tool provided by the Design Expert software was used to carryout the analysis of variances. The results of the four-way ANOVA-depicted by P-values less than 0.05 at 5% significance level, F-values less than F-table (Menkiti et al., 2012) and coefficient of determination (R^2) values nearing unity (Ghafari et al., 2009) are a pointer to the significances as well as the adequacies of the proposed models. For the turbidity removal efficiency studies, the ANOVA table 4, the P-values for main effects are 0.0489, 0.0383, 0.0483 and 0.039 respectively for p^H (X_1) coagulant dosage (X_2), settling time (X_3) and temperature (X_4). From the result, the coagulant dosage exhibits the most main effect with P-value of 0.0383, while the p^H (X_1) shows the least main effect with P-value of 0.0489. This result compares favourably with the result of Babayemi and fOnukwuli, (2005) who held the same opinion. However, this study disagreed with their view of dropping the p^H in the final model equation since its P-value is less than the 0.05 bench mark. The p^H is still retained in the final model equation of this study. Equally, there are interactive effects between X_1X_2 , X_1X_4 , and X_2X_4 , as their P-values are less than 0.05 and are accordingly included in the final model equation. However, those of X_1X_3 , X_2X_3 and X_3X_4 , are dropped because their P-values are greater than 0.05. The P-values for the quadratic effects X_1^2 , X_2^2 , X_3^2 and X_4^2 are all significant as they are less than 0.0001 in each of the cases and are equally included in the final model equations. A main effect is the effect of a single independent variable on a dependant variable ignoring all other independent variable while interactive effect occurs when the effect of one variable depends on the values of another variable. The quadratic effect is an interaction term where a factor interacts with its self.

Similarly, in the study of colour removal efficiency, the main effects are 0.0490, 0.0381, 0.0487 and 0.0384. The pattern exhibited above in turbidity removal efficiency is also repeated in the main effects, interactive and quadratic effect

respectively because the benchmark of 0.05 is met in those respective conditions and are accordingly included in the final model coded equation.

The model P-values for turbidity and colour removal efficiencies are all less than 0.0001 showing the models are significant for the PPSC-treated MVSW.

The model P-values for turbidity and colour removal efficiencies are all less than 0.0001 shaving the models are significant for the PPSC-treated MVSW. The probability value (P-value) indicates how likely it is that the data could have occurred under the null hypothesis (i.e that model terms are not significant). The smaller this value, the stronger the evidence that the null hypothesis should be rejected (Wasserstein and Lager 2016). The models F-values are 25.02 and 20.50 for turbidity and colour removal efficiencies. These values confirm that the models are significant and better fit the experimental data. It further shows the adequacies of the purposed models. The Lack-of-fit results show the values are 2.87 and 1.67 respectively for turbidity and colour removal efficiencies. These values confirm that the lack- of- fits are not significant. This implies that the model in each case adequately described the functional relationship between the experimental factors and the response variables. The regression coefficient (coefficient of determination) R^2 , for the responses of turbidity and colour are 0.9616 and 0.9535 respectively. R^2 is a statistical measure of how close the data are to fitted regression line. According to Ghaferi et al., 2009, R^2 values approaching unity lend credence to the significance as well as adequacy of the proposed models. According to Menkiti et al., 2012, R^2 close to unity is desirable and the closer the better. From the result therefore, it implies that the proposed models explained the experimental data up-to 96.16% for turbidity and 95.35% for colour removal efficiencies respectively. The results for the adjusted R^2 are 0.9231 and 0.9070 respectively for turbidity and colour responses.

TABLE 4: Result of the ANOVA for response surface quadratic model for turbidity removal efficiency for PPSC – treated MVSW.

| Source | Sum of squares | Coefficient estimate | df | Standard error | Mean square error | F-value | P-value Prob>F | | R ² | Ratios |
|--------------------------|----------------|----------------------|----|----------------|-------------------|---------|----------------|---------------|----------------|--------|
| Model | 1519.10 | | 9 | | 168.79 | 25.02 | < 0.0001 | significant | | |
| Intercept | | 100.35 | 1 | | | | | | | |
| A- X ₁ | 126.38 | 1.05 | 1 | | 126.36 | 66.70 | 0.0489 | | | |
| B- X ₂ | 166.95 | -2.64 | 1 | | 166.95 | 73.32 | 0.0387 | | | |
| C- X ₃ | 218.28 | -0.5875 | 1 | | 218.28 | 61.11 | 0.0398 | | | |
| D- X ₄ | 138.61 | 1.27 | 1 | | 138.61 | 53.68 | 0.0390 | | | |
| AB | 96.76 | 0.6500 | 1 | | 96.76 | 9.40 | 0.0414 | | | |
| AC | 12.96 | 0.9000 | 1 | | 12.96 | 0.1802 | 0.6777 | | | |
| AD | 105.89 | 2.81 | 1 | | 105.89 | 11.75 | 0.0391 | | | |
| BC | 25.60 | 1.27 | 1 | | 25.60 | 0.3560 | 0.5603 | | | |
| BD | 76.94 | -1.30 | 1 | | 76.94 | 7.45 | 0.0417 | | | |
| CD | 13.54 | 0.9200 | 1 | | 13.54 | 0.1883 | 0.6710 | | | |
| A ² | 208.48 | -17.16 | 1 | | 208.48 | 112.35 | < 0.0001 | | | |
| B ² | 277.35 | -17.89 | 1 | | 277.35 | 122.03 | < 0.0001 | | | |
| C ² | 211.17 | -18.23 | 1 | | 211.17 | 126.71 | < 0.0001 | | | |
| D ² | 299.54 | -18.47 | 1 | | 299.54 | 130.12 | < 0.0001 | | | |
| Residual | 59.54 | | 9 | | 6.62 | | | | | |
| Lack of fit | 59.54 | | 6 | | 9.92 | 2.87 | | Insignificant | | |
| Pure error | 0.140 | | 4 | | 0.035 | | | | | |
| R ² | | | | | | | | | 0.9616 | |
| Adjusted R ² | | | | | | | | | 0.9231 | |
| Predicted R ² | | | | | | | | | 0.7420 | |
| Adequate precision | | | | | | | | | | 13.954 |
| C.V (%) <10%) | | | | | | | | | | 7.77 |

TABLE 5: Result of the ANOVA results for response surface quadratic model for colour removal efficiency for PPSC- treated MVSW.

| Source | Sum of squares | Coefficient estimate | df | Standard error | Mean square error | F-value | P-value Prob>F | | R ² | Ratios |
|--------------------------|----------------|----------------------|----|----------------|-------------------|---------|----------------|----------------|----------------|--------|
| Model | 1760.74 | | 9 | | 195.64 | 20.50 | < 0.0001 | significant | | |
| Intercept | | 68.03 | 1 | | | | | | | |
| A- X ₁ | 117.00 | -0.0842 | 1 | | 117.00 | 78.00 | 0.0488 | | | |
| B- X ₂ | 263.73 | -3.32 | 1 | | 263.73 | 64.30 | 0.0385 | | | |
| C- X ₃ | 128.12 | 1.08 | 1 | | 128.12 | 85.45 | 0.0401 | | | |
| D- X ₄ | 217.32 | 3.01 | 1 | | 217.32 | 93.54 | 0.0391 | | | |
| AB | 44.89 | 1.68 | 1 | | 44.89 | 7.31 | 0.0417 | | | |
| AC | 12.01 | -0.8662 | 1 | | 12.01 | 0.1958 | 0.6649 | | | |
| AD | 70.06 | -1.03 | 1 | | 70.06 | 7.81 | 0.0395 | | | |
| BC | 9.00 | -0.7500 | 1 | | 9.00 | 0.1467 | 0.7074 | | | |
| BD | 120.89 | -2.75 | 1 | | 120.89 | 9.70 | 0.0412 | | | |
| CD | 28.84 | 1.34 | 1 | | 28.84 | 0.4702 | 0.5041 | | | |
| A ² | 136.17 | -13.98 | 1 | | 136.17 | 87.46 | < 0.0001 | | | |
| B ² | 234.09 | -15.21 | 1 | | 234.09 | 103.45 | < 0.0001 | | | |
| C ² | 130.60 | -15.16 | 1 | | 130.60 | 102.84 | < 0.0001 | | | |
| D ² | 204.30 | -14.85 | 1 | | 204.30 | 98.63 | < 0.0001 | | | |
| Residual | 58.65 | | 9 | | 6.52 | | | | | |
| Lack of fit | 58.65 | | 6 | | 9.78 | 1.67 | | in significant | | |
| Pure error | 0.025 | | 4 | | 0.0063 | | | | | |
| R ² | | | | | | | | | 0.9555 | |
| Adjusted R ² | | | | | | | | | 0.9070 | |
| Predicted R ² | | | | | | | | | 0.7670 | |
| Adequate precision | | | | | | | | | | 12.36 |
| C.V (%) <10%) | | | | | | | | | | 8.61 |

The adjusted R² is an adjustment for the R² that takes into account the number of variables in a data set. According to Menkiti et al., 2012, the closeness of R² with adjusted R² is a necessity. This implies from the results that the proposed models are able to account for the number of variables in the data set. For the predicted R², the results show that the response of turbidity has 0.7420 while colour has 0.7670. Predicted R² is used to determine how well a regression model

makes predictions. It helps to identify cases where the model provides good fit for the existing data but isn't as good at making predictions. From the results, the differences between the adjusted R² and the predicted R² are less than 0.200 implying that the predicted R² is in reasonable agreement with the adjusted R² (WWW.statease.com). From the above reasoning, the study therefore infers that the proposed models are predictive in addition to provision of good fit for the

experimental data. The adequate precision results for the responses are 13.95 and 12.36dB respectively for turbidity and colour. Adequate precision measures the signal power to noise power ratio. To detect the quality of a signal, the signal to noise ratio term is used. A ratio of greater than 4 is usually desirable (WWW.statease.com). All the values shown by the results are all greater than 4 indicating adequate signals. This implies that the proposed quadratic model equations can be used to navigate the design space. The coefficient of variation CV results are 7.77% and 8.61% for turbidity and colour responses. The CV measures the dispersion of data points around the mean. Since the values are all less than 10%, the reproducibility of the models are confirmed (Ahmadi et al., 2005), and indicate that the precision and reliability of the experiments are good. The diagnostic plots of the predicted response values against the actual values for turbidity and colour responses are shown in figures “7 and 8”.

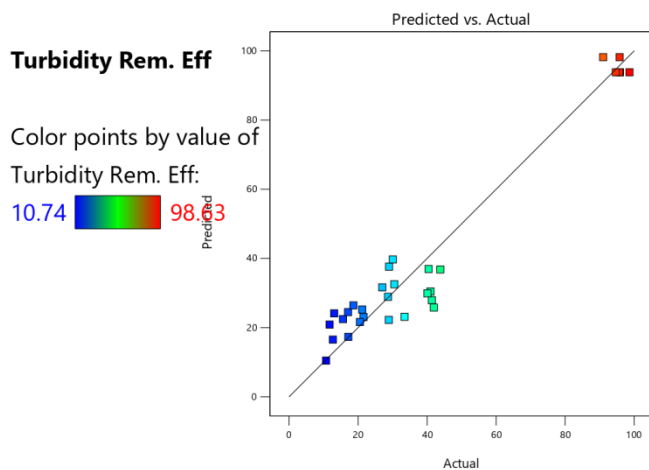


Figure 7: Contour plot for turbidity in PPSC-treated MVSW (Predicted vs Actual).

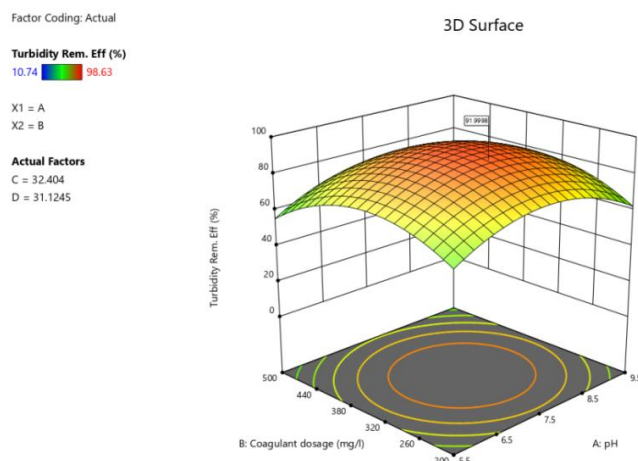


Figure 8: 3-D surface plot of turbidity (Coagulant dosage/ P^H)

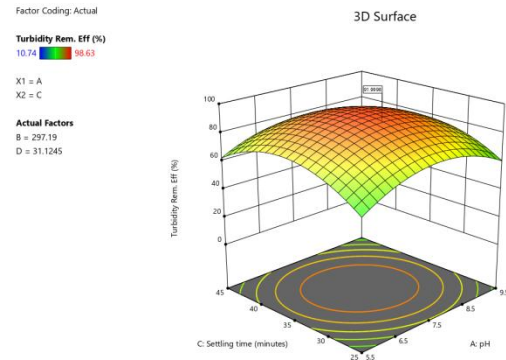


Figure 9: 3-D surface plot of turbidity (Settling time/ P^H)

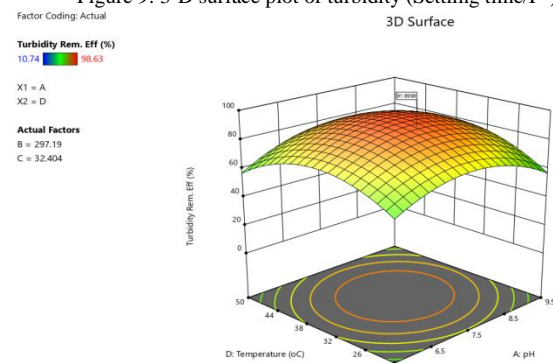


Figure 10: 3-D surface plot of turbidity (Temperature/ P^H)

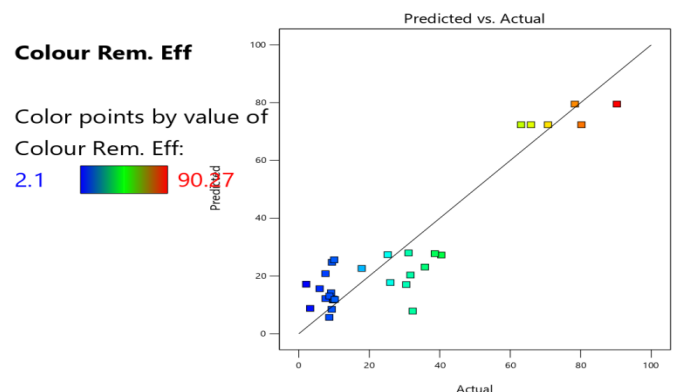


Figure 11: Contour plot for Colour in PPSC-treated MVSW (Predicted vs Actual).

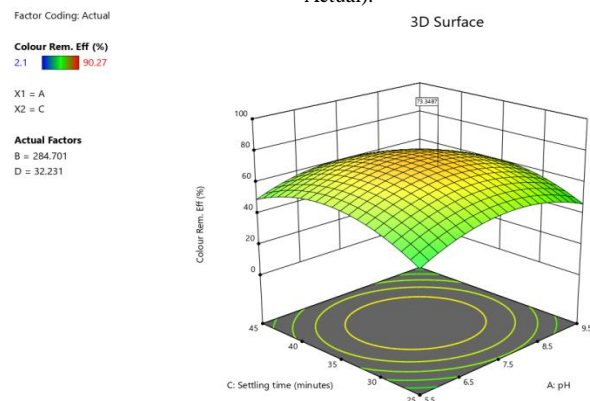


Figure 12: 3-D surface plot turbidity (Coagulant dosage/ P^H)

Factor Coding: Actual

Colour Rem. Eff (%)
2.1 90.27

X1 = A
X2 = B

Actual Factors
C = 33.0286
D = 32.231

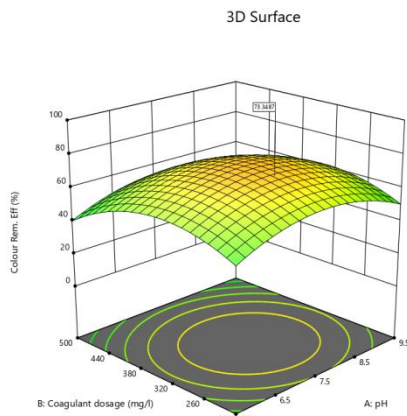


Figure 13: 3-D surface plot turbidity (Coagulant dosage/ p^H)

Factor Coding: Actual

Colour Rem. Eff (%)
2.1 90.27

X1 = A
X2 = D

Actual Factors
B = 284.701
C = 33.0286

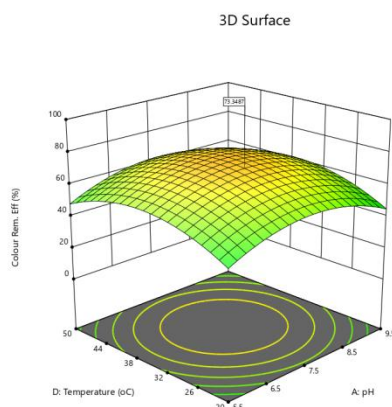


Figure 14: 3-D surface plot turbidity (temperature/ p^H)

The plots were employed to verify the suitabilities of the models for predictions and provide useful agreement between the experimental data and the values obtained from the models. They show the effects of the models and compare them against the null set. From the diagrams, most of the points are close to the straight lines with narrow confidence bands, showing that the predicted-against-actual-plots are satisfactory and the models fit well. The models in terms of coded factors are given in equations 6 and 7.

$$Y_1 = 100.35 + 1.05X_1 - 2.64X_2 - 0.5875X_3 + 1.27X_4 + 0.6500X_1X_2 + 2.81X_1X_4 - 1.30X_2X_4 - 17.16X_1^2 - 17.89X_2^2 - 18.23X_3^2 - 18.47X_4^2 \quad (6)$$

$$Y_2 = 68.03 - 0.0842X_1 - 3.32X_2 + 1.08X_3 + 3.10X_4 + 1.68X_1X_2 - 1.03X_1X_4 - 2.75X_2X_4 - 13.98X_1^2 - 15.21X_2^2 - 15.16X_3^2 - 14.84X_4^2 \quad (7)$$

Y_1 and Y_2 stand for turbidity removal and colour removal efficiencies respectively.

3.4 Process Optimization

Optimization of the process was carried out with the following optimization set goals:

X_1 : Operate at p^H of 6.0-10.0, the observed optimal region of p^H .

X_2 : Minimize the dosage to economize the coagulants, thereby saving cost.

X_3 : Minimize settling time to boost turnover per day.

X_4 : Minimize temperature to prevent floc breakage during reaction and reduce cost of heating.

Y_1 : Target turbidity removal efficiency of 90.0%. This is above the minimum of 88% that will give the WHO standard turbidity of 5NTU for portable water and FEPA standard of <1.0 for water disposal.

Y_2 : Target colour removal efficiency of 88%. This is above the maximum of 76% obtained from the OFAT experiment.

The results obtained from process optimization are presented in 3-D surface plots of figures 8, 9 10, 12, 13 and 14.

The 3-D surface plots are three-dimensional graph that are useful for investigating desirable response values and operating conditions. The graphs depict two major information: Optimal values of the response variables on one hand and the interactive effects of the cardinal coag-flocculation coordinates on the other hand. Contour plots are used to see how a response variable relates to two predictor variables. 3-D plots are companion plots to the contour plot. In the figures, A, B, C and D represent the independent variables (X_1 , X_2 , X_3 and X_4). The numerical optimization results show that under the optimization set goals and targets, the optimal process parameters for the PPSC-in-MVSW system were p^H of 7.48, 330mg/l coagulant dosage, settling time of 30mins and temperature of 34°C. At this point, the optimal turbidity and colour removal efficiencies we found to be 98.03% and 62.51% respectively.

3.5 Confirmatory Tests

Confirmatory tests were carried out at the predicted parameter points and the results of the experiment tabulated against the predicted results shown in table 6.

TABLE 6: Result of Experimental Versus Predicted Response Values of the PPSC-in-MVSW system.

| Independent variables optimal levels | | | | Response optimal levels | | | |
|--------------------------------------|-----------------------|---------------|------------------|-------------------------|---------------------|------------------------|---------------------|
| $X_1(p^H)$ | X_2 (dosage (mg/l)) | X_3 (min s) | $X_4(^{\circ}C)$ | Experimental Y_1 (%) | Predicted Y_1 (%) | Experimental Y_2 (%) | Predicted Y_2 (%) |
| 7.48 | 330 | 30 | 34 | 98.03 | 98.00 | 62.51 | 62.46 |

These results validate the predictions by the models; thus the models truly represent the behavior of the system studied. Finally, the result of the MVSW raw water characteristics, optimum treated values of PPSC-in-MVSW characteristics compared to WHO and FEPA standards is shown in table 7.

TABLE 7: Result of optimum treated values of PPSC-in-MVSW characteristic compared to WHO and FEPA Standard Values.

| Parameter | MVSW characteristic | Degree of optimum treatment (%) | Optimal values achieved | WHO | FEPA |
|-----------------|---------------------|---------------------------------|-------------------------|--------|-------|
| Turbidity (NTU) | 8.20 | 98.03 | 0.16 | ≤ 5.0 | < 1.0 |
| Colour (PCU) | 31.10 | 62.51 | 11.66 | ≤ 15.0 | 7.0 |

From the result, the treated water is within the WHO mandatory specification for portable water in both the turbidity and colour. It also met the FEPA limit for water disposal purpose in turbidity value but is outside the requirement in colour.

IV. CONCLUSION

From the result of physiochemical characteristics of MVSW studied, the values of contaminants of turbidity and colour are clearly above the WHO limits for portable water and FEPA standards for water disposal purposes. This is therefore a clear indication of their pollution tendencies and requirement of treatment to combat the consequences of pollution. The result of the comparison of optimum treated values against standards of WHO and FEPA concluded that PPSC is a useful plant-based coagulant effective for water treatment application. It is effective in the coag-flocculation treatment of the MVSW sample. The turbidity and colour removal efficiencies from the MVSW are described by quadratic models as indicated in this study. The optimal process parameter levels are as presented in this work.

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Conflict of Interest Statement

We declare that we have no conflict of interest.

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