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Removal of Acid Red 27 (Amaranth Dye) from Synthetic Wastewater using Natural Coagulants

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Abstract
A Physicochemical study for the treatment of synthetic dye wastewater was performed for the possible use of natural coagulants in the coagulation-flocculation method. The coagulation-flocculation method was used to treat aqueous solution containing varying concentrations of anionic dye. The effectiveness of this method was assessed using Chicken Bone Coagulant (CBC) and Bambara nut Shell Coagulant (BSC). The jar test method was used to measure the effects of pH, coagulant type, temperature and dosage on colour removal. The results showed that highest Acid Red 27 (AR27) removal efficiency for CBC is 94.7% at pH of 4 while that of BSC is 60.3% at settling time of 30 minutes. The results also showed that CBC is more efficient than BSC in the treatment of industrial textile wastewater sample.

Keywords: Removal, Acid red 27, Amaranth dye, wastewater, natural coagulants

1. Introduction

The problem many countries of the world are facing today is access to clean water. As the world becomes more populous, water becomes scarcer. According to UN 1998 world medium population projection, more than 2.8billion people in 48 countries will face water stress or scarce condition by 2025 and 40 of these countries are in west Asia, North Africa or sub-Saharan Africa (Nellemann and Kaltenborn, 2009). As a result of contamination, both boreholes and rivers generally have poor quality water in the affected areas leading to diseases such as cholera, bilharzias and diarrhea (Menkiti, Nnaji, Nwoye and Onukwuli, 2010). Some observers have estimated that by 2025 more than half of the world population will be facing water vulnerability to contamination, hence the importance of waste water treatment (Public Health News, 2004). Wastewater can be defined as a combination of water carrying waste from residences, institutions, industrial and commercial establishments, surface runoff or storm water as the case maybe (Metcalf and Eddy, 2003). Wastewater contains 98% water and rest, the contaminants. The contaminants in wastewater include suspended solids (body waste i.e. faeces, food waste, toilet paper etc.), biodegradable dissolved organic compounds, inorganic solids, nutrients, metals and pathogenic microorganisms. Wastewater can come from different industries like cosmetics industry, brewery industry, petrochemical industry, pharmaceutical industry, textile industry, coalmine, plastics industry, etc.

Amaranth is an anionic dye. The name was taken from amaranth grain, a plant distinguished by its red colour and edible protein-rich seeds. It can be applied to natural and synthetic fibres, leather, and paper and phenol-formaldehyde resins. Textile industries as an instance consume a large quantity of water and produce large volumes of coloured wastewater which is heavily polluted with these dyes, textile auxiliaries and chemicals used in the dyeing and finishing processes (Roussy, Vooren, Dempsey and Guibal, 2005). Such wastewater has harmful effects on the environments when discharged into water bodies. Regulatory bodies have emphasized the importance of reducing waste stream generation. Wastewater treatment methods abound, and they include: alkaline chemical precipitation by lime addition, adsorption, ion exchange, reverse osmosis, neutralization, coagulation and flocculation etc (Menkiti, Ndaji, Ezemagu, Oyoh, Menkiti, 2015). However, coagulation and flocculation process is used in this research work because of its little or no adverse effect to the environment coupled with availability of the coagulants.

Coagulation or flocculation is the tendency of the particulate phase of colloidal dispersion to aggregate into flocs to create large conglomeration of elementary particles with the occluded liquid (Coulson and Richardson, 2002). In clearer terms, coagulation is the destabilisation of colloids by neutralizing the forces that keep them apart while flocculation is the action of polymers to form bridges between the flocs and bind the particles into large agglomerates or clumps. Coagulation is a chemical reaction which occurs when a chemical or coagulant is added to the water. The coagulant encourages colloidal material in the water to join together into small aggregates or flocs. The most commonly used artificial coagulant in water treatment is alum, $Al_2(SO_4)_3$ but it can be harmful to human when used for long even at controlled concentrations. On the other hand, natural coagulants, unlike the artificial ones are biodegradable, non-toxic and locally available. They are mainly composed of polymers of natural origin extracted from plants, algae or animals which have the ability to destabilize or enhance flocculation of the suspended particles. These include polysaccharides and water-soluble substances that can coagulate and or flocculate.

Bambara groundnut is widely grown in many states in Nigeria. The Bambara nut shell just like chicken bone is a waste material which contributes to environmental pollution. Both are however rich in polymers, which make them potential good coagulants. Hence, this study focused on investigating the potential of chicken bone coagulant (CBC) and Bambara nut shell coagulant (BSC) in removing amaranth dye from synthetic wastewater by coagulation.

2.0 Material and methods

2.1 Materials

The coagulants were gotten from Chicken bone (CB) and Bambara nut shell (BS). CB was collected from Awka metropolis while BS was collected from Eke-Awka market, Anambra State, Nigeria. The chemicals used were obtained from Bridge head market Onitsha and Chemical Engineering Laboratory, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria and were of analytical grade.

2.2 Methods

2.2.1 Preparation of the coagulants

The CB and BS were washed and sundried for 3 days. They were then ground and sieved through 300mm sieve. The active substance in the BS was not extracted from the powder, as it will also aid coagulation and colour removal, when used as a whole.

2.2.2 Simulation of wastewater

0.1g of Amaranth dye i.e. 100mg was weighed on the digital weighing balance and added to a conical flask containing 1000ml of distilled water.

2.2.3 Characterisation of the coagulants and wastewater

The coagulants were characterized using AOAC (AOAC, 1984) to determine the proximate analysis while American Public Health Association, APHA (1992) method was used to characterise the wastewater to determine its physicochemical properties. The morphologies of the coagulants were examined using Scanning Electron Microscope (SEM) while XRF analysis (for elemental composition) of the coagulants was carried out using X-Ray fluorescence Spectrometer, Skyray EDX 3600B model.

2.2.4 Coagulation method

The treatment of the effluent by coagulation was carried out using simulated jar test procedure.

500ml of the synthetic wastewater was poured into five (5) various beakers. 0.5 g of CBC was mixed with the solution at a pH of 2 in a 500 ml beaker placed in a water bath at room temperature. The mixture was vigorously stirred at a speed of 400 rpm for 5 minutes then gradually stirred for additional 15 minutes. The suspension was allowed to settle for 30 minutes and 5 ml of the sample was withdrawn with a syringe for the AR27 removal analysis. The procedure was repeated for coagulant dosages (1 g, 2 g, 4 g and 6 g); pH (4.0, 6.0, 8.0 and 10.0); initial dye concentrations (20mg/l, 40mg/l, 60mg/l, 100mg/l and 200mg/l); settling time (0, 3, 5, 10, 15, 20, 40, 50 and 60 minutes) and temperature (35ºC, 40ºC, 50ºC and 60°C).

Destabilisation of the colour colloids in each case result from surface charge neutralisation followed by removal by filtration. The light absorbance and final concentration in each case were obtained using the UV Spectrophotometer, HACH DR/3000 model. And the AR27 removal efficiency for each case was obtained using equation (1) below:

$$Removal\ Efficiency, RE\ (\%) = \frac{Co-C}{Co}\ x\ 100\% \qquad (1)$$

Where Co = initial concentration = 100mg/l (apart from dye concentration variable), C = final concentration.

3.0 Results and Discussions

3.1 Characterisation of coagulants and wastewater

3.1.1 Proximate analyses of the coagulants

Table 1: Proximate analysis of the chicken bone and Bambara nut shell coagulants

Parameter %	CBC	BSC
Moisture content	5	4.9
Crude fibre	1.75	62.1
Ash content	47.6	3.8
protein	7	17.15
lipid	1.3	0.14
carbohydrate	37.35	11.91

The proximate analyses of the CBC and BSC are shown in Table 1. From the table, carbohydrate is dominant in the CBC while crude fibre has the highest percentage in BSC. It is also observed that CBC has higher moisture, ash, lipid and carbohydrates contents than BSC and this could have contributed to the effectiveness of the CBC in AR27 removal as compared to BSC.

3.1.2 XRF analysis of the coagulants

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Figure 1: XRF analysis of the BSC

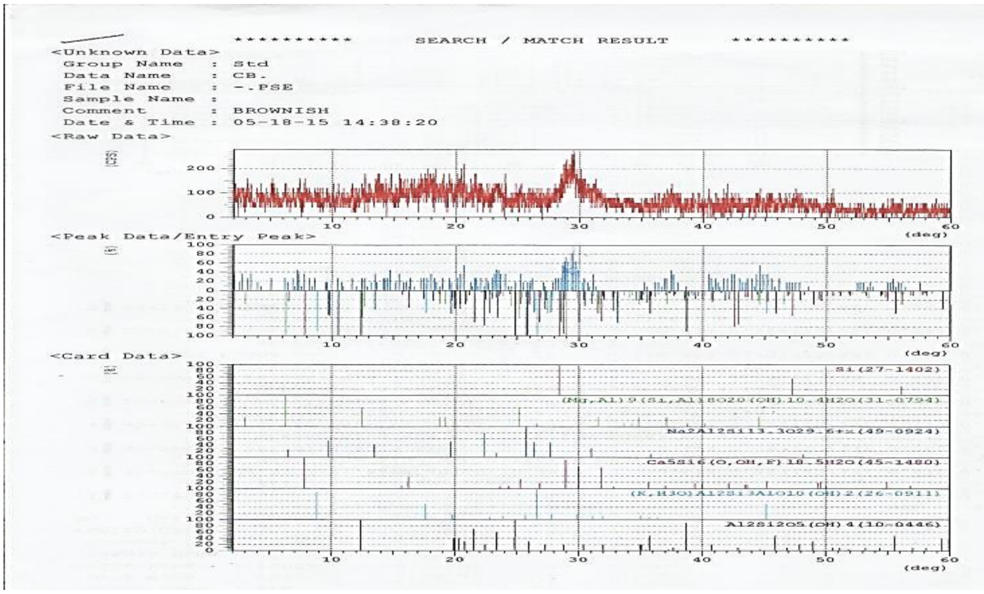

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Figure 2: XRF analysis of the CBC

The XRF (x-ray fluorescence) analysis of the coagulants CBC and BSC are shown in Figures 1 and 2 respectively. The Figures show the interaction of atoms in these coagulants.

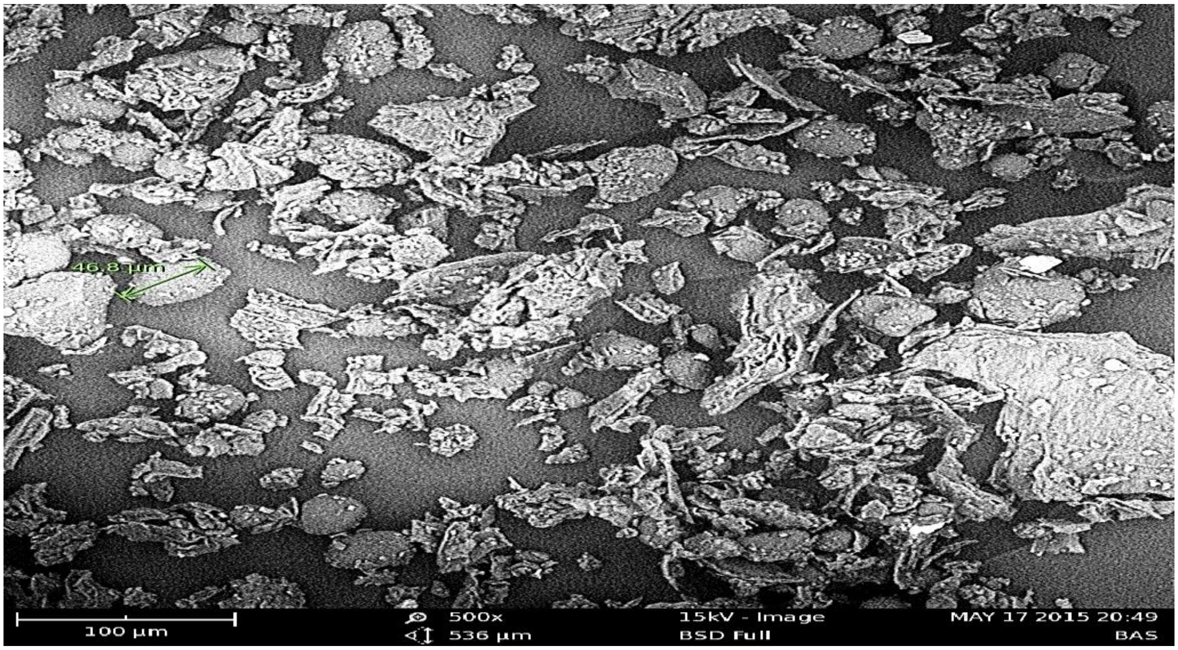

Figure 3: SEM analysis for BSC at a magnification of 500*

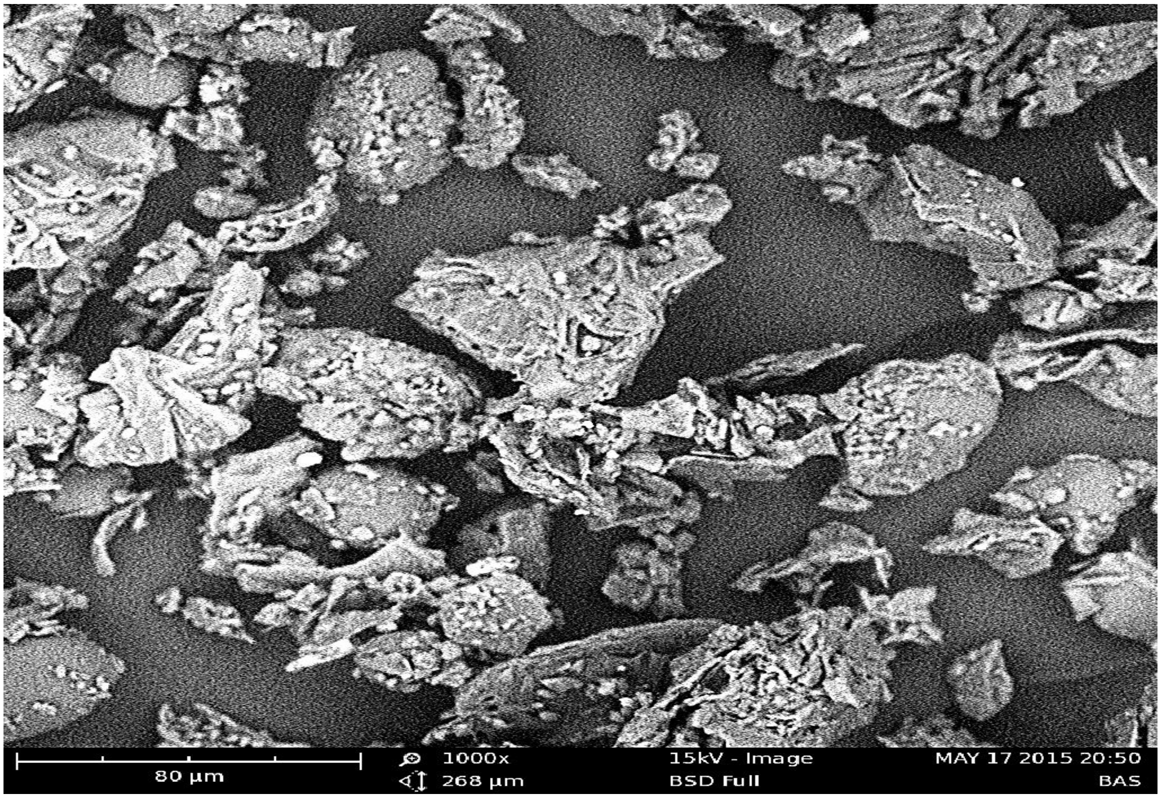

Figure 4: SEM analysis for BSC at a magnification of 1000*

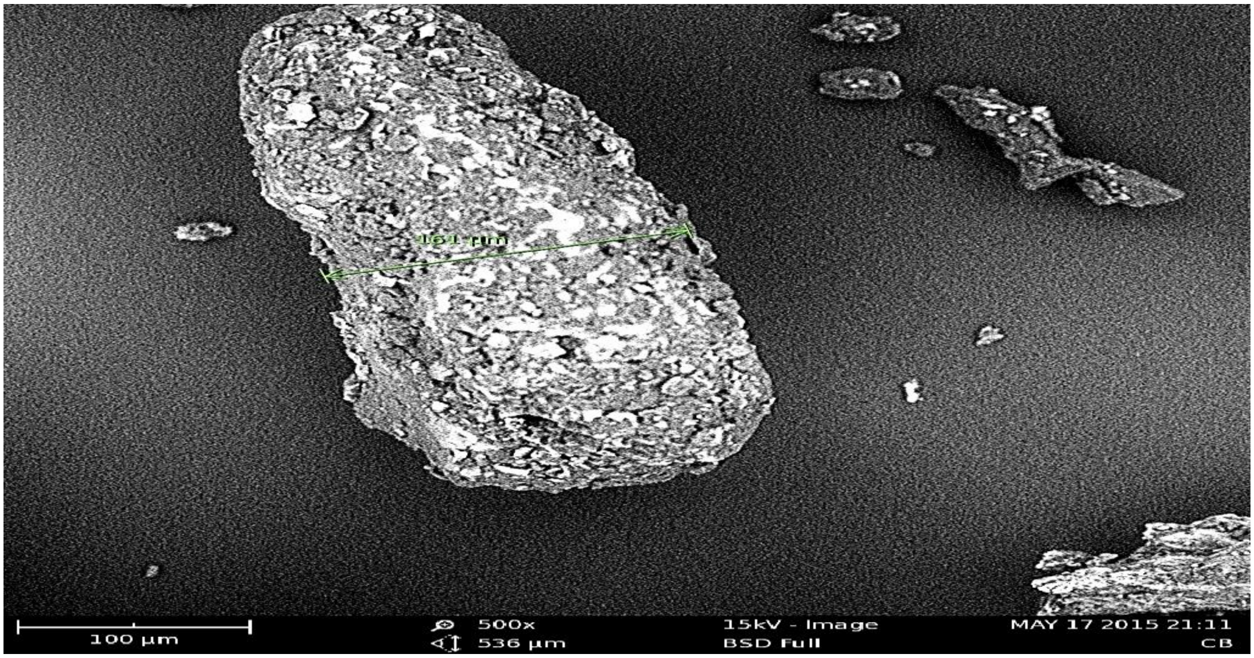

Figure 5: SEM analysis for CBC at a magnification of 500*.

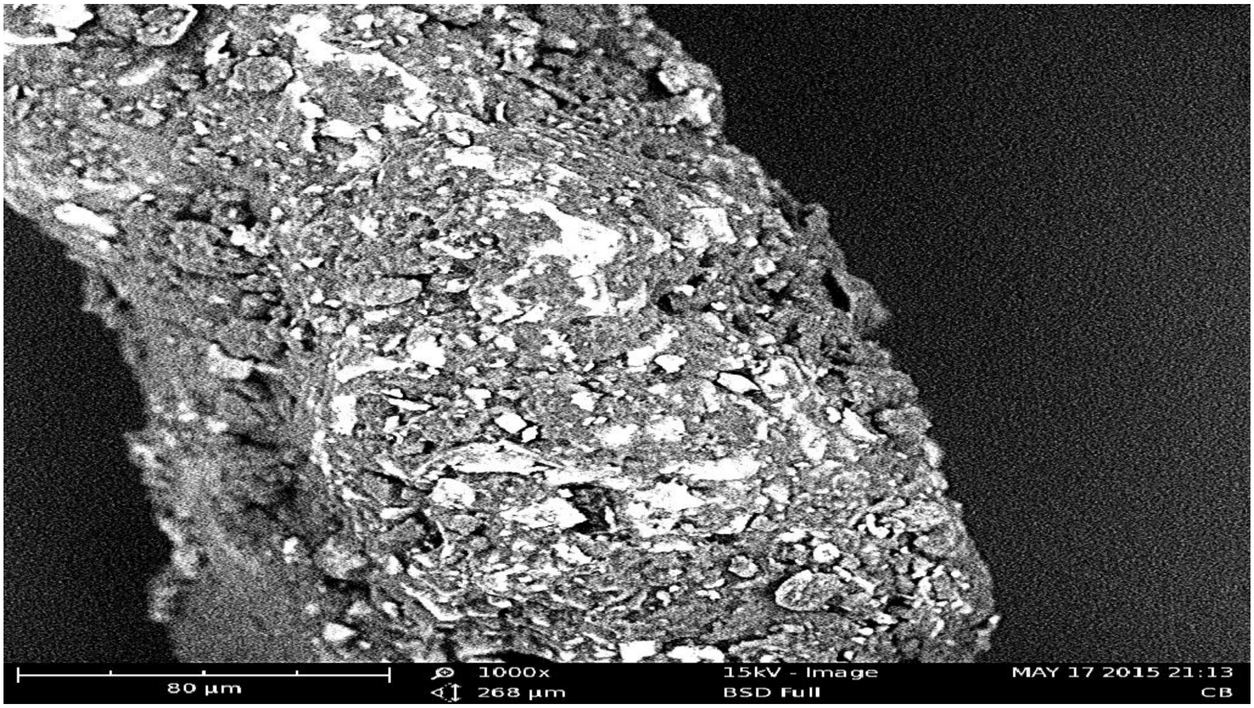

Figure 6: SEM analysis for CBC at a magnification of 1000*

The morphologies of the CSC at 500* and 1000* magnifications are shown in Figs 3 and 4 respectively and Figs 5 and 6 for BSC at 500* and 1000* magnifications respectively.

3.1.4 Physicochemical properties of the wastewater

Table 2: Physicochemical Properties of the simulated wastewater

PARAMETER	CONCENTRATION
Iron, ppm	0.286
Mercury, ppm	0.560
Lead, ppm	0.181
Copper, ppm	0.185
Manganese, ppm	0.384
pH	6.54
Conductivity, µS/cm	120.60
Hardness, mg/l	55.20
Alkalinity, mg/l	298
Turbidity, NTU	30
Total solid, mg/l	2.455
Total dissolved solid, mg/l	1.22
Total suspended solid, mg/l	1.235
OD,1 mg/l	50.50
OD, 5mg/l	41.20
Biological oxygen demand, mg/l	8.40
Chemical oxygen demand, mg/l	608.56

The result of the physicochemical analysis of the simulated wastewater is presented in Table 2. The turbidity of the wastewater is beyond the internationally acceptable limit. It also has colour. Hence there is need for treatment before discharging it to the environment.

3.2 Effect of process parameters on coagulation

3.2.1 Effect of coagulant dosage

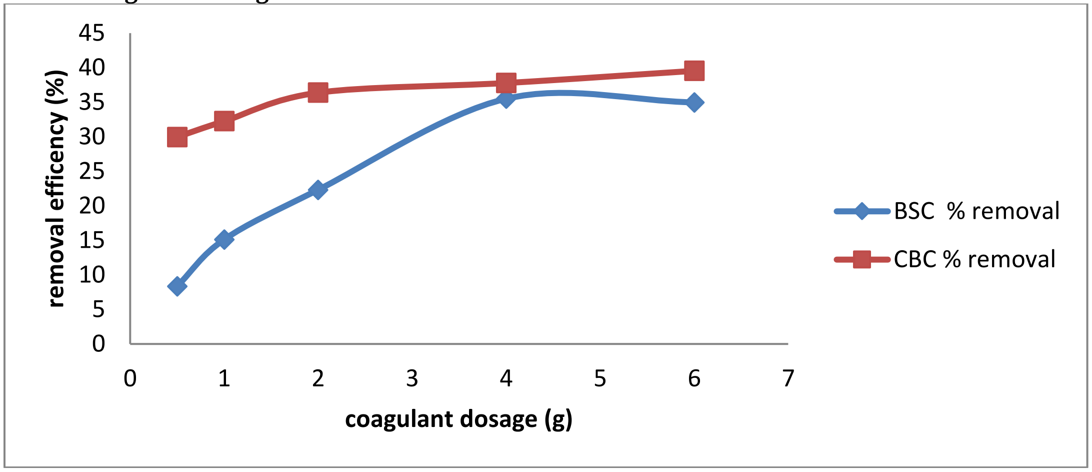

Figure 7: A graph of removal efficiency against coagulant dosage

From figure 7, it is observed that the highest percentage removal of the AR27 was at coagulants dosages of 4g and 6g for BSC and CBC respectively. Hence it can be said that at this point the positive charges present on the coagulants were able to neutralize to the highest extent, the negative charges in the wastewater. Also from the graph it is observed that the higher the chicken bone coagulant dosage, the greater the removal efficiency. On the other hand, with the BSC, the removal efficiency increased to a maximum at 4g dosage but started declining with increase in the coagulant dosage possibly due to re-stabilisation phenomenon and this tends to be in line with the explanation given by (Himanshu and Vashi, 2012).

3.2.2 Effect of pH

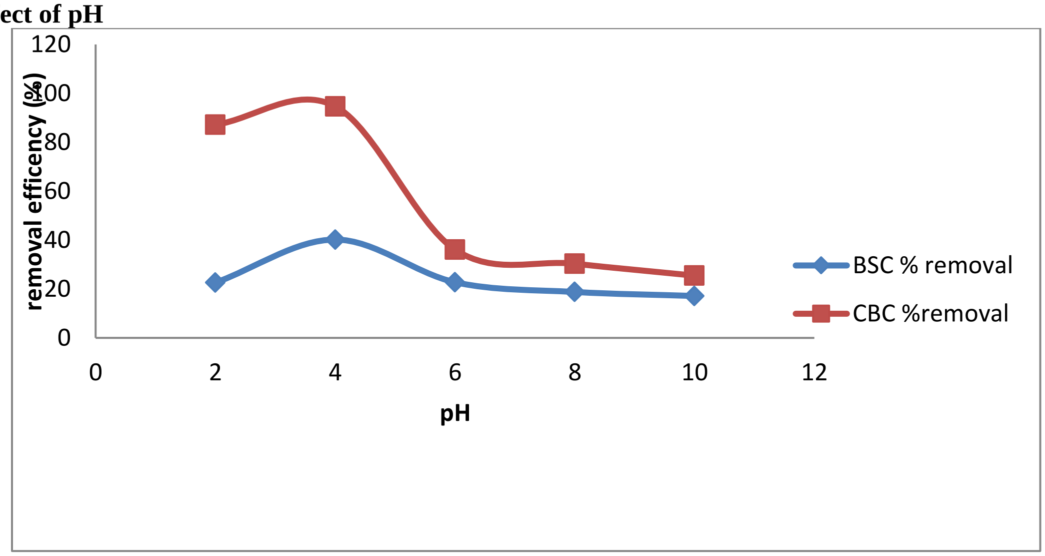

Figure 8: The effect of pH on the removal efficiency.

From figure 8, it is observed that at higher pH of the wastewater the coagulating power for both CBC and BSC decreases and at lower pH values of the wastewater their coagulating powers increase, making us to understand that the coagulants both coagulates well in an acidic medium. There is an increase in the positively charged hydrogen ion which makes the positive to negative charge ratio to be high at the surface of contact between the coagulants and the dyes in the wastewater hence making the removal percentage high by giving a high neutralization rate.

But at high pH (alkaline condition) of the wastewater the coagulating power of the coagulants tends to be weak, this is seen in the graph where the curve slopes downwards and this is because the ratio of the positive to negative charges present is low at the surface of contact between the coagulants and the dye in the wastewater hence making the removal percentage low. This result follows the trend provided by (Himanshu and Vashi, 2012).

3.2.3 Effect of settling time

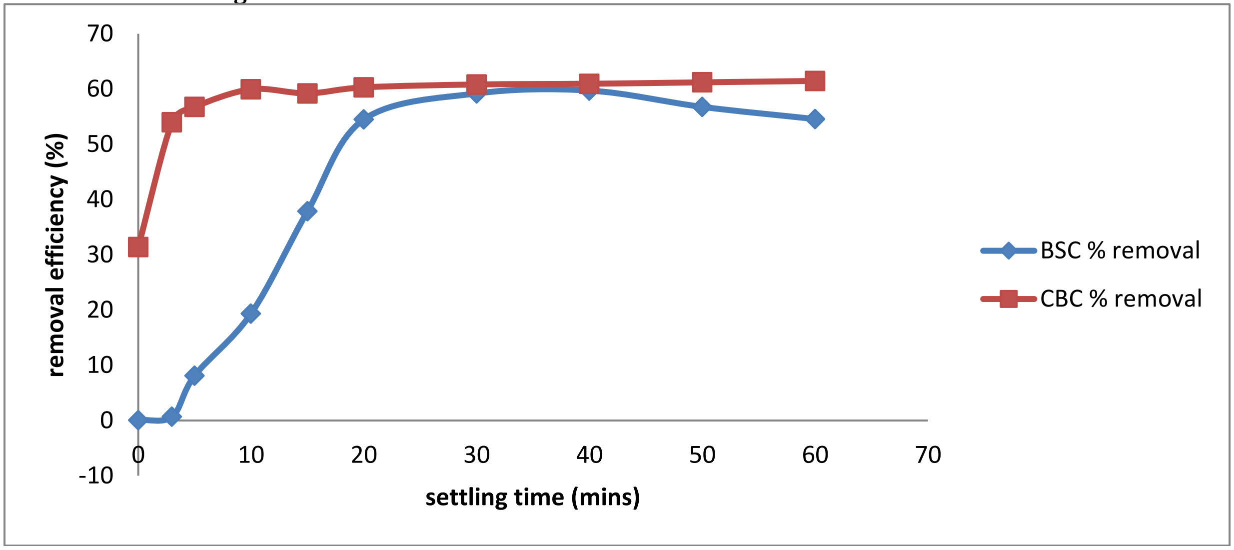

Figure 9: The effect of Settling time on the removal efficiency.

From figure 9, it is observed that the higher the settling times for each coagulant, the higher their removal efficiencies and vice versa. At zero minutes settling time, the removal efficiency was very low; this shows that sedimentation alone without coagulation can only remove large coarse suspended solids as reported by (Ndabigengesere, Narasiah and Talbot, 1995) However, with increase in time, there is sufficient time for more colloidal AR27 particles to coagulate and final settle.

3.2.4 Effect of dye concentration

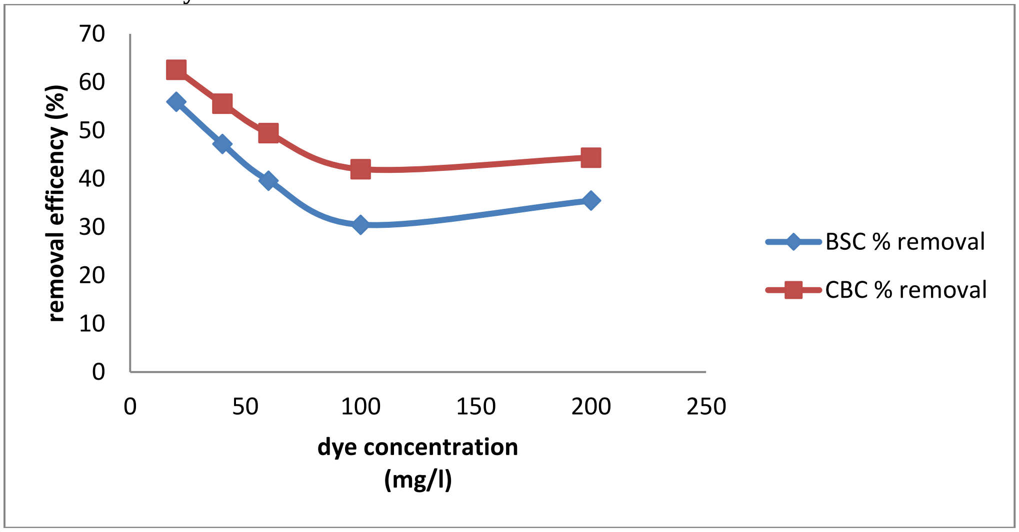

Figure 10: The effect of dye concentration on the removal efficiency

From fig 10, it is observed that as the initial concentration increases, giving rise to a little increase in turbidity, the removal efficiency decreases. But above 150mg/l it is seen that the percentage removal increased. Hence, at higher turbidity of synthetic wastewater, the removal efficiency of the coagulant is high. However, it is discovered that above the initial concentration of 200mg/l, which spells greater turbidity, the percentage removal of the dye tends to drop reasonably (Maryam, Mohammed and Mokhtar, 2008).

3.2.5 Effect of temperature

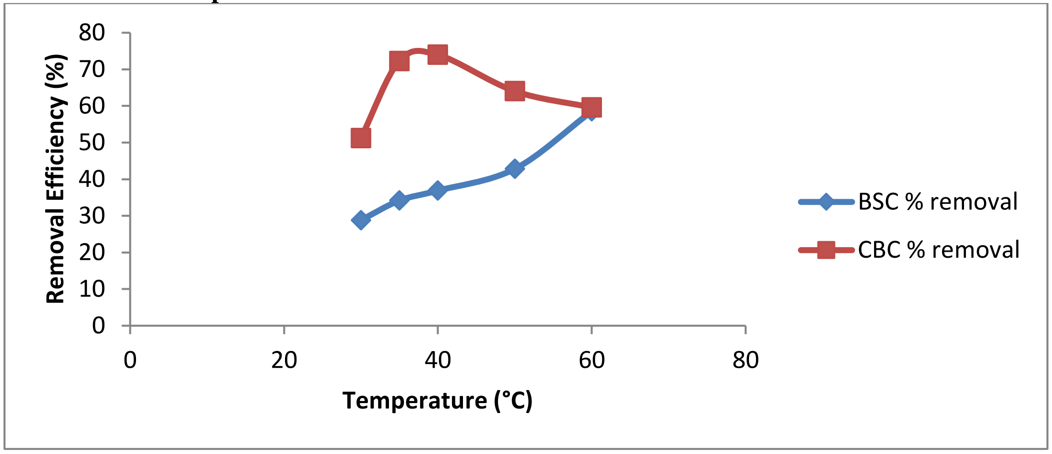

Figure 11: The effect of temperature on the removal efficiency

Figure 11 shows that at a low temperature, the removal efficiency is low and at moderate temperature the removal efficiency is moderately high. The optimum temperature for AR27 removal is 40^{o}C for CBC and 60^{o}C for BSC for the temperature range considered. At higher temperatures there tends to be a reduction in the percentage removal for CBC. Hence, moderate temperature is best for the removal of AR27 with CBC.

4.0. Conclusion

The experimental results obtained from this research work show that CBC and BSC can be successfully used to remove dye, but pH dependent. However, CBC is a better coagulant than BSC at the same operating conditions. This could possibly be as a result of the higher carbohydrates content in CBC compared to BSC. Though the proximate analysis shows that there is higher crude protein content in BSC, there is high possibility that the pH of the wastewater is above the isoelectric point of this protein, which is amphoteric. In that case, the protein will be negatively charged, which will result to repulsion instead of the destabilisation of the anionic AR27 solution. Carbohydrates on the other hand, are neutral and can easily be positively charged in an acid medium than protein.

The process employed here is a relatively cheap and cost effective because the coagulants used (CBC and BSC) are both waste products from animal and plant respectively. The treatment of the wastewater was seen to depend on the pH of the wastewater, the coagulant dosage used, the temperature at which the coagulation process is carried out, the settling time and as well as the initial concentration of the dye in the wastewater. Among these, pH is the most prominent factor, since coagulation follows neutralisation/destabilisation of the negatively charged wastewater.

The jar test experiments were performed on low to high turbidity water. The coagulation experiment using CBC and BSC indicated that coagulation process effectively removed turbidity from water using the coagulant dose of 2-6g. The optimum pH range for the turbidity removal was found to be 2-6 for both coagulants (CBC and BSC) and the removal efficiency was within 85-100% and 20-45% for CBC and BSC respectively

5.0 Recommendation

Better results could be obtained if one finds coagulants which contain positively charged polymers since many of the suspended solid particles in wastewater are negatively charged

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