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Original Research Article

The Effectiveness of Hydrated Lime as a Flocculating Agent in Water Treatment

Awodiji, C. T. G*, Nwachukwu, A. N, Onyechere, C. I, Iyidiobi, R. G & Nwabueze, B. J

The Federal University Of Technology, Owerri, Nigeria

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***Corresponding author:** Awodiji Chioma T.G

Abstract

The efficacy of hydrated lime (HL) as a flocculating agent in water treatment was studied in this work. Two water samples were used. Sample A was obtained from domestic sewage from Hostel A at the Federal University of Technology Owerri. While, sample B was sourced from storm water runoff from drains in Eziobodo Town, Owerri, Nigeria. The samples were treated separately using HL and sodium hydroxide (NaOH) as flocculants respectively. Alum $(Al_2SO_4)_3$ was used as the coagulating agent for all samples. The jar test was adopted. Treated samples were analyzed for pH, color and turbidity. It was noted that addition of HL and NaOH in all samples increased the pH of the water. pH values for sample A and B were 2.7 and 4.1 before treatment and increased to values between 6.9 to 7.2 after treatment. The use of alum and HL in treating both samples of water led to better color quality than using alum and NaOH. Sample B water treated with HL had lesser color quality than those of sample A. The best color quality of 1.0 PCU happened when treating sample A water using 25mg/l alum and 43.8mg/l HL. Treatment of sample B using alum and NaOH did not improve turbidity. Rather, a maximum increase of 1.8% was observed at 25mg/l alum and 17.0mg/l NaOH dosage. The use of alum and HL showed a remarkable improvement in turbidity. Best value of 3.12NTU was measured at 25mg/l alum and 43.8mg/l HL dosage. Treatment of sample A with alum and HL gave better turbidity values when compared to sample B. Removal efficiencies of 95% and 90% for both samples were observed respectively. In conclusion, HL can be effectively used as a flocculating agent in treating water when applied in the right proportion.

Keywords: Hydrated lime (HL), Alum, Flocculating agent, Coagulant, Water.

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INTRODUCTION

One of the various types of pollutants in the ecosystem is wastewater. It is a combination of liquid carrying waste from residence, industries and various agricultural plants and establishments including storm water [1]. This wastewater is generally made up of organic and inorganic matter and it has terrible effects on the environment. Over the years, the adverse effects of untreated wastewater on the ecosystem and the concern for public health have led to the development of various methods of treatment. In the 1800s, the general means of disposing human excretes and other sewage materials where majorly by outdoor privy and open means. Then, the method adopted in treating wastewater was, acquisition of large land mass and spreading of the sewage over the land allowing the actions of microorganisms to take its cause. In some areas, the act of discharging wastewater into various water bodies was also adopted [1]. Sewage borne bacterial disease outbreak was the result of this means.

But as the world's population grew, there was also increase in wastewater generation and it was discovered that the self- purification process of land and water bodies in which the wastewater are discharged was not enough. Due to the increased volume of discharge of wastewater into water bodies, it was discovered that it is now difficult for microorganisms in the water to completely decompose both organic and inorganic matter present in the water [2]. The discharge of wastewater into the water bodies leads to the depletion of dissolved oxygen, the deterioration and pollution of water bodies. When there is insufficient dissolved oxygen in water, aquatic disorder and malodorous gases production becomes the aftermath [3, 1].

According to Topare *et al.*, [1], in the 1900s, the first grades of wastewater treatment plants were developed with the objective of assisting the natural self- purification process by removing floatable and suspended materials from wastewater, treating biodegradable organics and getting rid of disease causing micro – organisms before discharging into water bodies. Further grades of treatment plants were later developed and they were designed such that each stage of treatment has its peculiar function.

The coagulation and flocculation processes are stages in water treatment. They are used to separate suspended solid particle from the water [4]. In coagulation, a floc forming chemical reagent is added to the wastewater and combines with non-settle able colloidal solids so that they can stick together and be removed through the sedimentation process [4]. While, the flocculation stage follows immediately after coagulation. It is a process that is usually adopted to ensure proper coagulation. It is the mild mixing stage which brings together the small flocs formed during coagulation into bigger noticeable flocs that can settle and be removed easily from the water [5].

Aluminum sulphate $(Al_2SO_4)_3$ commonly known as alum is one of the popular coagulating agents in water treatment. It has been observed to have the effect of adding dissolved solids in the treated effluent. Such dissolved solids give the effluent a brackish property which is normally difficult to remove by the natural self-purification process of water bodies and is not a good quality of water that is treated for reuse. Also, it is observed to only work on a certain pH range of water which means that the pH concentration of the treated water has to be at the required range, in order for alum to be used [6]. Sodium Aluminate which is another vastly used chemical in coagulation process has its cost effect. It is very costly to acquire and can only be used in treating soft water.

Aluminum chloride is a popular coagulant used by many for sanitary and industrial waste water treatment. It is a slightly acidic, colorless chemical with a freezing point of -27^{o}F. It is made of a blend of chemicals that can achieve the same or better coagulant results than alum. Although, is more expensive, hazardous and corrosive than alum [6]. Ferric sulphate $[Fe_2(SO_4)_3]$ is an effective and frequently used coagulant in wastewater treatment for water clarification and drinking water production. It forms flocs due to its sticky texture as well as negative charge. When mixed with water, it produces an acidic solution which makes it very dangerous when mishandled. HL which is obtained from the hydrated oxide of calcium is usually in powdered form and is composed of other compound such as magnesium oxide. It has the ability of raising the pH of water and is cheap. Therefore, this study seeks to ascertain if the use of HL as a flocculating agent will effectively aid the coagulant (alum) in removing the floatable and suspended solids from treated water.

Water Treatment

Objectively, water can be defined as a clear liquid with chemical composition of hydrogen and oxygen combined at a specific proportion [7]. It is an inorganic liquid composite, which is odorless and tasteless at room temperature. Water is virtually colorless except for the bluish color which it reflects from the white light from the sun into the ocean. It is absolutely the most considered chemical blend and is reported as the global solvent of life. It is by far, the largest abundant material on Earth and the only regular stuff to exist as a solid, liquid, and gas on Earth's surface. Water is the third most plentiful molecule in the universe and is needed for the survival of life on the planet earth [7].

Water molecules establish hydrogen bonds with each other and are strongly at variance. This opposition allows it to disconnect ions in salts and fasten to other polar substances such as alcohols and acids, thus breaking them down. Due to the hydrogen bonds, its solid form is less dense than its liquid form. It has a relatively boiling point of 100 °C and a high heat capacity [7].

Since water easily dissolves substances (dielectric constant property), a lot of contaminants and substances are usually contained in it. Rain water dissolves particles and oxygen which can be found in air; surface water also dissolves several different sand particles such as organic matter, andminerals. Although, water through some biological process can cleanse itself but its self – cleansing capacity is not entirely enough to produce safe water. Artificial treatment of water is still required [2]. Water treatment is defined as the purification and disinfection of contaminated water to improve its quality. It involves physical, chemical and biological processes to make water suitable for domestic and industrial use. The physical unit operations includes screening, grit removal, plain sedimentation, mixing, coagulation/flocculation, sedimentation and filtration [8].

Coagulation/ Flocculation Unit Processes

The suspended solids present in treated water cannot be removed by plain sedimentation operation because of the negative surface charge they possess. Since they have the same type of charge, they repel each other when they come close together. This makes them to remain in suspension and will not clump together and settle out of the water unless proper coagulation and flocculation is used. These suspended solids include suspended dissolved organic and inorganic matters that are retained in the water after passing through the previous treatment unit. Coagulation and flocculation processes are used to separate the dissolved and suspended particles from the water. The process involves the addition of polymers or chemical compounds that clump the dissolved, destabilized particles together into larger aggregates so

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that they can be easily separated from the water [9]. This process is relatively simple and cost effective provided that the required chemicals are available.

The first step in the chemical waste water treatment is coagulation. This process helps to trap small particles that have slipped through the filters. It achieves this by clumping the particles together so that they can be removed easily [10]. The process weakens the suspended particles charges through the outcome of the added coagulant. The coagulants are composed of charges that are inconsistence to those of the suspended solids. They neutralize the negative charges on the scattered non settle-able particles making them able to stick together and form sizeable particles called micro flocs. The flocs take time to settle. So, to properly distribute the coagulants and encourage particle cluster, a gentle mix is required [5].

Flocculation is a gentle mixing stage that increases the particle size from sub microscopic micro flocs to visible suspended particles. These micro floc particles continue to collide due to the slow mixing applied, causing them to bond to produce larger visible flocs called pin flocs. Floc sizes continue to build with additional collisions and interaction with added coagulants. This leads to formation of macro flocs. In this process high molecular weight polymers known as coagulant aids (flocculating agent) may be added to assist in binding, strengthening and adding weight to the flocs generated. This helps to improve settlement [5, 4]. Plate 1 shows an illustration of the coagulation-flocculation process.

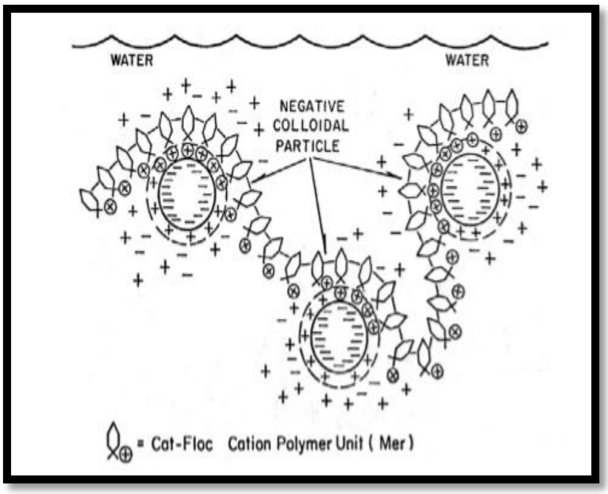

Plate 1: The process of coagulation and flocculation

Review of Related Works

Prakash *et al*., [4] conducted a laboratory test on treating water by coagulation and flocculation using the jar test mechanism and alum as the coagulant. They used sea water as sample and from their study, they observed that the optimum pH based on turbidity was 7.0. They also stated that the optimum coagulant dosage based on turbidity measurement was 120mg/l and they reported that alum was a more efficient coagulant at a removal percentage of 98.9% under optimum conditions. Abdelaal [11] in his quest to lower the cost of coagulants and flocculants used bentonitic natural clay as a coagulant in treating wastewater and compared its effectiveness with ferric sulphate. He carried out the study on two wastewater sample which were acidic wastewater from mining and oily wastewater with moderate degree of contamination. The Jar test method using cationic high-type chemicals (Zetag) as flocculants was carried out. The result obtained showed that using bentonite with Zetag as flocculant gave a turbid free effluent with no colour and negligible suspended solids at dosages of coagulant and flocculant being 0.1g/l and 14mg/l respectively. But, the ferric sulphate was not able to completely remove the colour and the turbidity of the wastewater even at a dosage of 5mg/l. He concluded that using bentonite as a coagulant is not only effective but also economical and is environmentally sustainable.

Patil and Hugar [12] carried out a laboratory test for treating diary wastewater by coagulation and flocculation using the Jar test. In their work, they made use of natural coagulants instead of chemical coagulants. These coagulants include Moringa oleifera (M. oleifera), Trigonellafoenum-graecum (Tfg), Dolicus lablab (DL) and Cicerarietimum. They observed that the optimum dosage of Tfg, M.oleifera, Cicer arietimum and DL were 0.05gm, 0.1gm, 0.1gm and 0.05gm respectively. Optimum pH was at 8, 9, 10 and 7.41 respectively. Among the three natural coagulants, the maximum reduction of turbidity and chemical oxygen demand chemical oxygen demand (COD) was observed to be 78.33% and 83% with Cicer arietinum. Hence, they concluded that Cicer arietinum is most effective in treating dairy wastewater. Amuda and Amob [13], also made attempt in their study to examine the effectiveness of coagulation and flocculation process using ferric chloride and organic polyelectrolyte (non – ionic polyacrylamide) for the treatment of beverage industrial wastewater. They investigated the effects, optimum dosages of coagulant and flocculants as well as the pH of the solution using the Jar test experiment. Their results revealed that the optimal operating pH was 9. The percentage removal of 73%, 95% and 97% for the COD, total phosphorus (TP) and total suspended solids (TSS) were achieved respectively. These values were obtained by the addition of 300mg/l of $FeCl_3.6H_2O$. However, a 91%, 99% and 97% removal of COD, TP and TSS were achieved respectively when 25mg/l of polyelectrolyte was added to 100mg/l of ferric chloride. From their results, they concluded that coagulation/flocculation is a useful pre – treatment process for beverage industrial wastewater prior to biological treatment and the use of flocculants to aid the coagulants in coagulation/flocculation process was very useful.

MATERIALS AND METHODS

MATERIALS

The materials used in conducting this research include the following; water collected from domestic sewage from hostel A at the Federal University of Technology, Owerri, Nigeria (sample A), water from drains of storm runoff in Eziobodo, Owerri-West, Imo State Nigeria (sample B), aluminum sulphate [$Al_2(SO_4)_3$] also known as alum, hydrated lime [$Ca(OH)_2$], sodium hydroxide [NaOH] and distilled water.

METHODS

The various methods adopted in this study are as shown;

i. Chemical property test on the hydrated lime (ASTM, C25).
ii. Jar test on the water sample according to (ASTM D2038-19).
iii. pH test on the treated water (ASTM D1293 – 18).
iv. Color test (ASTM D1209 -05, 2019).
v. Turbidity test (ASTM D6855- 17)
vi. Removal efficiency of color and turbidity properties. These were obtained using the eqn. 1 and eqn. 2 respectively

$$\text{Removal efficiency (\%)} = 100 - \{\frac{\text{the least color value}}{\text{the highest color value}} \times 100\} \ldots\ldots\ldots\ldots (1)$$

$$\text{Removal efficiency (\%)} = 100 - \{\frac{\text{the least turbidity value}}{\text{the highest turbidity value}} \times 100\} \ldots\ldots\ldots (2)$$

Plate 2: Set up of the Jar test

RESULTS

The results of the tests carried out are presented in Table 1 to 5.

Table-1: Result of chemical property test of hydrated lime

S/N	Parameter	Result	Name of oxide	Metallic oxide (mg/kg)	% by mass
1	pH	12.34	-	-	-
2	% moisture content	0.352	-	-	-
3	Calcium metal, (Ca)	163.163	CaO	228.2977	45.52
4	Magnesium metal, (Mg)	81.438	MgO	52.1336	10.39
5	Sodium,(Na)	1.882	Na_2O	2.5369	0.51
6	Potassium, (K)	147.5	K_2O	177.6785	35.43
7	Manganese, (Mn)	0.232	MnO	0.2996	0.06
8	Silicon, (Si)	0.863	SiO_2	1.8462	0.37
9	Lead, (Pb)	1.578	PbO	1.6998	0.34
10	Nickel, (Ni)	0.08	NiO	0.1018	0.02
11	Cobalt, (Co)	0.311	CoO	0.3954	0.08
12	Arsenic, (As)	0.012	As_2O_5	0.0184	0.0037
13	Cadmium, (Cd)	0.16	CdO	0.1828	0.04
14	Chromium, (Cr)	1.233	Cr_2O_3	1.8022	0.36
15	Iron, (Fe)	0.173	Fe_2O_3	0.2473	0.05
16	Zinc, (Zn)	0.192	ZnO	0.239	0.048
17	Aluminum, (Al)	7.728	Al_2O_3	14.6021	2.91
18	Mercury, (Hg)	0.044	HgO	0.0475	0.0095
19	Silver, (Ag)	0.088	Ag_2O	0.0945	0.02
20	Tin, (Sn)	0.048	SnO_2	0.0609	0.012
21	Phosphorus, (P)	8.4	P_2O_5	19.2478	3.84

Table-2: pH, color and turbidity values of sample A water treated with alum and NaOH

Jar	Alum dosage (mg/l)	NaOH dosage (mg/l)	pH	Color (PCU)	Turbidity (NTU)	WHO standard for color (PCU)	WHO standard for turbidity (NTU)
1	-	-	4.1	427×10^2	62.3		
2	5	10.6	6.9	258×10^2	30.4		
3	10	13	7	45×10^2	23.6	15	5
4	15	15	7.2	40×10^2	22.2		
5	20	17	7	47×10^2	25.4		
6	25	20	7.2	50×10^2	29.6		

Table-3: pH, color and turbidity values of sample A water treated with alum and hydrated lime

Jar	Alum dosage (mg/l)	Hydrated lime dosage (mg/l)	pH	Color (PCU)	Turbidity (NTU)	WHO standard for color (PCU)	WHO standard for turbidity (NTU)
1	-	-	4.1	427×10^2	62.3		
2	5	35	7.2	23	13.2		
3	10	31.1	7	3	4.8	15	5
4	15	38.6	7	2.6	4		
5	20	43.4	7	2	3.5		
6	25	43.8	7.2	1	3.12		

Table-4: pH, color and turbidity results of sample B wastewater treated with alum and NaOH

Jar	Alum dosage (mg/l)	NaOH dosage (mg/l)	pH	Color (PCU)	Turbidity (NTU)	WHO standard for color (PCU)	WHO standard for turbidity (NTU)
1	-	-	2.7	41×10^4	65.8	15	
2	5	7	7.2	42×10^4	65.9		
3	10	10	7	45×10^4	66.1		5
4	15	12	7	46×10^4	66.3		
5	20	14	7	47×10^4	66.4		
6	25	17	7.2	49×10^4	67		

Table-5: pH, color and turbidity results of sample B wastewater treated with alum and hydrated lime

Jar	Alum dosage (mg/l)	Hydrated lime dosage (mg/l)	pH	Color (PCU)	Turbidity (NTU)	WHO standard for color (PCU)	WHO standard for turbidity (NTU)
1	-	-	2.7	41×10^4	62.3	15	
2	5	11.8	7.2	7	6.2		
3	10	18	7	24	13.24		5
4	15	25.9	7	43	18.1		
5	20	33.9	7	47	18.7		
6	25	36.2	7.2	51	19.2		

Relationship between the turbidity of samples considered and the dosages of flocculating agents are presented in Fig 1 to 4.

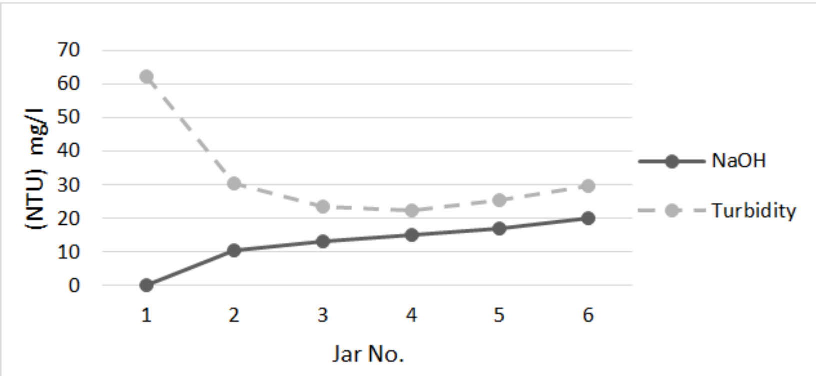

Fig-1: Relationship between turbidity of sample A with NaOH dosage

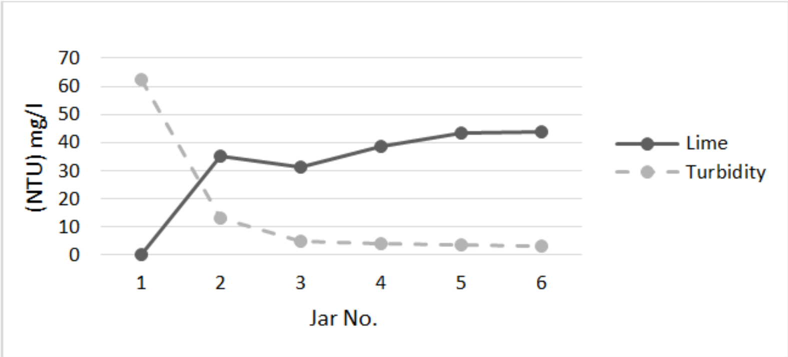

Fig-2: Relationship between turbidity of sample A with hydrated lime dosage

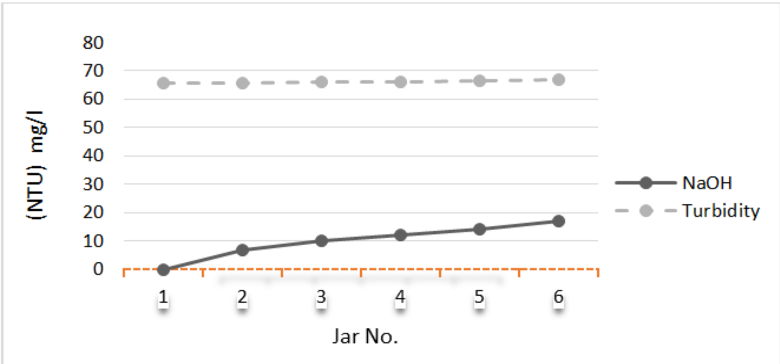

Fig-3: Relationship between turbidity of sample B with NaOH dosage

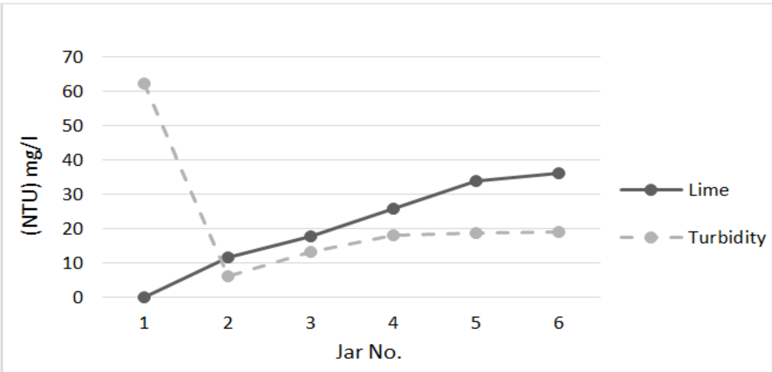

Fig-4: Relationship between turbidity of sample B with hydrated lime dosage

The optimum dosages and removal efficiency of hydrated lime and NaOH is shown in the Table 6 and 7.

Table-6: Removal efficiency in terms of turbidity

Coagulant/ Flocculant	**Optimum dosage** (mg/l)		**Optimum** pH		**Sample A** % removal efficiency	**Sample B** % removal efficiency
	A	B	A	B		
Alum /	15	0	7.2	2.7	64.4	0
NaOH	15	0				
Alum /	25	5	7.2	7.2	95	90
Hydrated lime	43.8	11.8				

Table-7: Removal efficiency in terms of color

Coagulant/ Flocculant	**Optimum dosage** (mg/l)		**Optimum** pH		**Sample A** % removal efficiency	**Sample B** % removal efficiency
	A	B	A	B		
Alum /	15	0	7.2	2.7	90.6	0
NaOH	15	0				
Alum /	25	5	7.2	7.2	99.9	99.8
Hydrated lime	43.8	11.8				

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DISCUSSION

Chemical property test results of hydrated lime

From Table-1, the quantities of the oxides that make up the hydrated lime used for the study are shown. It can be seen that the hydrated lime is made of 45.5% calcium oxide and 10.39% of magnesium oxide.

pH Test

The pH is a measure of hydrogen ion efficiency. It indicates the relative acidity or alkalinity of water. The pH scale usually ranges from 0 to 14 with 7 being the neutral point. pH less than 7 depicts acidity. While pH greater than 7 indicates alkalinity. When the pH value is high, it causes the taste of water to be bitter, reduces the effectiveness of disinfection using chlorine and results to the formation of deposits within the water pipes. But, when pH values is low it will led to the corrosion of metal pipes and other substances. pH of samples A and B before treatment were 4.1 and 2.7 respectively. After dosing with alum and the flocculants, the pH of the water were seen to fall within 7 and 7.2. In order to achieve this, as the dosage of alum was increased, that for the respective flocculants were also increased. These observations show that a solution of water with alum is acidic and its acidic nature increases with further dose of alum.

Color Test

Color in water may be caused by the presence of minerals such as iron and manganese or by vegetable origins. This tests indicate the efficacy of the water treatment system. From Table 2, it is seen that the use of NaOH as a flocculating agent in treating the water sample A, did not adequately improve color quality. Best color quality was obtained as 40 x 10^4PCU for a 15mg/l alum: 15mg/l NaOH dosage. The results were far above the value specified by the World Health Organization (WHO). From Table-4, dosing of the sample B with alum and NaOH further worsened the color quality of the treated water.

However, the use of alum and HL in treating the two water samples led to the improvement of their color qualities. The color readings before treatment were 427 x 10^2PCU and 41 x 10^4PCU for sample A and B respectively. After treatment, best properties were recorded at values of 3.12PCU and 7PCU respectively. This occurred at an optimal dosage of 25mg/l alum: 43.8mg/l HL for sample A and 5mg/l alum: 11.8mg/l HL for sample B. Overall, treating sample A (sewage water) with alum and HL produced better color qualities than that of sample B (storm runoff). From Table-3, it is seen that all test jars except jar 2, had color values well below the 15PCU requirement by the WHO. But, from Table 5, results from sample B had only test jar 2 falling below 15PCU. In conclusion, the use of alum with hydrated lime in water treatment produces better color quality than the use of alum with NaOH. Also, treating of the sewage using alum and hydrated lime generates better color qualities than its use in treating storm water.

Turbidity Test

Measuring of turbidity of water provides a rapid means of process control of when, how and to what extent the water must be treated in order to meet the required specification. High turbidity makes the filtration process expensive.

Considering sample A water, value of turbidity before treatment is 62.3NTU. After treatment with alum and NaOH, best turbidity value was recorded as 22.2NTU at 15mg/l alum and 15mg/l NaOH as shown in Table-2. This value is far lower than the recommended 5NTU by the WHO. However, from Table-3, treating sample A water using alum and HL led to a greater improvement in turbidity. All five jars experienced better turbidity with optimal value of 3.12NTU at a dosage of 25mg/l alum and 43.8mg/l HL. The values obtained from the five jars were less than 5NTU.

No improvement in turbidity was observed after treating sample B water with alum and NaOH. Rather, it increased. On the contrary, treating sample B water using alum and HL improved the turbidity. But none of the values obtained were less than 5NTU. The best value was 6.2NTU at a dosage of 5mg/l alum and 11.8mg/lHL as shown in Table-5.

Removal Efficiencies

Table 6 and 7 show the removal efficiencies of alum and NaOH as well as alum and HL in terms of turbidity and color respectively. From Table-6, alum and NaOH reduced the turbidity of sample A by 64.4% and sample B by 0%. Whereas, alum and lime reduced the turbidity level of sample A by 95% and sample B by 90%. From Table 7, the color of sample A was reduced by 90.6% when treated with alum and NaOH and 99.9% when treated with alum and HL. But, sample B water treated with alum and HL had a removal efficiency of 99.8%. But, had no removal efficiency when treated with alum and NaOH. These results show that treating water with alum and HL produced better removal efficiencies with respect to turbidity and color.

CONCLUSIONS

The inclusion of sodium hydroxide (NaOH) or hydrated lime (HL) helps to increase the pH of water. pH of the sample A and sample B before treatment were 4.1 and 2.7 respectively. These increased to values between 6.9 – 7.2 for various dosage of alum with sodium hydroxide and alum with hydrated lime. 99.9% optimum removal efficiency with respect to color was recorded from sample A having potion of alum and hydrated lime at 25mg/l and 43.8mg/l independently. For sample B, best color quality was observed at an alum: hydrated lime dosage of 5mg/l :11.8mg/l. Color quality of sample B treated with alum and sodium hydroxide did not improve but reduced with increase in dosage.

With respect to turbidity, the optimum removal efficiency of 95% was observed from sample A having a dosage of 25mg/l of alum and 43.8mg/l of hydrated lime. A 0% removal efficiency was observed from sample B treated with alum and NaOH. However, a 64.4% removal efficiency was recorded for sample A treated with alum and sodium hydroxide.

It is seen that the use of alum and hydrated lime (as coagulant and flocculant respectively) in treating water from the hostel A at FUTO produced better results in terms of color and turbidity when compared to the water sample obtained from storm water runoff from a drain at Eziobodo, in Imo state. The use of alum and sodium hydroxide in treating storm water did not yield a positive result and so should be discouraged. In general, treating water using alum and hydrated lime proved to be more effective than using alum and sodium hydroxide. On the other hand, sodium hydroxides work better in pH correction as lesser quantity of it is required to adjust the pH of the water sample to the required range when compared to the use of HL.

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