Influence of Variations in pH and Alum Concentrations on Colour and Turbidity Removal in Raw Water Treatment

K. U. Emerson[1] H. E. Jijingi[2] G. C. Obiechefu[3] A. U. Onuruka[4]
[1]Department of Civil Engineering and Geosciences [2]Department of Soil Science & Land Resources Management [3,4]Department of Agricultural & Bioenvironmental Engineering
[1]Newcastle University, United Kingdom [2]Federal University Wukari, Taraba State-Nigeria [3,4]Imo State Polytechnic, Owerri-Nigeria

Abstract— One characteristics of raw water is the presence of sediments and suspended particles, alongside dissolved organic matter (DOM). These constituents impart colour and turbidity including pathogens to the water, making it unsafe for human consumption. Coagulation-flocculation is a major step in the drinking water treatment process, allowing the removal of colloidal particles and organic matter which are precursors to potentially carcinogenic disinfection by-products. To provide a practical cost-effective solution to colour and turbidity removal, this work investigated the performance of alum ($Al_2(SO_4)_3$ at different levels of concentration for the treatment of raw water using the jar test procedure. Each aluminium dose was investigated on a pH level of 6.0, 6.5, 7.0, and 7.5 respectively. The results showed that optimum colour and turbidity removal was achieved at pH 6.5 for which 90 % colour and 70 % turbidity removals respectively were achieved using 90 mg/l alum dose. Above the optimum pH, end turbidity of the water was increased above the residual value for alum concentrations below 90 mg/l, while there was no appreciable reduction in end colour. This study demonstrated that the operating conditions of a water treatment plant can affect its treatment efficiency. It also highlighted the need to investigate the various conditions that could affect colour and turbidity removal in a conventional water treatment process.

Keywords: Turbidity, Pathogen, Alum, Coagulation, Flocculation

I. INTRODUCTION

One characteristics of raw water is the presence of sediments and suspended particles, alongside dissolved organic matter (DOM). Dissolved organic matter can be seen as a complex mix of organic material present in raw water; and it affects significantly many aspects of the water treatment process, such as the performance of unit processes, application of disinfectants, and system's biological stability. Among the DOMs present in raw water, coloured humic substances (mainly humic and fulvic acids) generally predominate, and a large proportion of these substances are soluble [1]. These constituents however impart colour and turbidity alongside pathogens to the water, making it unsafe for human consumption. There are numerous mechanisms for color removal, such as coagulation and flocculation, filtration, adsorption using granulated and powder activated carbon, chemical oxidation, biological process and nanofiltration [2], [3]. Color removal by chemical oxidation involving the use of chlorine as oxidative agent often results in the production of problematic disinfection byproducts.

Turbidity is described as an expression of optical property which causes light to scatter and get absorbed rather than transmitting same with no change in direction ([4]. Several materials in water can cause turbidity. These materials include clay, silt, and microorganisms, resulting to change in the taste and other aesthetic properties of the water. Turbidity is a major problem due to several health challenges associated with the suspended organic matter and other microorganisms [5]. It is reported that higher efficiency to treat turbid water has made inorganic chemicals favorite coagulants and they are not only low priced but are also readily available [6].

In natural water, DOM and nearly all colloidal impurities are negatively charged. These DOM, and particularly humic substances, can be regarded as natural anionic polyelectrolytes of rather indeterminate structure. These substances have various functional groups, including carboxylic and phenolic, and a framework of randomly condensed aromatic rings [1]. However, in water treatment process, the coagulants most often used are inorganic salts of aluminium. The aluminium ions hydrolyze rapidly when added to water to form a range of metal hydrolysis species [7]. Consequently, the cationic species formed are adsorbed onto the negatively charged colloidal and humic particles and neutralize the charge. As a result of this interaction, particles get destabilized and aggregation occurs [8]. The efficacy of aluminum salts in coagulation process depends on the physical and chemical characteristics of the raw water and the operating conditions [9]. pH and coagulant dose control of coagulation are the most important factors governing natural organic matter (NOM) removal [11].

The effect of turbidity in a water is to make it difficult for the penetration of chlorine and therefore the destruction of bacteria in particles of suspended matter [12]. Improving the quality of raw water requires various treatment processes which often form separate units of a typical water treatment plant. The principal objective of the plant is the production of a safe and aesthetically appealing water that is protective of public health and in compliance with current water quality standards (Crittendon et al, 2005). Coagulation-flocculation is a major step in the drinking water treatment process allowing the removal of colloidal particles (Gagnon et al, 1997). It also assists in the removal of organic matter which are precursors to potentially carcinogenic disinfection by-products. The control of pH is important in coagulation, not only in the removal of turbidity and colour but also to maintain satisfactory minimal level of dissolve residual aluminum in the clarified water [12].

This work aimed to determine conditions that affect colour and turbidity removal in raw water treatment plant.

This involves determining the effect of pH and coagulant (alum) concentration on colour and turbidity removal; how much colour and turbidity removal is achieved by the chemical coagulation step; and the optimum conditions of alum dose and pH necessary to achieve maximum colour and turbidity removal. It will provide a practical cost-effective solution to colour and turbidity removal from water.

Coagulation is a function of both coagulant dose and water pH. The pH at which unit processes in water treatment operations is carried out is particularly important; and, it is a major factor in the hydrolysis of aluminum salts [1]. It is thus important that optimum alum dose for efficient turbidity and colour removal within the range of the most usual pH of surface water is investigated.

II. EXPERIMENTAL PROCEDURE

A. *Jar test procedure*

A sample of river water with initial colour of 250 Hz and turbidity of 3.5 NTU was subjected to jar test experiment using different alum doses at different pH levels. The experiment was performed in triplicate using 500 ml of the river water for each pH and alum dose. Prior to the jar test procedure, each of the 500 ml samples was corrected to the require pH of 6.0, 6.5, 7.0, and 7.5 using 0.1 N HCl and 0.1 N NaOH respectively. The beakers were placed on magnetic stirrers and alum doses of 30 mg/l, 50 mg/l, 70 mg/l, and 90 mg/l respectively were added simultaneously and allowed for 1 minute while the apparatus was running at 600rpm. The speed was reduced to 40rpm for 10 minutes, after which it was reduced further to 8rpm for 10 minutes. Time and types of floc formation were noted. The machine was stopped at the expiration of the time and flocs were allowed to settle for 20 minutes after which samples for the end colour and turbidity were taken. Turbidity was measured using a HACH turbidimeter while colour was measured using a photometer. Average values of the triplicate samples corresponding to each sample pH and alum dose was calculated.

III. RESULTS AND DISCUSSION

A. *Influence of pH and alum ($Al_2(SO_4)_3$ dose on colour*

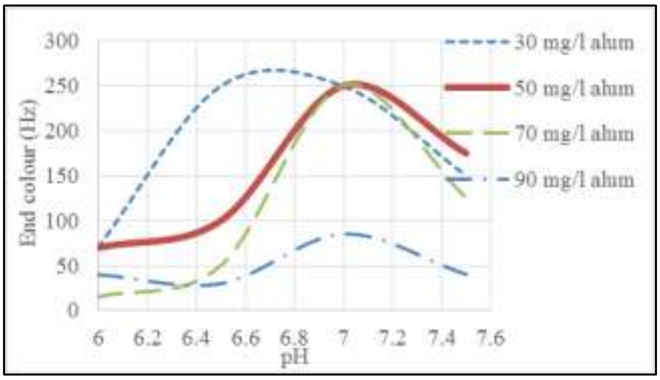

Fig. 1: Effect of pH and alum dose on colour removal

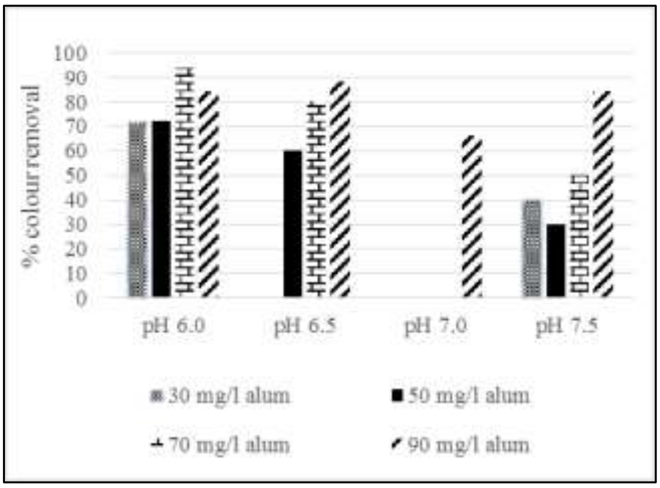

Fig. 2: Percentage colour removal for various alum doses and pH levels

Fig. 1 shows the effect of pH on colour for different coagulant concentrations, while Fig. 2 shows the percentage of colour removals for various alum doses at different pH levels. It is proposed that any improve of flocculation pH will reduce the alum dose required for the optimization of the system. It was also important to determine the influence of pH beyond the optimal concentration of the coagulant. Residual colour decreased steadily with increase in alum dose for pH levels not exceeding 6.5. At pH 6.0, highest colour removal of 94 % was recorded 70 mg/l alum concentration, followed by 85 % reduction for 90 mg/l, while 70 % colour reduction was recorded for 30 mg/l and 50 mg/l alum concentrations respectively. At pH level of 6.5, a reduction in removal efficiency was observed for all alum concentrations. Removal efficiency of 60 % was recorded for alum concentration of 50 m/l while 80 % and 90 % reductions were recorded for 70 mg/l and 90 m/l respectively. There was zero removal efficiency for alum concentration of 30 mg/l at this pH.

Beyond the pH level of 6.5, the various alum concentrations were seen to result in high residual colours. The reason different pH levels yielded different residual colours is that colour-producing substances in water behave inconsistently. The adjustment of pH may result to a change in the ionization of the colour molecules with corresponding effects on the bond lengths and configurations and thus light absorption [2]. The apparent fall in end pH values for the alum doses at high pH could have resulted from the sulphuric acid formed from the reaction of aluminium sulphate hydrolysis in water. For alum concentrations below 90 mg/l, treatment at pH 7.0 did not yield any reduction in residual colour.

The lowest removal percentage corresponds to low alum doses at around neutral pH, while maximum removal percentage corresponds to higher doses at low and above neutral pH. Results of this study are in line with colour removals by coagulation and flocculation processes (e.g. [13],[14]) where better results in colour removals were obtained at lower pH values. The result is also in agreement with findings that coagulant concentration and pH play significant role in colour removal, so that increasing coagulant concentration results in increase in colour removal efficiency [15].

However, it was discovered that increase or decrease in pH levels affects the effectiveness of coagulants used in colour removal [16]. The pH affects both the surface charge of coagulants and also the stabilization of the suspension [5].

$$Al_2(SO_4)_3 + 6\,H_2O \rightarrow 2\,Al(OH)_3 + 3H_2SO_4 \text{ (acid)} \qquad (1)$$

B. Influence of pH and alum ($Al_2(SO_4)_3$ dose on turbidity

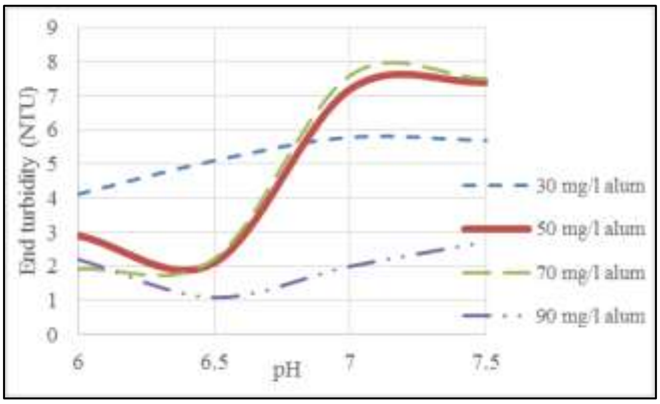

Fig. 3: Effect of pH and alum dose on turbidity removal

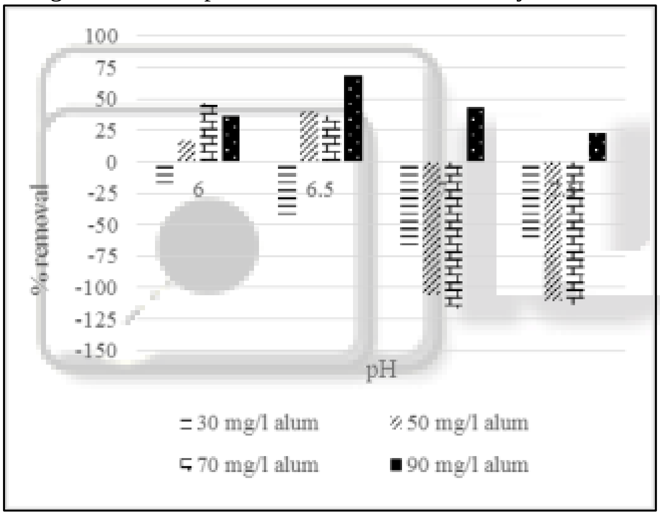

Fig. 4: Percentage turbidity removal for various alum doses and pH

The effect of pH and alum concentration on turbidity removal is shown in Fig. 3 while Figure 4 shows the percentage turbidity removals for the respective alum concentrations. Fig. 4 shows that alum concentrations below 50 mg/l did not result in any turbidity removal. It however resulted to increase in turbidity above the residual turbidity level. Least efficiency in turbidity removal was observed at pH above 6.5 for all alum concentrations, while best removal efficiencies were obtained at pH levels of ≤ 6.5. The obtained results have are in agreement with the optimum pH range for natural organic matter removal with alum coagulation which was generally between 5.5 and 6.5, depending on water quality factors [17]. Very low removal efficiencies (-17 % and 17 %) were observed for alum concentrations of 30 mg/l and 50 mg/l respectively at pH level of 6. This could have resulted from insufficient coverage of the aluminium ions to effectively destabilize the suspension and aggregate the dissolved organic matter in the raw water. However, as the quantity of the coagulant was increased to 70 mg/l, enhanced destabilization was particle aggregation observed, but this was achieved at pH level not exceeding 6.5. This is in agreement with the findings that application of higher alum dosage range may improve turbidity removal from relatively high turbidity waters, though it may increase aluminum concentration in drinking water [18]. However as residual pH increased above 6.5, there was great drop in efficiency removal of turbidity. This reduction may be attributed to charge reversal and destabilization of colloidal particles as suggested by authors [8].

At 90 mg/l dose of alum, highest turbidity removal of 70 % was observed at a pH level of 6.5. However, the same coagulant dose yielded a much lower removal efficiency as the residual pH increased above the optimum (6.5). At the above optimum pH, the applied dose has likely exceeded the solubility product of aluminium hydroxide, causing it to precipitate. When a high dose of coagulant is used to enhance turbidity and DOM removal, it is very likely that the process is predominated by sweep flocculation. According to the authors, sweep flocculation requires high dose of coagulant to promote aluminium hydroxide formation at pH range of 5.5-7.5 [9], [10]. Aluminum salts are rapidly hydrolyzed in water to give a range of products including cationic species, which can be absorbed by negatively charged particles and neutralize their charge. This is one processes whereby particles can be destabilized, so that flocculation can take place. However, overdosing of coagulant can disrupt this phenomenon, which makes it imperative to ensure a fairly precise control of coagulant dosage in water treatment plants [8].

End turbidity decreases with increase in concentration of alum dose and pH till about the pH of 6.5. Beyond this pH, further increase in alum dose was observed to result to increase end turbidity. Aluminium salts in water hydrolyses to form cationic species that adsorb the negatively charged turbidity-causing particles thereby neutralizing their charge. The particles which get destabilized form aggregates and thus settle or sediment. However, upon over-dozing of coagulant, net positive charges occur leading to charge reversal destabilization of already aggregated colloidal particles. This explains why less turbidity removal is achieved when a higher than the optimal coagulant concentration is applied. This result is in agreement with similar findings (e.g. [5], [8]).

Fig. 1 and Fig. 3 show that the pH which allows the best of both colour and turbidity removal is 6.5. At this pH, the colour removal is 88% and the turbidity removal 68%.Results of this study have shown that the efficiency of turbidity removal is a function of the pH, alum dose and initial turbidity of water. This agrees with the findings that show that show that the pH of coagulation was the most influential parameter affect turbidity removal from water [19].

IV. CONCLUSION

Improving the quality of raw water requires various treatment processes which often form separate units of a typical water treatment plant. The principal objective of the plant is the production of a safe and aesthetically appealing water that is protective of public health and in compliance with current water quality standards. This work investigated conditions that affect colour and turbidity removal in raw water treatment plant by determining the effect of pH and coagulant (alum) concentration on colour and turbidity, how much colour and turbidity removal is achieved by the chemical coagulation process, and identifying the optimum conditions of alum dose and pH necessary to achieve maximum colour and turbidity removal. Based on the findings, it has been demonstrated that the operating conditions of a water treatment plant can affect its treatment efficiency, and that efficient colour and turbidity removal in raw water do not only depend on the coagulant dose, but much greatly on the pH of the water. From the test, maximum colour removal of 90% and turbidity of 70% respectively were achieved with alum dose of 90mg/l at an optimum pH of 6.5.

REFERENCES

[1] G. D. Lancine, K. Bamory, L. Raymond, S. Jean-Luc, B. Christelle, & B. Jean, "Coagulation-Flocculation Treatment of a Tropical Surface Water with Alum for Dissolved Organic Matter (DOM) Removal: Influence of Alum Dose and pH Adjustment," *J. Int. Environmental Application & Science*, 3(4), PP. 247-257, (2008).

[2] J. C. Crittendon, R. R. Trussell, D. W. Hand, K. J. Howe, and G. Tchobanoglous, *Water Treatment: Principles and Design*, 2nd edn. John Wiley & Sons, Inc., New Jersey, 2005.

[3] G. R. Nabi Bidhenhi, A. Torabian, H. Ehsani, and N. Razmkhah, "Evaluation of industrial dyeing wastewater treatmentwith coagulation and polyelectrolyte as a coagulant aid," *Iran. J. Environ. Health. Sci. Eng.*, 4(1), pp. 29-36, 2007.

[4] A. D. Eaton, L. S. Clesceri, E. W. Rice, & A. E. Greenberg, *Standard methods of the examination of water and wastewater*, 21st edn. American Public Health Association, Washington, 2005.

[5] Q. H. Malik, "Performance of alum and assorted coagulants in turbidity removal of muddy water," *Applied Water Science*, 8(40), 2018. https://doi.org/10.1007/s13201-018-0662-5.

[6] J. Duan, and J. Gregory, "Coagulation by hydrolysing metal salts," *Adv Colloid Interface Sci*, 100, pp. 475–502, 2003.

[7] Q. Jiang, "The role of coagulation in water treatment," *Curr Opin Chem Eng*, 8, pp.36–44,2015.

[8] M. A. Yukselen, and J. Gregory, "The effect of rapid mixing on the break-up and re-formation of flocs," *J Chem Technol Biotechnol*, 79(7), pp. 782–788, 2004.

[9] J. E. Gregor, C. J. Nokes, and E. Fenton, "Optimising natural organic matter removal from low turbidity waters by controlled pH adjustment of aluminium coagulation," *Water Res.*, 31, pp. 2949-2958, 1997.

[10] S. H. Kim, B. H. Moon, H. I. Lee, "Effects of pH and dosage on pollutant removal and floc structure during coagulation," *Micro Chem J.*, 68(2–3), pp.197–203, 2001.

[11] K. C. Vol, B. K. Ibrahim, E. D. Verges, G. L. Amy, & M. Lechevalier, "Impact of enhanced and optimized coagulation on removal of organic matter and its biodegradable fraction in drinking water," *Water Res.*, 34, pp. 3247-3257, 2000.

[12] C. Twort, D. D. Ratnayaka, and M. J. Brandt, *Water Supply* 5th edn. Arnold, London, 2000.

[13] H. A. Aziz, S. Alias, M. N. Adlan, A. H. Asaari, and M. S. Zahari, "Color removal from landfill leachate by coagulation and flocculation processes," *Bioresource Technology*, 98, pp. 218–220, (2007.

[14] Z. P. Wang, Z. Zhang, Y. J. Lin, N. S. Deng, T. Tao, and K. Zhuo, "Landfill leachate treatment by a coagulation–photooxidation process," *J. Hazard. Mater*, B95, pp. 153–159, 2002.

[15] M. Malakootian, and A. Fatehizadeh, "Colour removal from water by coagulation/caustic soda and lime," *Iran J. Environ. Health. Sci. Eng.*, 10(3), pp. 267-272, 2010.

[16] V. Saritha, N. Srinivas, N. Srikanth, and N. S. Vuppala, "Analysis and optimization of coagulation and flocculation process," *Appl Water Sci*, 7(1), pp. 451–460, 2017.

[17] J. C. Crittenden, R. R. Trussell, D. W. Hand, K. J. Howe, K.J. and G. Tchobanoglous, G, *MWH's Water Treatment: Principles and Design*, Wiley, 2012.

[18] A. Baghvand, A. D. Zand, N. Mehrdadi, and A. Karbassi, "Optimizing Coagulation Process for Low to High Turbidity Waters Using Aluminum and Iron Salts," *American Journal of Environmental Sciences*, 6 (5), pp. 442-448, 2010.

[19] Volk, K. Bell, E. Ibrahim, D. Verges, G. Amy and M. Lechevaller, "Impact of enhanced and optimized coagulation on removal of organic matter and its biodegradable fraction in drinking water," *Water Res.*, 34, pp. 3247-3257, 2000