The Impact of Alum on the Bulking of a Full Scale Activated Sludge Plant

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Peter Ojo and Augustine O. Ifelebuegu

Abstract— The activated sludge plant (ASP) is one of the main wastewater treatment processes in the UK. With the increasing stringent requirement for effluent quality, there has been a considerable increase in the use of chemicals for phosphorus precipitation in ASPs to achieve effluent consents. Alum is one of the most widely used chemicals in the treatment of wastewater. In this study, we examine the impact of varying concentrations of alum on the bulking and settleability of a full-scale activated sludge plant with simultaneous co-precipitation. The results showed an improvement in the settleability of the activated sludge with the initial stirred sludge volume index (SSVI) before alum dosing dropping from 105 to 85 after one sludge age. The SSVI increased to 155 with the settleability and floc compactability deteriorating at a dose rate of 145mg/L of alum. The bulking of the sludge was caused by a combination of the filaments present and the surface chemistry of the activated sludge flocs.

Keywords— Activated Sludge, Bulking, FST, Settleability

I. Introduction

The activated sludge treatment is one of the most widely used processes for biological treatment of wastewater (**Thompson et al., 2001**; **Hammer, 2008).** The treatment process comprises of two (2) unit operations namely; aeration and secondary clarification. The aeration process occurs within an aeration tank where organic carbon, ammonium and phosphate are removed from the wastewater using microbial population like algae, protozoans, bacteria and metazoan (**Richard, 1989; Jeniken, 2003; Bitton, 2005;**). The secondary treatment takes place within the final sedimentation tank (FST) where both clarification and thickening of activated sludge is performed for an effective final effluent quality (**Metcalf and Eddy 2004**).

The separation of the mixed liquor suspended solids (MLSS) from treated wastewater in the FST is one of the fundamental challenges of the ASP process. Poor MLSS separation often occurs due to bulking of the activated sludge. Bulking is a phenomenon that takes place in an activated sludge plant when the sludge occupies an excessive volume that does not settle readily and in extreme cases results in effluent that contains an an excessive amount of suspended solids (**Tomlinson, 1976). Gerardi (2002)** also defined bulking sludge as the excessive growth of filamentous bacteria. Moreover, research has reported that the estimated volume fraction of filamentous bacteria that could result in bulking sludge ranges between 1-20% (**Palm et al., 1984; Kappeler and Gujer, 1994**). However, **Wanner (1994)** reported that the filamentous bacteria is not just vital to the floc formation process but its filaments act as a backbone for the flocs development and as an attachment for fingered zoogloeal ramigera organism. This filamentous bacteria and zoogleal organism are both vital in achieving a satisfactory sludge quality and efficient clarification in the FST.

As a result of the increasingly strigent requirements for effluent quality; there has been increased used of chemicals for nutrient removal in the UK. Ferric and alum salts are the predominantly used salts for phosphorus removal in the UK. While there is a significant body of work on the impact of various parametres on sludge settleability (**Jobbagy et al., 2002; Jenkins et al., 2003; Jin etal., 2003),** there is limited research on the effects of chemical dosing. This Paper examines the impact of alum dosing on bulking properties of a full scale activated sludge plant.

II. Methods and Design Approach

The work was carried out on full scale wastewater treatment plant located in the West Midlands, UK. The site flow data and operating parameters are reported in Table 1. Aluminium sulphate was dosed at varying dose rates (20 mg/L to 185 mg/L) during a plant trial for several months. The bulking properties were determined as a function of the stirred sludge volume index (SSVI) and zone settling velocity (ZSV). The settleability of the activated sludge at various dose rates was also modelled using the Pitman and White settling curves as has been previously described in **Ojo and Ifelebuegu, 2015.**

Table 1. Site Flow Data for Sewage Treatment Works

Parameters	Data
FFT (m^3/day)	6462m^3/day
DWF (m^3/day)	2743m^3/day
RAS = 0.5 *DWF (m^3/day)	1371.5m^3/day
Normal flow= 1.2 *DWF (m^3/day)	3291.6m^3/day
Max. RAS=1.5 *DWF	4114.5m^3/day
Influent MLSS (mg/l)	3000mg/l
Tank Diameter	24m
Side wall Depth	5m

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A. *Sludge Settleability Index*

1. *SVI (sludge volume Index) and ZSV (zone settling velocity) Expression*

According to (**Metcalf and Eddy 2004**), the SVI has been defined as the volume of 1g of sludge after 30 mins of settling. The approach of measurement reported was placing a mixed liquor sample in either a 2 L measuring cylinder and settled volume was measured after 30min and equivalent sample MLSS concentration. The numerical value was computed using the following expression (**Eqn 1.0**):

$$SSVI \text{ (ml/g)} = \frac{Volume\ of\ Settled\ Sludge\ after\ 30\ mins\ ,ml/l(100mg\ /g)}{MLSS\ Concentration\frac{mg}{l}} \quad \textbf{Eqn 1.0}$$

1. *ZSV (Zone Settling Velocity) Expression*

Although, various studies have been conducted to examine the relationship between zone settling velocity and activated sludge concentration, the most acceptable models are those suggested by **Vesilind (1968)** and **Dick (1972).** These models define the connection between zone settling velocity and sludge concentration which is considered as follows:

Vesilind Equation

$$ZSV = V_0 * \exp(-k.X_a) \quad \textbf{Eqn 1.1}$$

Dick's Equation

$$ZSV = V_0 * (X_t)^K \quad \textbf{Eqn 1.2}$$

Where,

ZSV = zone settling velocity

X = activated sludge concentration

V_0, k, v_0 and k = sludge settleability constants

Also, following the research conducted by **Pitman (1984)** involving analysis of six years full scale study which resulted in the development of an empirical relationship between the constants of vesilind's equation and SSVI. The correlation obtained was as follows:

$$\frac{v_0}{K} = 68 * \exp(-0016 * SSVI_{3.5}) \quad \textbf{Eqn 1.3}$$

The data of **Ekama and Marias (1986)** was analysed along with that of other researchers (**White 1975; Koopman and Cadee 1983**) and came up with the findings that pitman's empirical expression in **Eqn 1.3** resulted in a good description for all and that a relationship exists between $\frac{V_0}{K}$ and k. This is expressed as follows:

$$K = 0.88 - 0.393 * \log(V_0 * k) \quad \textbf{Eqn 1.4}$$

However, since the value of k is known then the value of V_0 can be computed as follows using **Eqns (1.3 and 1.4):**

$$V_0 = \left(\frac{v_0}{K}\right) * k \quad \textbf{Eqn 1.5}$$

According to suggestions from **Catunda et al. (1989),** rearranging **Eqn 1.4 to 1.5** will make it possible to express k and V_0 as a function of $SSVI_{3.5}$ which can be expressed as follows:

$$k = 0.16 + 2.7 * 10^{-3} * SSVI_{3.5} \quad \textbf{Eqn 1.6}$$

Upon substituting **Eqns (1.5 and 1.6)** into **Eqn (1.4)** the following expression would be realised:

$$V_0 = (10.9 + 0.18 * SSVI_{3.5}) * \exp(-0.016 * SSVI_{3.5}) \quad \textbf{Eqn 1.7}$$

$SSVI_{3.5}$ Values are of great importance for activated sludge process and hence **Eqn 1.7** can be expressed as follows:

$$V_0 = (11.2 - 0.06 * SSVI_{3.5}) \quad \textbf{Eqn 1.8}$$

III   *Results and Discussion*

Impact of Dosing on Bulking

The results of the impact of alum dosing (20, 40, 60, 80,100, 125, 145, 165 and 185) mg/l on activated sludge settleability index (ZSV and SSVI) are presented in Figures 1 and 2. It was noticed that the ZSV values (1.9, 2.0, 2.3 and 2.5 m/h) increased initially with increasing concentration of alum doses (20, 40, 60 and 80 mg/l) and started to decrease (2.3, 1.4, 0.6, 0.5, and 0.4 m/h) after 100 mg/L dose concentration (100, 125, 145, 165 and 185 mg/l). A similar trend is observed with the SSVI, which started increasing at a dose rate of 100 mg/L.

The improvement of the sludge settleability (lower SSVI values) at initial dose rates (20 to 100 mg/L) is linked to the surface chemistry of the sludge and the decreased number of filaments usually within the first sludge age (**Eikelboom et al., 1998, Agridiotis et al., 2007).** The action of alum on enhancing the settleability can also be further explained by charge neutralization of negatively charged sludge flocs by the positively charged aluminium hydroxides that are absorbed onto the floc particles (**Urbain et al., 1992; Agridiotis et al., 2007**). This agrees with the work of **Mikkelsen, 1996 and Thompson and Foster, 2003** who demonstrated that low SVI values are associated with low surface charges.

Furthermore, the increasing dose of alum which increases the activated sludge pH contributed to improving settling during the initial dose rates. Previous work by **Ghanizadeh and Sarrafpour (2001)** showed that increasing pH in the aeration basin of an ASP reduces SVI values and improves settleability due to improved biofloculation.
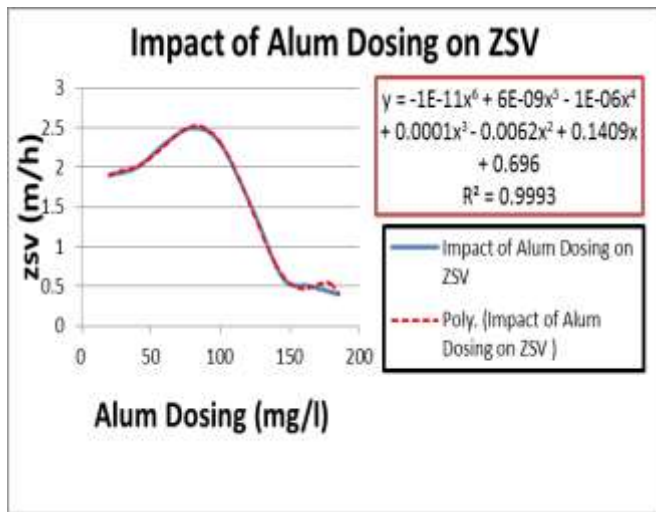
Figure 1. Effects of varying concentrations of alum (mg/L) on ZSV (m/h)
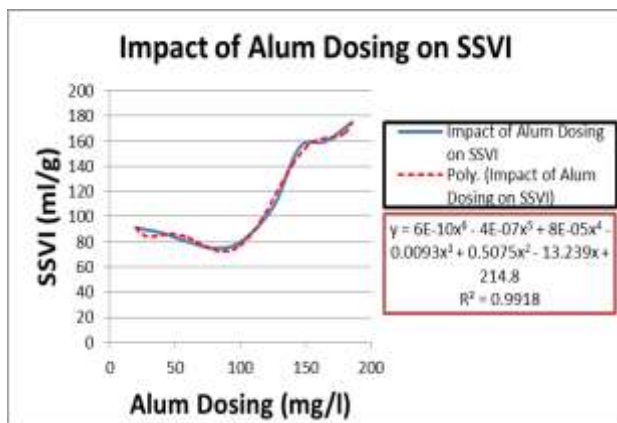

Figure 2. Effect of varying concentrations of alum (mg/L) on SSVI (ml/g)

At a dose concentration of 145 mg/L of alum, the SSVI exceeded the 120 mark which is considered the maximum concentration at which bulking sets in (**Agridiotis et al., 2007**). The increase in SSVI with increasing alum dosing at 145 mg/L and beyond may be due to the formation of an open, large precipitate that has a slow settling rate which hinders compressibility of the activated sludge biomass and concentrated underflow, resulting to bulking sludge. As surface charges play a significant role in sludge settleability; the bulking experience at the higher dose rate could also be attributed to the possibility of charge reversal (Agridiotis et al., 2007).

Modelling the Settleability of Alum Dosed Sludge in the FST (at 20, 145 and 185 mg/L)

Evaluation of Pitman and White Settling Curves for Alum Dosed Sludge at 20mg/l

Fig 1 reveals an adequate settling within the clarifier with an alum dosing concentration of 20mg/l. Permissible flux and actual flux value were 1.54 kg/m²/hr and 3.18 kg/m²/hr with an SSVI of 91 ml/g. The ratio of actual flux to the permissible was 48.37 %. The clarifier has its underflow line completely under the pitman and white settling curve which shows that the clarifier did not fail in clarification because the solid entering the clarifier has enough settling time to settle in the clarifier before going over the effluent weir. The clarifier had its underflow rate line (UFR) below the descending limb of the settling flux curve and this shows that the clarifier is performing its thickening function. This is an indication that the sludge was adequately compacting and settling and was significantly enhanced by the 20 mg/L alum dose.
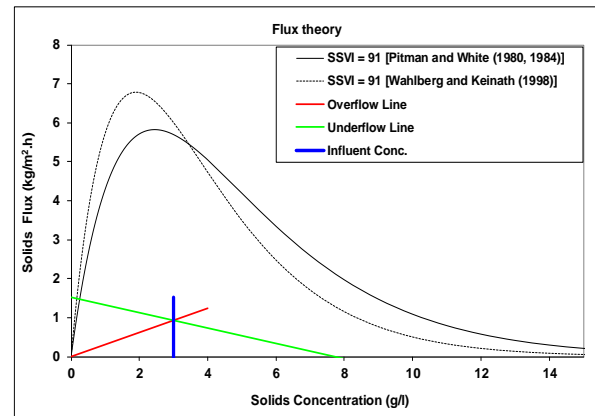

Fig 1. Settling Curve for alum dosed sludge at 20mg/l

Evaluation of Pitman and White Settling Curves for Alum Dosed Sludge at 145 mg/l

It was observed that settling within the clarifier was adversely affected at dose rates of 145 mg/L and beyond (Figure 2). The actual flux value for the various concentrations (145, 165 and 185 mg/l) was constant at 1.54 kg/m²/hr but at an alum dosing concentration of 145mg/l with an SSVI of 155ml/g the permissible flux value was 2.11 kg/m²/hr. While at an increased alum dosing of 165mg/l with an SSVI of 160ml/g the permissible flux value was 2.06 kg/m²/hr and at alum dosed concentration of 185mg/l and SSVI of 175ml/g the permissible flux value was 1.92 kg/m²/hr. The ratio of the actual to permissible flux for various concentration (145, 165 and 185mg/l) was 72.90%, 74.70% and 80.04% respectively.
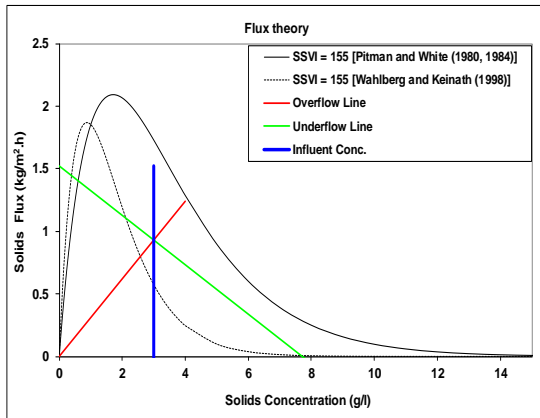
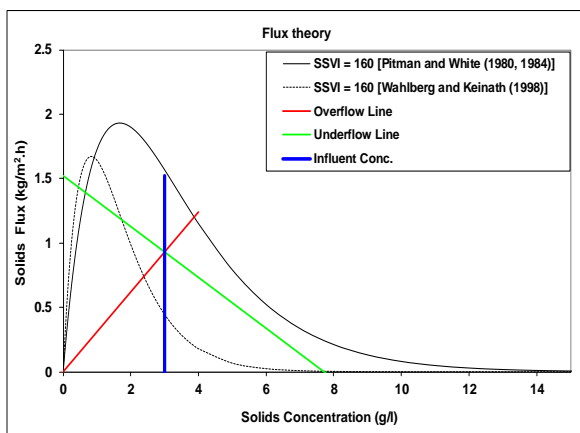**Fig 2 Settling Curve for alum dosed sludge at 145 mg/l**

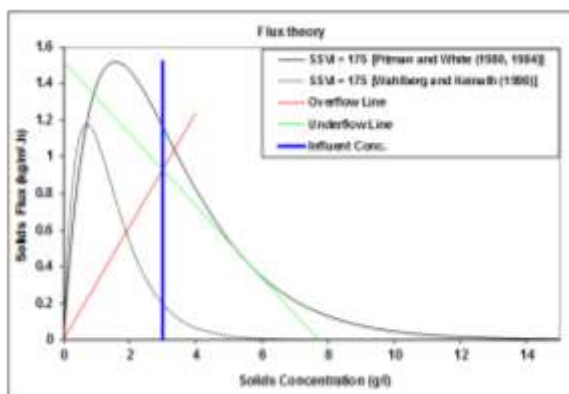**Fig 3 Settling Curve for alum dosed sludge at 165 mg/l**

Fig 4 Settling Curve for alum dosed sludge at 185 mg/l

However, evaluating Fig 2, Fig 3 and Fig 4, it can be deduced that the state point (SP) was outside the pitman and

white operational settling curve and the underflow line (UFR) intersects the descending limb of the curve. This showed that the clarifier was failing in thickening and clarification with sludge blanket levels rising within the clarifier and hence bulking activated sludge. This supports the initial finding that at higher alum dosing (145 mg/L and beyond) bulking sets in due mainly to changes in surface chemistry and possible charge reversal.

III.   Conclusion

The impact of alum dosing on a full scale treatment plant in the UK was investigated. Alum dosing was found to enahnce sludge settleability through charge neutralisation and the reduction of filaments at lower dose rates. At a higher dose rate of 145 mg/L there was bulking of the ASP as a result of the formation of an open, large precipitate that had a slow settling rate which hindered compressibility of the activated sludge biomass and concentrated underflow.

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