

ADVANCED TREATMENT FOR DRINKING WATER RESOURCE BY THE ULTRA RAPID COAGULATION PROCESS (KOREA)

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(received August 2002, accepted November 2002)

Abstract : This study was performed to evaluate the applicability of the URC (ultra rapid coagulation) process in efficiently treating eutrophicated water that is to be used for drinking purposes. The results were compared to conventional coagulation-sedimentation processes via the use of jar testing. The injection of weighted coagulant additives (WCA), e.g. clay, bentonite and glass particles, significantly reduced the level of turbidity and aluminum concentrations. However, there was no significant removal of NOM (natural organic matter). Polymer addition reduced turbidity by up to 95% and UV₂₅₄ absorbed material by as much as 10%. The addition of secondary sludge into the URC system decreased sand filter head loss to the lowest extent when compared to the conventional coagulation-sedimentation processes. In addition, *Synedra acus*, a seasonally found diatom in the water-uptake process, was removed by up to 95% and dissolved aluminum reduced to levels as low as 0.02 mg/L. However, there was no significant change in the UV₂₅₄ of absorbed NOM. A pilot scale URC process was capable of efficiently treating rainfall run-off as demonstrated by the reduction of levels of aluminum to as low as 0.05 mg/L. The URC process can improve conventional water treatment systems as it has the advantages of removing residual aluminum and turbidity faster than the conventional processes, while maintaining a lesser extent of sand filter head loss.

Key Words : aluminum, NOM, sand filtration, ultra rapid coagulation (URC), UV₂₅₄, weighted coagulant additives (WCA)

INTRODUCTION

Nutrient enriched source waters flowing into the water treatment facility have led to a deterioration in water quality. This has extended to the enhancement of residual NOM and algae growth, which in turn has increased DBP (disinfect by-product) formation after chlorination has been implemented.^{1,2)} Residual aluminum sustained after the use of aluminum based coagulants can ascribe to Alzheimers disease.³⁾ Furthermore, water with high levels of turbidity and low levels of alkalinity entering the treatment

facility during a rainfall event can not be properly treated. Solid separation is not efficiently achieved even when the duration of the flocculation and sedimentation processes are extended. This subsequently increases sand filter head loss, thus shortening the backwash interval during the filtration process. Such problems will be improved such that occurrence of NOM, residual aluminum and *Synedra acus* should be efficiently minimized.

This study was thus conducted to evaluate the removal of NOM and residual aluminum in eutrophicated lake water by the use of jar testing, pilot scale URC and sand filtration experiments. The removal of *Synedra acus* by filtration (a readily observed diatom which sea-

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sonally impacts water treatment efficiency) was also investigated. The URC process was used to treat water flowing into the lake during a rainfall event to gauge its future applicability as an advanced water treatment process. The amount of settled sludge in the lamella settler was also returned to a coagulation basin to enhance performance of coagulation process.

MATERIALS AND METHODS

Source water was obtained from a lake, located in Incheon, Korea, with a capacity of 2,300 m³, depth of 0.7 m and retention period of 28 days. Water quality parameters such as COD_{Mn}, TSS, T-N, T-P, Chl-a, alkalinity, UV₂₅₄, DOC, turbidity, and aluminum were characterized in accordance with Standard Methods.⁴⁾ The level of dissolved aluminum had been obtained after the sample was filtered with 0.2 μm of membrane filter. Zeta potential was obtained by a Zeta-Meta System 3.0 (USA). *Synedra acus*, diatom that was naturally present in the test lake, was observed by the Sedge-wick-Rafter method. Powdered glass particles, clay and bentonite were used as weighted coagulant additives. Alum of liquid phase and anionic polymer of polyacrylamide (FLOPAM AN 934, SNF Floerger, France), generally used as a food processing additive, were utilized for the coagulant and flocculent, respectively. The anionic polymer has been used for water treatment in France, while it replaces the anionic groups on a colloidal particle and eventually permitting hydrogen bonding between the colloid and the polymer.

Coagulant and flocculent demands were determined from a number of jar tests using Gators Jar. A pilot scale URC process was designed to treat 5 m³/hr at rapid mixing (5 min), slow mixing (7 min) and settling (8 min) in a lamella separator. Meanwhile, secondary sludge was partly returned to the rapid mixing reactor, Figure 1. The URC system was also operated during a rainfall event. The effluent was introduced into a sand filter at a rate of 300 m³/m².

Figure 1. The pilot scale URC process.

Figure 2. Sand filter (dimension, mm).

day so that any residual polymer, turbid material and/or diatom could be efficiently removed (Figure 2). Employing 300 m³/m²·day of filtration rate in the filter can be optimally come up with 300 m/day of overflow rate induced from the lamella separator. Backwash of the sand filter was conducted after nominal head loss had been reached. The filter was packed with 5 to 10 mm in diameter of gravel overlaid by 0.8 to 1.2 mm in effective size of sand with 1.4 of uniformity coefficient.

RESULTS AND DISCUSSION

Source Water Quality

Water quality parameters of the lake water were characterized, Table 1. The lake was in a

Table 1. Water quality parameters of the lake water

Parameter	Concentration	Parameter	Concentration
COD _{Mn} (mg/L)	18.2	UV ₂₅₄ (1/cm)	0.033
TSS (mg/L)	47.7	DOC (mg/L)	12
T-N (mg/L)	3.63	Turbidity (NTU)	19
T-P (mg/L)	0.094	Total Al (mg/L)	0.3
Chlorophyll-a (mg/m ³)	91.5	Dissolved Al (mg/L)	<0.1
Alkalinity (mg/L)	100	<i>Synedra acus</i> (cells/mL)	52,833

state of over-eutrophication as signified by the OECD, with the concentration of chlorophyll-a exceeding more than 75 mg/m³.⁵⁾ Levels of T-N and T-P were extremely presented over eutrophication state at the lake. The ratio of T-N/T-P was 38.6, which was also exceeded over minimal eutrophication level i.e. 20.⁵⁾ Most of artificial water resources are highly eutrophicated such that the proposed lake will simulate whether if the water resources could be efficiently treated by the methods proposed in this study.

The Effect of Varying Alum Dose and pH on Residual NOM and Aluminum Concentrations

Dissolved aluminum and UV₂₅₄ absorbency decreased as the alum dose was increased, Figures 3 and 4. However, this is not necessarily indicative that the use of alum was solely decreasing the dissolved aluminum and UV₂₅₄ absorbency. It may be rather related with pH reduction due to CO₂ formation when Al₂(SO₄)₃ was converted into Al(OH)₃. It was necessary to clarify if this pH dependency was significant. Jar tests were thus conducted with an alum dose of 50 mg/L while the pH was varied from 4 to 9 using 1 N HCl or 0.1 N NaOH. The lowest level of dissolved aluminum corresponded to a pH of 6 while UV₂₅₄ absorbency was at its lowest for pH's of 5 and 6. This indicates that the low solubility of aluminum was at pH 6, while aluminum ion was more competitively reacted with negatively charged NOM rather than OH⁻ ion over the pH range of 5-6 leading to the greatest reduction in UV₂₅₄ absorbency.³⁾

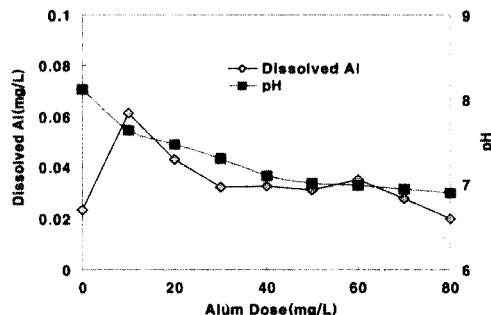


Figure 3. The variance of dissolved aluminum concentrations and pH with increased alum dosage.

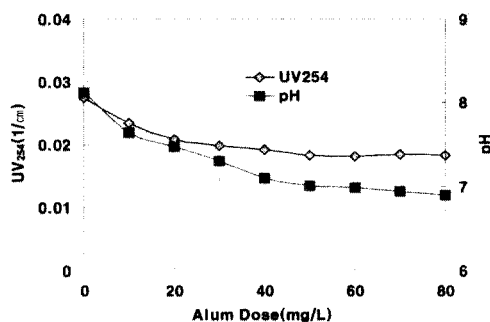


Figure 4. The variance of UV₂₅₄ and pH with increased alum dosage.

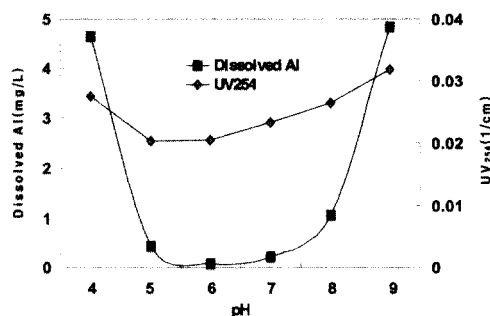


Figure 5. The variance of dissolved aluminum concentrations and UV₂₅₄ with increased pH (alum: 50 mg/L added).

Their reductions were generally dependent upon pH while NOM removal was simultaneously related to the presence of the aluminum ion.

The Effect of Adding Weighted Coagulants on Residual NOM and Aluminum Concentrations

Three different weighted coagulants (glass particles, clay and bentonite) were added at a

concentration of 50 mg/L to comparatively assess the capacity for the reduction of UV_{254} absorbed organic material present in the lake water. Similar tests were performed using distilled water (to act as a control). The degree of reduction of UV_{254} absorbed organic material removed from the lake water was not significant when compared to that of the control, Figure 6(a). Among them, bentonite displayed relatively greater magnitude of UV_{254} absorbency being reduced. This is due to its higher adsorption capacity.⁶⁾ Specific surface area was also observed at 28.5, 86.2 and 113.9 m^2/g for glass, clay and bentonite, respectively.⁷⁾

This indicates that the 50 mg/L of weighted coagulants might be immediately saturated as it came into contact with the NOM present in the lake water. However, the addition of clay led to the observation of a higher extent of UV_{254} and was possibly due to the amount of soil organic matter retained in the clay. In the contrast, the level of UV_{254} observed in the distilled water sample was marginally reduced over the extended reaction time (Figure 6(b)). It showed that the adsorption capacity of weighted coagulants was gradually saturated with NOM in distilled water.

UV_{254} and dissolved aluminum were observed upon varying dose of weighted coagulants (glass particles, clay and bentonite) with 50 mg/L of alum and 1 mg/L of anionic polymer also added. UV_{254} did not significantly differ for each WCA (Figure 7(a)). The UV_{254} value observed for clay displayed the highest value for a WCA concentration of 200 mg/L indicating the release

Figure 6. The effect of WCA on UV_{254} using: (a) lake water; (2) distilled water.

Figure 7. Comparison of variations of coagulation and flocculation parameters upon increased WCA dosages: (a) UV_{254} ; (b) dissolved aluminum; (c) turbidity.

of soil organic matter. Bentonite displayed the highest NOM adsorption capability as it had the lowest UV_{254} values when compared to the other two WCA's. Dissolved aluminum concentration generally decreased with increasing dosage of weighted coagulants (Figure 7(b)). The addition of clay led to the lowest degree of residual dissolved aluminum, as it has the greatest cationic exchange capacity of the three WCA's. Glass particles and clay reacted identically in removing more turbid suspended solids than that of bentonite. This indicates that bentonite reacts more efficiently with residual soluble organic and inorganic compounds rather than with fixed compounds.

The Effect of Added Settled Sludge on Residual NOM and Dissolved Aluminum Concentrations

Secondary sludge was added (12,000 mg TS(total solids)/L) immediately before alum was dosed at 50 mg/L into the jar. Weighted coagulants and anionic polymer were added at 50 and 1 mg/L, respectively. The addition of secondary sludge (Figure 8(a)) reduced zeta-potential as the negatively charged sludge shifted the charge balance in a more negative direction.⁸⁾ Sludge added in concentrations greater than 3,000 mg/L increased the turbidity by a factor of four when compared to concentrations of less than 3,000 mg/L. Within the sludge concentration range of 500 to 1,000 mg TS/L (Figure 8(b)), total aluminum was at the lowest due to the culmination of sorption of aluminum onto the

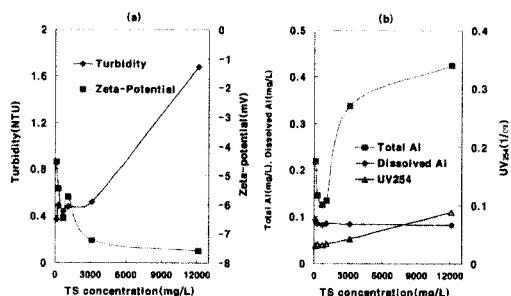


Figure 8. Variation of water quality parameters on the addition of sludge: (a) turbidity, zeta-potential; (b) aluminum, UV₂₅₄.

sludge.⁹⁾ However, as the sludge concentration increased, the total concentration of aluminum exponentially increased due to the release of aluminum ions and its complex from the sludge itself. In comparison, soluble aluminum concentration marginally decreased as soluble aluminum had been steadily adsorbed onto the sludge. The addition of sludge incessantly increased the release of organic matters, thereby the UV₂₅₄ increased in response with the escalation of the concentration of sludge solids.

The Effect of Polymer Addition on Concentrations of Residual NOM and Dissolved Aluminum

Recently in the EU and USA there have been an increased number of water treatment facilities using polymers dosing as part of an efficient soil-liquid separation protocol. Polymer use can also reduce costs by a factor of ten when compared with the sole use of inorganic coagulants.¹⁾ In this study, a food additive polymer was used as the flocculent. 500 mg/L of settled sludge was added into the jar just before alum was dosed at 50 mg/L based on zeta-potential. 1:1:1 of mixtures of weighted coagulants (i.e. glass particles, clay, and bentonite) were added at 50 mg/L. A 0.2 mg/L dose of polymer lowered turbidity by up to 95%, while total aluminum was reduced by up to 92% (Figure 9(a)). Dissolved aluminum was removed up to 63% for a 0.5 mg/L of polymer dose, while UV₂₅₄ was only removed up to 11% as shown (Figure 9(b)).

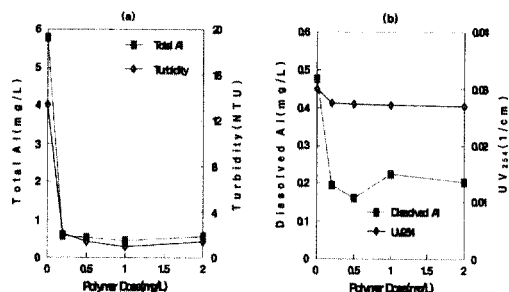


Figure 9. Variation in water quality parameters on the addition of polymer: (a) total Al, turbidity; (b) dissolved Al, UV₂₅₄.

Sand Filtration

Five different sand filtration experiments were performed (Figure 10). In the first experiment, polymer was not added. Dosing conditions and reaction times were as follows; 1:1:1 of WCA mixtures (i.e. glass particles, clay and bentonite) added through runs 2 to 5 (70 mg/L); alum added through runs 1 to 5 (50 mg/L); secondary sludge added at runs 3 and 5 (10%); reaction time given through runs 1 to 3 (120 min), and run 4 and 5 (20 min). For runs 2 and 3, head loss and turbidity were similarly reduced, Figure 10(a). Furthermore, run 3, with 10% of secondary sludge added produced a slightly lower value than that of run 2. However, turbidity observed from run 3 was present at a higher level indicating that the amount of residual particulate material occurring from the sludge addition passed through the sand filter, Figure 10(b).

Nevertheless, dissolved aluminum concentrations observed from the filtrate at run 3 was at its lowest (less than 0.02 mg/L), Figure 10(c). This indicates that the turbid material observed from run 3 might be more dominantly ascribed to glass particle type materials contained in the sludge than clay and bentonite because the dissolved aluminum was more efficiently removed by clay and, Figure 7(b). Extended reaction times of up to 120 min contributed to a greater decrease of head loss, turbidity and dissolved aluminum concentration as shown in run 3 than when compared to run 5 for a reaction time of 20 min.

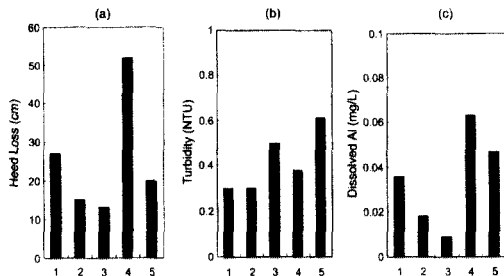


Figure 10. Evaluation of sand filtration without adding polymer: (a) head loss; (b) turbidity; (c) dissolved aluminum.

Ebie and Amano¹⁰⁾ concluded that the level of dissolved aluminum could be more efficiently removed by adsorption on clay type particles, which are in turn captured by the filter. No significant removal of UV₂₅₄ absorbed material among the five runs was found as humic substances adsorbed on flocs can be readily released through the sand media during filtration.⁹⁾

Synedra acus was removed by as much as 95% in run 3. It was removed by sweep coagulation rather than charge neutralization as *Synedra acus* size averaged 300 m, the similar size as alum flocs, which are more readily removed in the filtration run.¹¹⁾

URC Pilot Test on Treating the Lake Water during Rainfall Event

Pilot tests were carried out under six different experimental conditions to treat rainwater run-off, Figure 11. Dosing conditions and reaction times were as follows; 1:1:1 of WCA mixtures (i.e. glass particles, clay and bentonite) added through: runs 2 to 6 (70 mg/L); alum dosed through runs 1 to 6 (50 mg/L); polymer added through runs 2 and 4 to 6 (0.2 mg/L); secondary sludge added at run 4 and 6 (10%); reaction time: given through runs 1 to 4 (120 min) and runs 5 and 6 (20 min).

In general, rainwater runoff contains low alkalinity and high turbidity. The addition of polymer can reduce turbidity far below 1 NTU from runs 2, 4, 5, and 6. However, UV₂₅₄ absorbed materials did not vary under different

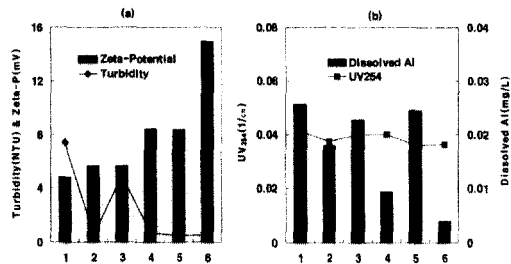


Figure 11. Pilot testing of the URC process treating the lake water during a rainfall event: (a) turbidity, zeta potential; (b) dissolved alum, UV₂₅₄.

dosing conditions. Dissolved aluminum decreased the greatest for runs 4 and 6, which correspondingly reflected the results observed from Figures 7(b) and 10(c) reporting 10% of added sludge. The level of dissolved aluminum was reduced by a factor of 3 for run 6 when compared to run 4 as polymer addition can further enhance dissolved aluminum removal during a short reaction time of 20 min. Extended reaction times of up to 120 min (run 4) may attribute to the occurrence of polymer derived flocs being broken-up, which consequently cause the increased release of dissolved aluminum from the flocs. This also correlates with a positive increase of zeta potential observed from run 6 when compared to run 4, Figure 11(a). The reaction time was very dependent upon the addition of the polymer. If a polymer was added, the reaction time should be shortened to achieve a high dissolved aluminum removal efficiency. In comparison, when the polymer was not added, the reaction time would need to be extended.

CONCLUSIONS

UV₂₅₄ absorbed matters were most reduced within the pH range of 5 to 6 by increasing the alum dosage, while dissolved aluminum was exposed to the lowest degree at pH ranging from 6 to 7, which is equivalent to its solubility limit. The addition of weighted coagulants did not significantly decrease UV₂₅₄ absorbed material. Of the three WCA's tested, bentonite

reduced UV₂₅₄ absorbed material the most. The addition of clay reduced dissolved aluminum and turbidity the greatest magnitude of up to 50%. The introduction of secondary sludge at 1,000 mg/L decreased the total aluminum concentration up to 40%. Low concentrations of polymer (0.2 mg/L) improved turbidity and dissolved aluminum removal by factors of 5 and 2, respectively, while UV₂₅₄ absorbed matters were lowered by as much as 10%. Without polymer addition, secondary sludge reduced sand filter head loss to the greatest extent. It also resulted in up to 95% of *Synedra acus* being removed. A pilot scale URC process successfully removed dissolved aluminum at a rate six times faster than conventional processes. However, without polymer addition, the reaction time should be extended to enable sufficient time for the dissolved aluminum to react with the sludge. The introduction of secondary sludge and weighted coagulants can efficiently remove turbidity and dissolved aluminum over a given reaction time. However, the effective reduction of UV₂₅₄ required the proper addition of the food additive polymer.

ACKNOWLEDGEMENT

This work was partly supported by the Regional Research Center (RRC) program, the Ministry of Science and Technology (MOST) and the Korea Science and Engineering Foundation (KOSEF).

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