

Removal of Nitrogen and Phosphate from Fertilizer Industry Wastewater by Magnesium Ammonium Phosphate Formation and Electrochemical Treatment

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A pilot-scale MAP (magnesium ammonium phosphate) precipitation system was applied for the removal of high-strength nitrogen compounds from fertilizer industry wastewater. The system was composed of a biological pre-treatment process for nitrate removal and a physico-chemical MAP precipitation process for ammonia removal. Although influent nitrogen loading was severely fluctuated, the stable nitrogen removal could be achieved. For the recovery of magnesium and phosphate from crystallized MAP, ammonia stripping was also conducted. The MAP precipitants could be transformed to MHP (magnesium hydrogen phosphate), and the magnesium and phosphate used for MAP formation was recovered to above 90%. Also, most phosphate increasing by the supplement of phosphate and magnesium for the formation of MAP precipitants could be eliminated rapidly within 3 minutes by electrocoagulation during the electrolysis procedure.

Keywords: Fertilizer industry wastewater, Nitrogen and phosphate removal, MAP, MHP, electrolysis

1. INTRODUCTION

Water scarcity has increased rapidly over recent years as a result of urbanization, industrialization, and population growth. The lack of available water resources is also accelerated by municipal and industrial wastewaters discharged from domestic and industrial activities.

Excessive release of nutrients such as nitrogen and phosphorus contained in wastewater to water resources can lead to a high productivity of algae, called eutrophication [1,2]. In particular, high levels of nitrogen in water resources can cause hazards to human health and the environment. In many watersheds, nitrogen from wastewater contributes 40 to 80 percent of total nitrogen loads [3].

Ammonium nitrogen (NH_4^+) is one of the most commonly encountered nitrogenous pollutants in wastewater [4], and nitrogen in the ammonia (NH_3) form is toxic to certain aquatic organisms [5].

Major high-strength nitrogen compounds are contained in wastewater discharged from fertilizer manufacturing industries [6], and the main pollutant in nitrogenous fertilizer manufacture is ammonium nitrogen [7,8]. Nitrogen removal from wastewater can be generally performed by physico-chemical methods such as ammonia stripping, ion exchange, and so on, or biological methods using nitrification and denitrification [9]. In biological treatment of industrial wastewater, however, nitrogen removal can be frequently deteriorated due to unstable nitrification caused by severe fluctuation of influent loading, relatively higher content of nitrogen (especially ammonia), and localized specific pollution sources [10,11].

As one of the resource recycling technologies for the removal of high-strength ammonia and phosphorus from wastewater, the precipitation of MAP (magnesium ammonium phosphate; $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$), known as struvite, has been extensively studied [12-14]. It is an attractive physico-chemical technology which can strongly contribute for the removal of ammonium nitrogen or phosphorous forming complex under alkaline conditions [15-19]. It is also an ecologically sound technology which is not only cost-effective, but also sustainable in terms of possible recovery of recyclable constituents from industrial effluent rich in nutrients [6]. However, MAP precipitation can also be used to remove abundant ammonium nitrogen contents in wastewater by additional supplements of elements of phosphate (PO_4^{3-}) such as H_3PO_4 and magnesium (Mg^{2+}) such as MgO or MgCl_2 , which have relatively lower content than nitrogen in wastewater.

In this study, a pilot-scale MAP precipitation system combined with biological pre-treatment was applied for the removal of many different types of high-strength nitrogen compounds in fertilizer industry wastewater, and its nitrogen removal characteristics by adding supplements of phosphate and magnesium were evaluated. The performance and economic efficiency of magnesium and phosphate recycled from MAP precipitate were also estimated, and the removal characteristics of phosphate in final effluent caused by adding supplements of phosphate and magnesium for MAP precipitants formation was assessed additionally by electrolysis method.

2. EXPERIMENTAL

A pilot-scale MAP system was installed at the head of a treatment plant of chemical fertilizer industry wastewater in Korea. Many different types of nitrogen compounds such as organic nitrogen, nitrate, and high-strength ammonia were contained in the wastewater, as shown in Table 1. All analyses were conducted as per procedures outlined in the American Public Health Association (APHA) Standard Methods [20].

Table 1. Characteristics of fertilizer industry wastewater [Unit : mg/L, minimum~maximum (average)]

	Influent	Effluent	Removals (%)
Total Nitrogen (mg/L)	270~457 (350)	34~58 (42)	83.9~91.2 (88.1)
Organic Nitrogen (mg/L)	4~64 (27)	0.5~18 (5)	41.6~99.8 (85.7)
Urea (mg/L)	14~109 (54)	2~8 (4)	78.8~99.9 (93.2)
Ammonia (mg/L)	146~311 (245)	25~50 (31)	80.8~91.5 (86.8)
Nitrate (mg/L)	10~33 (21)	1.2~2.7 (1.8)	87.2~94.3 (92.0)

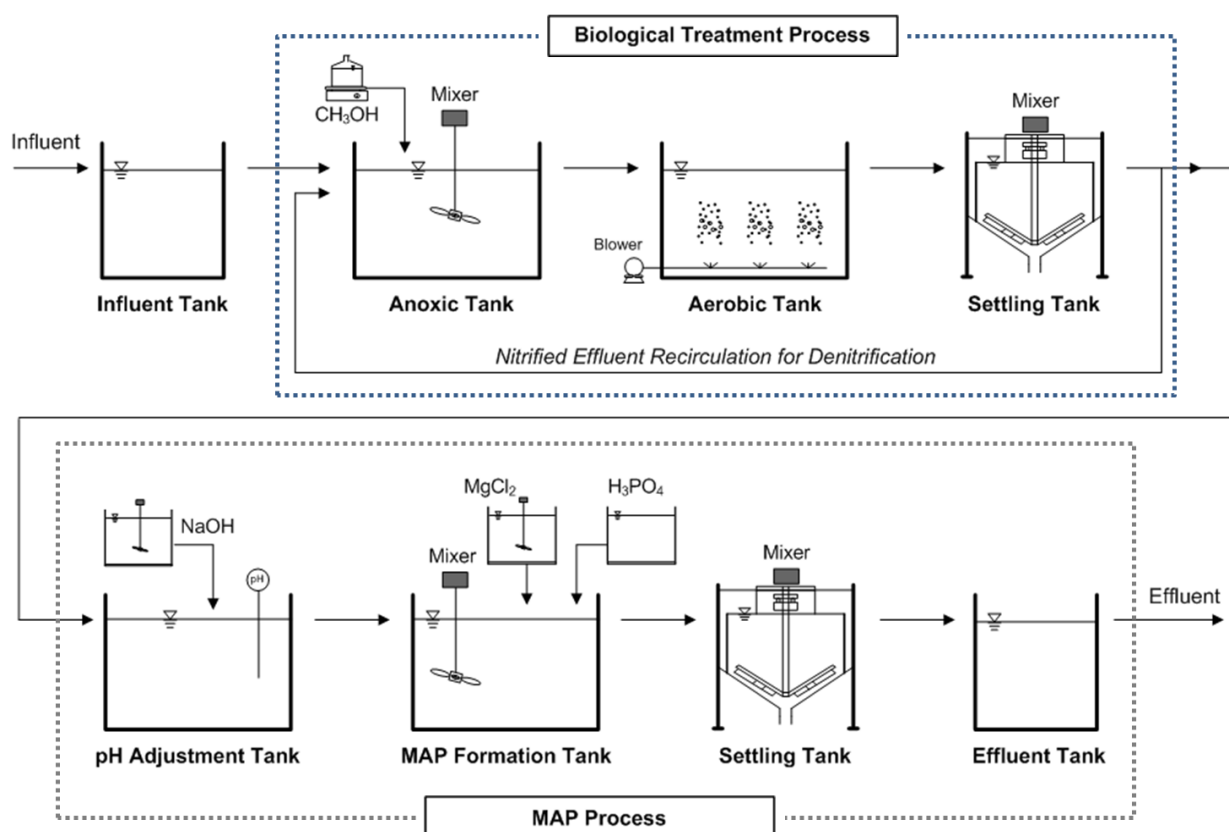


Figure 1. Pilot-scale magnesium ammonium phosphate precipitation system

As illustrated schematically in Fig.1, therefore, the pilot-scale MAP system is composed of a biological pre-treatment process for preferred removal of nitrate in wastewater and a subsequent physico-chemical MAP precipitation process. Ammonia is removed from wastewater in the MAP process by struvite formation and precipitation through the supplement of phosphate and magnesium. The biological pre-treatment process consists of an anoxic tank for denitrification, an aerobic tank for organics removal and nitrification, and a settling tank for solids separation. The MAP precipitation process is also comprised of a pH adjustment tank, a MAP formation tank for crystallization of struvite, and a settling tank for clarification of precipitates. The specifications and operating conditions of both

the biological pre-treatment process and the MAP precipitation process in this system are as shown in Table 2 and Table 3, respectively.

Table 2. Specifications of the pilot-scale magnesium ammonium phosphate precipitation system

Biological Pre-treatment Process		MAP Process	
Influent tank	2m ³	pH adjustment tank	3m ³
Anoxic tank	0.7mL×0.7mW×1.2mH (0.59m ³)	MAP formation tank	0.6mL×0.45mW×1.2mH (0.32m ³)
Aerobic tank	0.7mL×0.2mW×1.2mH (0.17m ³)	Settling tank	Φ0.8m×1.3mH (0.5m ³)
Settling tank	Φ0.8m×1.3mH (0.5m ³)	Effluent tank	2m ³

Table 3. Operating conditions of the pilot-scale magnesium ammonium phosphate precipitation system

	Biological Pre-treatment Process	MAP Process
Hydraulic Retention Time (hours)	8~20	0.1~0.3
pH	7~8	11~12
Mixed Liquor Suspended Solids (mg/L)	3,000~4,000	-
Added CH ₃ OH (mg/L)	150~200	-
Organics Loading Rate (kgCOD/m ³ /d)	0.1~0.4	-
Nitrogen Loading Rate (kgN/m ³ /d)	0.6~1.3	48~72
Addition ratio of PO ₄ ³⁻ (PO ₄ ³⁻ -P/NH ₄ ⁺ -N)	-	1.5~1.8
Addition ratio of Mg ²⁺ (Mg ²⁺ /NH ₄ ⁺ -N)	-	1.5~1.8

In general, the MAP process has limitations from an economical point of view. The precipitants such as soluble phosphate and magnesium salts are expensive and this can raise the processing cost [21]. In this study, therefore, ammonia stripping was also conducted for the recovery of magnesium and phosphate from crystallized MAP (MgNH₄PO₄·6H₂O) under the condition of heating to moderate temperatures. The MAP could be converted to magnesium hydrogen phosphate (MHP; MgHPO₄) by the release of ammonia. The MHP is used for removal of ammonia in wastewater by being converted back to MAP. As shown in Fig.2, the performance and economic efficiency of magnesium and phosphate recycled from MAP precipitate were also estimated.

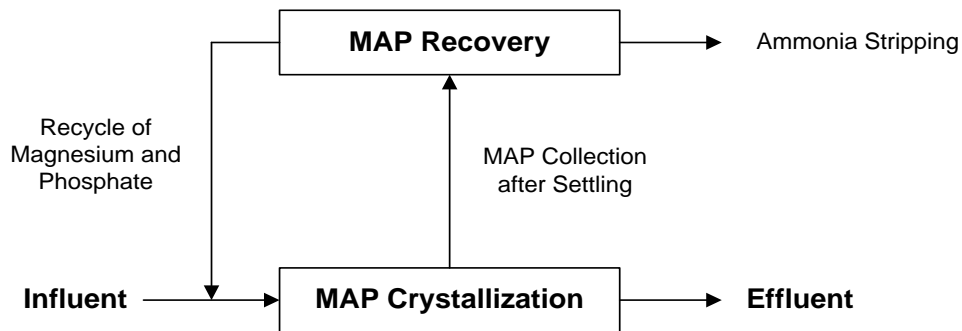


Figure 2. Experimental diagram of magnesium ammonium phosphate regeneration and reuse

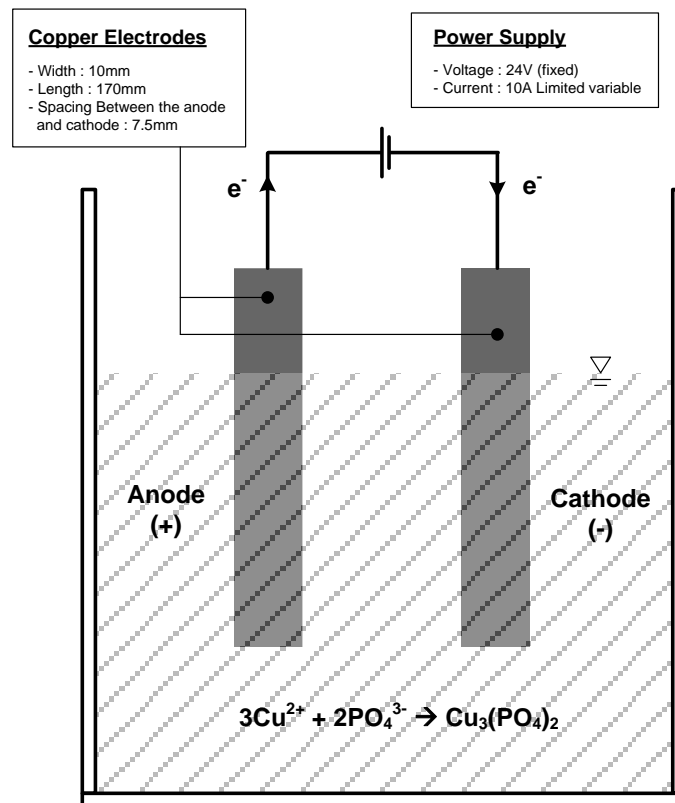


Figure 3. Schematic diagram of electrolysis experiment for removal of residual phosphate in effluent

However, the adding of phosphate and magnesium salts for MAP precipitants formation can cause the increase of phosphate concentration in final effluent of the system. Therefore, the electrolysis method was additionally used for the removal of residual phosphate ion in effluent. As illustrated in Fig.3, the electrochemical experiment was conducted in a 250 mL cylindrical batch reactor. A pair of copper electrodes were also used by advantages such as slower exhaustion rate and easier maintenance than other metals as presented in our previous study [23]. The experiments were also performed under a variable current with an upper limit of 10A and a fixed voltage of 24V. The width and length of each electrode were 10 and 170 mm, respectively, and the spacing of 7.5 mm between the anode and cathode was set by using a clamp.

3. RESULTS AND DISCUSSION

3.1 Feasibility evaluation of biological nitrification

For the biological removal of different types of nitrogen compounds in the chemical fertilizer industry wastewater used in this study, nitrification of ammonia, organic nitrogen, and urea is required prior to beginning any treatment. However, the nitrification can be adversely affected due to the high-strength ammonia and non-degradable pollutants contained in the wastewater [11]. Thereby, the feasibility of biological nitrification needs to be reviewed, and a batch-type experiment for evaluation of nitrification performance was conducted in this study. Two types of wastewater, synthetic wastewater and chemical fertilizer industry wastewater were used. Ammonium chloride (NH_4Cl), as a source of ammonia supply and inorganic nutrients such as calcium, magnesium, and phosphate, was added for the manufacture of synthetic wastewater for the controlled experiment. Nitrifying microorganisms cultured purely by ammonium chloride was used, and its concentration was around 8,300 mg/L. Having about seven times the alkalinity every milligram of oxidized ammonia was also added to the artificial wastewater for sufficient nitrification reaction.

During 120 minutes, as shown in Fig.4, nitrification efficiency above 95% could be achieved in synthetic wastewater. In chemical fertilizer industry wastewater, however, about 5% of ammonia was converted to nitrate during the same retention time. Even when the retention time was extended to 240 minutes, moreover, enhancement of nitrification performance was not observed, and it seemed that biological nitrification of chemical fertilizer industry wastewater could not be achieved due to the high-strength ammonia concentration and non-degradable pollutants. Zhang *et al.* [19] also reported that the biological process is often not effective for removal of nitrogen with high-strength ammonium.

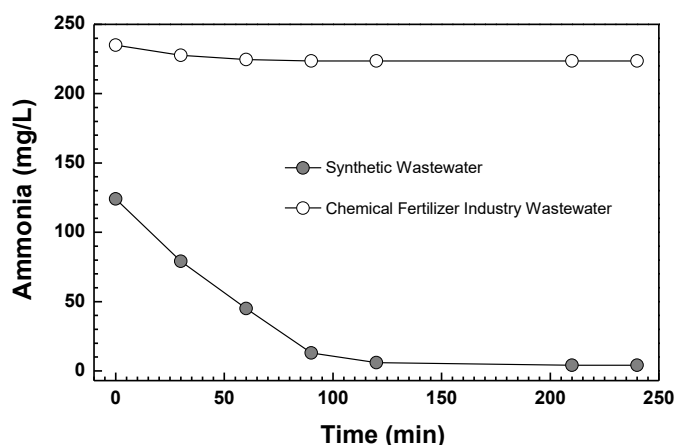


Figure 4. Nitrification feasibility test of both synthetic and chemical fertilizer industry wastewater

3.2 Effect of magnesium and phosphate dosing on ammonia removal

Physico-chemical processes can be applied to treatment high concentrations of ammonium nitrogen. and chemical precipitation of ammonium nitrogen removal by adding magnesium salt and

phosphate to form magnesium ammonium phosphate hexahydrate (MAP) is a useful method [24]. Therefore, additional supplements of phosphate and magnesium is necessary for removal of ammonium nitrogen contents in wastewater by MAP precipitation using the chemical combination of magnesium, phosphate, and ammonium nitrogen.

Determination of an optimal supplement ratio of phosphate and magnesium is very important from an economical point of view, therefore, because the phosphate and magnesium salts are very expensive and it can raise the operation cost [6,21]. It can also be useful for the correlation between on the variation of influent ammonia loading and water quality criteria.

In this study, a batch-type experiment for determining the optimal supplement ratio of phosphate and magnesium salts was conducted additionally. A phosphate and magnesium salts to ammonium nitrogen ratio ($\{Mg^{2+}$ and $PO_4^{3-}-P\}/NH_4^+-N$) of 1.5-2.0 was applied. For the MAP crystallization, NH_4^+-N , Mg^{2+} and $PO_4^{3-}-P$ are removed according to the stoichiometric relationship 1:1:1 theoretically. However, in order to improve phosphorus removal rate, NH_4^+-N and Mg^{2+} need to be excessive [25]. Fig.5 shows the effect of the supplement ratio of phosphate and magnesium salts on ammonia removal. At a $\{Mg^{2+}$ and $PO_4^{3-}-P\}/NH_4^+-N$ of 1.5, the effluent concentration of ammonia was 33mg/L and an ammonia removal of 83.7% was achieved. Ammonia removal increased to 90% under the conditions of $\{Mg^{2+}$ and $PO_4^{3-}-P\}/NH_4^+-N$ of 1.8-2, however, and the effluent concentration of ammonia also decreased to 33mg/L. Even though the supplement ratio of phosphate and magnesium salts increased above 1.8, enhanced removal of ammonia was not observed.

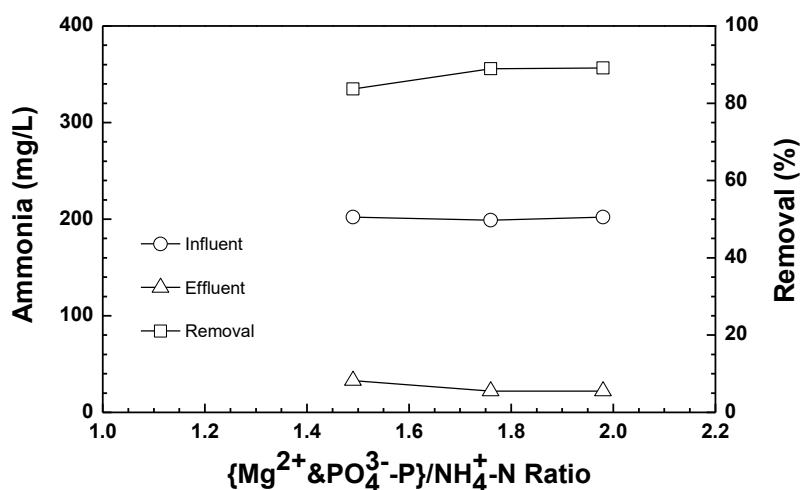


Figure 5. Effect of supplement ratio of phosphate and magnesium on ammonia removal

3.3 Effect of pH value on ammonia removal

Solution pH value is one of the important factors controlling the reaction for MAP crystallization [22]. Conditions that result into struvite formation are highly dependent on the ionic compositions, temperature, pH, and ion speciation characteristics [26]. The effect of initial pH value on ammonia removal by MAP formation was evaluated under the conditions of pH 9.5, influent ammonia

concentration of about 195mg/L, and $\{Mg^{2+}$ and $PO_4^{3-}-P\}/NH_4^+-N$ of 1.5, as presented in Fig.6. As the initial pH value increased from 10.5 to 12.5, the removal of ammonia nitrogen could be elevated from 78.2% to 87% and a concentration decrease of effluent ammonia nitrogen was observed from 42mg/L to 25mg/L. Even though higher removal of ammonia nitrogen could be achieved at the initial pH value of 12.5, an initial pH range of 11.5-12 might be most appropriate considering the costs of NaOH supplement for increasing the pH value and the performance of ammonia removal. The solubility of MAP precipitants is lowest under alkalinescent conditions, whereas the effluent concentration of ammonia nitrogen can be elevated because the solubility can increase at strong alkaline conditions [21]. Therefore, effluent pH value, as well as initial pH value, is also very important for formation of MAP precipitants. Fig.6 presents the effect of effluent pH on the behavior of the ammonia nitrogen in effluent.

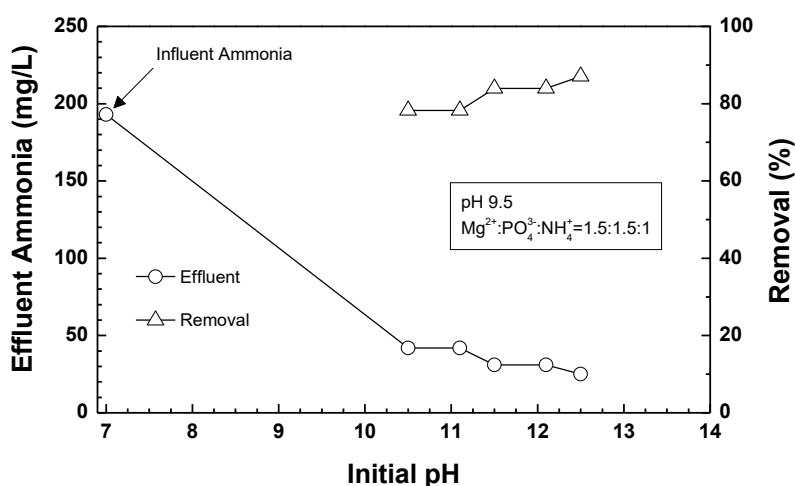


Figure 6. Effect of initial pH value on ammonia removal by magnesium ammonium phosphate formation

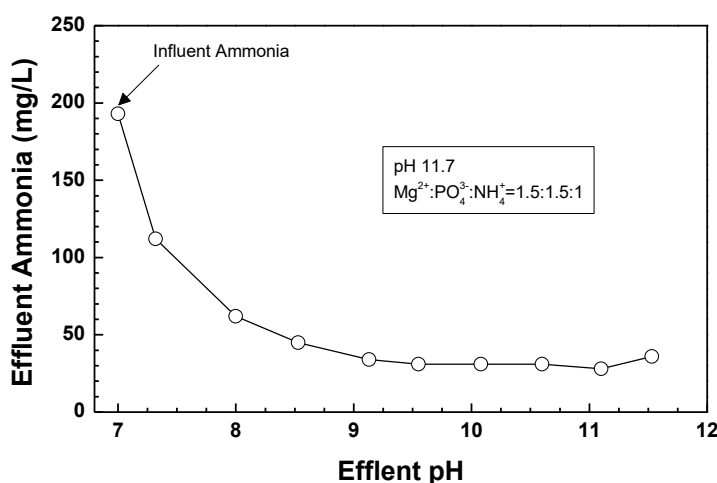


Figure 7. Effect of effluent pH value on ammonia removal by magnesium ammonium phosphate formation

Fig.7 shows the effect of effluent pH on ammonia removal by MAP formation. This was evaluated under conditions of pH value of 11.7, influent ammonia concentration of about 195mg/L, and $\{Mg^{2+}$ and $PO_4^{3-}-P\}/NH_4^+-N$ of 1.5, and sodium hydroxide was also added for the control of pH in the effluent.

An effluent ammonia nitrogen concentration of 45mg/L was observed at pH values below 9, whereas the concentration decreased to 28-31mg/L under pH values of 9-11. The ammonia nitrogen concentration in effluent increased to 36mg/L at an effluent pH value of 11.5, however, and this might be explained by the solubility of MAP precipitants elevated at pH values above 11.5, i.e. a strong alkaline condition. Although the formation of MAP could be very effective at an effluent pH of 10.5, the effluent pH range of 9-10 might be the most optimal condition considering easier operation and maintenance.

3.4 Nitrogen removal in pilot-scale MAP system

In this study, nitrogen compounds contained in chemical fertilizer industry wastewater were primarily ammonia nitrogen, with nearly 70%, followed by urea at 16%, organic nitrogen at 8% and nitrate at 6%. Therefore, not only should specific components of nitrogen be considered but also the overall nitrogen must be eliminated for the removal of total nitrogen (TN) in wastewater.

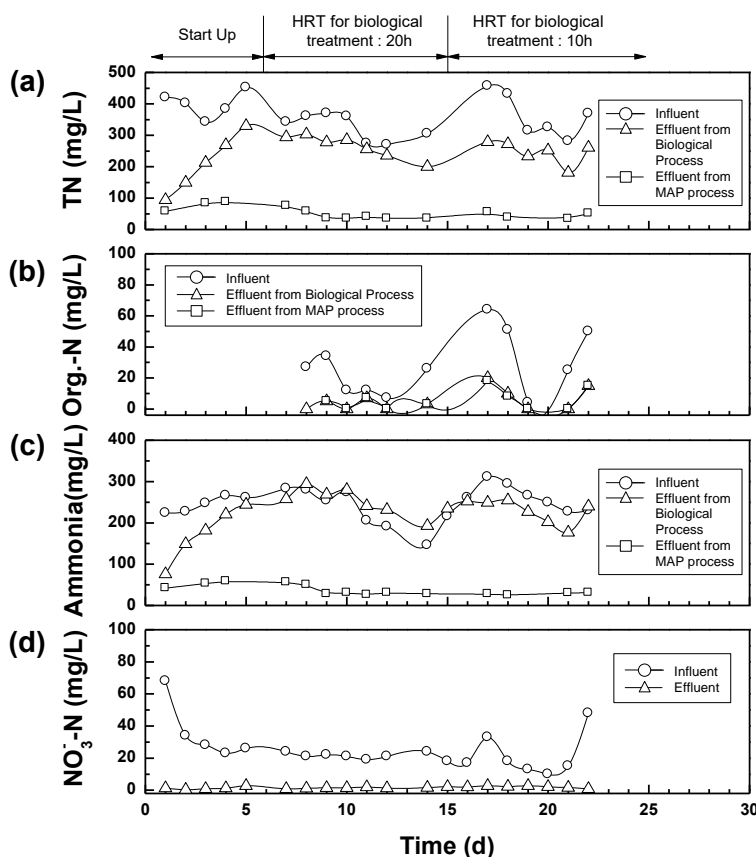


Figure 8. Profiles of various nitrogen compounds in the pilot-scale magnesium ammonium phosphate system

The pilot-scale MAP system was composed of a biological pre-treatment process for the preferential removal of nitrate in wastewater and a subsequent physico-chemical MAP precipitation process. The biological pre-treatment process consists of an anoxic tank for denitrification, an aerobic tank for organics removal and nitrification, and a settling tank for solids separation. The hydraulic retention time in the initial operation was 20 hours, and it was also operated at an HRT of 10 hours after achieving steady-state. Ammonia was removed from wastewater in the MAP process by struvite formation and precipitation through supplements of phosphate and magnesium.

Fig.8 shows the profiles of various nitrogen compounds in the pilot-scale MAP system. Severe fluctuation of influent TN was observed in the range of 270-450mg/L, and the system was capable of producing an effluent TN below 55mg/L, as shown in Fig.8 (a). About 87mg/L of TN was removed in the biological pre-treatment process through denitrification of nitrate, assimilation of ammonia nitrogen, and settling of organic nitrogen. Specifically, stable TN removal of about 24.9% could also be achieved in the biological pre-treatment process regardless of HRT.

The organic nitrogen contained in chemical fertilizer industry wastewater used in this study consists of soluble and insoluble forms. In the pilot-scale system, insoluble organic nitrogen can be removed by settling and biosorption, whereas the elimination of soluble organic nitrogen can be achieved by ammonia removal in the subsequent MAP process after transformation to ammonia nitrogen in the biological pre-treatment process. Fluctuation of organic nitrogen in the range of 4-64mg/L was observed in chemical fertilizer industry wastewater, as shown in Fig.8 (b). Effluent organic nitrogen between 0.5-7mg/L was observed during the biological pre-treatment procedure at an HRT of 20 hours. The process was capable of producing 0.5-18mg/L of effluent organic nitrogen. This may be due to the relation between increment of organic nitrogen loading and reduction of retention time. Removal of organic nitrogen was also not observed during the MAP procedure.

Ammonia nitrogen represents about 70% of the overall nitrogen compounds contained in chemical fertilizer industry wastewater, and it is also discharged with high-strength. The removal of ammonia nitrogen in wastewater should be performed by physico-chemical methods such as MAP precipitation, because biological nitrification could not be achieved, as mentioned in Fig.4. Organic nitrogen and urea were transformed to ammonia nitrogen during the biological pre-treatment procedure, and the ammonia was removed in the subsequent MAP process.

When the biological pre-treatment process was operated at an HRT of 20 hours, the process was capable of producing ammonia nitrogen in the range of 146-283mg/L, as presented in Fig.8 (c). Ammonia nitrogen could also be decreased below 50mg/L after the MAP precipitation procedure. Although the influent concentration of ammonia nitrogen is greatly increased to the range of 227-311mg/L under the condition of the biological pre-treatment process HRT decreasing to 10 hours, higher ammonia nitrogen removal with a concentration of below 31mg/L in final effluent could be achieved after MAP precipitation. The ammonia nitrogen concentration of effluent was higher than that of influent during the biological pre-treatment procedure, in some cases, because the amount of ammonia nitrogen transformed from organic nitrogen and urea was larger than that used by microorganisms. However, overall ammonia nitrogen could be removed successfully by the subsequent MAP precipitation process in the pilot-scale system.

Fig.8 (d) shows the profiles of nitrate in the pilot-scale MAP system. The nitrate contained in influent wastewater was denitrified in the biological pre-treatment process, and methanol was used as an external carbon source for the denitrification reaction. Most nitrates could be removed by biological denitrification, and the pilot-scale system was capable of producing effluent nitrate of below 2.7mg/L.

3.5 Estimation of produced sludge amounts and MAP recovery for economic improvement

The MAP precipitation has been widely studied as the resource recycling methods for the removal of high-strength ammonia and phosphorus from wastewater [12-14]. As mentioned above, nitrogen removal in chemical fertilizer industry wastewater could be successfully performed by the pilot-scale combined MAP process with biological pre-treatment process. In particular, high-strength ammonia nitrogen representing about 70% of overall nitrogen compounds contained in the wastewater was eliminated during the MAP precipitation procedure. However, large amounts of by-product, i.e. sludge, were produced by the addition of elements such as magnesium and phosphate for MAP formation.

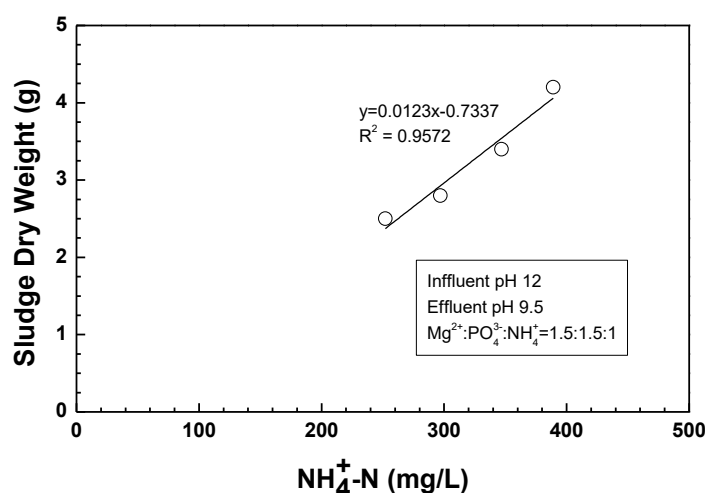


Figure 9. Sludge production by magnesium ammonium phosphate precipitation

Fig.9 presents the amount of produced sludge due to ammonia nitrogen removal by the MAP precipitation method. A sludge mass of 2.5g was produced for a removal of ammonia nitrogen of 250mg/L, and the mass rose linearly as the ammonia nitrogen removal increased. In this study, the cost for sludge treatment and addition of elements such as magnesium and phosphate for MAP formation rose up to around 9.8 dollars per milligram of removed ammonia nitrogen. Thus, cost-reduction in operation and maintenance by a decrease of added magnesium and phosphate should be required to overcome the economical limitations. In this study, a batch-type experiment was also performed for the recovery and reuse of magnesium and phosphate from crystallized MAP precipitants. The pH value was adjusted to 12 by addition of sodium hydroxide (NaOH) to the wastewater containing high-strength ammonia nitrogen, and the ammonia was removed through MAP precipitation by addition of magnesium

and phosphate. The molecular weight of crystallized MAP ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) was 245g/mol, and it decreased to 137 after removal.

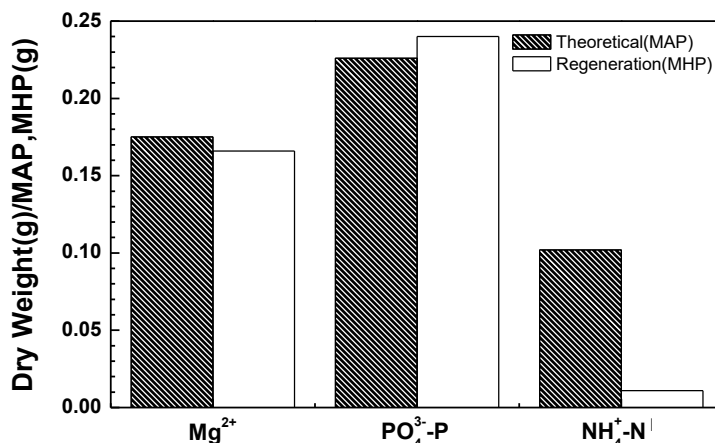


Figure 10. Variation of composition before and after recovery of magnesium ammonium phosphate

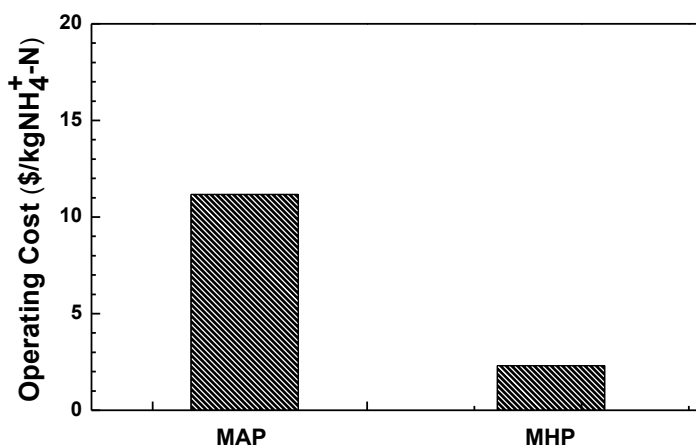


Figure 11. Cost reduction before and after regeneration of magnesium ammonium phosphate

Fig.10 shows the variation of compositions before and after recovery of MAP. Compositions of magnesium, phosphate, and ammonium per dry weight of MAP precipitant were about 0.175, 0.226, and 0.102, respectively. Ammonia gas was stripped from the MAP precipitants by heating at 103-110°C for 18 hours, and the weight ratio of magnesium, phosphate, and ammonium per dry weight of residuals were 0.166, 0.240, and 0.011, respectively. From this result, it seemed that the MAP ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) precipitants might be transformed to MHP (MgHPO_4) by releasing ammonia, and the magnesium and phosphate used for MAP formation would be substantially recovered, to above 90%. In this study, MHP was used for removal of ammonia in wastewater by being converted back to MAP. The reduction of operation and maintenance costs for sludge treatment and element addition before and after regeneration of MAP is presented in Fig.11, and the cost decreased significantly from 9.8 dollars to 2.0 dollars per milligram of ammonia nitrogen.

3.6 Phosphorus removal in final effluent of the MAP system by electrochemical Treatment

However, the phosphate concentration in final effluent of the system can be increased by the supplement of phosphate and magnesium salts for the formation of MAP precipitants. In actual, the average concentration of phosphate in final effluent was about 15mg/L after MAP precipitants formation by the adding of phosphate and magnesium salts. The electrochemical reaction is a very useful method guaranteeing higher phosphorus removal from wastewater [27]. In this study, therefore, the removal feasibility of residual phosphate in effluent was conducted additionally by electrochemical method using the copper electrodes with advantages such as slower exhaustion rate and easier maintenance than other metals as presented in our previous study [23]. The electrolysis experiment was also performed in a batch manner, as shown in Fig.3.

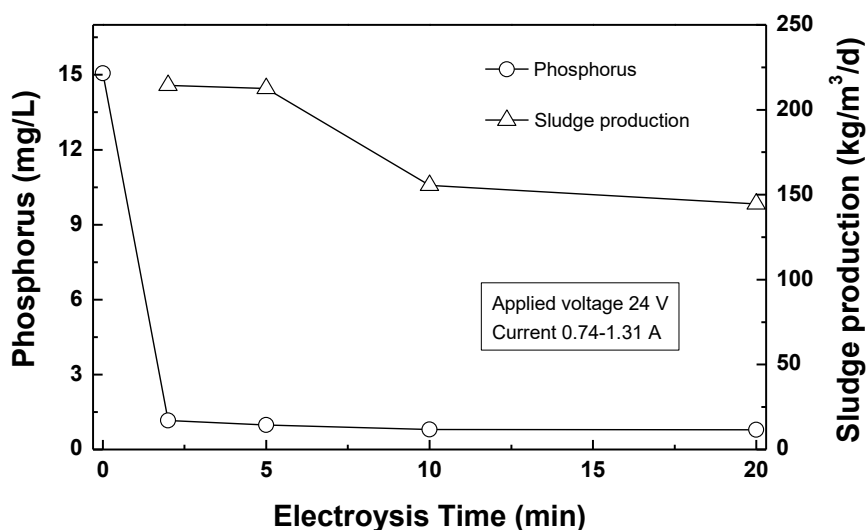


Figure 12. Phosphate removal and sludge production by electrochemical treatment

Fig.12 exhibits the profiles of phosphate concentration and sludge production during the electrolysis time. Remarkable phosphate removal could be accomplished by electro-coagulation mechanism, and most phosphate was eliminated rapidly within 3 minutes. Electro-coagulation involves the coagulants generation in situ by electrically dissolving metal ions from respectively metal electrodes [28] Electro-coagulation is effective for removal of suspended solids as well as oil and greases. It has been proven to be effective wastewater treatment for small- or medium-sized community. It is very effective in removing the colloidal found in natural water. The sludge above 200kg/m³/d was also produced during the initial electrolysis time within 5 minutes, whereas it was reduced as the phosphate removal was finished. As the electrolysis time is progressed, the mass of sludge production declined because the phosphate removed by electro-coagulation reaction decreased gradually in the water. From this result, therefore, the phosphate removal is seemed to be performed by the mechanism of electrocoagulation ($3 \text{ Cu}^{2+} + 2 \text{ PO}_4^{3-} \rightarrow \text{Cu}_3(\text{PO}_4)_2$) at the cathode. Thus, it was believed that the modified electrochemical treatment process using copper electrode devised in this study would be a good

alternative to existing phosphorus removal process, and it could be contributed to the control of eutrophication.

4. CONCLUSION

For the removal of high-strength nitrogen compounds in fertilizer industry wastewater, a pilot-scale MAP precipitation system combined with biological pre-treatment was applied. A phosphate and magnesium salts to ammonium nitrogen ratio ($\{Mg^{2+}$ and $PO_4^{3-}-P\}/NH_4^+-N$) of 1.5-2.0 was applied for determining the optimal supplement ratio of phosphate and magnesium salts, and the highest ammonia removal could be achieved in the range of 1.8-2.0. Although the severe fluctuation of influent TN was observed, the system was capable of producing an effluent TN below 55mg/L. Organic nitrogen and urea were transformed to ammonia during the biological pre-treatment procedure, and the ammonia was removed in the subsequent MAP process. Ammonia could be successfully removed below 50mg/L after the MAP precipitation procedure, and most nitrates were removed by biological denitrification. The MAP ($MgNH_4PO_4 \cdot 6H_2O$) precipitants was transformed to MHP ($MgHPO_4$) by releasing ammonia, and the magnesium and phosphate used for MAP formation could be recovered to above 90%. The MHP was used for removal of ammonia in wastewater by being converted back to MAP, and the operation and maintenance costs for sludge treatment and element addition significantly decreased from 9.8 dollars to 2.0 dollars per milligram of ammonia nitrogen. Phosphate increasing by the adding of phosphate and magnesium for the formation of MAP precipitants could be also removed rapidly within 3 minutes by electrolysis. It seemed that the remarkable phosphate removal could be performed by the formation of copper phosphate during the electrolysis procedure.

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