A NOVEL ION-EXCHANGE/ELECTROCHEMICAL TECHNOLOGY FOR THE TREATMENT OF AMMONIA IN WASTEWATER

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ABSTRACT

Increased public concern about water quality coupled with regulatory pressure is forcing municipalities to examine their wastewater treatment practices. Of particular concern is the discharge of nitrogenous compounds into receiving bodies. Current technology for treating ammonia relies on biological activity to convert ammonia to nitrate. Total nitrogen removal requires an additional biological process to remove nitrate from the wastewater prior to discharge. Biological treatment systems are adversely affected by cold temperatures and changes in effluent composition. Enpar Technologies Inc. has developed a novel ion-exchange/electrochemical technology, the AmmEl System (patents pending), to treat ammonia in wastewater streams. The AmmEl System uses electrochemistry to convert ammonia to nitrogen gas.

The AmmEl System uses a two-stage approach to treat ammonia; the first stage utilizes ion-exchange to remove ammonia from the wastewater followed by electrochemical oxidation of the captured ammonia directly to N_2 gas.

The AmmEl system has been pilot tested at the City of Guelph wastewater treatment plant. Two separate wastewater streams were tested; Case (I) as a pretreatment system for sludge dewatering wastewater and Case (II) as a tertiary treatment system for clarified secondary activated sludge effluent. The system was very effective at removing ammonia for both treatment scenarios. In Case I, the AmmEl system was able to remove >93% of the ammonia from the effluent with inlet ammonia-N concentrations ranging between 200 to 1000 mg/L. The AmmEl system was also effective at removing the ammonia-N from the clarified secondary effluent wastewater stream (NH_3-N concentration up to 5 mg/L), producing an average concentration of 0.6 mg/L in the treated effluent.

The AmmEl system has been proven to be an effective method for removing ammonia from both high strength and low strength waste streams. Furthermore, the system is a robust and cost effective alternative to existing ammonia removal technologies. Advantages of the AmmEl system include: i) completely eliminates nitrogen loading, ii) not affected by cold wastewater temperature, iii) relatively small footprint, and iv) no start-up or acclimation period required.

Operating costs for the AmmEl system are expected to be between $2.20 to $2.40

per kg N removed. Capital cost for an add-on tertiary ammonia removal system for the post-treatment of lagoon effluent is estimated at $1.6 M for the AmmEl system. Typical attached growth nitrification systems are expected to cost between $1.65 to $2.9 M for the same treatment scenario.

KEY WORDS: ammonia oxidation, ion-exchange, electrochemistry, total N removal

INTRODUCTION

Conventional municipal wastewater treatment plants consisting of settling and activated sludge treatment are effective at removing BOD and suspended solids from the effluent prior to discharge to receiving bodies. However, the wastewater often contains significant quantities of nutrients, notably ammonia, that can adversely impact the receiving body. The listing of ammonia as a toxic substance by Environment Canada (Environment Canada and Health Canada, 2001), coupled with increased public concern is forcing municipalities to examine their wastewater treatment practices. It is expected that discharge requirements for ammonia will become more stringent in the near future.

Current technology for treating ammonia relies on biological activity, i.e nitrification, to convert ammonia to nitrate. Total nitrogen removal requires an additional biological process to remove nitrate from wastewater prior to discharge. Biological treatment systems are adversely affected by cold temperatures and changes in effluent composition.

A novel ion-exchange/electrochemical treatment technology (the AmmEl system) has been developed by Enpar Technologies Inc. This paper presents the principals behind the technology and summarizes the results of pilot testing of the AmmEl system at the City of Guelph wastewater treatment plant.

SCIENTIFIC BASIS OF THE TECHNOLOGY

Electrochemical Oxidation of Ammonia

A basic electrochemical reactor consists of four main components; i) an anode, ii) cathode, iii) electrolyte and iv) a direct current (DC) power source (Figure 1). The DC power source provides energy to the system to drive the transfer of electrons from the anode to the cathode of the cell. Oxidation reactions occur at the anode and reduction reactions occur at the cathode. The electrolyte completes the circuit and provides a medium for the transport of ions in the solution (for a more detailed explanation of electrochemical principles see Pletcher and Walsh, 1993).

The AmmEl system utilizes the following anodic reactions:

$$2NH_4^+ \rightarrow N_2 + 8H^+ + 6e^- \qquad 1)$$

$$2Cl^- \rightarrow Cl_2 + 2e^- \qquad 2)$$

Which promotes the following chemical reactions in the bulk solution:

$$Cl_2 + H_2O \rightarrow HOCl + HCl \qquad 3)$$

$$2NH_4^+ + 3HOCl \rightarrow N_2 + 3H_2O + 5H^+ + 3Cl^- \qquad 4)$$

The overall result is the oxidation of ammonia to N_2 gas.

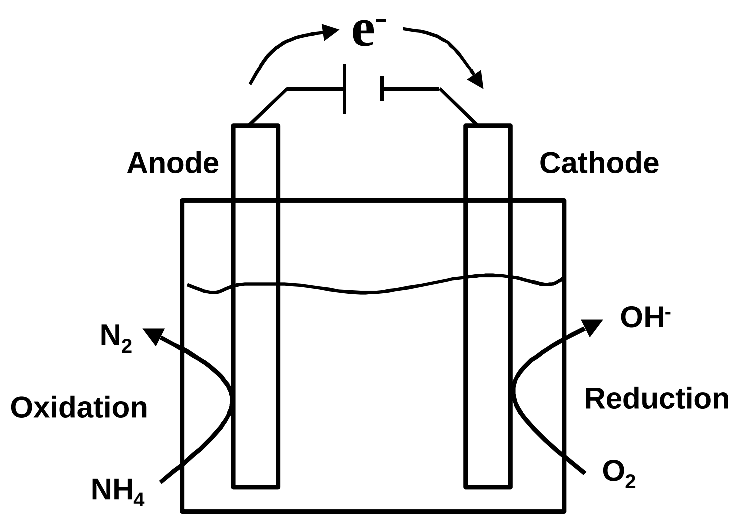

FIGURE 1: ELECTROCHEMICAL CELL

The AmmEl Process

Previous studies conducted by Enpar Technologies demonstrated that the composition of the electrolyte was a key factor for effective oxidation of ammonia. For low ionic strength solutions, such as municipal wastewater, a two-stage system was developed. Whereas, for high ionic strength solutions, such as seawater, direct oxidation of the ammonia in the wastewater is possible.

The two-stage AmmEl system utilizes ion-exchange (IX) as the first stage to remove the ammonia from wastewater. Zeolites, naturally occurring aluminosilicate minerals, are used for the ion-exchange media. Zeolite minerals have been shown to have a high exchange capacity for various ions, including the ammonium ion, and are inexpensive and durable. The use of zeolites in municipal wastewater treatment for the removal of ammonia has been well documented by Liberti (1982).

A schematic of the overall process illustrating the combined system is presented in Figure 2. Once the IX media is loaded with ammonium (Stage 1), the media is regenerated by circulating a brine solution through the column. The ammonium ion is transferred into the regenerant solution and is subsequently oxidized to N_2 gas using an electrochemical reactor (the reactions described in the previous section). Thus, the regenerant solution can be continuously reused.

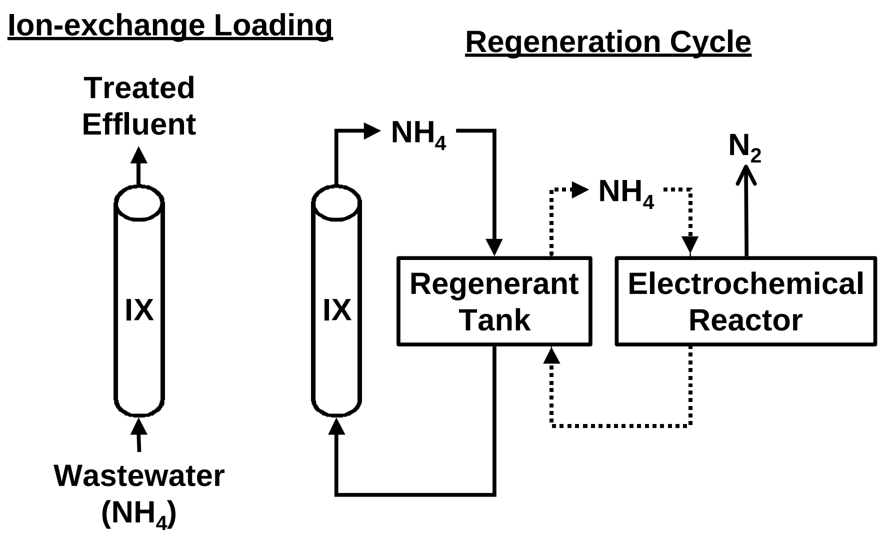

FIGURE 2: THE AMMEL PROCESS

PILOT TESTING AT THE CITY OF GUELPH

Background on City of Guelph WWTP

The City of Guelph wastewater treatment plant (WWTP) has an existing treatment capacity of 64 ML/day of wastewater with a planned expansion for 2007 to a capacity of 73.3 ML/day. The WWTP currently utilizes rotating biological contactors (RBCs) for tertiary treatment for ammonia nitrification. The sludge treatment circuit consists of anaerobic digestion followed by dewatering using a belt press. The dewatering filtrate and wash water is directed to the headworks of the treatment plant with ammonia-N concentrations ranging between 200 to 700 mg/L at an average flow of 800 m^3/day.

There is no specified limit on ammonia concentration in the effluent during the summer discharge period (Apr. 1 to Oct. 31). However, the WWTP must meet a total oxygen demand concentration limit of 22 mg/L and a daily loading limit of 1,210 kg/day during the summer months. During the winter discharge period, an ammonia-N concentration limit of 3.4 mg/L and a loading limit of 217.6 kg/day must be met. With the planned expansion, the WWTP will be required to meet ammonia-N discharge limits of 1.0 mg/L (22 kg/day) and 1.5 mg/L (37 kg/day) in the summer and winter discharge periods, respectively.

Scope of Testing

Two distinct wastewater streams were tested during the pilot programme; i) sludge dewatering effluent and ii) clarified secondary activated sludge effluent.

Pilot System

The pilot system consisted of three IX columns, 20 cm in diameter by 1.7 m high coupled with a 2.4 kW electrochemical reactor. The basic operation of the system is presented in Figure 3. Two of the IX columns (1 and 2) are operated in series to treat the wastewater while the third column undergoes regeneration. The columns are cycled, using a programmable controller, to provide continuous treatment of the wastewater.

For example, the sequence progresses as follows:

- the lead column (column 1) is isolated for regeneration,
- column 2 becomes the lead column,
- column 3 becomes the secondary column.

The system can be configured with a recirculation loop for the treatment of high concentration effluent (dashed line).

During the regeneration cycle, the brine solution is circulated through both the column and the electrochemical reactor. The electrochemical reactor is operated at a current of 600 A DC and a potential of 4 V to oxidize the ammonia to N_2 gas.

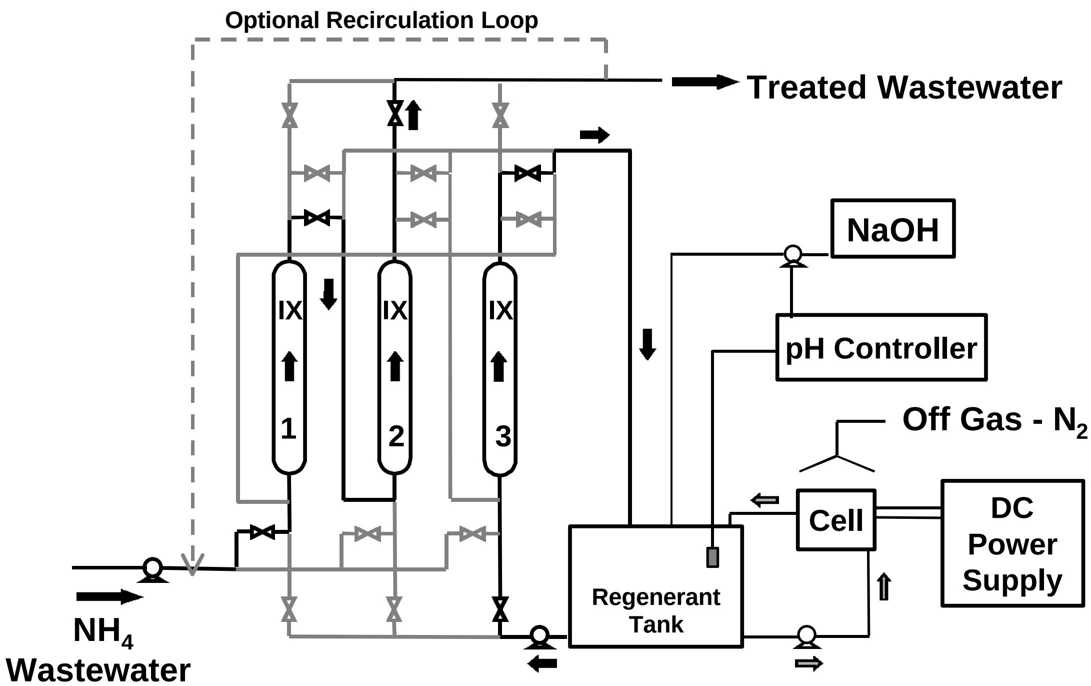

FIGURE 3: SCHEMATIC OF PILOT SYSTEM

TREATMENT OF SLUDGE DEWATERING EFFLUENT

Objective

The AmmEl system was investigated for use as a pre-treatment system to remove ammonia from sludge dewatering effluent prior to returning the effluent to the WWTP for further processing. The treatment objective was to decrease the ammonia concentration in the effluent by 90%, and thus decrease the ammonia loading to the WWTP.

Wastewater Characteristics and Operating Conditions

A side stream was collected directly from the belt press and pumped to the AmmEl pilot system. The only pre-treatment of the effluent consisted of coarse filtration using a series of screens to remove the majority of solids. The suspended solids content of the stream remained relatively high in the range of 200 to 400 mg/L of TSS.

The ammonia-N concentration of the dewatering effluent was found to vary from 200 to 1000 mg/L over the course of the trial.

The treatment system was operated at an effluent flow rate of 2 L/min. The system was configured with a recycle loop to maintain a column flow rate of 18 L/min.

Treatment Results - Sludge Dewatering Effluent

The results of a typical treatment run are presented in Figure 4. The AmmEl system was effective at removing >93% of the ammonia-N from initial levels of 700 mg/L. The high levels of suspended solids in the effluent did not appear to have an adverse impact on operation of the system.

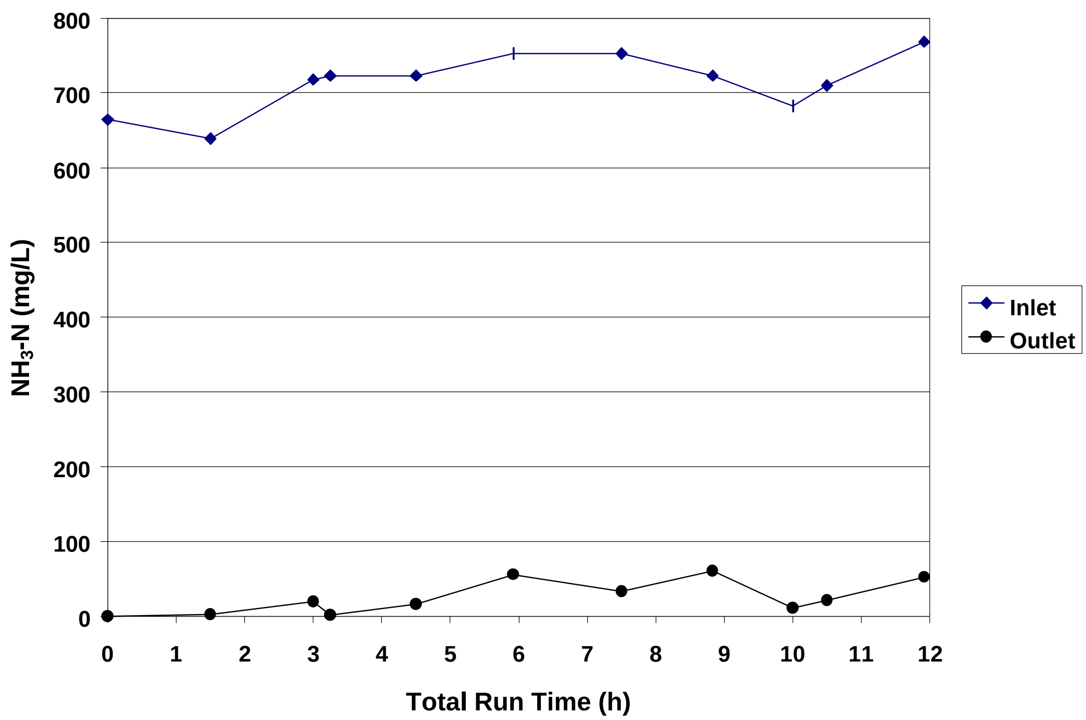

FIGURE 4: TREATMENT OF SLUDGE DEWATERING EFFLUENT

TREATMENT OF CLARIFIED SECONDARY EFFLUENT

Objective

The objective of this phase of testing was to evaluate the AmmEl system for use as a polishing system to remove ammonia-N from clarified secondary activated sludge effluent prior to discharge. The treatment objective was to reduce the ammonia-N to less than 1 mg/L in the treated effluent.

Wastewater Characteristics and Operating Conditions

A side stream from the secondary clarifier was directed to the pilot AmmEl system at a flow rate of 14 to 16 L/min. The ammonia-N concentration was found to vary from <1 to 5 mg/L. Sampling revealed that the ammonia-N concentration fluctuated on cyclic basis with a peak ammonia-N level occurring between 18:00 to 20:00 h daily.

The control program for the treatment system was modified such that the treatment system was shut down and bypassed when the effluent concentration was less than 1 mg/L NH_3-N. In other words, the system was turned off when not required. Therefore, during bypass operation, the inlet and outlet sampling points are identical. The mode of operation is summarized in Figure 5.

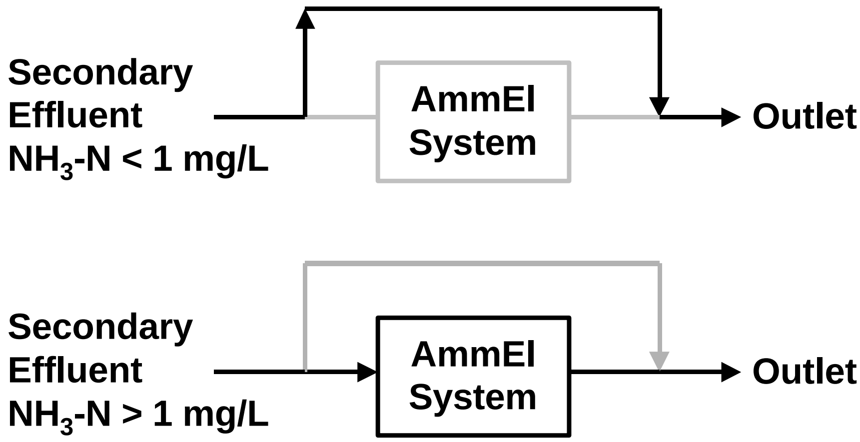

FIGURE 5: MODE OF OPERATION

Results - Treatment of Clarified Secondary Activated Sludge Effluent

The results of a typical treatment run are presented in Figure 6. As indicated by Figure 5, the inlet and outlet sample points are the same for the system during bypass. The AmmEl system was effective at reducing the ammonia-N concentration in the wastewater stream to less than 1 mg/L with an average of approximately 0.6 mg/L. The results also demonstrate a unique feature of the AmmEl system; intermittent operation is possible if required.

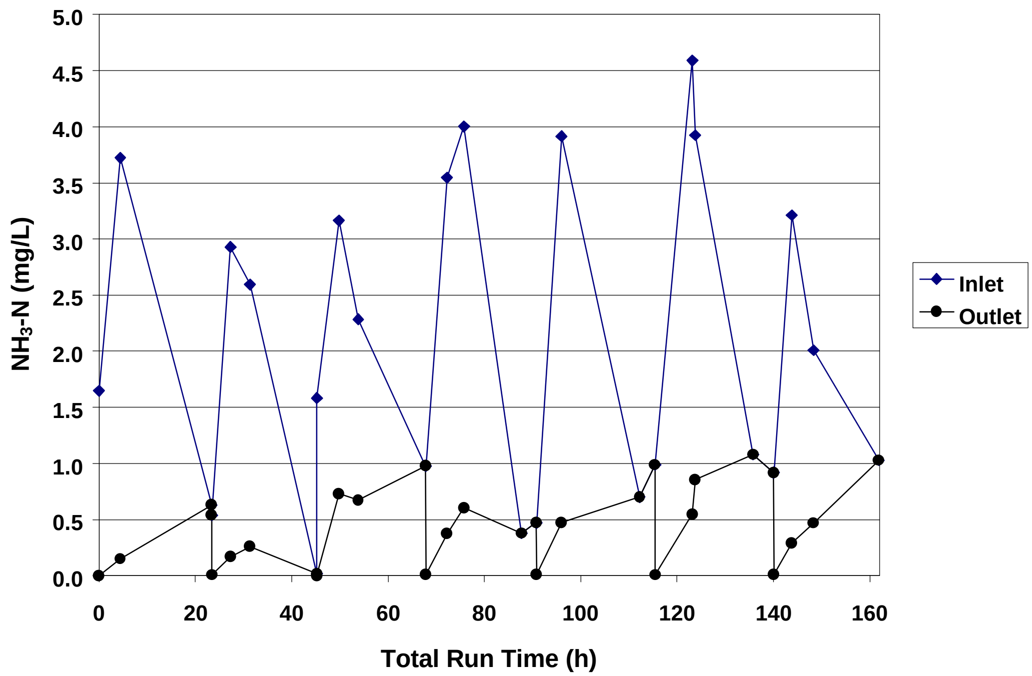

FIGURE 6: TREATMENT OF CLARIFIED SECONDARY EFFLUENT

OFFGAS CHARACTERIZATION

As part of pilot testing, gas samples were collected from the headspace of the reactor and analyzed for volatile organic compounds (VOCs), NH_3, total NOx and Cl_2. The results of the sampling are presented in Table 1. The only contaminant detected in the offgas stream was small quantities of Cl_2. The Cl_2 can be readily removed from the gas stream and recovered for reuse in the regenerant.

TABLE 1: OFFGAS SAMPLING

Compound	Concentration
VOCs	nd
NH3	nd
NOx	trace
Cl_2	1 - 8 ppm

The offgas composition from the pilot system confirmed previous laboratory work which determined that N_2 gas was the main end product of ammonia oxidation (>99.99%).

TREATMENT COSTS

Operating

The operating costs (power and chemicals) for the AmmEl system are estimated to be between $2.20 to $2.40 per kg NH_3-N removed.

Capital Cost Comparison

The capital cost of the AmmEl system was compared against attached growth nitrification systems according the scenario presented by Environment Canada (2003). The scenario consisted of an add-on tertiary ammonia removal system for the post-treatment of lagoon effluent with the following characteristics:

- ammonia-N concentration of 20 mg/L
- discharge requirement <5 mg/L
- flow rate of 1000 m^3/day.

The capital cost for the AmmEl system for the above scenario is estimated at $1.6 M; by comparison typical attached growth nitrification systems are expected to range from $1.65 to $2.9 M (Environment Canada 2003).

It should be noted that the attached growth systems are converting the ammonia to nitrate, whereas, the AmmEl system completely removes the nitrogen.

SUMMARY

The AmmEl system has been demonstrated to be effective at removing ammonia in a variety of wastewaters.

The main advantages of the AmmEl system are:

1. Completely eliminates total nitrogen loading, i.e. no conversion to nitrate.
2. Able to achieve low effluent ammonia concentrations.
3. Can handle effluent containing high suspended solids.
4. The treatment system is not effected by cold wastewater temperature.
5. No start-up or acclimation period required; intermittent operation is feasible if required.
6. Can be fully automated and remotely monitored.
7. Cost competitive with existing treatment technologies.

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