

## Use of a rotating biological contactor for removal of ammonium from mining effluents

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### ABSTRACT

Mine and mill effluents often contain appreciable quantities of ammonia. The discharge of effluents containing ammonia to aquatic systems can have significant environmental effects because ammonia is toxic to fish and other organisms. The Rotating Biological Contactor (RBC) technology has been in use for several years for the treatment of municipal and industrial wastewater. This study evaluates the application of RBC technology for the removal of ammonia from mining industry effluents. The research shows that the RBC is very effective in the removal of ammonium ( $\text{NH}_4\text{-N}$ ) from simulated mining effluents in the temperature range of 4.5 to 24°C and pH values ranging from 7.5 to 8.0. The RBC was able to remove more than 95% of the influent  $\text{NH}_4\text{-N}$  (at a concentration of 45mg/l) at a hydraulic retention time (HRT) of 1.7h and a hydraulic loading rate (HLR) of 0.04m<sup>3</sup>/m<sup>2</sup>d at ≈8°C. At 4.5°C the RBC produced an effluent with  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentrations of 0.1 and 0.7mg/l, respectively, at HRT of 3.2h and HLR of 0.02m<sup>3</sup>/m<sup>2</sup>d. The results show that RBC biological treatment systems are capable of treating mine effluents at cold temperature conditions (4 to 5°C) for ammonia removal. The RBC was observed to recover approximately 50% to 75% of normal ammonia removal process efficiency in about a day after process upsets. © 2003 SDU. All rights reserved.

Keywords: Ammonia; Effluents treatment; Rotating biological contactor; Biotechnology; Environmental

### 1. INTRODUCTION

Rotating biological contactors (RBC) are attached growth biological reactors with a series of closely spaced circular disks made of plastic media mounted on a rotating horizontal shaft. The rotating discs on which microorganisms grow is partially submerged (typically 40%) in wastewater and rotated at one to three revolutions per minute to alternately expose the microorganisms to wastewater and air. The microorganisms attached on the rotating disks as 'biofilms', degrade organic matter and nitrogen containing compounds in the wastewater. Figure 1 shows a schematic diagram and the treatment processes occurring in the RBC. RBCs have been most commonly used for the treatment of municipal wastewater. RBCs have also been used in the treatment of wastewater from industries such as food processing, mining, fertilizer production, petroleum refineries, photo finishing, explosives and semiconductor manufacturing (Iggleden, 1981). In this paper the application of RBC technology for the treatment of mining effluents is reviewed and is followed by the results from an experimental study evaluating the potential application of RBC's for the removal of  $\text{NH}_4\text{-N}$  from simulated mining effluents.

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## 2. PROCESS DESCRIPTION

The RBC circular disks provide a support media for the growth of microorganisms and rotate at a speed of 1 to 3rpm. The rotation of the disks can be achieved by a motor and drive system on each shaft or by an air drive system with a coarse bubble diffuser at the bottom of the tank supplying air that is caught by the air cups attached to the disks. The media is made of high-density polyethylene containing UV inhibitors such as carbon black. Individual RBC units are placed in series to maximize the treatment efficiency. Baffles are placed in a RBC to separate the shafts into a series of completely mixed bioreactors; each one is referred to as a stage. These baffles are moveable to allow the number of stages and their sizes to be adjusted in response to variations in process loading. Normally, the first stage of the RBC sees the highest biological activity. The rotation of the disks imparts a shear force to the biofilm, keeping its thickness relatively constant by removing the cells generated by consumption of the substrates. Rotation of the disks also serves to provide oxygen required for the growth of biomass and substrate degradation. A settling tank is normally required to remove the biomass from the effluent. A cover made of fiberglass is generally provided over RBC units to provide protection against inclement weather, freezing, and sunlight. Covers also reduce the heat loss, allow the off-gas to be collected for odor control and minimize algae growth. The microorganisms on the disks consume organic matter, nitrogen and nutrients in wastewater and grow attached to the disc as a biofilms. The advantages of the RBCs include lower energy requirements, ease of operation, little maintenance and minimal operator attention. Additionally, they are resistant to toxic shock loads due to the large inventory of microorganisms on the media (Iggleden, 1981).

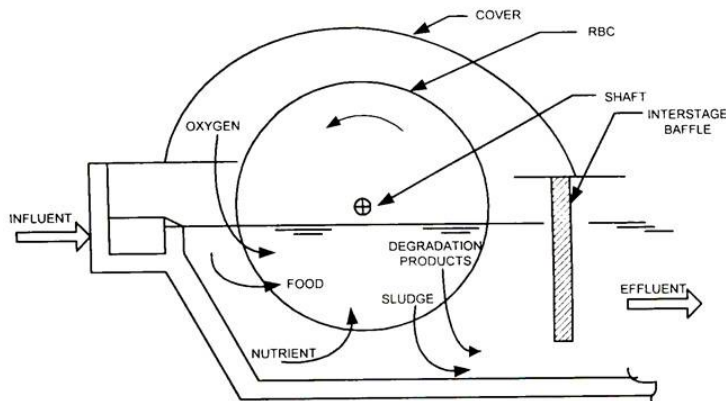


Figure 1. RBC process schematic (Grady *et al.*, 1999)

## 3. APPLICATION OF RBC FOR THE TREATMENT OF MINING EFFLUENTS

RBCs have been used for the removal of contaminants such as ferrous iron ( $\text{Fe}^{2+}$ ), cyanide in its various forms, oxalate, and selenium from mining effluents. These applications are discussed below.

### 3.1. Treatment of acid mine drainage by ferrous oxidation

Acid mine drainage contains high concentrations of ferrous ion, in addition to a variety of heavy metals and acidity. Iron oxidizing bacteria, such as *Thiobacillus ferrooxidans*, are present in acid mine drainage and are capable of oxidizing ( $\text{Fe}^{2+}$ ) to ferric ( $\text{Fe}^{3+}$ ) ions. The  $\text{Fe}^{3+}$  ions can then be easily removed by pH adjustment to approximately 3.0. Olem and Unz (1977) conducted a pilot scale RBC study near a coal mine at Hollywood, Pennsylvania to evaluate the effectiveness of  $\text{Fe}^{2+}$  oxidation using a four stage RBC with a disk diameter of 0.5m and a total volume of 156L. The RBC was operated at a disk rotation of 6rpm and hydraulic loading rates

of 0.11 and 0.22m<sup>3</sup>/m<sup>2</sup>d. Under these operating conditions, the influent Fe<sup>2+</sup> concentration of 240mg/l was reduced to 5mg/l and the oxidation was observed to follow a first order reaction rate. Iron oxidizing bacteria present in the acid mine drainage colonized the surface of the rotating disks at average populations of 70,000cells/cm<sup>2</sup> to mediate the Fe<sup>2+</sup> oxidation. Olem and Unz (1980) also studied the application of RBCs for Fe<sup>2+</sup> oxidation (influent concentrations ranging from approximately 30 to 400mg/l) at mine sites near Morgantown, West Virginia and Philipsburg, Pennsylvania. Temperatures as low as 0.4°C did not inhibit Fe<sup>2+</sup> oxidation in the RBC units. Hydraulic retention times (HRT) of 40 to 60 minutes were found to be adequate for Fe<sup>2+</sup> oxidation. RBCs were observed to recover their treatment efficiency very quickly (after one HRT) after unscheduled shutdowns due to failure of the RBCs drive motor.

### 3.2. Cyanide degradation

Mudder and Whitlock (1983) evaluated various chemical, physical and biological treatment processes for the removal of cyanide from effluent produced at the Homestake Gold Mine at Lead, South Dakota. Pilot studies showed RBCs to be effective and economical for the removal of cyanide, thiocyanide and ammonia from effluent produced at the Homestake mine. The Homestake mine has been using RBC process since 1984 for the wastewater treatment (Whitlock, 1995). The plant treats 21,000m<sup>3</sup> of wastewater per day using 48RBCs, each consisting of a corrugated plastic media disk of 3.6m in diameter and 7m long. The disks are made of high-density polyethylene (HDPE) corrugated sheets with a surface area of 9,300 to 14,000m<sup>2</sup> per disk RBC. The disks rotate at 1.5rpm and are 40% submerged. The HRT in the RBCs system ranges from 1.2h to 2.5h. The wastewater from the underground mine and decant water from the tailings pond are mixed in a 60/40 ratio. Blowers add supplemental air at 5000scfm and 4.8psi mainly to promote removal of sloughed biomass. Phosphoric acid as a nutrient for microorganisms and soda ash for alkalinity control are also added to the treatment system. The plant treatment efficiency is as follows: 99-100 % removal of thiocyanate, 96-98% total cyanide removal, 98-100% removal of weak and dissociable cyanides, 95-99% ammonia removal. The daily operational costs were \$0.10 (€0.09) per m<sup>3</sup> in 1990 (Whitlock, 1990).

### 3.3. Removal of selenium (Se) from smelter effluents

Selenium is often present in effluents from zinc hydrometallurgy circuits. Various microorganisms have been found to be effective in the reduction of selenium oxyanions to elemental selenium. McCready *et al.* (1990) studied the removal of selenium from weak smelter effluent using bench and pilot scale RBC's. Greater than 97% selenium removal from weak acid smelter effluent containing 33ppm Se was achieved using a 30L RBC with disk surface area of 9.29m<sup>2</sup> at a hydraulic retention time of 4h. A pilot scale RBC, operated at Kidd Creek mine in Timmins, Ontario, showed that 90% selenite reduction to elemental Se could be achieved at a hydraulic retention time of 4h and a Se: BOD ratio of 1:20. However, Se recovery from biomass was marginal (Ontario Research Foundation, 1987).

### 3.4. Removal of oxalate

Oxalate accumulates in Bayer process circuits during the beneficiation of bauxite ores. CANMET-Mining and Mineral Sciences Laboratories (MMSL), in collaboration with ALCAN and Carleton University, studied the biodegradation of oxalate ions by RBCs (Brassinga *et al.*, 1992; Beaudette *et al.*, 1993). A lab scale RBC with a 12L capacity and a 3.7m<sup>2</sup> disk surface area was used. The RBC was seeded with a mixed bacterial culture isolated from the rhizosphere soil of two plants, rhubarb and dieffenbachia. The RBC system was able to completely remove 4500mg/l of oxalate ions at a hydraulic residence time of 5h with disks rotating at 3rpm. The oxalate degradation rate was observed to be 77.8g oxalate/m<sup>2</sup>/day. The total cost of oxalate removal by the treatment system was estimated to be US\$158.42 (145.34) per ton of sodium oxalate. A full-scale RBC system is being used in Jamaica for oxalate removal.

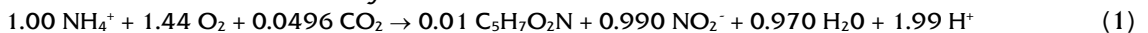
#### 4. SOURCES OF AMMONIA IN MINING EFFLUENTS AND ITS ENVIRONMENTAL EFFECTS

Mining effluents can contain appreciable quantities of ammonium ions. Common sources of ammonium in mining effluents are from the use of the blasting agent ammonium nitrate fuel oil (ANFO), nitrogen containing reagents such as amines used in the milling operations and the use of ammonium ions to precipitate uranium, and the use of ammonia as a lixiviant in copper and nickel hydrometallurgy. In gold mining effluents, ammonia can also be generated by the degradation of cyanide used in gold extraction and also thiocyanate that is formed by the interaction of labile sulfur and cyanide during the cyanidation process. The discharge of effluents containing significant amounts of ammonia to receiving waters can have significant environmental effects because of its toxicity to fish and other aquatic organisms. Since ammonia-N is a nutrient for algae and aquatic plants, significant discharge of ammonia-N could also result in algal blooms and eutrophication depending on the nutrient status of the receiving water body.

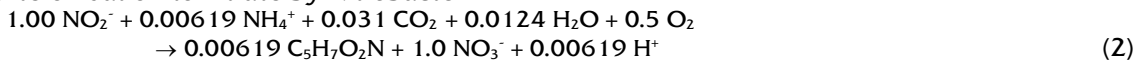
#### 5. BIOLOGICAL CONVERSION OF AMMONIA TO NITRATE

Bacteria that convert ammonia to nitrate are commonly known as nitrifiers and obtain their energy for growth from the oxidation of ammonia. Nitrifiers sequentially oxidize ammonium to nitrite ( $\text{NO}_2^-$ ) followed by oxidation to nitrate ( $\text{NO}_3^-$ ). The process of biological oxidation of ammonia to nitrate is commonly referred to as "nitrification". The two principal genera of importance for carrying out this process are *Nitrosomonas*, for conversion of ammonium to nitrite and *Nitrobacter*, for conversion of nitrite to nitrate (US EPA, 1993). The reactions involved in the nitrification process can be represented by the following three equations (US EPA, 1993):

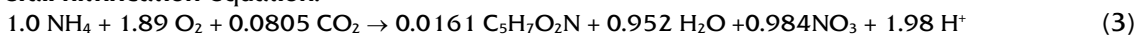
Ammonium oxidation to nitrite by *Nitrosomonas*



Nitrite oxidation to nitrate by *Nitrobacter*



Overall nitrification equation:



The nitrification systems are designed assuming that the nitrification process requires 4.6g  $\text{O}_2$  per g  $\text{NH}_4\text{-N}$  oxidized, produces approximately 0.1g biomass per g of  $\text{NH}_4\text{-N}$  oxidized and consumes 7.1g alkalinity (as  $\text{CaCO}_3$ ) per g  $\text{NH}_4\text{-N}$  oxidized (US EPA, 1993). Various environmental factors that impact the nitrification process are temperature, dissolved oxygen concentration, pH, and a variety of toxic organic and inorganic contaminants. Nitrification has been demonstrated to occur over a temperature range of 4 to 45°C. In RBC systems, for  $\text{NH}_4\text{-N}$  concentrations greater than 5mg/l, the nitrification rate is limited by oxygen transfer for temperatures higher than 13°C (WEF and ASCE 1992). The concentration of dissolved oxygen (DO) also has a significant effect on the rate of nitrification. US EPA (1993) recommends that a DO level of 2.0mg/l be maintained in the treatment system to prevent peak load ammonia breakthrough. Optimum pH values ranging from 6.5 to 8.0 have been reported in the literature. For the design of nitrification systems, it is important to recognize that nitrification rates decrease significantly as the pH is lowered below the neutral range (< 6.5). A pH in the range of 6.5 to 8.0 is normally required for performance stability (US EPA, 1993). The nitrification rate is sensitive to a wide variety of organic and inorganic chemicals. It is beyond the scope of this paper to discuss the effect of various chemical species on nitrification, readers interested are directed to reviews by Painter and Loveless (1968) and Hockenbury and Grady (1977) on the effect of inorganic and organic chemical species on nitrification.

## 6. MATERIALS AND METHODS

A research project to study the biological removal of ammonia utilizing RBC's was initiated in April 2000 at the CANMET-MMSL. A four stage RBC with a hydraulic capacity of 19.2L was used in this research. Each stage of the RBC has 17 disks with a diameter and thickness of 0.27m and 0.005m, respectively. The total surface area provided by the rotating disks is 7.2m<sup>2</sup>. Figure 2 shows the schematic of the experimental set up. The RBC was inoculated with a culture of nitrifying bacteria that were enriched from an activated sludge sample collected from the City of Ottawa municipal wastewater treatment plant. During the initial start-up phase, the RBC was operated in 100 percent re-circulation mode for three weeks in order to colonize the disks. After three weeks the RBC was operated in a flow through mode with the influent feed flow rate of 10ml/min. The flow rate was slowly increased to a desired flow of 100ml/min. The start up phase lasted approximately eight weeks. The feed solution was prepared using the City of Ottawa tap water. Ammonium sulfate [(NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>] was added to the tap water as an NH<sub>4</sub>-N source and mono-basic potassium phosphate (KH<sub>2</sub>PO<sub>4</sub>) was added to supply the phosphorus required for the bacterial growth at approximately 0.5mg/l. Metals salts such as zinc sulfate heptahydrate (ZnSO<sub>4</sub>.7H<sub>2</sub>O), copper sulfate pentahydrate (CuSO<sub>4</sub>.5H<sub>2</sub>O), nickel chloride hexahydrate (NiCl<sub>2</sub>.6H<sub>2</sub>O), cobalt chloride hexahydrate (CoCl<sub>2</sub>.6H<sub>2</sub>O), and lead chloride (PbCl<sub>2</sub>), were added to the feed water in order to have average Zn, Cu, Ni, Co and Pb concentrations of 0.5, 0.5, 0.1, 0.05 and 0.3mg/l, respectively.

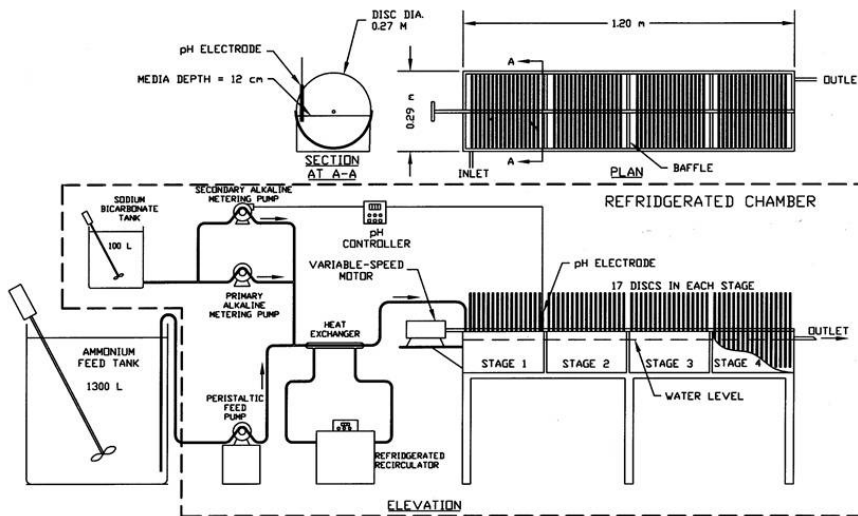


Figure 2. The experimental set

The feed solution was pumped from a tank (1300L) to the RBC using by two peristaltic pumps. The alkalinity required by the RBC was supplied by a sodium bicarbonate (NaHCO<sub>3</sub>) solution (15g/l). The rate of the alkalinity addition was adjusted routinely to maintain alkalinity (HCO<sub>3</sub><sup>-</sup>) to NH<sub>4</sub>-N ratio > 7.0 for neutralization of hydrogen ions released during the oxidation of ammonia and also to maintain the effluent pH of 7.5. The sodium bicarbonate solution was mixed with the feed to the RBC. The standby alkalinity feed pump (controlled by a pH controller) was also used to feed alkalinity to the RBC system. Experiments at temperatures >13°C were conducted in the experimental mill area of the CANMET laboratory. Low temperature studies were conducted in a temperature controlled room. For low temperature studies, the temperature of the feed to the RBC unit was controlled using a heat exchanger unit as the feed tank due to its size and space requirements was kept at room temperature outside the cold room. The RBC rotation speed was maintained at approximately 3rpm. The ammonium-N concentration in the influent to the RBC was maintained at approximately 45mg/l. The average flow rate to the RBC ranged from approximately 100ml/min to 255ml/min. The studies were conducted at temperature ranging from 4 to 24°C. Ammonium, nitrate, and nitrite were routinely measured

using a Hach colorimeter DR890 and DR 2010. The ammonia, nitrite and nitrate analysis was conducted using the salicylate method, diazotization method, chromotrophic methods respectively. The results from the above methods were regularly verified by the results from an ion selective electrode for ammonia and with ion chromatograph (HPLC) for nitrate and nitrite. The RBC temperature, flow, pH, DO, effluent suspended solids and alkalinity were also monitored.

## 7. RESULTS AND DISCUSSION

### 7.1. Performance at moderate temperature

Initially the RBC was operated in a complete re-circulation mode for three weeks to inoculate the disks at a flow rate of approximately 20ml/min with an initial  $\text{NH}_4\text{-N}$  concentration of approximately 125mg/l at a temperature of  $21\pm 2^\circ\text{C}$ . For an additional five weeks, the RBC was operated in a flow-through mode at a flow rate of approximately 30ml/min and the  $\text{NH}_4\text{-N}$  concentration in the feed was slowly decreased to the desired concentration of approximately 45mg/l. The feed flow rate to the RBC was slowly increased to 100ml/min. When the flow rates were increased from approximately 30ml/min to 100ml/min, a high  $\text{NO}_2\text{-N}$  (30mg/l) concentration in the effluent was observed. After approximately one month of RBC operation at flows of 100ml/min and a feed  $\text{NH}_4\text{-N}$  concentration of 45mg/l, the  $\text{NO}_2\text{-N}$  concentration in the effluent decreased to below 1mg/l and more than 99% oxidation of  $\text{NH}_4\text{-N}$  to  $\text{NO}_3\text{-N}$  was observed. Figure 3 shows the performance of the RBC at influent flow rates of 100ml/min (HRT of 3.1h and HLR of  $0.02\text{m}^3/\text{m}^2$  of disk area per day) and influent  $\text{NH}_4\text{-N}$  concentration of approximately 45mg/l. The average  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  concentrations in the effluent were 0.18mg/l, 0.03mg/l and 43.2mg/l respectively (Table 1). The average  $\text{NH}_4\text{-N}$  removal rate of  $0.90\text{g NH}_4\text{-N}/\text{m}^2\text{d}$  was achieved at these operating conditions (Table 2). The temperature during this experimental phase ranged from 18 to  $24^\circ\text{C}$ . These experiments were conducted in the open mill experimental area and this made it difficult to control the temperature. The temperature variations (18 to  $24^\circ\text{C}$ ) did not seem to have an impact on the RBC effluent  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentrations (Figure 3). The  $\text{NH}_4\text{-N}$  oxidation to nitrate was observed to take place mostly in Stages 1 and 2 of the RBC. On average, 96% of the  $\text{NH}_4\text{-N}$  in the feed was oxidized to  $\text{NO}_3\text{-N}$ .

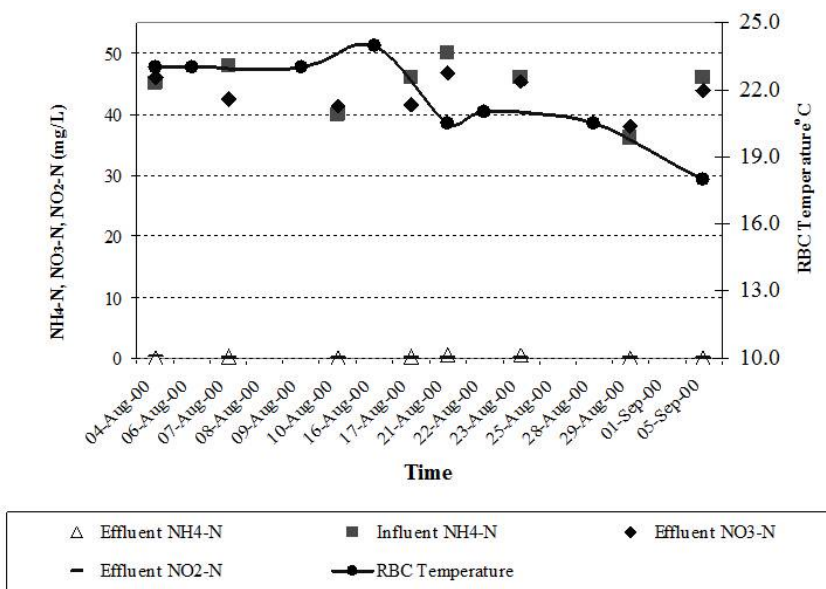


Figure 3. The RBC operating data at feed flow rate  $\approx 100\text{ml}/\text{min}$  and average temperature of  $22^\circ\text{C}$

Table 1

The concentration of NH<sub>4</sub>-N, NO<sub>2</sub>-N, and NO<sub>3</sub>-N in the four stages of the RBC at various operating conditions

Operating Conditions	Average Influent NH <sub>4</sub> -N (mg/l)	Average NH <sub>4</sub> -N at End of Stage 1 (mg/l)	Average NH <sub>4</sub> -N at End of Stage 2 (mg/l)	Average NH <sub>4</sub> -N at End of Stage 3 (mg/l)	Average NH <sub>4</sub> -N at End of Stage 4 (mg/l)
Flow Rate = 100ml/min, Temperature ≈ 22°C	44.6	10.3	0.38	0.17	0.18
Flow Rate = 200ml/min, Temperature ≈ 18°C	41.7	26.4	13.7	7.34	2.66
Flow Rate = 100ml/min, Temperature ≈ 8°C	48.1	22.6	3.46	1.24	0.92
Flow Rate = 200ml/min, Temperature ≈ 8°C	44.6	29.6	17.7	9.10	4.70
Flow Rate = 100ml/min, Temperature ≈ 4.5°C	43.1	20.5	5.50	0.53	0.07

Operating Conditions	Average Influent NO <sub>2</sub> -N (mg/l)	Average NO <sub>2</sub> -N at End of Stage 1 (mg/l)	Average NO <sub>2</sub> -N at End of Stage 2 (mg/l)	Average NO <sub>2</sub> -N at End of Stage 3 (mg/l)	Average NO <sub>2</sub> -N at End of Stage 4 (mg/l)
Flow Rate = 100ml/min, Temperature ≈ 22°C	1.14	7.05	0.60	0.04	0.03
Flow Rate = 200ml/min, Temperature ≈ 18°C	0.05	6.62	6.58	3.65	1.03
Flow Rate = 100ml/min, Temperature ≈ 8°C	0.01	9.73	10.4	1.27	0.13
Flow Rate = 200ml/min, Temperature ≈ 8°C	0.01	10.5	12.7	8.06	3.27
Flow Rate = 100ml/min, Temperature ≈ 4.5°C	0.03	23.1	18.7	4.46	0.70

Operating Condition	Average Influent NO <sub>3</sub> -N (mg/l)	Average NO <sub>3</sub> -N at End of Stage 1 (mg/l)	Average NO <sub>3</sub> -N at End of Stage 2 (mg/l)	Average NO <sub>3</sub> -N at End of Stage 3 (mg/l)	Average NO <sub>3</sub> -N at End of Stage 4 (mg/l)
Flow Rate = 100ml/min, Temperature ≈ 22°C	0.77	28.1	42.7	43.0	43.2
Flow Rate = 200ml/min, Temperature ≈ 18°C	0.28	5.40	23.1	33.1	37.3
Flow Rate = 100ml/min, Temperature ≈ 8°C	0.57	10.3	27.7	38.5	41.0
Flow Rate = 200ml/min, Temperature ≈ 8°C	1.29	7.51	16.5	30.2	45.1
Flow Rate = 100ml/min, Temperature ≈ 4.5°C	0.52	6.10	17.5	35.6	39.7

Table 2

The RBC hydraulic retention time, hydraulic loading rate and ammonia removal rates at various operating conditions

Operating Temperature Range**, °C	Average flow Rate, ml/min	Average Influent NH <sub>4</sub> -N, mg/l	Hydraulic Retention Time, h	Hydraulic Loading Rate, m <sup>3</sup> /m <sup>2</sup> d	NH <sub>4</sub> -N Removal Rate, g NH <sub>4</sub> -N/m <sup>2</sup> d
18 - 24 (22)	100	44.6	3.1	0.020	0.90
15.5 - 21.3 (≈18)	200	41.7	1.7	0.040	1.28
14.5 - 20.5 (≈18)	255	43.8	1.3	0.051	2.18
7.1 - 9.6 (≈8)	100	48.1	3.2	0.020	0.93
7.1 - 8.8 (≈8)	200	44.6	1.7	0.038	1.5
4.1 - 5.3 (4.5)	100	43.1	3.2	0.020	0.8

Note: \*\*The values indicated in the brackets is the average temperature for the period.

Figure 4 shows the performance of the RBC at average flow rates of approximately 200ml/min (HRT of 1.6h and HLR of 0.04m<sup>3</sup>/m<sup>2</sup>d) and an average temperature of 18°C. The average concentration of NH<sub>4</sub>-N, NO<sub>2</sub>-N and NO<sub>3</sub>-N in the RBC effluent were 2.66, 1.03 and 37.3mg/l respectively. At flow rates of 200ml/min, higher concentrations of NH<sub>4</sub>-N were observed in all Stages 1, 2 and 3 as shown in Table 1. The NH<sub>4</sub>-N concentration in the effluent reached concentrations of up to 8mg/l when the effluent pH in the RBC effluent was below 7.0, but an increase in the RBC pH to 7.5, led to a decrease in the effluent NH<sub>4</sub>-N concentration. To study the effects of the peak flows on the RBC performance, the flow rates to the RBC were increased from approximately 200ml/min (HRT of 96 minutes) to peak flows of up to 300ml/min (HRT of 65 minutes). With an increase in flow rates, the average concentration of NO<sub>2</sub>-N in the effluent increased to approximately 11.0mg/l, thus leading to incomplete oxidation of NH<sub>4</sub>-N to NO<sub>3</sub>-N. Figure 5 shows the affect of the increase in flow rates from 200ml/min to peak flow rate of 300ml/min. The effect of peak flow rate on effluent NO<sub>2</sub>-N concentration was observed to be only temporary, as the NO<sub>2</sub>-N concentrations in the effluent decreased as flow rates decreased to 200ml/min.

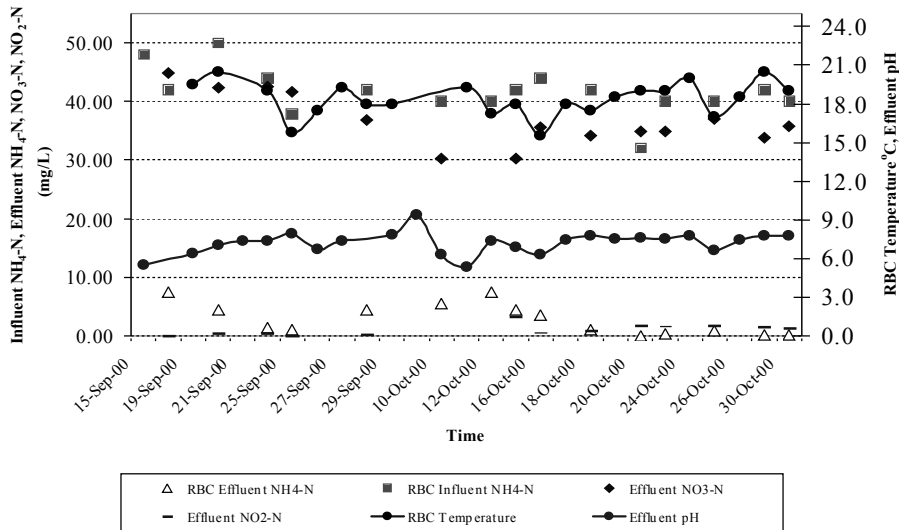


Figure 4. The RBC operating data at flow rate  $\approx$  200ml/min and average temperature of 18°C

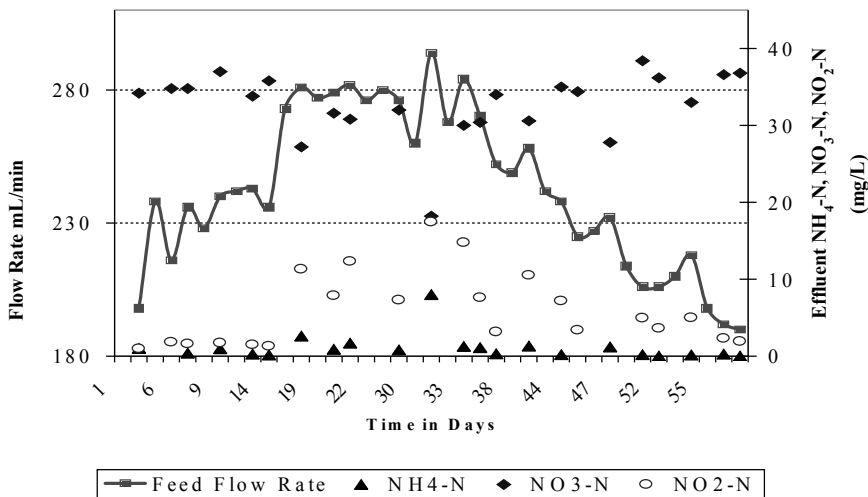


Figure 5. The effect of peak flow rate on the RBC effluent quality at temperature  $\approx$  18°C.



## 7.2. Performance at lower temperature

The nitrification process is sensitive to temperature. The temperature correction factor for the design of RBC systems is applied based on Figure 6 from the US EPA 1993 manual for municipal wastewater treatment applications. Figure 6 shows that temperature correction factors are available for temperatures ranging from 42°F ( $\approx 9^\circ\text{C}$ ) to 55°F. Temperature correction factors are not available for temperature below 42°F ( $\approx 9^\circ\text{C}$ ). Therefore, low temperature studies were carried out to evaluate the performance of the RBC at temperatures in the range of 4.5 to 8°C. These tests were carried out in a room with temperature control. Figure 7 shows the RBC operational data at flow rates of approximately 100ml/min and an average temperature of  $\approx 8^\circ\text{C}$ . The average effluent  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  concentrations were 0.92, 0.13 and 41.1 mg/L respectively. The RBC effluent  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentrations were consistently below 1mg/l. Table 1 shows that both  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentrations in Stage 2 and 3 at 8°C were higher than the concentration observed at  $\approx 22^\circ\text{C}$  for flow rates of 100ml/min. Therefore, at lower temperatures, additional disk area was required to produce effluent with  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentrations of less than 1mg/l. When flow rates were increased from 100ml/min to 200ml/min (at average temperature ( $\approx 8^\circ\text{C}$ )), the average effluent  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentration increased to 4.7 and 3.27mg/l respectively. Table 1 shows that higher concentrations of  $\text{NH}_4\text{-N}$  were observed in all four stages of the RBC at flow rates of 200ml/min compared to operation at 100ml/min. The  $\text{NH}_4\text{-N}$  removal rates observed at  $\approx 8^\circ\text{C}$  for 100ml/min and 200ml/min were 0.93 and 1.5 $\text{NH}_4\text{-N}/\text{m}^2\text{d}$  (Table 2). The performance of the RBC in the temperature range of 4 to 5°C was studied at a flow rate of 100ml/min (Figure 8). The RBC was able to produce effluent with  $\text{NH}_4\text{-N}$  and  $\text{NO}_2\text{-N}$  concentrations consistently below 1 mg/l. At  $\approx 4.5^\circ\text{C}$  significant accumulation of  $\text{NO}_2\text{-N}$  in Stages 1 and 2 of the RBC was observed compared to 8°C.

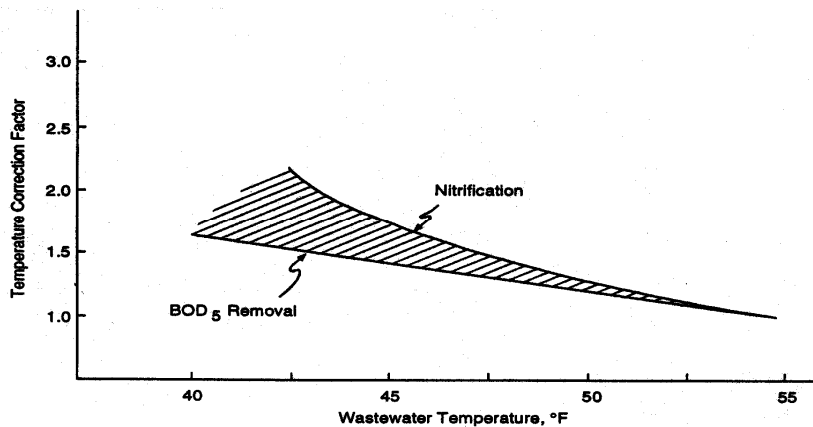


Figure 6. The temperature correction factor curve for design of RBCs (USEPA 1993)

The results of the low temperature studies show that RBCs are capable of achieving  $\text{NH}_4\text{-N}$  oxidation to  $\text{NO}_3\text{-N}$  at temperatures as low as 4°C. This result is important for countries, such as Canada, USA, Russia, and Greenland, where mines may have to treat effluents under low-temperature conditions. The Homestake Mine, South Dakota, USA uses RBCs to treat a mixture of wastewater from the underground mine which has a steady warm temperatures, and decant water from tailing ponds (mixed in a 60/40 ratio). The water temperature of the mixture ranges from 10 to 25°C (Whitlock, 1989). Whitlock (1989) indicated that the treatment efficiencies of RBCs at 5°C are similar to those obtained under warmer water conditions. The present research demonstrates that, at low temperatures (4 to 5°C), a RBC is capable of producing effluents that are comparable in quality to effluents produced at higher temperatures. Table 2 further shows that the RBC  $\text{NH}_4\text{-N}$  oxidation efficiency at low temperatures is maintained at operating conditions (HRT and ammonia loadings) similar to the RBC operating conditions at higher temperatures.

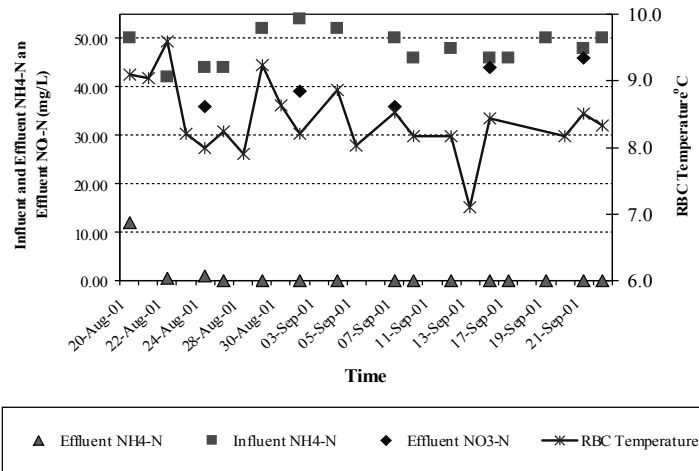


Figure 7. The RBC effluent  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  at flow rate  $\approx 100\text{ml/min}$  and average temperature  $\approx 8^\circ\text{C}$

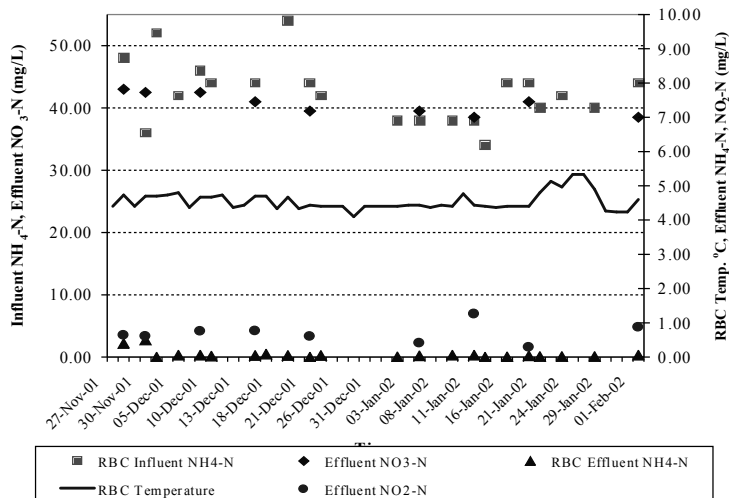


Figure 8. The RBC effluent  $\text{NH}_4\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  at flow rate  $\approx 100\text{ml/min}$  and average temperature of  $4.5^\circ\text{C}$

### 7.3. Process recovery after unscheduled upsets

The success of a biological process depends on the response of the process to unscheduled upsets in operating conditions and the recovery time required to restore its treatment efficiency. Figure 9 shows the response of the RBC to the two different unscheduled process upsets. Figure 9A shows the response of the RBC to a process upset due to the rupturing of the feed line to the RBC, which caused an interruption of the  $\text{NH}_4\text{-N}$  containing feed to the RBC for approximately 36h, while alkalinity was being pumped to the RBCs. The RBC was operating at a feed flow rate of  $200\text{ml/min}$  at  $18^\circ\text{C}$  prior to the rupturing of the feed line. As a result, the pH in the RBC increased from the normal operating range of 7.4 - 7.8 to 9.2. The  $\text{NH}_4\text{-N}$  concentration in the feed decreased from  $42\text{mg/l}$  to  $27\text{mg/l}$  in the effluent within 24 hours of restoration of feed to the RBC. The RBC achieved its normal  $\text{NH}_4\text{-N}$  removal capacity in approximately a week. The  $\text{NH}_4\text{-N}$  oxidation process produces  $\text{H}^+$  ions and is sensitive to pH, and as a result requires alkalinity addition for optimum performance. Alkalinity addition to the RBC stopped for approximately 16 hours due to the failure of the alkalinity feed pump, while the feed solution was being constantly fed to the RBC at a feed flow rate of  $200\text{ml/min}$  and at  $8^\circ\text{C}$ . The pH in the RBC dropped from 7.8 to 6.1. The pH in the RBC was restored to 7.6 in approximately 4 h after

the alkalinity feed was restored to normal flow conditions and in 24h the RBC achieved  $\text{NH}_4\text{-N}$  oxidation efficiency of 75%. The RBC achieved  $\text{NH}_4\text{-N}$  oxidation efficiency of 98% in approximately a week after the process upset.

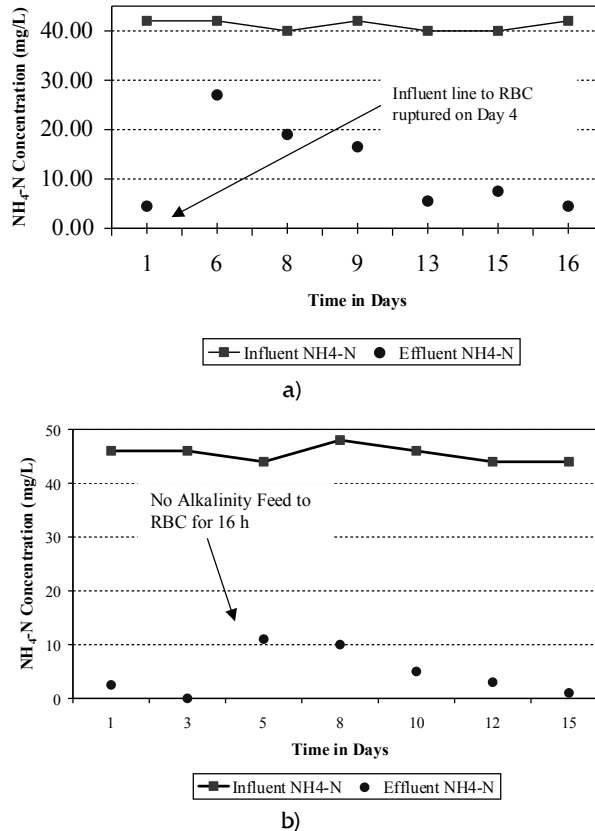


Figure 9. The effect of process upsets on the final effluent  $\text{NH}_4\text{-N}$  concentration in the RBC effluent a) Influent flow to RBC stopped for 36h at RBC operating conditions of  $\approx 200\text{ml/min}$  and temperature  $\approx 18^\circ\text{C}$  and b) No alkalinity addition to RBC for 16h at RBC operating conditions of  $\approx 200\text{ml/min}$  and temperature  $\approx 8^\circ\text{C}$

## 8. CONCLUSIONS

RBC technology has been effectively used for the treatment of municipal and industrial wastewaters. The RBC process is being used at the Homestake Mine, USA for the removal of cyanide, thiocyanide and ammonia and other potential applications of RBCs for treatment of mining effluents for various pollutants have been explored. The application of biotechnology based processes for the treatment of mining wastewaters in cold mining regions has been limited as the biological processes are sensitive to low temperatures.

The typical design curve for RBCs for the treatment of municipal wastewaters is available in the literature (US EPA, 1984). The RBCs for municipal wastewater treatment are designed for hydraulic loading rates exceeding  $0.02\text{m}^3/\text{m}^2\text{d}$ . In municipal wastewater treatment processes, primarily organic carbon removal is desired. RBC systems are designed typically for a maximum  $\text{BOD}_5$  loading rate of  $30\text{g BOD}_5/\text{m}^2/\text{d}$  that are much higher than the maximum achievable  $\text{NH}_4\text{-N}$  removal rate of  $1.61\text{g NH}_4\text{-N}/\text{m}^2\text{d}$ . The RBCs in the present study were operated at hydraulic loading rates of  $0.02$  to  $0.04\text{m}^3/\text{m}^2\text{d}$  and achieved  $\text{NH}_4\text{-N}$  reduction in excess of 90% at low temperatures. The maximum nitrogen removal rate of  $2.71\text{g NH}_4\text{-N}/\text{m}^2\text{d}$  was achieved during the RBC operation at peak flow conditions of approximately  $300\text{ml/min}$ . At  $4.5^\circ\text{C}$  the RBC was

able to achieve 0.8g NH<sub>4</sub>-N/m<sup>2</sup>d. The RBC effluent was clear and the average concentration of suspended solids in the RBC effluent was 7 mg/l.

The separation of RBC shaft into stages is important, as the treatment process relies on the surface area available for microbial growth and substrate transfer. It also helps prevent short-circuiting within the RBC. Nitrification has been shown to be a first-order reaction for NH<sub>4</sub>-N concentrations below 5mg/l and a zero-order for NH<sub>4</sub>-N concentrations greater than 5mg/l (US EPA 1984). At NH<sub>4</sub>-N concentrations greater than 5mg/l, the rate of nitrification for RBCs is oxygen transfer limited at temperatures of 13°C or greater. Therefore, staging does not increase the NH<sub>4</sub>-N flux into the biofilm when its concentrations exceeds 5mg/l, but it does increase the over all flux when the NH<sub>4</sub>-N concentration is less than 5mg/l. As a result, staging does become important when NH<sub>4</sub>-N concentrations of below 5mg/l are desired in the effluent. The benefits of staging were evident (Table 1) at low temperature for NH<sub>4</sub>-N conversion to NO<sub>2</sub>-N and subsequent NO<sub>2</sub>-N oxidation to NO<sub>3</sub>-N. Staging also affects the nature of the biomass that develops in the individual stages and their resultant pollutant removal capability. The profile of NH<sub>4</sub>-N, NO<sub>2</sub>-N and NO<sub>3</sub>-N suggests that *Nitrosomonas* bacteria that oxidize NH<sub>4</sub>-N to NO<sub>2</sub>-N are likely dominant on the RBC disks in Stages 1 and 2 and *Nitrobacter* bacteria that oxidize NO<sub>2</sub>-N to NO<sub>3</sub>-N are likely to be dominant in Stage 3 and 4. The *Nitrosomonas* and *Nitrobacter* bacterial population distribution and activity in various stages were also dependent on the hydraulic loadings and the temperature. The concentration profile of NO<sub>2</sub>-N and NO<sub>3</sub>-N (Table 1) suggests that an increase in hydraulic loadings from 0.02 to 0.04m<sup>3</sup>/m<sup>2</sup>d resulted in a comparatively higher *Nitrobacter* populations in later stages (3 and 4).

A cost estimate was obtained from a municipal wastewater treatment RBC supplier for the treatment of 6000m<sup>3</sup>/day of wastewater containing 37.5 NH<sub>4</sub>-N mg/l. The cost estimates were developed based on an effluent NH<sub>4</sub>-N target level of 1 mg/L for summer and 2mg/l for winter operating conditions. The total capital cost was estimated to be CDN\$3.75 million. The power consumption was estimated to be 33 kilowatts per day. The other operating cost would be to maintain an adequate supply of alkalinity and phosphorus for growth of microorganisms.

The present research shows that the RBC is very effective for the removal of NH<sub>4</sub>-N from simulated mining effluents in the temperature range of 4.5 to 24°C and pH ranging from 7.5 to 8.0. The RBC was able to remove more than 95% NH<sub>4</sub>-N at a HRT of 1.7h and HLR of 0.4m<sup>3</sup>/m<sup>2</sup>d at ≈ 8°C. At 4.5°C the RBC produced effluent with NH<sub>4</sub>-N and NO<sub>2</sub>-N concentration of 0.1 and 0.7mg/l respectively at HRT of 3.2h and HLR of 0.02m<sup>3</sup>/m<sup>2</sup>d.

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