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SUSTAINABLE NITROGEN REMOVAL USING APPROPRIATE TECHNOLOGIES

KRISHNANAND MAILLACHERUVU and DEREK HARTMANN

Dept of Civil Engineering and Construction, Bradley University, Peoria, USA

Nitrogen and phosphorus are two major pollutants that lead to eutrophication, adversely impact ecosystems, and lead to degradation of water quality, which impacts human health and sustainability. Pollution from point sources like wastewater and industry discharge is easier to control than non-point source pollution due to agricultural runoff and related activities. The USEPA is considering more strict standards for nitrogen and phosphorus discharge from point sources. The objective of this study was to use an appropriate low-cost wastewater technology to demonstrate removal of nitrogen from wastewater discharge using rotating biological contactors (RBCs) using different C:N ratios. The first-order nitrogen removal rate constant was found to be about 3.88 day^{-1} in experimental reactor systems, using RBC media from a local wastewater treatment plant (Greater Peoria Sanitary District). Phase I experiments, at C:N ratio of 2:1, with nitrogen removal rates of 60% in a single flow-through system. Phase II experiments for the limited carbon availability condition showed that the removal rate constant reduced by 30% and N-removal efficiency dropped to around 48%. Modeling showed that even under these conditions, multiple bioreactors operated in series could help achieve design treatment goals. The system achieved stability within a week of operation. Economics and sustainability issues are analyzed to determine if the process developed in this research is scalable to pilot- and full-scale conditions.

Keywords: Water quality, Pollution control, Rotating biological contactor, Nitrate, Removal kinetics.

1 INTRODUCTION AND BACKGROUND

Nitrate is a colorless, odorless, and tasteless compound and the USEPA Maximum Contaminant Level (MCL) is 10 mg/l NO_3-N. If high amounts of nitrate are ingested during pregnancy, the nitrate is reduced to nitrite in the digestive system and binds irreversibly to the hemoglobin, which renders the hemoglobin unavailable for oxygen transport and leads to methemoglobinemia where the fetus is entirely deprived of oxygen. High nitrate levels have also been known to adversely affect young children. If nitrogen and phosphorus concentrations in wastewater effluent are not controlled, algal blooms are likely to proliferate in the receiving stream. These algal blooms eventually drive the DO concentration in the water down towards zero, thus making it uninhabitable for aquatic life and for use of the water body for other purposes, including recreational activities. The adverse economic impact of such conditions on local economies, particularly those dependent on tourism, is readily evident.

Removal of nitrogen requires nitrification of reduced nitrogen compounds in the waste followed by denitrification to nitrogen gas. The basic biochemistry of these processes is well known (Sawyer *et al.* 2003). For nitrification, which is an aerobic process, the electron donor (energy source) is ammonia and the electron acceptor (agent used for respiration) is oxygen. For denitrification, the electron donor may come from the waste or may be added to the system and the electron acceptor is the nitrate.

Nitrogen removal studies are available in the literature (Mohseni-Bandpi and Elliot 1996, Mohsen-Bandi and Elliot 1998, Cortez *et al.* 2009). Typically, nitrification is achieved in activated sludge process type reactors (mixed flow reactors) with a longer solids retention time (SRT) is essential because nitrifying bacteria require a longer time to grow and multiply to reach a critical mass. Nitrification in attached-growth or biofilm-type systems is an attractive alternative (Ouyang *et al.* 1999, Pynaert *et al.* 2002). Denitrification has been shown to occur in mixed reactors and in biofilm-type systems like rotating biological contactors (RBCs).

Recent and emerging USEPA regulations on nutrients have forced many wastewater treatment plants around the country to consider different alternatives for nitrogen removal. Innovative and appropriate treatment technologies are therefore essential to achieving compliance at a reasonable cost, while engaging the social dimension of the sustainability equation (Asolekar *et al.* 2014). RBCs offer an attractive alternative for biological nitrogen denitrification. RBCs are simple to operate, have relatively low startup costs, require low maintenance and operating costs, and have the potential for application in different climates. This paper presents results on nitrogen removal in RBC systems under carbon-rich and carbon-starved conditions. Results from studies on inoculation and accelerated growth of biofilm on RBC media (for nitrogen removal) are also presented.

2 MATERIALS AND METHODS

Working with engineers from the Greater Peoria Sanitary District, sections of high-density polyethylene (HDPE) RBC media used at GPSD were cut to fit the two bench-scale reactors approximately 10” long by 9” diameter (volume = 20 L). The total surface area for the media in each tank was estimated to be 13.39 ft^2 (1.244 m^2). The system was set up to allow operation in parallel or series mode. An AC gear motor was mounted at the center of the media to rotate a 3/8” stainless steel shaft at a constant 1 rpm. The 50 in-lb of torque as per the manufacturer specifications was sufficient to handle mechanical stress due to the RBC (HDPE) media and the biofilm build-up. Influent was gravity-fed into the RBCs. The tops of reactors were covered to prevent potential algal growth.

Several studies in the literature have been reported using methanol, acetate, citrate, and other chemicals as a carbon source (Ouyang *et al.* 1999, Cortez *et al.* 2009). In this study citrate (sodium citrate) was selected as the carbon source. The composition of the synthetic wastewater is available in Teixeira and Oliveira (2001). Chemicals were obtained from Fisher Scientific and were of ACS grade.

Method 352.1 was used to prepare the brucine sulfanilic acid solution with the assistance of a professional laboratory technician at GPSD. Daily grab samples were obtained immediately following the influent batch mixture. 250 mL plastic containers with screw-on caps were used to collect samples. Standard methods were used to measure dissolved oxygen, pH, suspended solids, temperature, chemical oxygen demand (COD) was measured as per Method 410.3 (1993), and other routine parameters. Nitrate was measured using a spectrophotometric method (Method 352.1 at a wavelength of 410 nm).

3 RESULTS AND DISCUSSION

Results showed that the seeding of the biofilm media was slow, which was consistent with observations at the full-scale RBC plant at GPSD. The two reactors were operated under various conditions to accelerate biofilm growth. In this research, it was found that for the RBC system reached stable operating conditions when operated in parallel mode. It is likely that if such systems are operated in series mode, the first few tanks would use up majority of the carbon source, thus, starving out the microorganisms in later stages and delaying the process of seeding of microorganisms on the biofilm media. After the system achieves stability, the system may be transitioned to a treatment train in which this process operates as multiple RBCs in series.

Results from Phase 1 experiments are shown in Figure 1 and Figure 2. In Phase I, BOD (electron donor) and carbon source were provided in excess of the stoichiometrically required minimum. Under these conditions, denitrification occurred in the biofilm of the RBCs, as shown by the statistical calculations for the differences between the influent and effluent. Phase I experiments also showed that a minimal amount of sludge was produced in the process and that the sludge produced had good settling properties. These latter results are important in wastewater treatment plant operations because sludge that settles quickly cost substantially lower than poorly settling sludge that needs additional treatment. For a laboratory scale, two-stage RBC system utilizing both anoxic and aerobic units, Hiras *et al.* (2004) found that in the anoxic chamber, a removal rate of nearly 65% was achieved using a covered 1.0-liter anoxic reactor at a DO concentration below 0.6 mg/L in the anoxic unit and the temperature was maintained above 13°C. These results are consistent with this study. Hiras *et al.* (2004) also reported low sludge production, similar to the results observed in this study. A low sludge production implies lower sludge handling and treatment costs for the wastewater treatment plant.

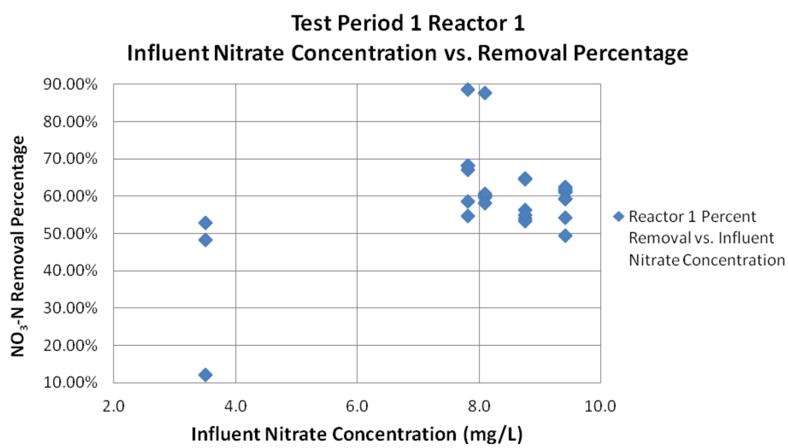

Figure 1. Percent removal in Reactor 1 for Phase 1.

Denitrification typically requires an electron donor (or energy source) and a carbon source to drive the reaction. In most systems, soluble BOD or sludge provides the carbon source for denitrification. When BOD is limited, an external carbon source helps maintain healthy and consistent biofilm stabilization and growth. Ouyang *et al*. (1999) noted that BOD was generally not sufficient for denitrification since the anoxic reactor is typically placed in sequence behind the anaerobic reactor, and the short chain fatty acids (SCFA) are used primarily for phosphate release in the anaerobic digester. Although denitrification tends to require a longer startup period, the addition of a carbon source and sludge from an activated sludge process has been shown to benefit both the startup and recovery of these systems.

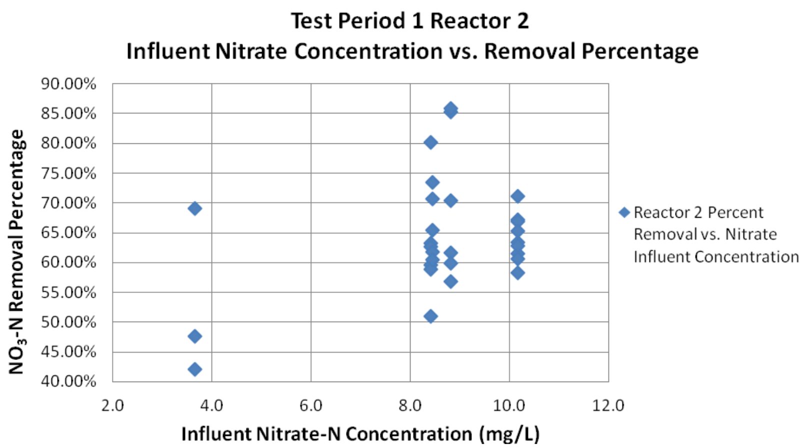

Figure 2. Percent removal in Reactor 2 for Phase 1.

In Phase II experiments, the correlation between carbon availability and nitrogen removal was tested by changing the C:N ratio. Sodium citrate in the influent was halved in Phase II experiments compared with Phase I experiments. Some marked changes were observed in Phase II experiments after these changes were implemented. The DO levels increased from around 0.8 mg/L to over 1.5 or more. A noticeable lag time was observed in Phase I, even after the biofilm build-up occurred. In Phase II, the lag time was not observed and the RBC system reached steady operation in a week. Figure 3 shows the results from Phase II experiments.

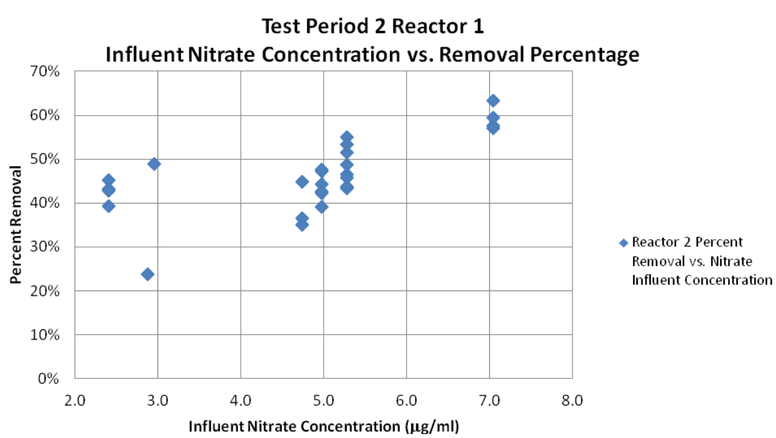

Figure 3. Percent removal in Reactor 1 for Phase II.

The average nitrogen removal dropped from Phase I levels of over 60% to around 48% in Phase II. Clearly, halving the carbon had a measurable effect on the removal rate. Statistical analysis indicated that at a 95% confidence level, effective denitrification occurred in Phase I experiments. For Phase II experiments, statistical analysis confirmed that denitrification occurred even under carbon-limited conditions as supported by statistical calculations. Results also indicated that the RBC biofilm has rapidly matured, after a relatively short lag time, to be able to handle higher influent nitrate loads.

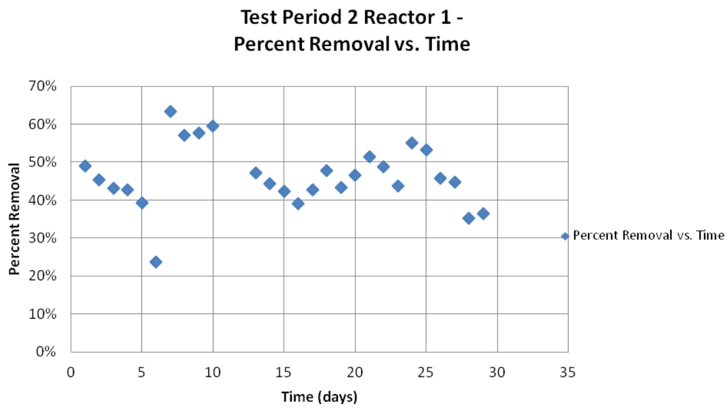

Figure 4. Percent nitrate removal as a function of time in Reactor 1 for Phase II.

In Phase I experiments, average nitrogen removal rates were calculated to be about 190 mg-N/m^2/d after just 30 days of operation. It is expected that a mature biofilm, established in will produce a greater removal rate. In Phase II, under carbon-limited conditions, the average removal rate under carbon-limited conditions dropped to 89 mg-N/m^2/d. These results show that the carbon limitation can seriously impact the nitrogen removal rate in denitrification using RBCs. Carbon source dosage must therefore be calculated carefully at a wastewater treatment plant to avoid excessive drop in nitrogen removal rate. If the carbon source dosage is very high, the quality of the effluent again suffers because of excessive discharge of carbonaceous biochemical oxygen demand (CBOD) in the effluent.

These results indicate that effective denitrification can be achieved under carbon-limited conditions, as long as biofilm growth is well established and the system has operated for at least more than a month. The RBC system was able to handle varying loads of nitrogen and carbon and yet operate effectively with very little maintenance. In addition, RBC performance typically improves as the biofilm matures. These characteristics make the RBC system an attractive alternative to provide the required degree of treatment, particularly when economics are not favorable for a more advanced and energy-intensive alternative. From a social sustainability standpoint, appropriate technologies like the RBC have a better buy-in by rural communities, particularly in low-income regions because of the obvious benefits of producing clean water, while productively engaging the local population in the workforce.

4 SUMMARY AND CONCLUSIONS

One of the objectives of this study was to identify a process to rapidly develop biofilm culture on RBC media around 20°C. Seeding the RBC system with return activated sludge from a local wastewater treatment plant (Greater Peoria Sanitary District) and enriching the denitrifying microorganisms on the RBC media by ramping up nitrate in the influent helped accelerate the process of growing and maintaining a healthy mixture of denitrifying organisms, which could flourish under anoxic conditions. Phase I studies (SRT of 30 days, Temperature of 20°C) at a C:N ratio of 2:1 showed average nitrate removal efficiencies around 60% (single pass RBC), with pH over 7.0 and average DO levels in the system were around 0.80 mg/L or lower throughout the study. Stable bioreactor operation was achieved within a week. The second objective of this study was to investigate the impact of carbon-limited conditions on nitrate removal efficiency of the system. When the C:N ratio was halved (phase II studies), the nitrate removal dropped to 48% (single pass RBC) but the system was able to tolerate higher DO levels (1.4 to 4 mg/L). Modeling indicates that using multiple RBCs in series (typical configuration in full-scale operations in the field) will achieve discharge standards. Innovations to the traditional RBC process can lead to development of appropriate technologies to meet increasingly stringent water quality standards for nitrogen in order to protect human health and the environment, while providing an economical long-term and low-maintenance solution.

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