Efficient, Simultaneous Destruction of Multiple Drinking Water Contaminants Using Biological Filtration

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The use of bacteria for the degradation of contaminants has been common in the wastewater field since the 1900s, but the biological treatment of drinking water has been much more limited in the U.S. Their ability to develop a stationary gradient of redox potential across the depth of a media bed makes fixed-bed bioreactors (biological filters) particularly well-suited for destroying multiple contaminants within a single reactor.

This article describes the results of three biological filtration studies that cover the simultaneous degradation of (1) nitrate, perchlorate, and organic carbon, (2) nitrate, perchlorate, endocrine disruptors (EDCs), and pharmaceutically-active compounds (PhACs), and (3) geosmin, MIB, and organic carbon. For each application, the biological filters were used in a direct filtration mode (i.e., raw water was fed directly to the biological filters).

Nitrate, Perchlorate, and Organic Carbon

In January 2004, Carollo Engineers completed a six-month pilot study at the Castaic Lake Water Agency (Santa Clarita, California) to demonstrate the efficacy of using biological filtration for removing perchlorate (ClO_4^-) and nitrate (NO_3^-) from the local groundwater. Background total organic carbon (TOC) and biodegradable organic carbon (BDOC) concentrations were approximately 2.0 and 1.5 mg/L, respectively, and 7.8 mg/L of acetic acid carbon was added as substrate for perchlorate and nitrate reduction.

Carollo's granular media filtration pilot skid was used for the biological testing. The skid included three 12-foot, 4-inch inner-diameter columns and was operated in a down-flow, pressurized mode. The columns were filled to a depth of seven feet (approximately 0.6 ft^3) with virgin F-400 granular activated carbon (GAC), allowing for bed expansion up to 50 percent.

Three phases of pilot testing were performed: (1) biological acclimation, (2) process optimization, and (3) challenge testing.

The purpose of the biological acclimation phase was to determine whether or not efficient nitrate- and perchlorate-reducing biological activity could be developed in the GAC beds using microorganisms indigenous to the local groundwater. The filters were contacted with groundwater until nitrate- and perchlorate-reducing biological activity was observed. No microbial seed was used.

The purpose of the process optimization phase was to develop design parameters for contact time, feed acetic acid concentration, and feed nutrient concentration. The backwashing protocol was also developed for the bioreactors during this phase.

The purpose of the challenge testing phase was to determine how the bioreactors respond to various process upsets such as backwash events, perchlorate spiking, nitrate spiking, system shutdown periods, and electron donor feed failures.

Results of the pilot testing were as follows:

- Consistent nitrate and perchlorate removal to below detection (<0.1 mg/L NO_3^- and <4 mg/L ClO_4^-) was achieved in the fixed-bed bioreactor using only organisms indigenous to the local groundwater. With influent dissolved oxygen (DO) and nitrate concentrations of 7 and 15 mg/L, respectively, the lowest empty-bed contact time (EBCT) that allowed consistent perchlorate removal to below detection was 15 minutes. Run times ranged from 24 to 72 hours ($\geq$ 97% water recoveries).
- Effluent TOC concentrations were very low; generally below the reporting limit of 0.7 mg/L. Effluent BDOC concentrations were <0.1 mg/L. In other words, the biofiltration process removed not only the exogenous acetic acid, but also removed most of the background organic carbon, leaving the effluent biologically stable.
- Backwashing events, transient changes in feed-water quality, extended periods of system shutdown, and simulated acetic acid feed failures did not impact nitrate or perchlorate removal performance in the fixed-bed bioreactors.

Nitrate, Perchlorate, EDCs, and PhACs

In February 2005, a six-month pilot study was completed at the Magna Water District (Magna, Utah). The objective of the study was to investigate the viability of treating nitrate- and perchlorate-laden electrodialysis reversal (EDR) concentrate in a biofilter after blending it with scalped municipal wastewater.

The municipal wastewater served four purposes: (1) decreased the overall solution salinity (salt decreases the kinetics of microbial metabolism), (2) decreased the concentration of DO (DO inhibits biological nitrate and perchlorate reduction), (3) provided the substrate required for biological nitrate and perchlorate reduction (i.e., no exogenous electron donor was required), and (4) provided a robust microbial seed.

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Carollo Engineers' fixed-bed biological pilot skid was used for the pilot testing. The fixed-bed skid included three 10-foot, 8-inch inner-diameter columns and was operated in a down-flow, pressurized mode. The columns were filled to a depth of four feet (~1.4 ft^3) with GAC or plastic media.

Four phases of pilot testing were performed: (1) biological acclimation, (2) process optimization, (3) sustained removal, and (4) challenge testing.

The purpose of the biological acclimation phase was to determine whether or not efficient perchlorate-reducing biological activity could be developed in the GAC beds using microorganisms indigenous to the local wastewater. The bioreactors were contacted with blended EDR concentrate/municipal wastewater until perchlorate-reducing biological activity was observed. No microbial seed was used.

The purpose of the process optimization phase was to develop design parameters for blend ratio and contact time. The backwashing protocol was also developed for the bioreactors during this phase.

The purpose of the sustained removal phase was to demonstrate that effective nitrate and perchlorate removal could be maintained using the optimal blend ratio and EBCT determined during Phase 2 testing.

The purpose of the challenge testing phase was to determine how the bioreactors respond to various process upsets such as backwash events, system shutdown, wastewater feed failure, temperature fluctuations, and diurnal variations in wastewater quality.

Results of the pilot testing were as follows:

- Using a blend ratio of 0.5 (Qww/[Qww + QEDR conc]), perchlorate removal to below detection was achieved and sustained using EBCTs as low as 10 minutes. No exogenous substrate or microbial inoculum was added to the system.
- Average feed and effluent nitrate concentrations (as NO_3^-)were 40 mg/L and < 5

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mg/L respectively.

- Approximately 50 percent of the 70 mg/L feed biochemical oxygen demand was removed across the FXB bioreactor.
- Nitrate and perchlorate removal performance was not impacted by backwashing episodes, a two-week system shutdown, diurnal variations in wastewater characteristics, or cold season groundwater temperatures (~14°C).
- GAC with an effective size of approximately 1.4 mm was optimal as a biogrowth support medium.
- The removal of 23 different endocrine disruptors and pharmaceutically active compounds was also observed, with removal as high as 83 percent at a 10-minute EBCT.

Geosmin, MIB, and Organic Carbon

Conventional approaches for mitigating the impact of algal metabolites (tastes, odors, toxins - TOTs) on drinking water include reservoir management and metabolite removal at the water treatment facility. Reservoir management has shown some success at reducing algal populations, but the growth of copper-resistant algal strains and increased nutrient loading to surface waters limit the effectiveness of this approach. Furthermore, conventional treatment methods, such as pre- and post-chlorination, coagulation, sedimentation, and filtration, are marginally effective at reducing algal metabolite concentrations. Powdered activated carbon is often supplemented to these processes to achieve adequate removal, though its use can be cost prohibitive over lengthy or intense algal events.

Recently, some utilities have begun to ozonate settled water and then feed it to biological activated carbon (BAC) filters. This process, also known as ozone-enhanced biofiltration, oxidizes natural organics to form assimilable organic carbon , which serves as a substrate for bacteria present in the BAC filter.

While potentially effective, ozone-enhanced biofiltration is relatively expensive and has been shown to provide limited robustness (e.g., diminished removal performance during metabolite feed concentration fluctuations). Known and emerging ozone-generated disinfection-by-products also present a concern.

An innovative method of improving these deficiencies in biological systems targeting algal TOT degradation would be to dose a readily degradable primary substrate (e.g., acetic acid) to the water immediately prior to treatment in a biofilter. The objective would be to increase the concentration of active biomass in the reactor, which could subsequently increase the rate of secondary substrate degradation. By increasing the rate of cell synthesis, this approach could also minimize bioacclimation time requirements and enhance the robustness of the system during process upsets.

An alternative (or complementary) approach to substrate addition would be to position the biofilter at the head of a water treatment plant to ensure that the maximum concentration of available degradable organic compounds reaches the influent to the biofilter. This could minimize or eliminate the need to dose a primary substrate and may coincidentally achieve significant removal of raw water organics, alleviating downstream treatment requirements.

In February 2006, a six-month, bench-scale biofiltration study was completed at the Manatee County Water Treatment Plant (Brandenton, Florida). The objective of the study was to investigate the viability of the above treatment concept.

Two-inch glass columns were filled to a depth of 8 inches with F-400 GAC, and raw water from Lake Manatee was pumped across the GAC beds to biologically acclimate the columns. Two mg/L acetic acid carbon or ethanol carbon was added to one GAC column while no exogenous substrate was added to a second GAC column (i.e., background organics served as the substrate). A hot-water circulation loop was used during part of the study to investigate the impact of temperature on system performance. MIB and geosmin were spike to the feed water at 50-100 ng/L.

Results of the direct biofiltration bench testing were:

- Greater than 90-percent MIB and geosmin degradation was achieved in the biofilters using a 10-minute EBCT.
- Background TOC concentrations decreased by 2-3 mg/L using a 10-minute EBCT.
- MIB removal, and to a lesser extent geosmin removal, improved as raw-water temperature increased.
- MIB, geosmin, and TOC removal performance was minimally impacted when feed MIB and geosmin concentrations were intentionally varied between 50 and 5 ng/L.

Significance

Conventional drinking water treatment typically requires the application of several unit processes to meet multiple water-quality objectives. This work has demonstrated that direct biological filtration can provide an alternative to this approach by eliminating multiple organic and inorganic contaminants in a single reactor using reasonable contact times, potentially minimizing costs and plant footprint. This work has also shown that direct biological filtration converts contaminants to innocuous byproducts, is robust, and can be simple in design and operation. These characteristics make it a highly efficient and environmentally sustainable process that could garner increased utility attention as the gap between water demand and supply curves widens.

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