Batch studies on nitrate removal from potable water

A Darbi[1], T Viraraghavan[2*], R Butler[3] and D Corkal[4]
[1] *Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada*
[2*] *Faculty of Engineering, University of Regina, Regina, Saskatchewan, S4S-0A2, Canada*
[3] *Prairie Farm Rehabilitation Administration, Winnipeg, Manitoba Canada*
[4] *Prairie Farm Rehabilitation Administration, Saskatoon, Saskatchewan, Canada*

Abstract

A sulphur/limestone autotrophic denitrification process was used to achieve the biological removal of nitrate from groundwater. The feasibility of the system was evaluated under anaerobic conditions using laboratory-scale batch reactors. The optimum sulphur/limestone ratio was determined to be 1:1 (wt/wt). Different initial nitrate-nitrogen concentrations (94, 57, and 10 mg NO_3^--N/ℓ) were used during the batch tests to examine nitrate removal efficiencies. The results showed that the higher the initial concentration, the longer it takes before nitrate removal commences. Both total suspended solid (TSS) and mean size of particles increased with time, which may be related to bacterial growth in the system.

Introduction

Many water agencies are faced with problems related to high concentrations of nitrate in groundwater. Evidence suggests that in many parts of the world, agricultural practices may be a contributing factor. In some instances, high concentrations may be due to natural background levels or other causes such as on-site wastewater disposal systems. The farming communities in Canada are well aware of the problem and are taking steps to address this issue with full support of local, provincial and federal agencies. Mitigative measures almost always include adjusting land management practices to prevent nitrate accumulation in aquifers. However, where high nitrate levels exist, water treatment dealing with the problem may also be required. Nitrate can cause a significant health problem to humans. Methemoglobinemia is the most common among infants and is potentially the most serious complication of nontherapeutic, excessive nitrate and nitrite exposure. A study made by Weyer et al. (2001) showed that for all cancers there was no association with increasing nitrate in drinking water, nor were there clear and consistent associations for non-Hodgkin lymphoma; leukemia; melanoma; or cancers of the colon, breast, lung, pancreas, or kidney but there were positive associations for bladder cancer.

Because of these possible health impacts, a maximum acceptable concentration of 10 mg/ℓ as nitrate-nitrogen is specified in *Guidelines for Canadian Drinking Water Quality* (1996).

A wide range of physico-chemical processes such as ion exchange, reverse osmosis, electrodialysis, chemical denitrification and biological denitrification processes are currently being developed for removal of nitrate from drinking water, essentially for large-scale water treatment plants (Kapoor and Viraraghavan, 1997). Regarding drinking water denitrification numerous substrates have been evaluated including methanol, ethanol, acetic acid, methane, carbon monoxide, hydrogen and various sulfur compounds (Gayle et al., 1989).

There is no specific nitrate removal system in operation in Canada as part of municipal drinking water treatment. Only limited research on nitrate removal from drinking water has been conducted in Canada.

Autotrophic bacteria such as *Thiobacillus denitrificans* and *Thiomicrospira denitrificans* are capable of reducing nitrate to nitrogen gas. The energy source of autotrophic denitrifying micro-organisms is derived from oxidation-reduction reactions with elements such as hydrogen or sulphur as the electron donor. Autotrophic denitrifiers utilise inorganic carbon compounds (such as CO_2, HCO_3^-) as their carbon source (Baalsruud and Baalsruud, 1954; Bachelor and Lawrence, 1978a,b,c; Claus and Kutzner, 1985). In contrast, no organic carbon is needed as in heterotrophic denitrification. Another advantage of autotrophic denitrificans is that reproduction rate is low resulting in less sludge production and minimises the handling processes. Autotrophic denitrification has been divided into hydrogen-based and sulphur-based processes. Autotrophic organisms such as *Micrococcus denitrificans* are capable of reducing nitrate to nitrogen while oxidising hydrogen to water. Gross et al. (1986) developed a process known as DENITROPUR using hydrogenotrophic micro-organisms present in the aquifer. A synthetic material was used as a biomass support for a fixed bed reactor. The DENITROPUR plant at Mönchen-gladbach, Germany, was constructed to treat 2 384 m^3/d of ground-water. The reactor operated at a loading rate of 0.12 kg N/m^3·d, reduced the nitrate concentration from 75 to less than 1 mg/ℓ. Although treatment has been very successful, it is quite expensive due to costs of generating and handling hydrogen gas. Therefore, much more attention has been concentrated recently on sulphur-based autotrophic denitrification. Flere and Zhang (1998) conducted a study of nitrate removal by using sulphur and limestone autotrophic denitrification. The influent NO_3^--N concentration was 30 mg/ℓ with a hydraulic retention time of 30 d. It was observed that nitrate removal efficiency was 95 to 100% with alkalinity control and 80 to 85% without alkalinity control.

The sulphur/limestone process for groundwater nitrate removal is based on autotrophic denitrification by *Thiobacillus denitrificans*, where nitrate is converted into nitrogen gas under anoxic conditions. Sulphur is used as electron donor and limestone is used to maintain the pH, while sulphur is converted to sulphate and biomass is produced (empirical cell mass formula $C_5H_7O_2N$). *Guidelines for Canadian Drinking Water Quality* (1996) stipulates a maximum

* To whom all correspondence should be addressed.
☎ (306) 585-4094; fax: (306) 585-4855; e-mail: t.viraraghavan@uregina.ca
Received 11 October 2001; accepted in revised form 4 April 2002.