Nitrification in Sand Filters for Drinking Water Production

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Introduction Oasen

Nitrification

Origin of the problem

Subsurface aeration

Some research issues
Oasen Drinking Water Company in the province of South Holland
Fenland area
Ammonium in groundwater

Ammonium (GEM) (verzameld) Ruw
Alle PS in NL, REWAB 2003
Groundwater in fenland area
WTP Lekkerkerk

<table>
<thead>
<tr>
<th>Ammonium</th>
<th>Iron</th>
<th>Manganese</th>
<th>Methane</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg/l NH4</td>
<td>mg/l Fe</td>
<td>mg/l Mn</td>
<td>mg/l CH4</td>
<td>-</td>
</tr>
<tr>
<td>2 to 10</td>
<td>3 to 7</td>
<td>0,5 to 1</td>
<td>0,6 to 10</td>
<td>7,1 to 7,3</td>
</tr>
</tbody>
</table>
Drinking water from anaerobic groundwater

Air \( (O_2) \)

Raw water \( \text{CH}_4, \text{Fe}, \text{NH}_4, \text{Mn} \)

Air\( (\text{CH}_4, \text{CO}_2) \)

\( \text{NH}_4 \leftrightarrow \text{NO}_3 \)

\( \text{Fe}, \text{Mn} \downarrow \)

Filtrate \( \text{NO}_3 \)
Full-scale trickling groundwater filters
Nitrification is “delicate”

• Two step microbial conversion by different microorganisms:
  - $2 \text{NH}_4^+ + 3 \text{O}_2 \rightarrow 2 \text{NO}_2^- + 4 \text{H}^+ + 2 \text{H}_2\text{O}$
    by Nitrosomonas and Archaea
  - $2 \text{NO}_2^- + \text{O}_2 \rightarrow 2 \text{NO}_3^-$
    by Nitrospira not by Nitrobacter

• Autotrophic, slow growing microorganisms

• Per m$^3$ filter sand filter coating contains:
  - 150 g biomass
  - 30-50 kg iron and 5-20 kg manganese
Nitrification problem at Oasen

Ammonium in filter effluent [ppm NH₄⁺]

October 1997 to October 2000
High maintenance: so what?

Filter sand has to be renewed every 1-3 year
- Labor-intensive: 4-9 man days per filter
- High costs
  - €21000 new sand per filter (2004);
  - Per year 25 filters = 0,5 M € (Oasen only!)
- Hygienical risks
- Startup period (> 1 month per filter)
What’s up Doc?

Inhibition by other substances?

– Methane: competition of substrates and space by large yield of biomass

– Iron: coating of grains

– Other mechanisms ??
Methane: “mother earth’ bad breath”

- Methane (CH$_4$) or ‘moor gas’ is formed by fermentation of plants in sediments from Tertiary (65 to 2.5 million years ago) and Quartary (1.81 million years ago to present)
- In the Netherlands 25% of the WTP > 1 mg/l methane
- Zuid Holland, Friesland, Overijssel and Drenthe
Methane removal = proven technology
Methane removal proves to be irrelevant to nitrification problem.
What’s up Doc?

Inhibition by other substances?

- Methane: competition of substrates and space by large yield of biomass
- Iron: coating of grains
- Other mechanisms ??
External washing as curative measure

- Pump filter sand out and in again
- Labor intensive and heavy work
- External washing mainly removes iron coating
External washing as temporary measure

- Restoration (startup nitrification) quicker than new sand
- Effect decreases in time

![Graph showing filtration data over time, comparing new filter sand, external washing, and filtrate ammonium levels.]
Prevention of iron accumulation is effective

- Backwash with expansion in double layer filter maintains nitrification

![Graph showing ammonium in filter effluent versus days from startup with new filter material. The graph compares single layer (sand only) and double layer (anthracite+sand) systems.]
What’s up Doc?

Inhibition by other substances?

- Methane: competition of substrates and space by large yield of biomass
- Iron: coating of grains
- Other mechanisms ??
The **miracle** of Nieuw Lekkerland
Subsurface Aeration (SA)
Subsurface aeration

• Old technique (patents around 1900)
• Original meant for de-ironing
• At Oasen minimal subsurface iron removal...
• ... but still very positive effect on nitrification
Improvement of nitrification by subsurface aeration ...

•... is not caused by:
  – lowering ammonium or iron content of groundwater
  – inoculation of nitrifiers

•.. might be caused by:
  – stimulating the growth of iron-oxidizing Gallionella ferruginea bacteria
  – formation of iron hydroxide colloids
PhD-research hypothesis

Iron oxidizing bacteria or SA-colloids shift the iron removal mechanism and thus stimulate porous filter coating.

Nitrifying activity is higher on porous filter coating.
Iron (II) oxidation by air-oxygen

The graph shows the oxidation grade of iron (II) over time for different pH values. The curves indicate that the oxidation rate increases with increasing pH, with pH=8.0 showing the highest oxidation rate. The pH values considered are 7.1, 7.3, 7.5, 7.8, and 8.0.
Two iron removal mechanisms

Oxidation-floc formation mechanism

Fe²⁺ → Fe³⁺
O₂ → Hydrolysis → Floc formation → Filtration

Adsorption-oxidation mechanism

Fe²⁺ dissolved → Fe²⁺ adsorbed + O₂ → Fe³⁺ → Sand grain

I Sand grain
II newly adsorbed Fe²⁺

Sharma, 2001

Dissertation, Adsorptive iron removal from groundwater
Full-scale filter research

- Samples from full-scale trickling filters
- Mass and composition of the coating
- Sand-specific nitrification rate (batch experiments)
- Q-PCR
- Mercury intrusion porosimetry
  - ‘Non-wetting’ liquid
  - Pore size distribution of porous materials
Column setup
Interaction iron removal and nitrification

Uitdagend stagemwerk mogelijk!
Thank you for your attention!

Any questions?

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