• Introduction and research question
• Theoretical background
• Methods and material
• Results
• Discussion
• Ion exchange column design
• Conclusion
Introduction and research question

The current treatment processes

![Drinking water treatment plant De Hooge Boom](image)

![Treatment scheme in “De Hooge Boom” treatment plant](image)

The plan of new treatment processes

![New treatment scheme for “De Hooge Boom” treatment plant](image)
• Problem

In the new to build treatment plant, the water after RO membrane filtration is still high.

The NH4 concentration in the permeate: 0.1 mg/L

• The target: 0.03 mg/L

• Ion exchange technology is selected

• The research question

  What should be the design of the ion exchange post treatment step for permeate when it comes to surface loading and bed height?

Sub questions:

  What is the influence of the surface loading?

  What is the influence of the bed height of the ion exchange for the effectiveness of ammonium removal?
Theoretical background

SYNTHETIC ION EXCHANGER

![Schematic cation exchange resin bead (Rohm and Haas, 2008)](image)

- $Na^+$ = mobile ions (counter-ions)
- $SO_3^-$ = fixed group
- Dark line = polymeric skeleton

Manufactured by introducing functional groups into a 3D crosslinked polymer matrix.

NATURAL ION EXCHANGER

![Ion-Exchange on a zeolite (Source: Schmidt, 2008)](image)

Zeolites are crystalline aluminosilicates
• Kinetics

- Ions in solution travel through the bulk of the solution (diffusion in solution)
- Diffusion of the specific ions from bulk liquid to a boundary layer surrounding the bead. (film diffusion)
- Diffusion from the bead surface into the pores of the bead. (particle diffusion)
- Exchanging of counterions at the fixed site.
• Breakthrough capacity

adce represents the overall capacity of ion exchange
Abcd represents the breakthrough capacity
The breakthrough begins at breakthrough point c
Point e is where no ion exchange occurs
METHODS AND MATERIALS

SET UP

Specifications of the pilot column setup

Number of columns: 4, diaphanous PVC
Column height: 1 m, Inner diameter: 34 mm
Filter plates holes: 0.4 mm
Taps at the top and bottom of the columns
Feed water: RO permeate
Direction of flow: inflow and outflow
• Materials
Lewatit S2568H
Cation exchange resin in the H form with functional group sulfonic acid provided by Lanxess.

Zeolite
Zeolite is in the form of natural clinoptilolite received from Zeolite Products.
The chosen size for zeolite is 0.3-1.0 mm and 1.0-2.5 mm.

• Analyzing equipments
Spectrophotometer Hach-Lang DR 2800 using Hach-Lang cuvettes LCK 304
Analyzer Applikon Colorimeter
Results

Breakthrough curve of Lewatit S2568H with different flow rate measured by ammonium analyzer Applikon Colorimeter and Hach Lang spectrometer DR 2800 (flow rate of 12L/h)

Breakthrough curve of 10 cm Lewatit S2568H with different flow rate measured by ammonium analyzer Applikon Colorimeter
The performance of 10 and 20 cm Lewatit S2568H

<table>
<thead>
<tr>
<th>Bed height (cm)</th>
<th>Flow rate (L/h)</th>
<th>Surface loading (m/s)</th>
<th>Average permeate concentration (NH4 mg/L)</th>
<th>Breakthrough capacity (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
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<tr>
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</tbody>
</table>

Breakthrough capacity of Lewatit S2568H at different bed heights and flow rates
• Comparison between Lewatit S2568H and clinoptilolite

Breakthrough curve of 20 cm clinoptilolite and Lewatit S2568H measured by ammonium analyzer Applikon Colorimeter and that of clinoptilolite by Hach Lang spectrometer DR 2800

The chosen particle size range here for the zeolite is 0.3-1.0 mm.

Performance of zeolites in different particle size at bed height of 30cm, flow rate of 12 L/h measured by Hach Lang spectrometer DR 2800

<table>
<thead>
<tr>
<th>Zeolite</th>
<th>Duration (h)</th>
<th>NH4 (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3-1.0mm</td>
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</tr>
<tr>
<td>1.0-2.5mm</td>
<td>2</td>
<td>0.02</td>
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</table>

The chosen particle size range here for the zeolite is 0.3-1.0 mm.
DISCUSSION

• Influence of bed height
The NH$_4^+$/H$^+$ separation factor is 1.9. The breakthrough capacity would remain the same for different bed height.
The results showed differently
Probably due to the fact that the feed water would flow downward along with the column walls

• Influence of flow rate
As the flow rate increases, the flow rate of ions arrived on the beads is faster than ions diffuse through the film.
The breakthrough capacity is expected to be lower at a higher flow rate, if the thickness of the film remains the same.
The loss of breakthrough capacity would be minimized by the thicker film.
• Kinetics
If the particle diffusion is rate determined, the breakthrough capacity would increase proportional to the flow rate.
The film diffusion is rate controlling.

• Performance of zeolite and resin
The resin performed much better than zeolite.
the surface of zeolite was much rougher than that of resin.

• Influence of particle size
Smaller particle size provides a larger surface area.
ION EXCHANGE COLUMN DESIGN

• ASSUMPTIONS:

- Each unit with a capacity of 120 m³/hour
- Average breakthrough capacity of 2.17 mg/g (1606 mg/L) at 20 cm bed height is used for calculation for different bed heights. It is assumed that the breakthrough capacity remains the same.
- The ammonium concentration of permeate is 0.14 mg/L.

<table>
<thead>
<tr>
<th>Flow rate (L/h)</th>
<th>Surface loading (m/h)</th>
<th>Resin bed height (m)</th>
<th>SFR (BV/h)</th>
<th>Required resin volume (m³)</th>
<th>Required surface area (m²)</th>
<th>Diameter (m)</th>
<th>Break-Through Time (h)</th>
<th>Break-Through time (days)</th>
<th>Material cost per year (euro)</th>
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The cost per m³ water produced would be=0.06 euro
To have a cost as low as possible while maintaining quality, the ion exchange process with regeneration might be a good solution.

The following assumptions are made:

- Bed height is 2m (feasible, a common bed height for ion exchange)
- Regeneration cost is maximum 25% of the resin cost

<table>
<thead>
<tr>
<th>flow rate (L/h)</th>
<th>linear velocity (m/h)</th>
<th>Resin Bed Height (m)</th>
<th>SFR (BV/h)</th>
<th>Required resin volume (m3)</th>
<th>Required surface area (m²)</th>
<th>Diameter (m)</th>
<th>Break-through time (days)</th>
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<th>Material cost per m³ water (euro)</th>
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Overview of column design with 2m resin bed height
CONCLUSION

• **What is the influence of the surface loading**
  The breakthrough curves demonstrated the similar trend at the flow rate between 12L/h and 100L/h.

• **What is the influence of the bed height of the ion exchange for the effectiveness of ammonium removal?**
  The ion exchanger with a higher bed height also has a higher breakthrough capacity.
  It was expected that the rate of an increase in breakthrough capacity would be lower as the bed height increases.

• **What would the design in the future treatment plant look like?**

  Based on the experiment results and calculation, the ion exchange is design as follows:
  Number of vessels: 4 – each with a capacity of 120m$^3$/h  
  Surface loading: 99m/h
  Bed height: 2m  
  EBCT: 1.2 minutes
  Column height: 3.4m  
  Breakthrough time: 10 days
  Material cost of resin per m$^3$ water produced: €0.014
THANK YOU FOR YOUR ATTENTION