Water Quality Modelling of Drinking Water Storage Reservoir Noardburgum

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Vitens water supply company

- Deliverance to 5.4 million customers
- 350 million m³/year
- 100 production sites
- Well fields: 0.5 – 15 million m³/y
- 100% use of fresh ground water
- Soil as a natural filter
- Stable quality
- No disinfection needed (e.g. chlorination)
Water storage reservoir

- Even out demand and supply
- Stable production
- Emergency situations

Distribution pumps

WSR1

WSR2

Filtration

Softening reactors

Even out demand and supply
Stable production
Emergency situations
Current situation

Fill and Draw

- Fill time: $t_f$
- Mixing time: $t_m$
- Condition: $t_m < t_f$

Level WST Noardburgum

Length and width = 45 m
Height = 2.5 m
Inlet diameter = 1000 mm

During filling mixing takes place: Jet mixing
Inspection en cleaning
WSR Noardburgum
29-1-2013
Problem

• Insufficient mixing: $t_m > t_f$?
  – Low velocities due to reduction production capacity
  – Inlet=outlet (LIFO)
  – Water aging (long residence time) (4 days)
  – Deterioration of water quality (bacteria count)
  – Accumulation of particles from treatment process

• Reservoir (full scale)
  – No measurements possible

Aims

• What are the mixing conditions in current situation
• How to improve mixing conditions by improving the existing design
  → Comsol Multiphysics model and scale model
Comsol Multiphysics

- 3D geometry
  - Pillars
- Transient turbulence model (k-ε/k-ω)
  - Inlet: velocity
  - Walls: wall functions
  - Pressure constraint point: p0=0
  - Wall (water surface): moving wall in z-direction
- Transient convection-diffusion model
  - Continuous injection of tracer
  - Probe points
Scale model 1:25

- Validation Comsol model
- Similitude concept
- Dimensionless numbers Froude, Reynolds en Weber
- Not possible to achieve simultaneous equality
- Fr governing factor in flows with a free surface

\[
Fr = \frac{U}{\sqrt{gL}}
\]

\[
Re = \frac{UL\rho}{\mu}
\]

\[
W = \frac{U^2L\rho}{\sigma}
\]

Length scale=\(L\)
Velocity scale=\(L^{0.5}\)
Area scale=\(L^2\)
Flow scale=\(L^{2.5}\)
Time scale=\(L^{0.5}\)
Volume scale=\(L^3\)
- Dye (Rhodamine WT) and salt (NaCl) as tracer
- Comparison of camera images with Comsol model
- Determination of mixing time (conductivity sensors)
Scale model 1:25
Determining of mixing time

- Continuous injection of a tracer (NaCl) during filling (time dependent)

- Measuring concentration at different points (point probes) in reservoir and conductivity sensors in scale model

![Graph showing concentration over time](image)
Determination of mixing time

• Tank tracer concentration homogeneous (95%) in tank

• Mixing time: Coefficient of variation CV drops to 5%

\[
CV = \frac{\text{St. dev. local tracer concentration}}{\text{Average tracer concentration}}
\]
Figure 1: Snapshots of model and tracer experiment at 120 s, 240 s and 400 s
Mixing time : validation

- Model 1 no water level rising
- Model 2 including water level rising
- Scale model experiments

\[
t_m = K \cdot \frac{D^{1.5} \cdot H^{0.5}}{M^{0.5}}
\]

\[
M = v \cdot Q_v
\]

<table>
<thead>
<tr>
<th>Okita en Oyama 1963</th>
<th>K=4.6</th>
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<tbody>
<tr>
<td>Rossman en Grayman 1999</td>
<td>K=10.7</td>
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Design improvement: current situation

• Mixing time $t_m = 13$ h; Fill time $t_f = 7$ h
• No complete mixing during fill cycle $t_m > t_f$
• Velocity to low (0.07 m/s)
• Variables:
  – Velocity, momentum (diameter inlet)
  – Dimensions reservoir
  – Height initial water level
  – Location inlet

\[
t_m = K \cdot \frac{D^{1.5} \cdot H^{0.5}}{M^{0.5}}
\]

\[
M = v \cdot Q_v
\]
Design improvement

- Location of inlet/outlet
  - 25% improvement in mixing time

- Inlet/outlet pipe diameter
  - 1000 mm -> 500 mm
Conclusions

• Results Comsol Multiphysics are consistent with scale model results
• Condition $t_m < t_f$ is met if inlet/outlet diameter is 500 mm or less

• Comsol Multiphysics powerful (design) tool
• Validation necessary (experiments full scale on location or with scale model)
Further studies

• Complete Fill and draw cycle
• Coupling bacterial growth in relation to aging
• Particle Tracing (Calciumcarbonate particles)
• Coupling heat transfer
  – Water Storage reservoir above groundlevel
  – Influence Temperature on Water Quality
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