Engineering Design Considerations

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Aims and Objectives

- To be able to calculate resin volumes and vessel sizes
- To appreciate hydraulic effects
- To understand regeneration sequence
  - counter flow regeneration systems
  - stratified bed operation
  - mixed beds
- To be familiar with vessels and internals
- To understand EDI
Process Design Parameters

- **Regeneration Ratio** = \frac{\text{regeneration level (eq/l)}}{\text{exchange capacity (eq/l)}}
- **Hydraulic loading (BV/h)** = \frac{\text{flow rate (m}^3/\text{h})}{\text{resin volume (m}^3\text{)}}
- **EBCT (h)** = \frac{1}{\text{hydraulic loading}}
- **Turndown ratio** = \frac{\text{Maximum flow rate (m}^3/\text{h})}{\text{Minimum flow rate (m}^3/\text{h})}
Process Design Parameters

- The volume of treated water produced per cycle \((Q \text{ m}^3)\) by \(V\) litres of resin with capacity \(C_{eq}/l\) treating water with ion exchange load \(L\) meq/l is:

\[
Q = (F \times T) = (V \times C)/L
\]

- The resin volume is given by:

\[
V = (F \times T \times L)/C
\]

where the treatment plant operates for \(T\) hours between regenerations at \(F\) m\(^3\)/h
Hydraulic Design

• For a resin of capacity \( C \text{ eq/l} \) treating a water with ionic concentration \( L \text{ meq/l} \) at a flow of \( Q \text{ m}^3/\text{h} \) the run time, \( T \text{ h} \), is:

\[
T = \frac{V \times C}{Q \times L}
\]

• where \( V \) is the resin volume in litres. Now if the maximum hydraulic loading is \( W \text{ BV/h} \) then:

\[
W \leq \frac{Q \times 1000}{V} \quad \text{and} \quad T \geq \frac{C \times 1000}{Wc}
\]
Hydraulic Design

- So for a typical minimum run of 8h on an anion resin of capacity 0.6 eq/l at 30 BV/h:

\[ L \leq 2.5 \text{ meq/l} \]

- If the anion concentration is greater than 2.5 meq/l the run time will be shorter than the minimum 8 h.

- If the concentration is less than 2.5 meq/l, the resin volume will be determined by the maximum hydraulic loading and this will set the run time.
Hydraulic Design

- **Head loss through resin,**

\[ h = l \cdot k \cdot v_a \cdot 1.02^{(15-\theta)} \]

where

- \( l \) = bed depth, m (typically 1 - 3m)
- \( v_a \) = approach velocity, m/h
- \( T \) = temperature, °C
- \( k \) = constant (0.10 - 0.15 depending on bead size)

- \( h \leq 10 \)m (1bar) to avoid resin compaction
- **Minimum velocity 1m/h to ensure good distribution**
Hydraulic Design

- Deeper bed
  - sharper exhaustion front
  - smaller diameter - lower capital cost
  - higher headloss - higher operating cost

- Shallower bed
  - more diffuse exhaustion front
  - larger diameter - higher capital cost
  - lower head loss - lower operating cost
Hydraulic Design

• Uniform bead size
  – lower head loss (close hexagonal packing)
  – allows use of smaller beads
  – which have higher area:volume ratio
  – and hence higher capacity
  – with faster kinetics
  – allowing higher hydraulic loading

• Short Cycle Designs
  – Run time around 2-4h
  – Regeneration around $\frac{1}{2}$h
Regeneration Sequence

- **Regenerant Injection**
  - Treated water
  - 4 - 7BV/h
  - 10 - 20BV/h sulphuric acid

- **Regenerant Injection Strength**
  - Sodium chloride 10%
  - HCl 4 - 6%
  - $\text{H}_2\text{SO}_4$ 1 - 3% to avoid $\text{CaSO}_4$ precipitation
  - NaOH 3 - 5%
Regeneration Sequence

• Regenerant Displacement
  – Treated water
  – Same direction and rate as injection

• Rinse
  – Raw water
  – Service direction to drain
Counter Flow Regeneration

CO-FLOW REGENERATION

COUNTERFLOW REGENERATION
Reverse Flow Regeneration

- Relies on preventing bed mixing during or after regeneration
- Maintaining bed compaction
  - air hold down
  - split flow
  - Schwebbebett (upflow service)
  - UPCORE (downflow service)
  - Amberpack upflow service packed bed
  - Puropack upflow or downflow service packed bed
Air Hold Down

- Bed held by downwards air flow
- Complicated buried collector 150mm below top of bed
- Top 150mm resin not used
- Full bed backwash possible
- Active resin volume fixed by collector position
- Suitable for stratified bed
- Expensive design
Split Flow

- Regenerant enters top and bottom simultaneously
- Complicated buried collector
- 3:1 split
- Top resin regenerated in co-flow
- Top of bed backwash possible
- Resin volume can be increased
- Not suitable for stratified bed
- Expensive design
Schwebbebett

- Freeboard 50-100mm based on expanded resin
- Service flow is upwards at rate to lift and compact bed
- Inert resin protects top nozzles
- Flow must be continuous to maintain compaction through run – recirculation commonly used
- Regeneration is downflow
- Simple distributor design
- Low cost vessel design
- No backwash – needs low SS feed
- Resin volume is fixed
- Stratified bed requires an expensive and complicated central nozzle plate
- External resin cleaning vessel may be needed
UPCORE

- Freeboard 50-100mm based on expanded resin
- Service flow is downwards
- Regeneration is upwards
- High initial flow to lift and compact bed
- Simple distributor design – source of this can be a problem
- Low cost vessel design
- Resin volume is fixed
- Suitable for stratified bed
- No backwash – needs low SS feed
- External resin cleaning vessel may be needed
Packed Bed - Amberpack/Puropack

- Minimal freeboard based on expanded resin volume
- Service flow can be upflow (Amberpack) or downflow (Puropack)
- Regeneration is counterflow
- Bed compaction implicit in design
- Simple distributor design
- Low cost vessel design
- Resin volume is fixed
- No backwash – needs low SS feed
- External resin cleaning vessel needed
- Can be retrofitted into existing co-flow, AHD or Split Flow vessels
- External resin cleaning vessel may be needed
Packed Stratified Bed

- Design as for single resin bed
- Minimal freeboard based on expanded resin volume
- Total resin volume is fixed
- Specially graded resins
- Care is needed because weak and strong resins have different swelling/shrinking characteristics
- External resin cleaning vessel may be needed
- Potential problems of weak and strong resins mixing if resin bed has to be removed for cleaning
Packed Stratified Bed

- Division plate to prevent resin mixing
- Minimal freeboard in each compartment based on expanded resin volume
- Total resin volume is fixed
- Standard grade resin
- Care is needed because weak and strong resins have different swelling/shrinking characteristics
- External resin cleaning vessel may be needed
- Potential problems of weak and strong resins mixing if resin bed has to be removed for cleaning
Mechanical Construction

- Vessels
- Valves and pipework
- Underdrains
- Internals
Vessels in polyester and vinylester up to 1500mm dia
Two Stage Deionisation

Packaged DI units with multi-port control valves
Two Stage Deionisation

$30m^3/h$ two bed DI unit with individual control valves and intermediate degasser
Vessels

Larger vessels in rubber lined or PVC dipped carbon steel up to 3600mm dia
Concrete fill with unwrapped laterals and gravel
For custom engineered steel vessels > 1000mm diameter
Vessel Internals

Header with drilled laterals
Vessel Internals

For good distribution in drilled laterals

- Ratio of the kinetic energy of the inlet stream to the head loss across an outlet hole should be about 0.1.
- For turbulent flow inlet stream kinetic energy is $KE = \frac{v^2}{2g}$
- The headloss across the outlet hole is $H = \frac{u^2}{2g}$
- So $\frac{1.0 \cdot \frac{v^2}{2g}}{\frac{u^2}{2g}} = 0.1$
- That is $u \approx 3.2 \times v$
  - For $v$ around 1-2 m/s distributor headloss is about 0.5 – 1.0m

Senecal (Ind Eng Chem 1957)
Concrete fill with wrapped laterals
For custom engineered steel vessels > 1000mm diameter
Vessel Internals

Wrapping for Drilled Laterals

- CABLE TIE
- 300micron POLYPROPYLENE MESH
- POLYNET SLEEVE
- DRILLED LATERAL
Vessel Internals

Stainless steel wedgewire laterals
Vessel Internals

Hub and radial underdrain
For vessels up to 1000\(\phi\)
Vessel Internals

Nozzle plate underdrain
For custom engineered steel vessels > 1000mm diameter
Nozzles for Nozzle Plates

STANDARD NOZZLE  AIR DISTRIBUTION  COUNTERFLOW
Nozzles for Nozzle Plates

Counter flow regeneration nozzle
Vessel Internals

Internals arrangement
Vessel Internals

Internals arrangement
Polishing

RAW WATER

SAC H⁺ CYCLE

Ca²⁺
Mg²⁺
Na⁺
K⁺

HCO₃⁻
Cl⁻
SO₄²⁻
NO₃⁻
CO₂
SiO₂

SBA OH⁻ CYCLE

HCl
H₂SO₄
HNO₃
H₂CO₃
SiO₂
NaCl (trace)

SO₄²⁻
NO₃⁻
Cl⁻
HCO₃⁻
SiO₂
OH⁻

DEIONISED WATER

H₂O
NaOH (trace)
SiO₂ (trace)
Cation Polishing

• Second cation exchanger post anion
• ~100BV/h
• Regenerated in series with main cation
• Removes sodium leakage
• Conductivity 0.06 – 0.1 µS/cm
• Does not remove silica

Two bed with HiPol cation polisher
Mixed Bed Polishing

Non-regenerable
cartridge mixed beds
Regenerable Mixed Beds

- Polishing - post cation-anion
- Working - post RO
- Hydraulic loading
  - up to 100BV/h for polishing MB
  - Up to 50BV/h post RO
  - $\Delta P \leq 1$ bar
Regenerable Mixed Beds

• Resins must separate completely
• Separation is by backwashing
• Separation is a function of density and size

• Stokes Law \[ v = \frac{gd^2(\rho_s - \rho)}{18\mu} \]

• Regenerated separately
• After regeneration thorough remixing with air

Ambersep system with inert
Mixed Bed Regeneration

- **Backwash to separate resins**
  - 10 - 12m/h
  - about 5 - 10 minutes

- **Settle**
  - May be separate stage

- **Drain down**
  - to about 100mm above the top of the bed
  - controlled by level probe
  - or timer
Mixed Bed Regeneration

- Simultaneous regenerant injection
  - acid and caustic at the same time
  - about 15 - 20 minutes
- Caustic Soda
  - downwards through anion bed
  - 4 - 6%
  - 4 - 6 BV/h
- Hydrochloric Acid
  - up through cation bed
  - 4 - 6%
  - 4 - 6 BV/h
Mixed Bed Regeneration

- Regenerant Displacement
  - follows after injection
  - 1.5 - 2.5 BV

- Air mix
  - oil free air to re-mix the resins
  - 80 - 100 Nm$^3$/h/m$^2$
  - 500 - 700mbar
  - 5 - 10 minutes

- Settle
  - Settlement for 2 - 3 minutes
  - Can result in separation of anion resin
  - May be “forced settle” with downflow from caustic distributor
Mixed Bed Regeneration

- Final Rinse
  - initially to drain
  - controlled by conductivity
  - usually 4 - 5 BV
  - may use recirculation to feedwater tank to minimise waste water
Mixed Bed Anatomy

- **Post Two Bed Demin**
  - Cation load \((Na^+)\) > anion load \((SiO_2 + CO_2)\)
  - Anion:cation 1:1 by volume for \(H_2SO_4\) regen
  - Anion:cation 1.5:1 by volume for \(HCl\) regen

- **Post RO**
  - Anion load \((TA+SiO_2+CO_2)\) > Cation load \((TC)\)
  - Anion:cation 2:1 by volume for \(H_2SO_4\) regen
  - Anion:cation 2.5:1 by volume for \(HCl\) regen

- **Strong Acid Cation Resin**
  - Minimum depth 600mm
  - Sets collector position
EDI Water Quality

- Feed Water
- RO permeate
  - pH: 6 - 8
  - TDS: < 20 mg/l
  - Total Hardness: < 1 mg/l CaCO₃
  - TOC: < 0.4 mg/l
  - Carbon dioxide: < 5 mg/l
  - Temperature: 5 – 28 °C
- Ex DI
  - Conductivity: < 1 μS/cm
  - Silica: < 0.1 mg/l
EDI Water Quality

- Diluate product
  - Resistivity: 10 – 17 MΩ.cm
  - Conductivity: 0.058 – 0.1 µS/cm
  - Silica: < 0.02 mg/l
  - CO₂: as influent
Equipment

*Industrial EDI Unit*
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