SCI
where science meets business

Engineering Design Considerations

Richard Hill

Whitewater Limited
Consulting Engineers & Scientists

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* = $\dfrac{\textit{regeneration level (eq/l)}}{\textit{exchange capacity (eq/l)}}$
- *Hydraulic loading (BV/h)* = $\dfrac{\textit{flow rate } (m^3/h)}{\textit{resin volume } (m^3)}$
- *EBCT (h)* = $\dfrac{1}{\textit{hydraulic loading}}$
- *Turndown ratio* $\dfrac{\textit{Maximum flow rate } (m^3/h)}{\textit{Minimum flow rate } (m^3/h)}$

Process Design Parameters

- The volume of treated water produced per cycle (Q m^3) by V litres of resin with capacity Ceq/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 eq/l treating a water with ionic concentration L meq/l at a flow of Q m^3/h the run time, T 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 BV/h then:

$$\boldsymbol{W \le \frac{Q \times 1000}{V}} \quad \text{and} \quad T \ge \frac{C \times 1000}{Wc}$$

SCI

where science meets business

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,*

$$h = l.k.v_a.1.02^{(15-\theta)}$$

where	l	= *bed depth, m (typically 1 - 3m)*
	v_a	= *approach velocity, m/h*
	T	= *temperature, ^{o}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 ½h

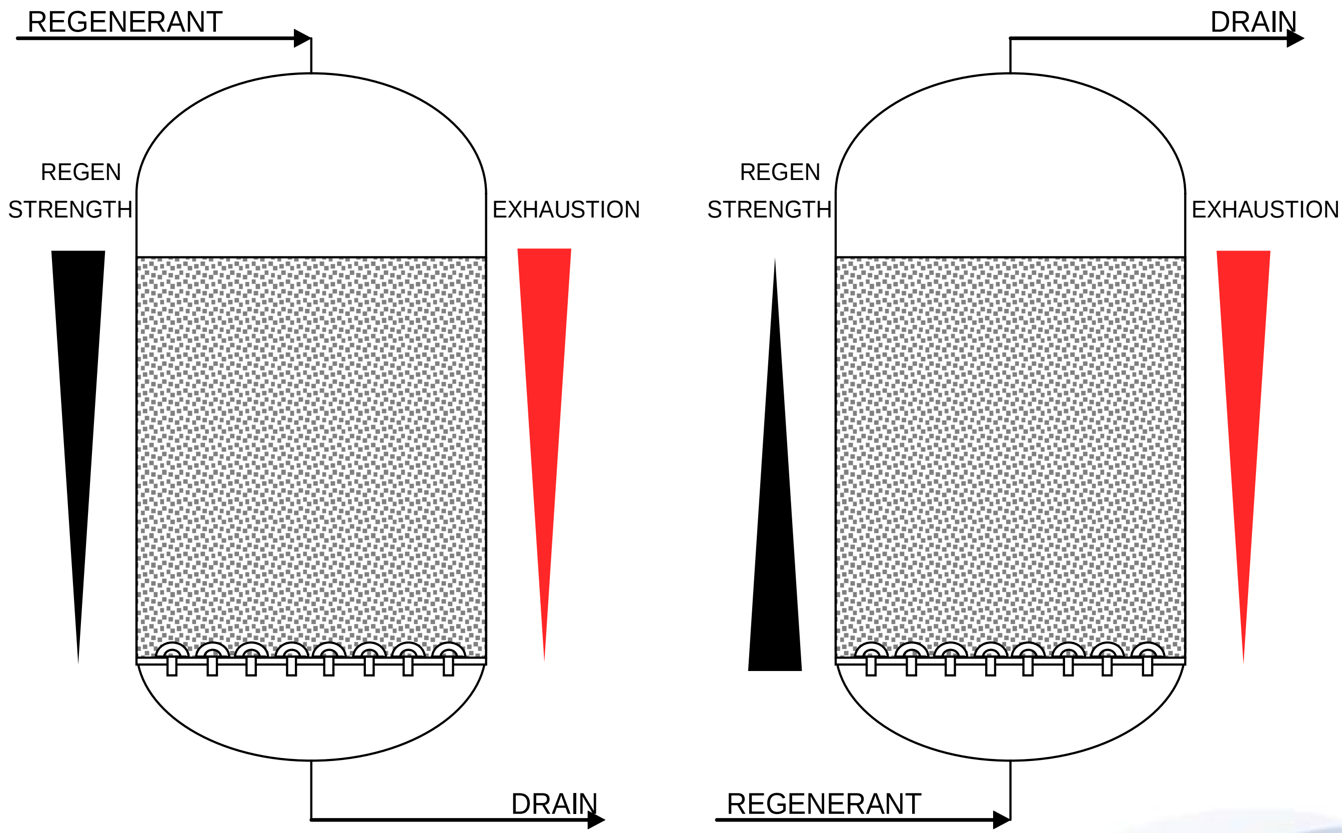
Regeneration Sequence

- Regenerant Injection
  - Treated water
  - 4 - 7BV/h
  - 10 - 20BV/h sulphuric acid
- Regenerant Injection Strength
  - Sodium chloride 10%
  - HCl 4 - 6%
  - H_2SO_4 1 - 3% to avoid $CaSO_4$ 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



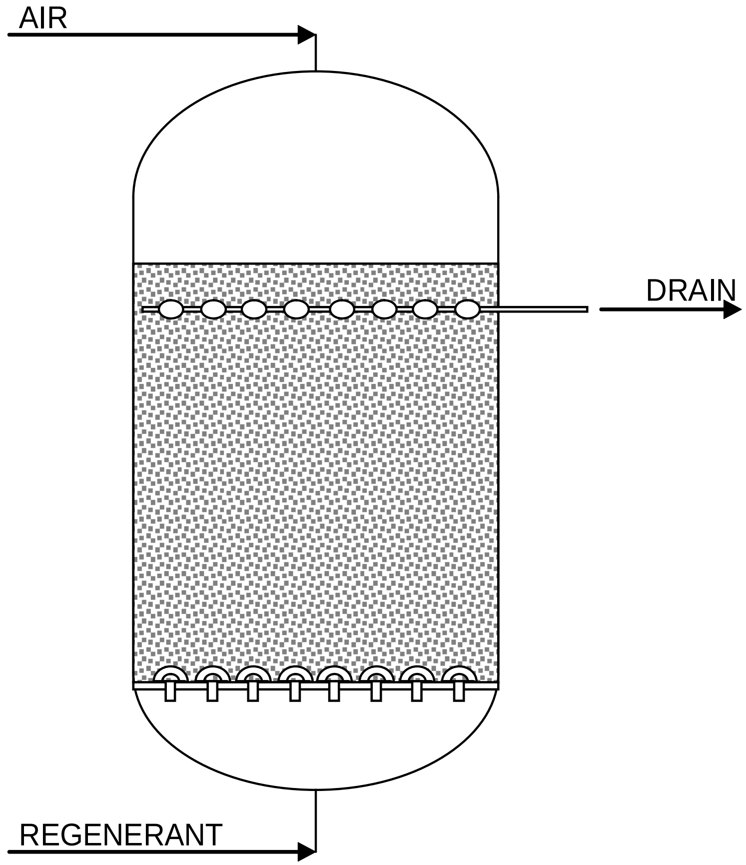
CO-FLOW REGENERATION

COUNTERFLOW REGENERATION

Reverse Flow Regeneration

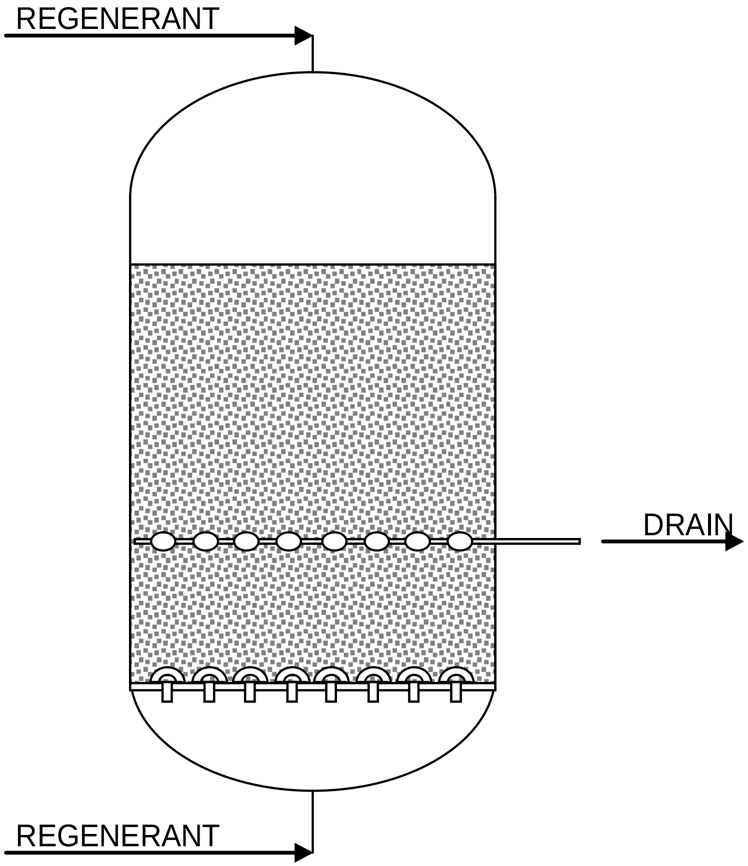
- Relies on preventing bed mixing during or after regeneration
- Maintaining bed compaction
  - air hold down
  - split flow
  - Schwebbebett (upflow service)
  - UPCORE (downflow service)
  - Amberpack upflow service packed bed
  - Puropack upflow or downflow service packed bed

Air Hold Down



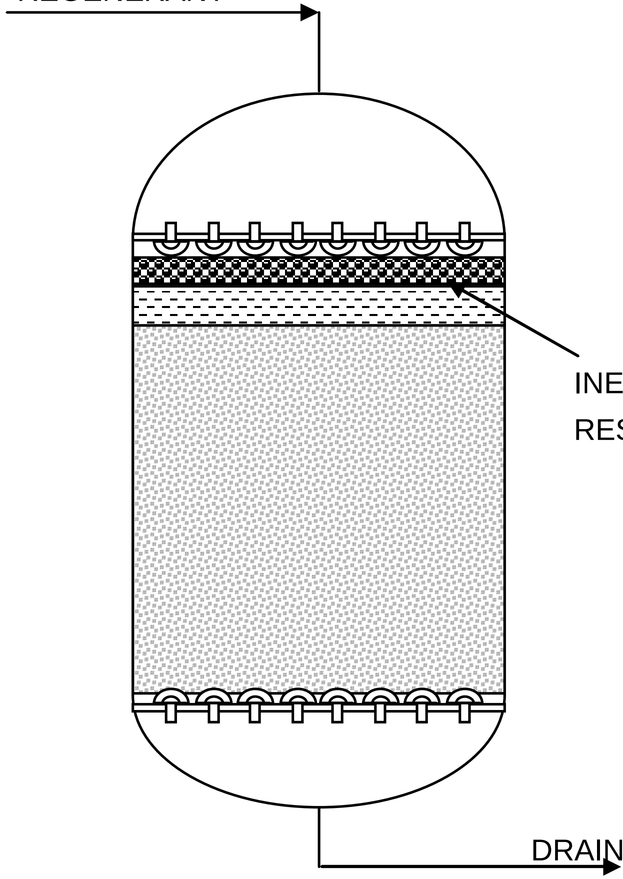
- Bed held by downwards air flow
- Complicated buried collector 150mm below top of bed
- Top 150mm resin not used
- Full bed backwash possible
- Active resin volume fixed by collector position
- Suitable for stratified bed
- Expensive design

Split Flow



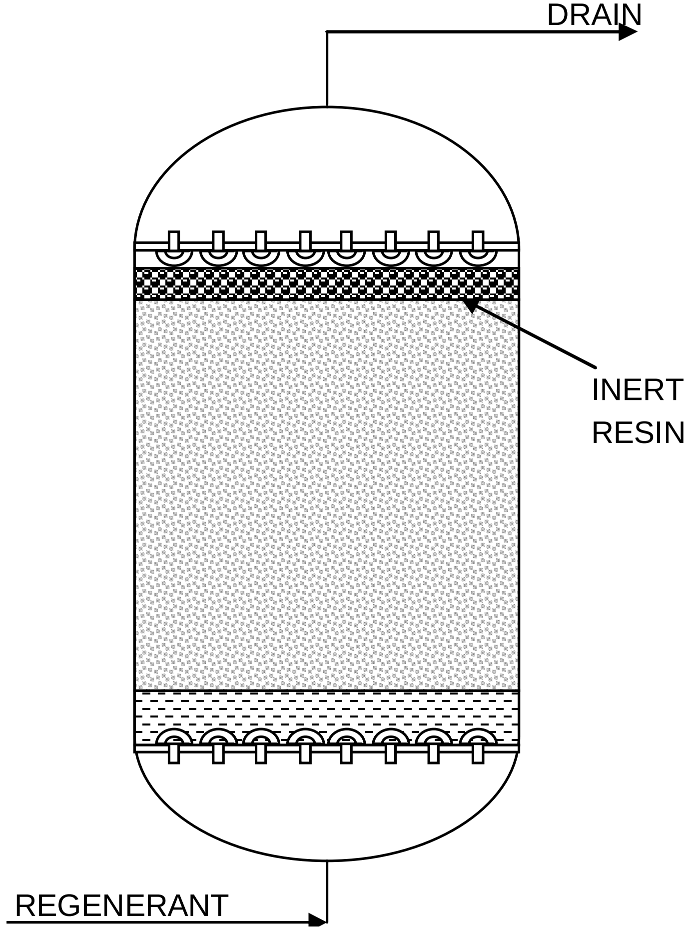
- Regenerant enters top and bottom simultaneously
- Complicated buried collector
- 3:1 split
- Top resin regenerated in co-flow
- Top of bed backwash possible
- Resin volume can be increased
- Not suitable for stratified bed
- Expensive design

Schwebbebett



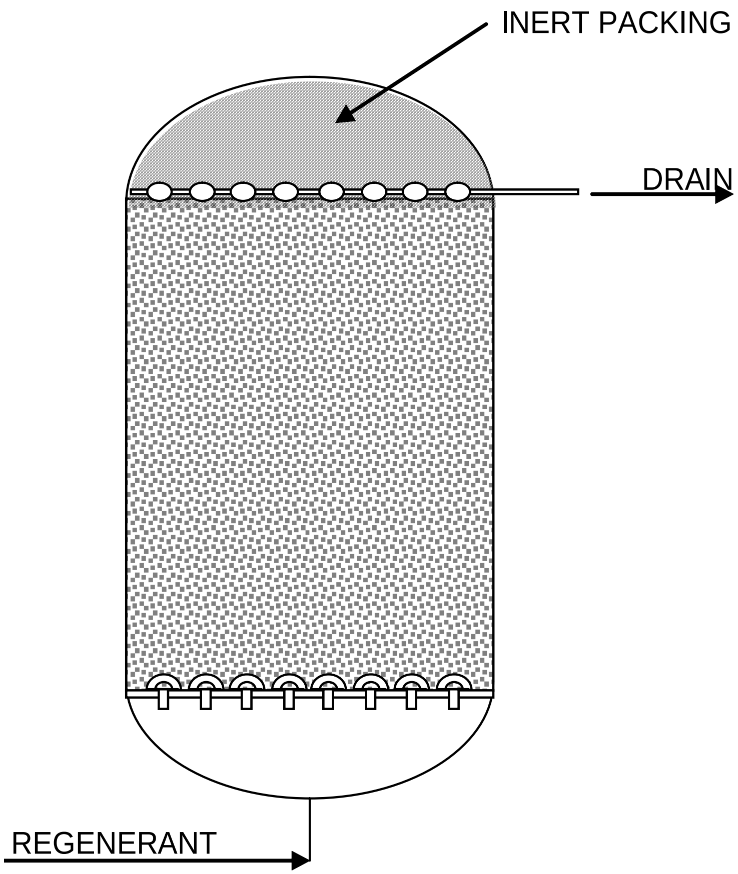
- Freeboard 50-100mm based on expanded resin
- Service flow is upwards at rate to lift and compact bed
- Inert resin protects top nozzles
- Flow must be continuous to maintain compaction through run – recirculation commonly used
- Regeneration is downflow
- Simple distributor design
- Low cost vessel 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



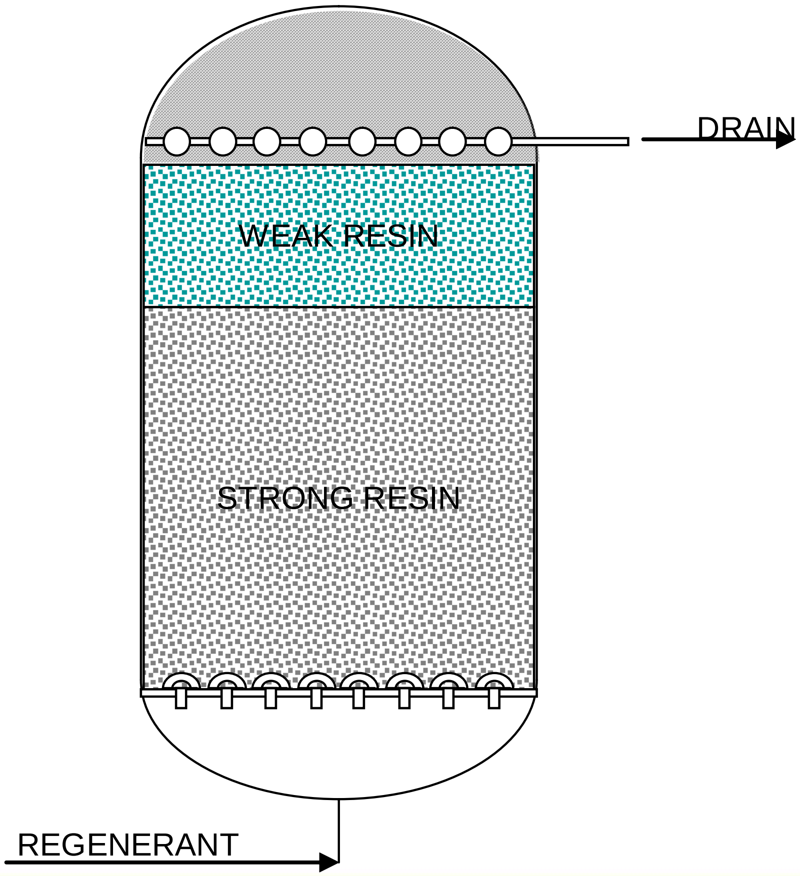
- Freeboard 50-100mm based on expanded resin
- Service flow is downwards
- Regeneration is upwards
- High initial flow to lift and compact bed
- Simple distributor design – source of this can be a problem
- Low cost vessel design
- Resin volume is fixed
- Suitable for stratified bed
- No backwash – needs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

Packed Bed - Amberpack/Puropack



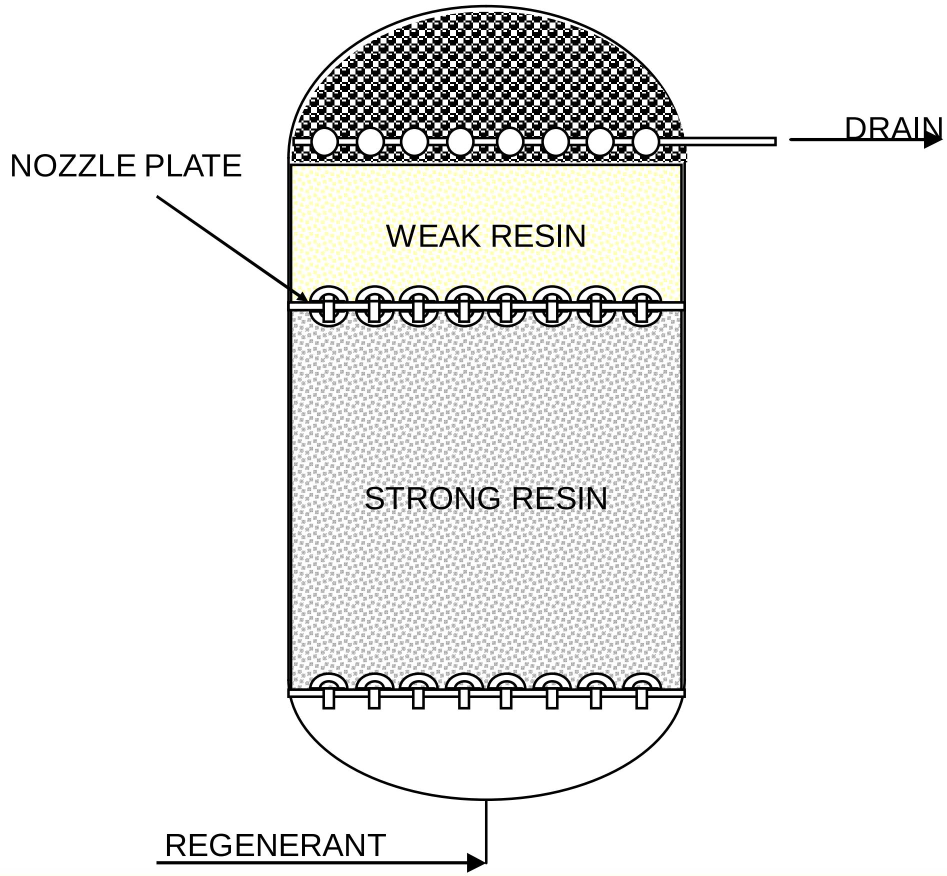
- Minimal freeboard based on expanded resin volume
- Service flow can be upflow (Amberpack) or downflow (Puropack)
- Regeneration is counterflow
- Bed compaction implicit in design
- Simple distributor design
- Low cost vessel design
- Resin volume is fixed
- No backwash – needs low SS feed
- External 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

Vessels in polyester and vinylester up to 1500mm dia

Two Stage Deionisation

Packaged DI units with multi-port control valves

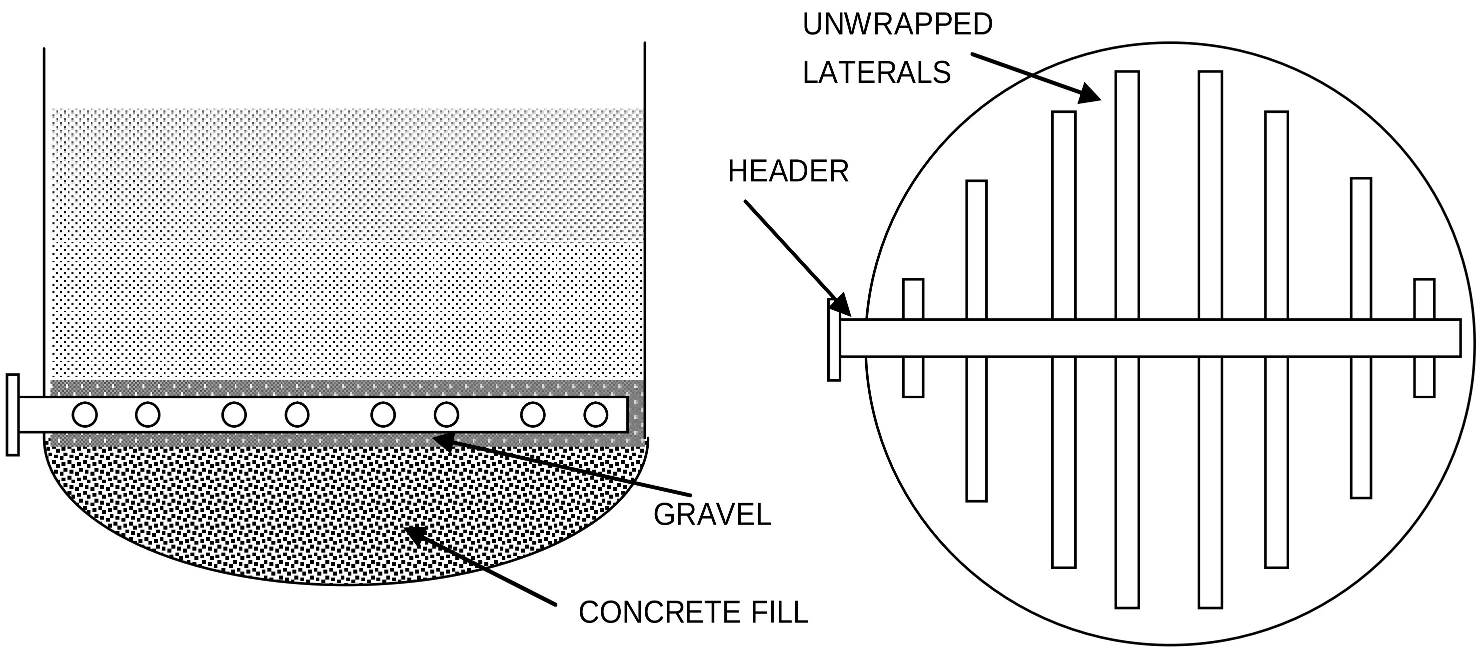
Two Stage Deionisation

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

Vessels

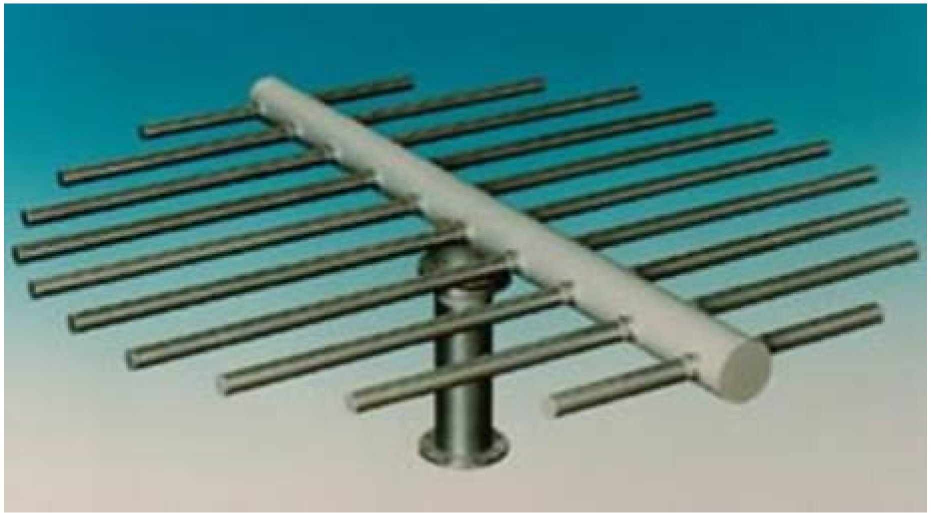
Larger vessels in rubber lined or PVC dipped carbon steel up to 3600mm dia

Vessel Internals



Concrete fill with unwrapped unwrapped laterals and gravel
For custom engineered steel vessels > 1000mm diameter

Vessel Internals



Header with drilled laterals

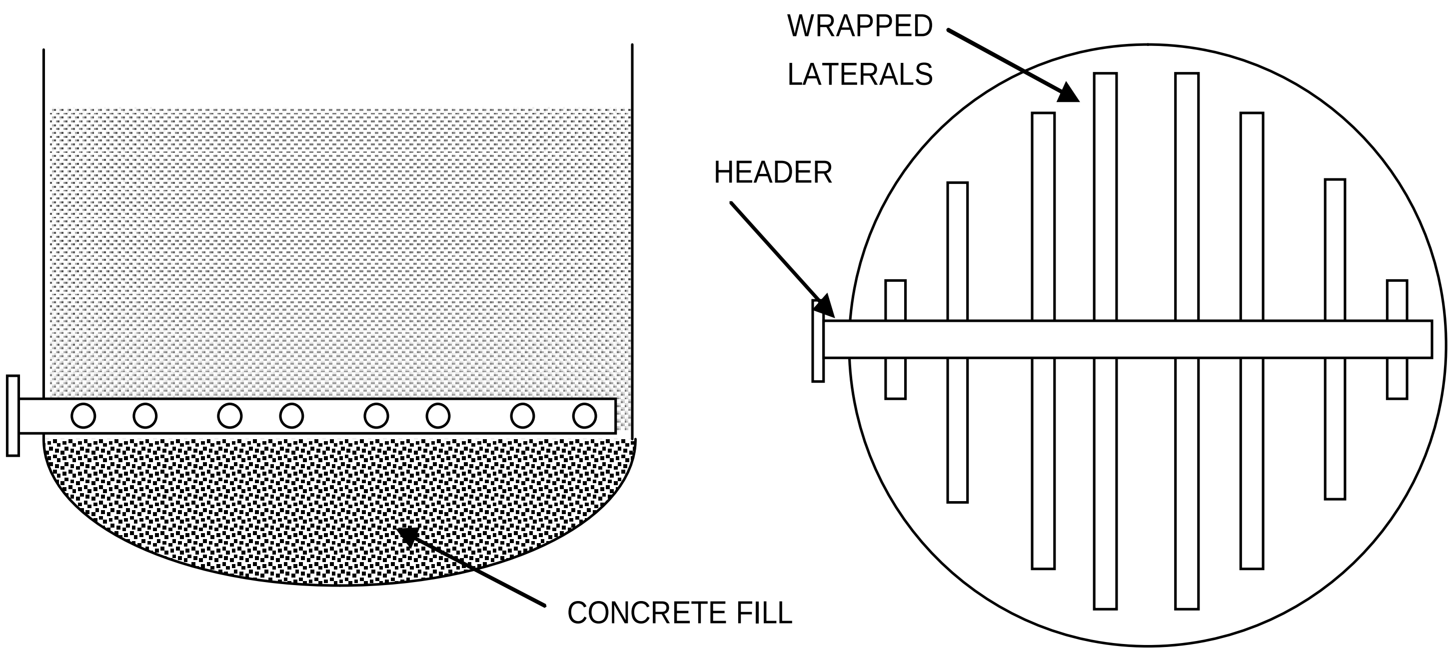
Vessel Internals

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 = $v^2/2g$
- The headloss across the outlet hole is H = $u^2/2g$
- So $(1.0.v^2/2g)/(u^2/2g) = 0.1$
- That is $u \approx 3.2 \times v$
  - For v around 1- 2 m/s distributor headloss is about 0.5 – 1.0m

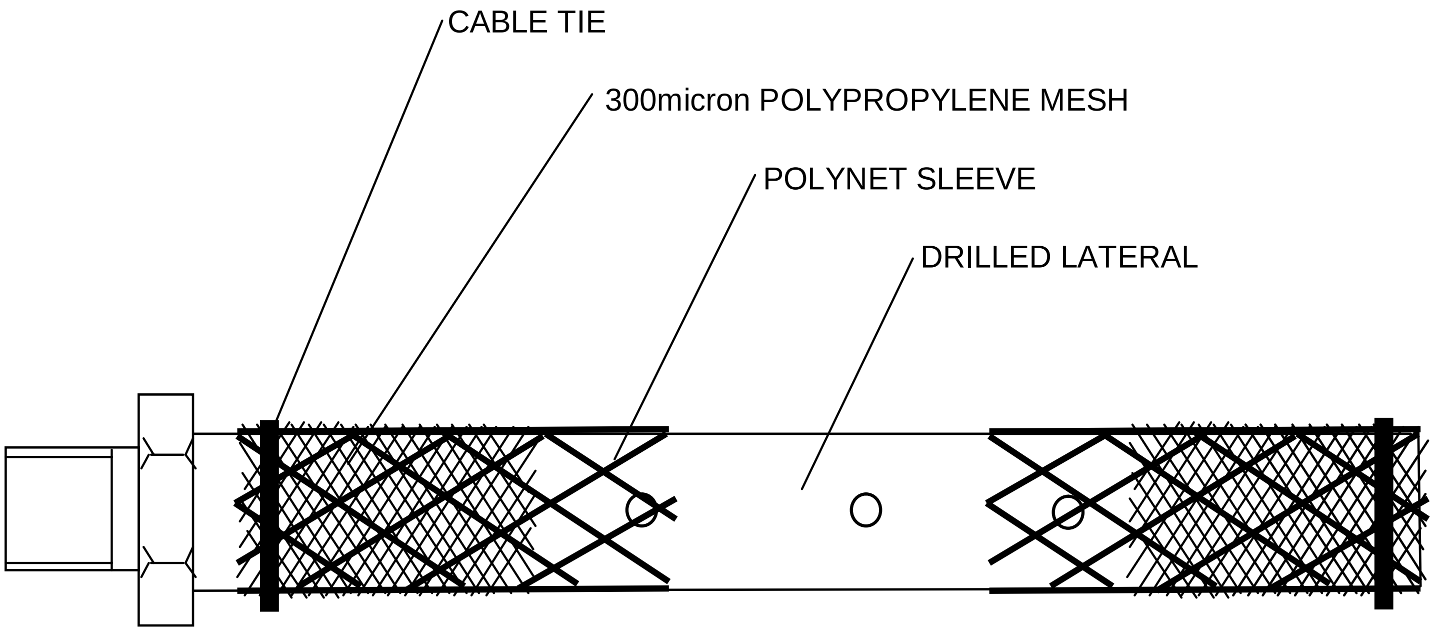
Senecal (Ind Eng Chem 1957)

Vessel Internals



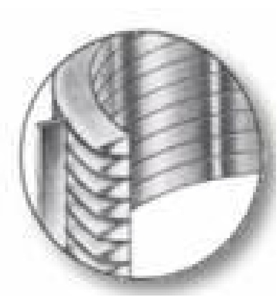
Concrete fill with wrapped laterals
For custom engineered steel vessels > 1000mm diameter

Vessel Internals



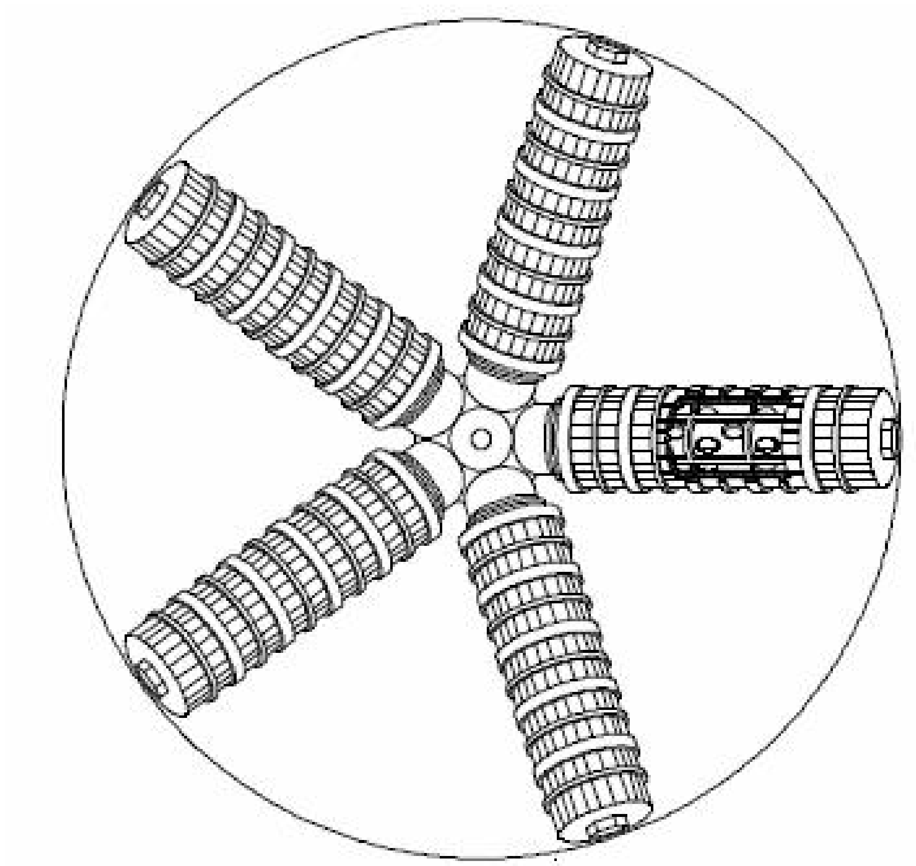
Wrapping for Drilled Laterals

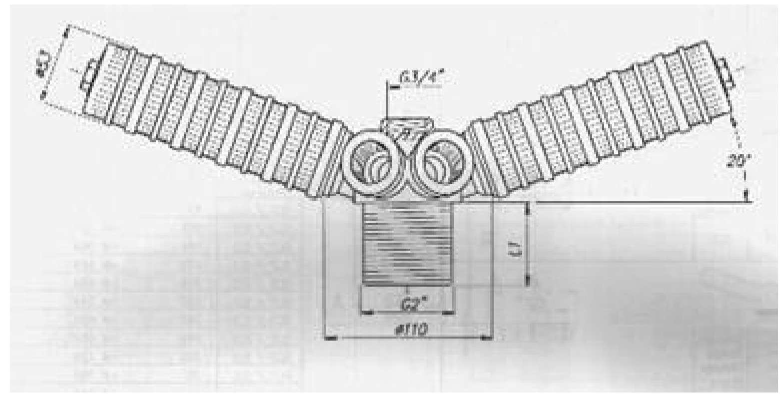
Vessel Internals



Stainless steel wedgewire laterals

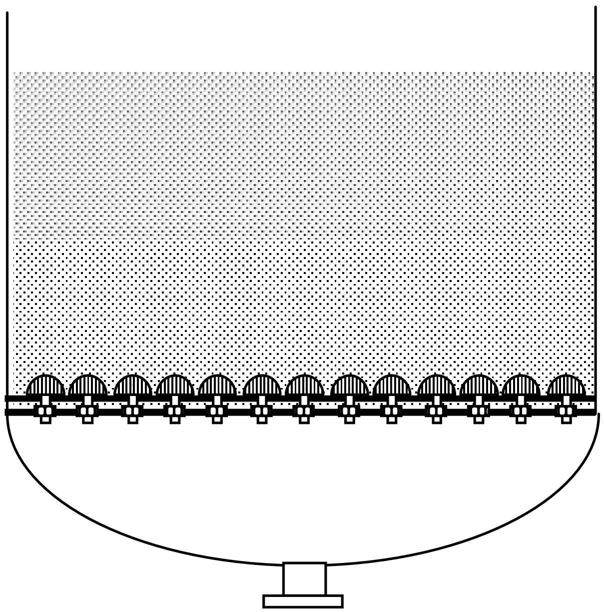
Vessel Internals

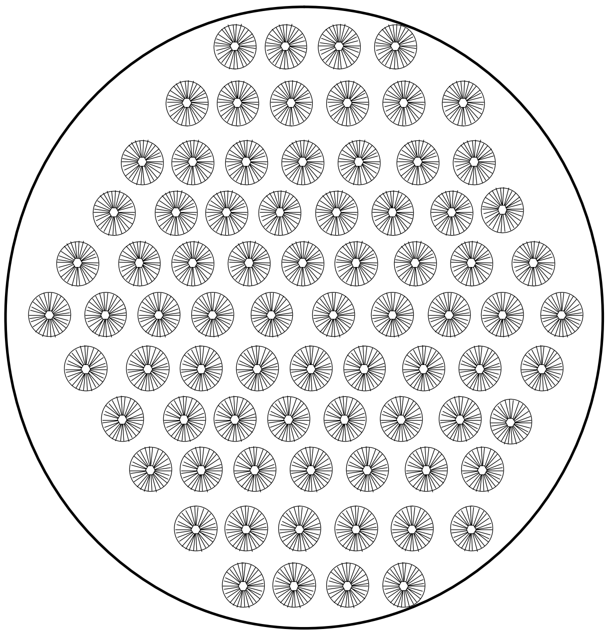




Hub and radial underdrain
For vessels up to 1000ϕ

Vessel Internals





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

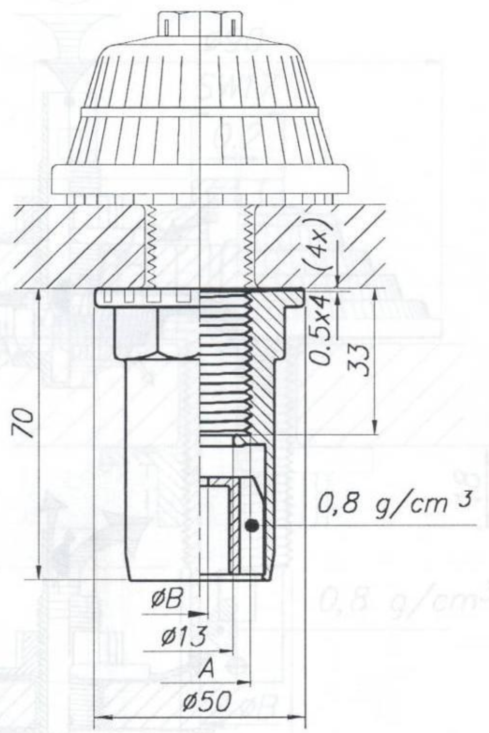
Nozzles for Nozzle Plates

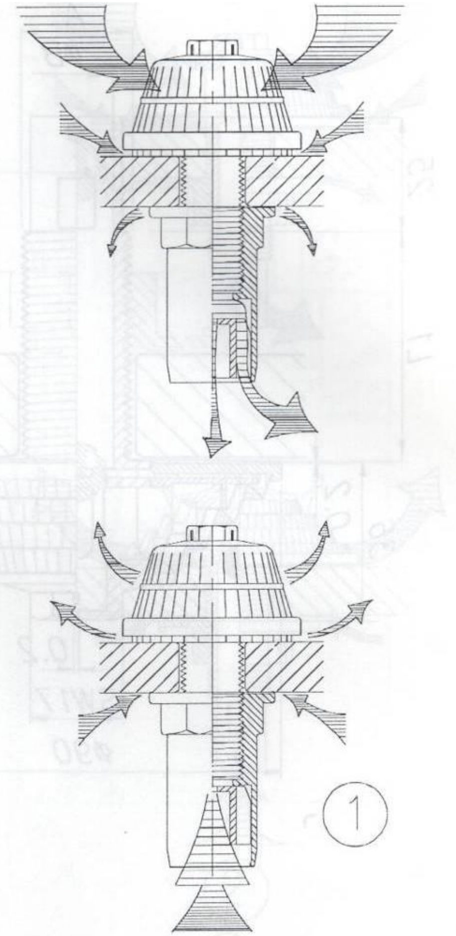
STANDARD NOZZLE

AIR DISTRIBUTION

COUNTERFLOW

Nozzles for Nozzle Plates





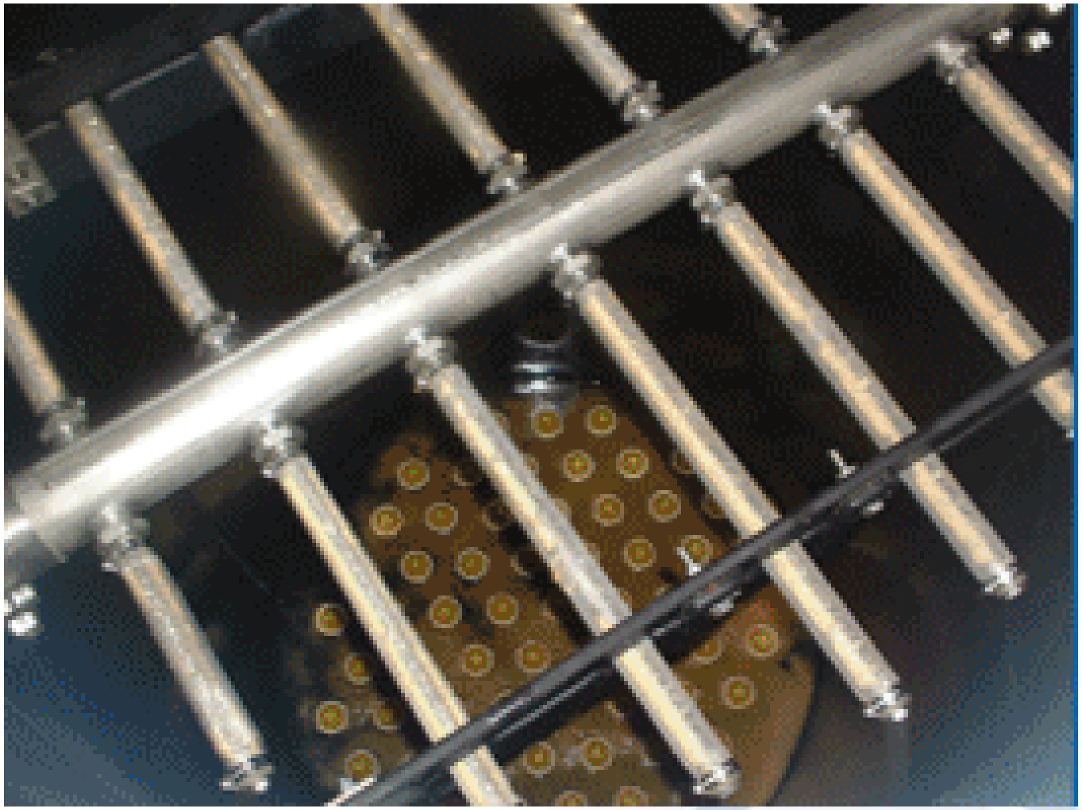
Counter flow regeneration nozzle

Vessel Internals

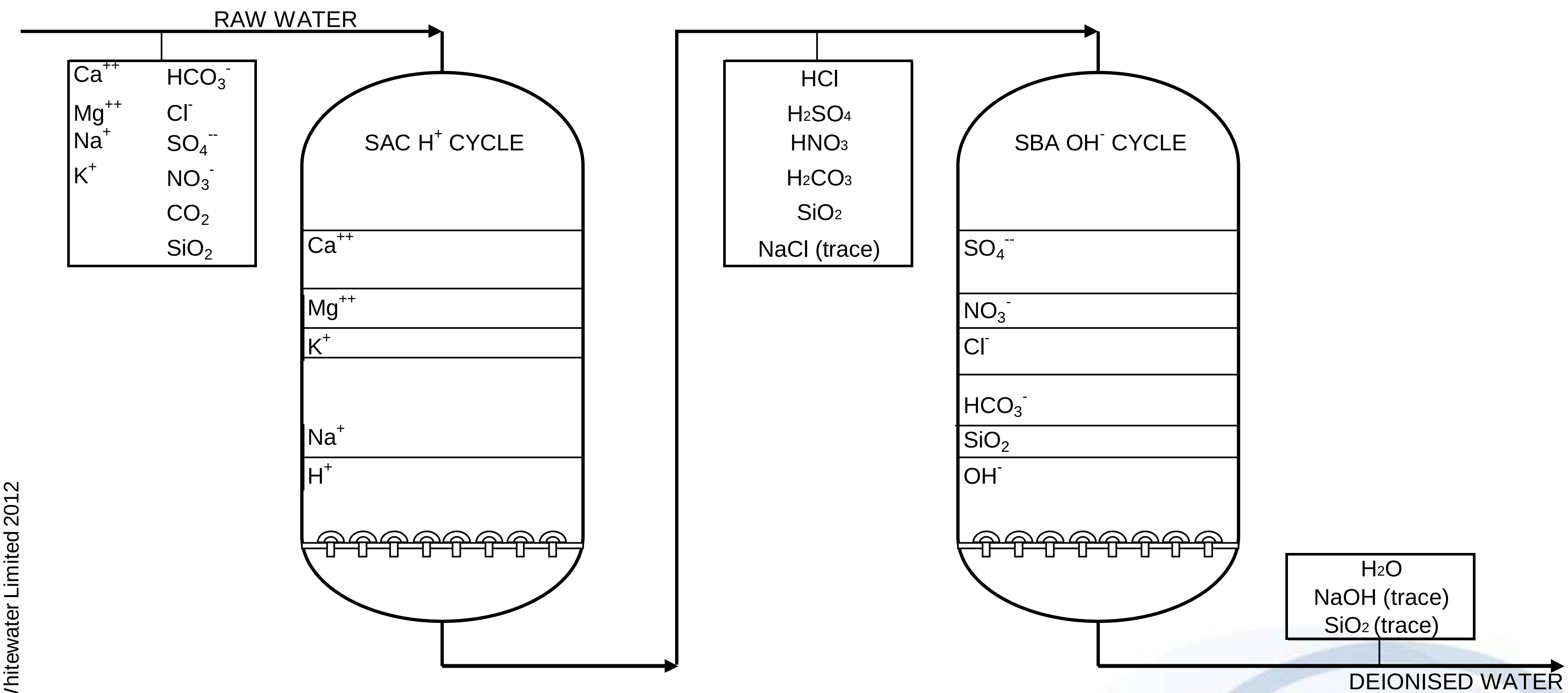
Internals arrangement

Vessel Internals

Internals arrangement

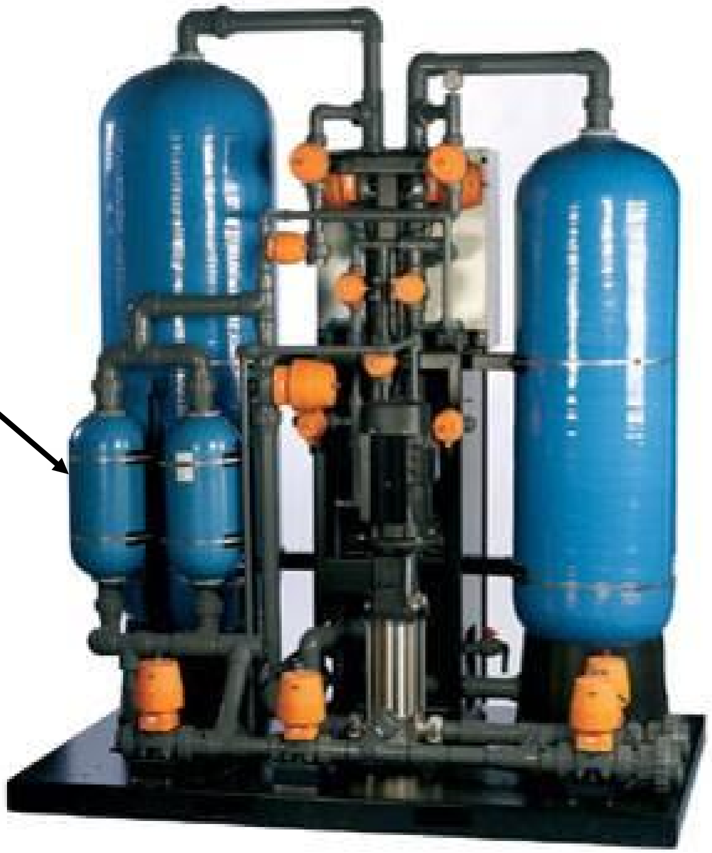


Polishing


RAW WATER
Ca++ HCO3-
Mg++ Cl-
Na+ SO4--
K+ NO3-
CO2
SiO2
SAC H+ CYCLE
Ca++
Mg++
K+
Na+
H+
HCl
H2SO4
HNO3
H2CO3
SiO2
NaCl (trace)
SBA OH- CYCLE
SO4--
NO3-
Cl-
HCO3-
SiO2
OH-
H2O
NaOH (trace)
SiO2 (trace)
DEIONISED WATER

Cation Polishing

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



Two bed with HiPol cation polisher

Mixed Bed Polishing

Non-regenerable cartridge mixed beds

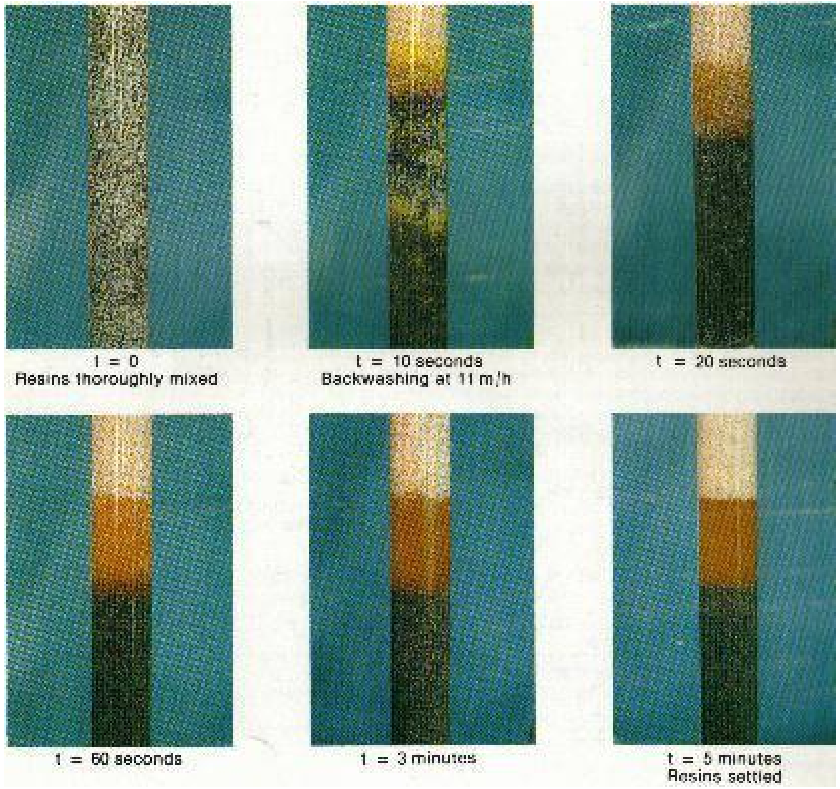
Regenerable Mixed Beds

- 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 $v_t = \frac{gd^2(\rho_s - \rho)}{18\mu}$

- 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

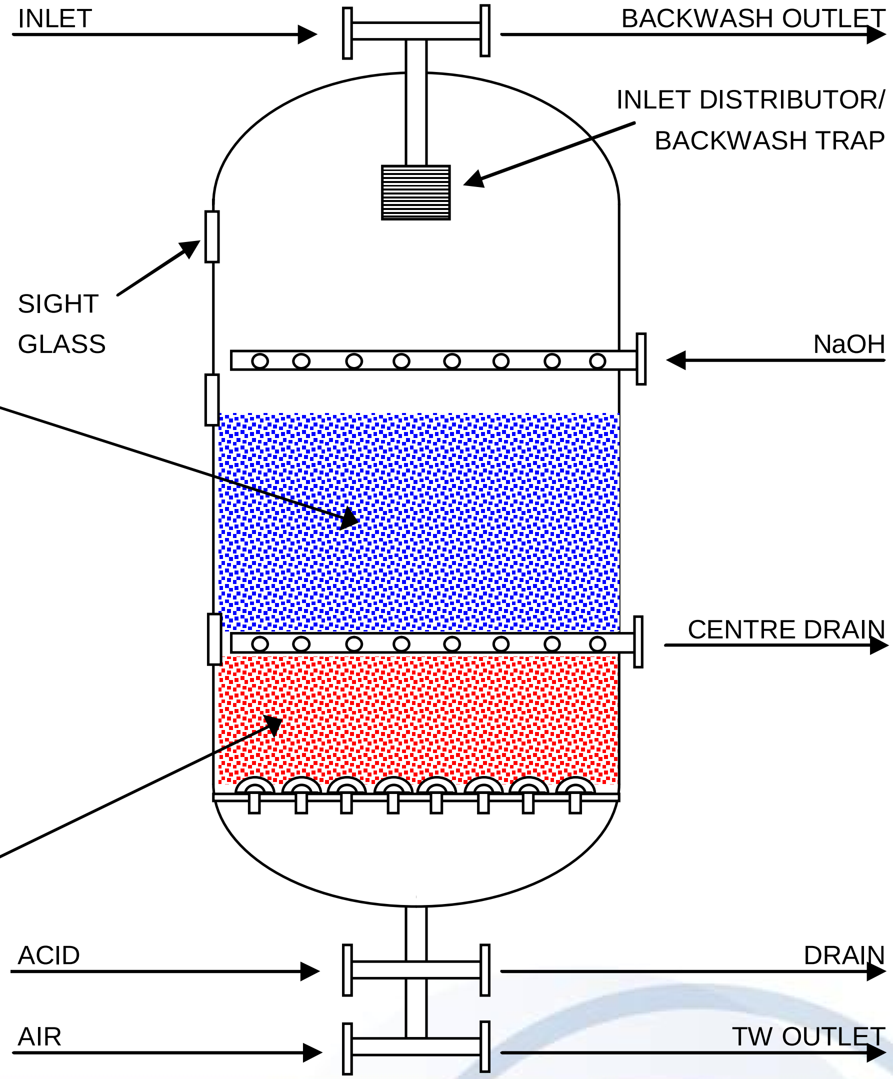
- Regenerant Displacement
  - follows after injection
  - 1.5 - 2.5 BV
- Air mix
  - oil free air to re-mix the resins
  - 80 - 100 $Nm^3/h/m^2$
  - 500 - 700mbar
  - 5 - 10 minutes
- Settle
  - Settlement for 2 - 3 minutes
  - Can result in separation of anion resin
  - May be “forced settle” with downflow from caustic distributor

Mixed Bed Regeneration

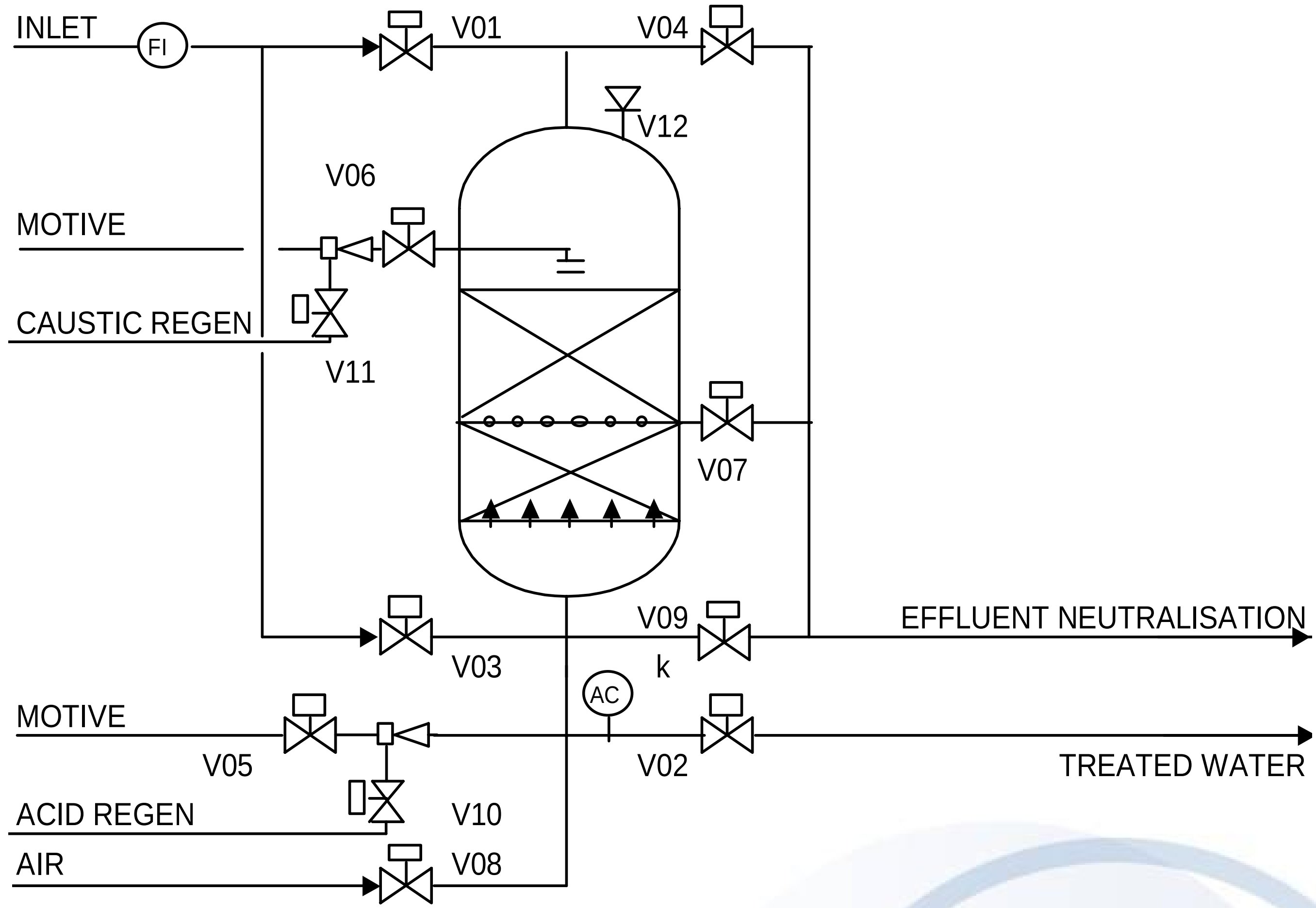
- Final Rinse
  - initially to drain
  - controlled by conductivity
  - usually 4 - 5 BV
  - may use recirculation to feedwater tank to minimise waste water

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

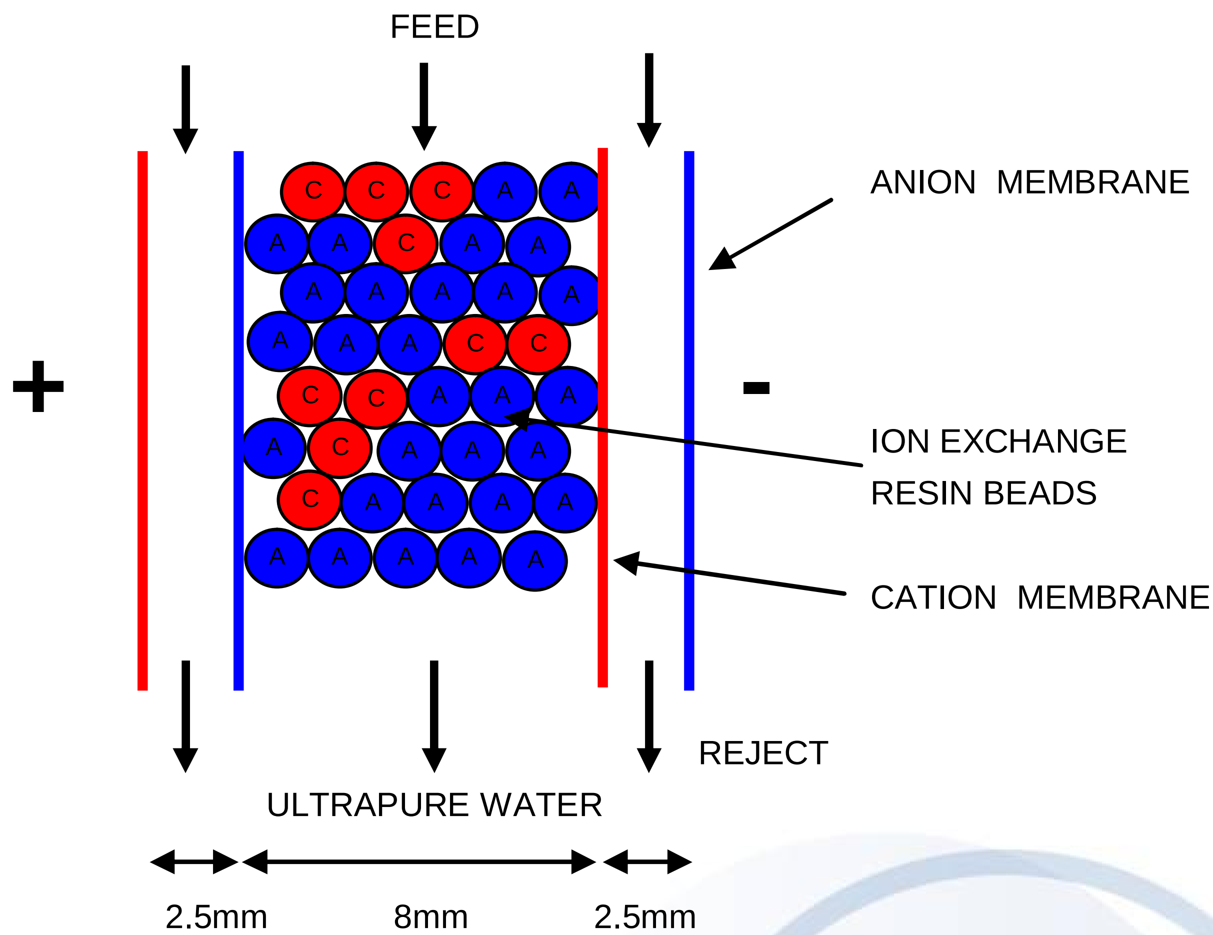


Mixed Beds


INLET
FI
V01
V04
V12
V06
MOTIVE
CAUSTIC REGEN
V11
V07
V09
EFFLUENT NEUTRALISATION
V03
k
AC
MOTIVE
V05
V02
TREATED WATER
ACID REGEN
V10
AIR
V08

Electrodeionisation

EDI Cell



EDI Water Quality

- Feed Water
- RO permeate

– pH	6 - 8
– TDS	< 20 mg/l
– Total Hardness	< 1 mg/l $CaCO_3$
– TOC	< 0.4 mg/l
– Carbon dioxide	< 5 mg/l
– Temperature	5 – 28 ^{o}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
  - CO_2 as influent

Equipment

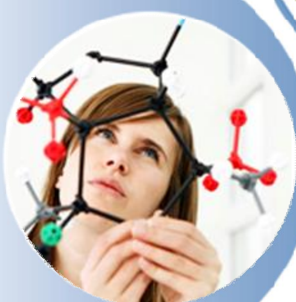
Industrial EDI Unit

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

SCI

where science meets business



www.soci.org