NOM removal by Suspended Ion Exchange (SIX®)

PWN Technologies

Erik Koreman

DOC2C Andijk 21 September 2016

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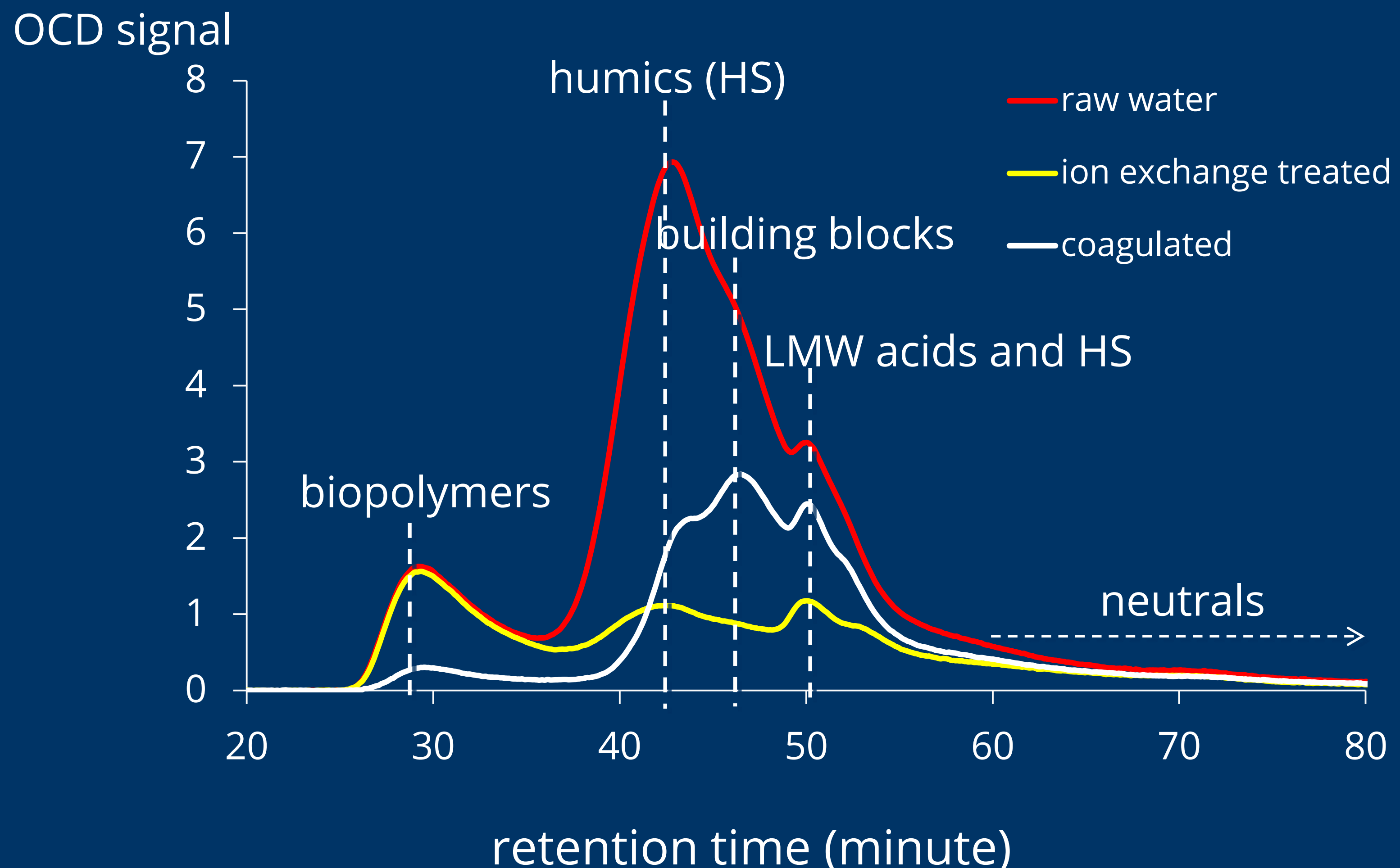
background – application

- world wide need to remove NOM/DOC to:
  - improve efficiency downstream treatment processes
    - **coagulation**
    - **membrane filtration**
    - **oxidation**
    - **adsorption**
    - **disinfection**
  - improve water quality
    - **color**
    - **disinfection by-products (THM's, HAA's)**
    - **bio stability**
- **technical and economical feasible technologies:**
  - **(enhanced) coagulation**
  - **anion ion exchange**

background - application

- coagulation
  - removes mainly the hydrophobic DOC and the HMW fraction of hydrophilic DOC
  - designed for turbidity removal (suspended solids) needs to be enhanced (lower pH) to remove higher amounts of DOC
- anion ion exchange
  - removes mainly the LMW fraction of the hydrophilic DOC (humic and fulvic acids)
  - ‘state of the art’ packed bed columns not feasible on waters containing suspended solids

IX *vs.* coagulation
IJssel Lake raw water matrix



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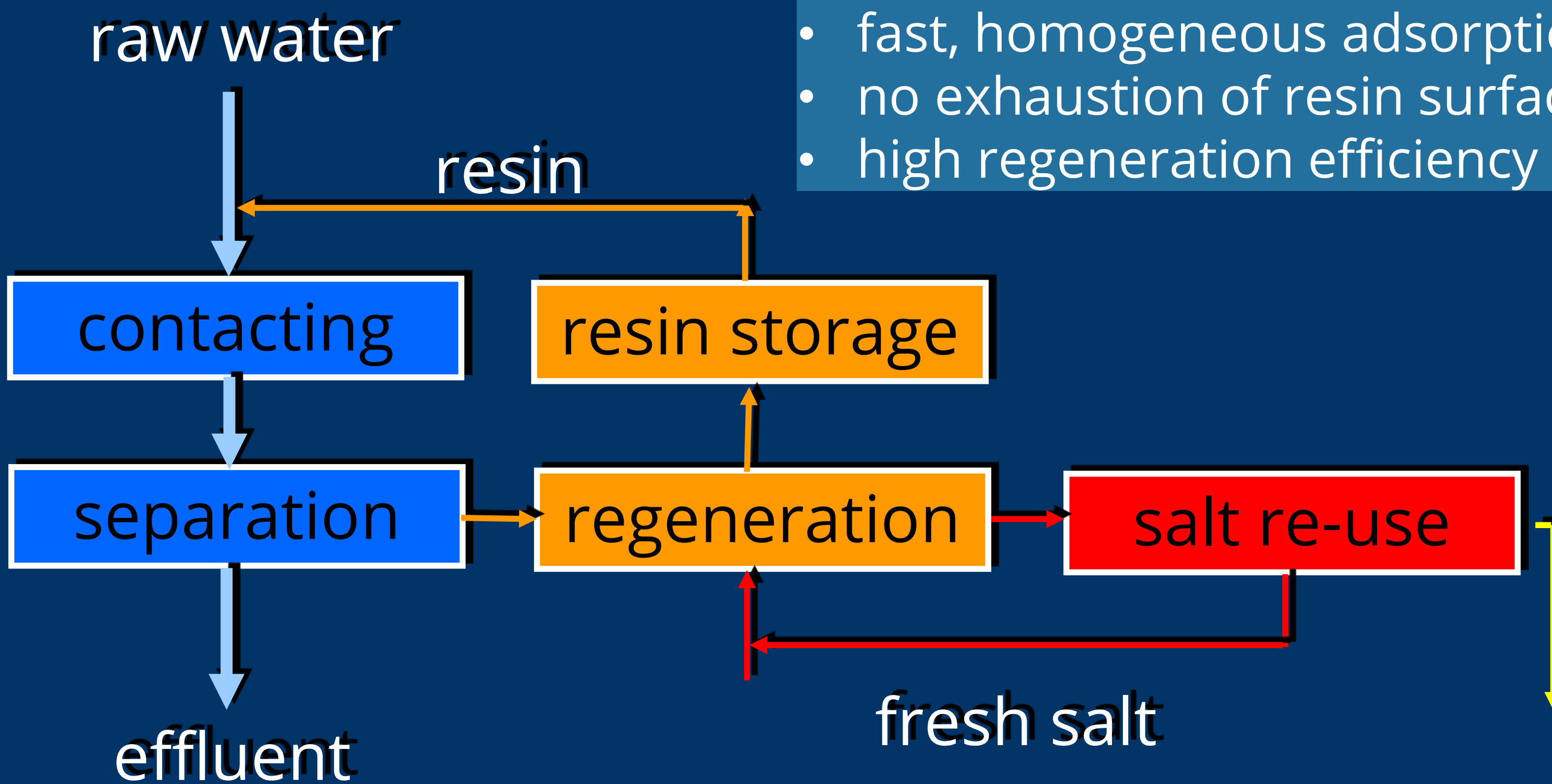
SIX® process- key features

- fast, homogeneous adsorption
- no exhaustion of resin surface
- high regeneration efficiency

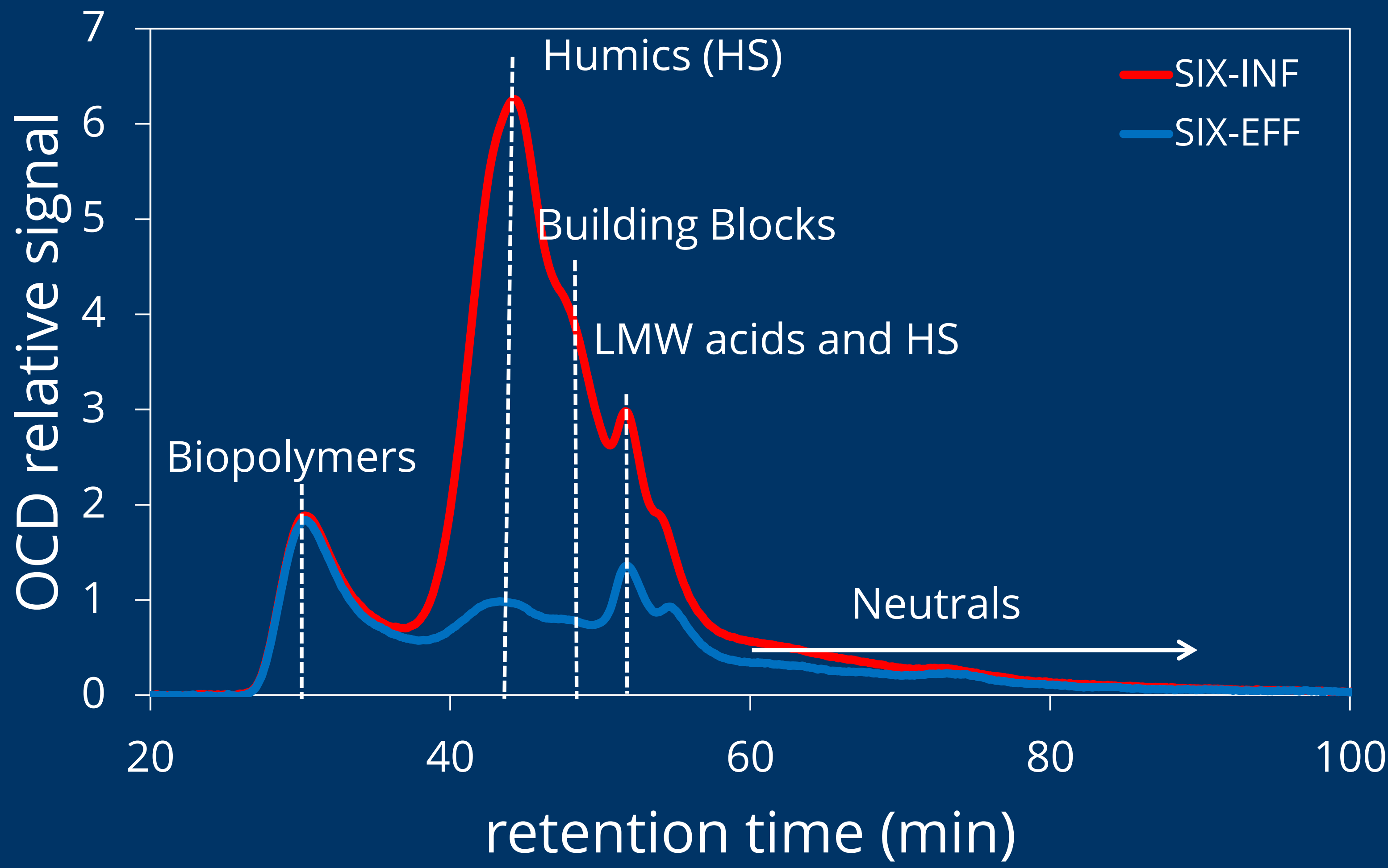


1. NOM and UV absorbance

90 – 110 m3/h fully automated

IJssel Lake NOM composition

90 m3/h SIX pilot influent/effluent (15-6-16)



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IJssel Lake NOM composition

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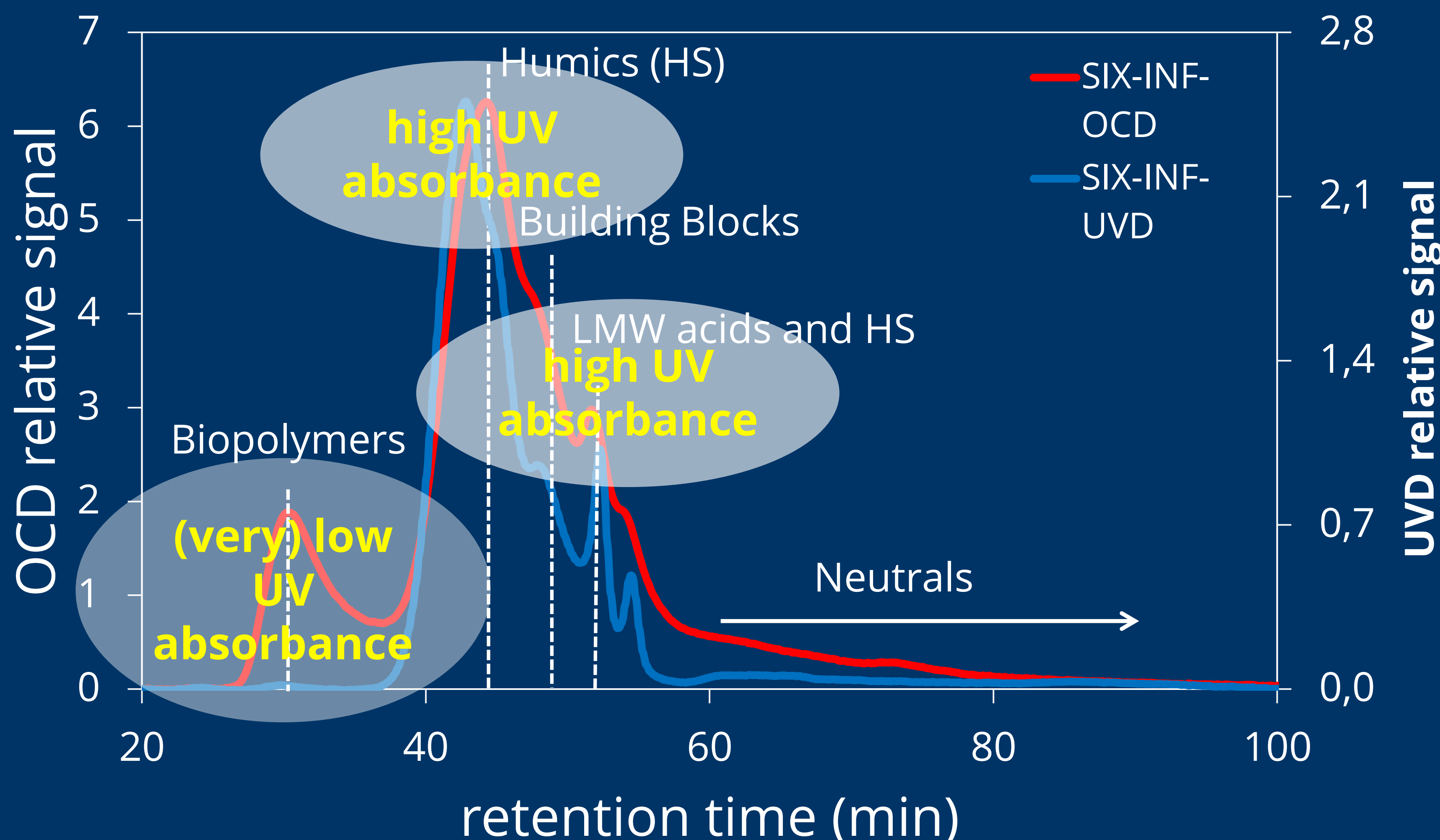

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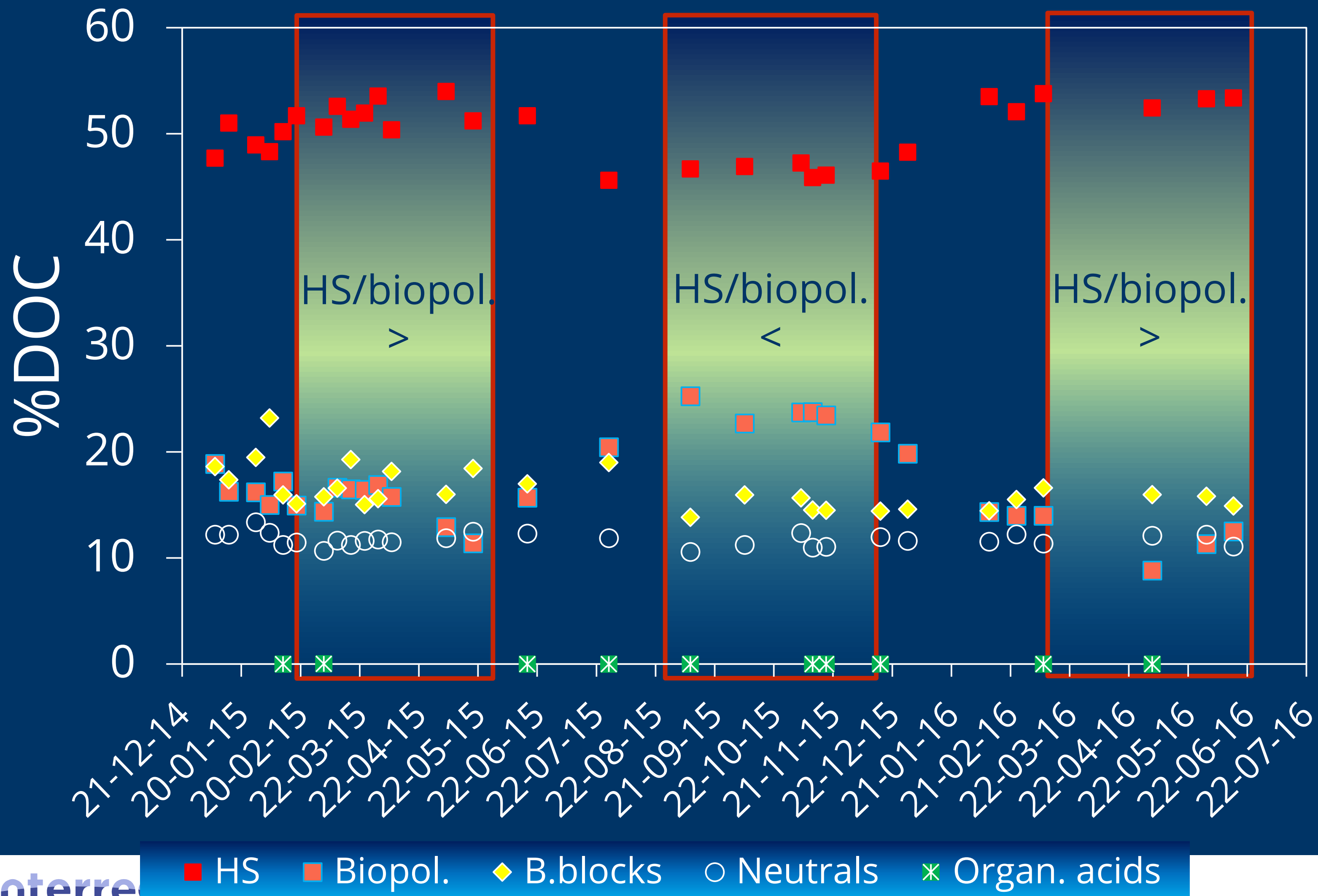
NOM composition SIX influent



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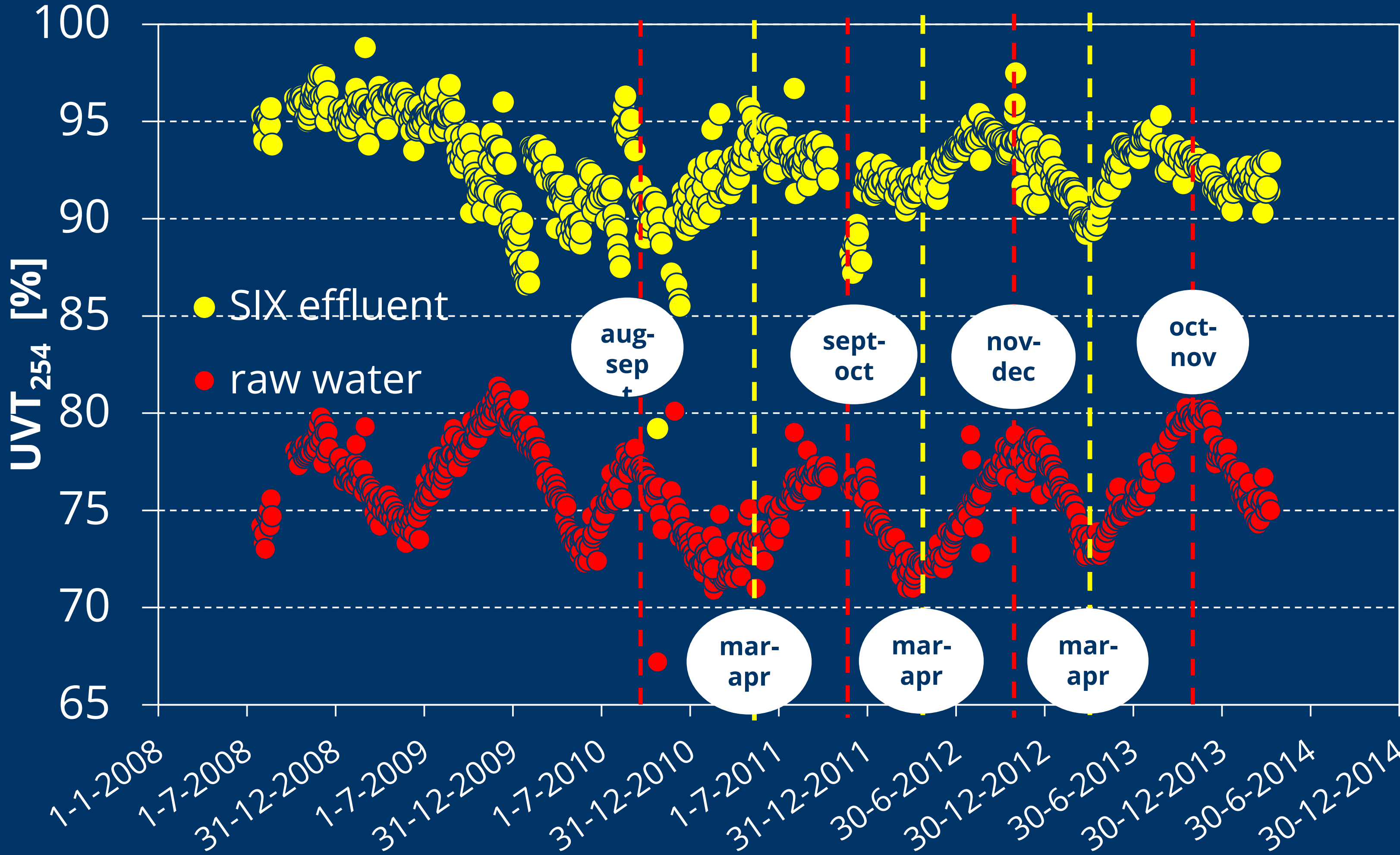
UV-transmittance (254 nm)

raw vs. SIX pilot effluent



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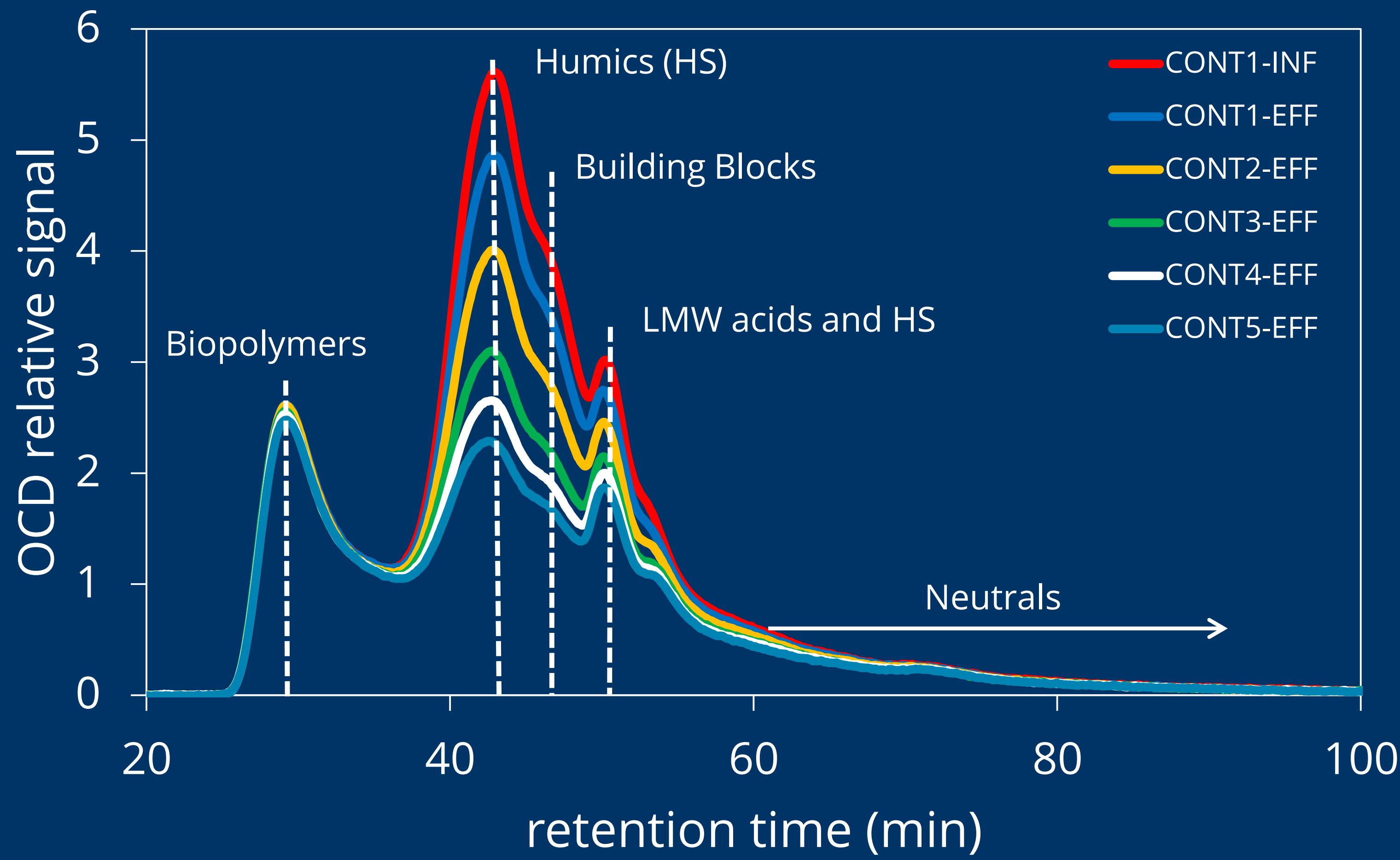
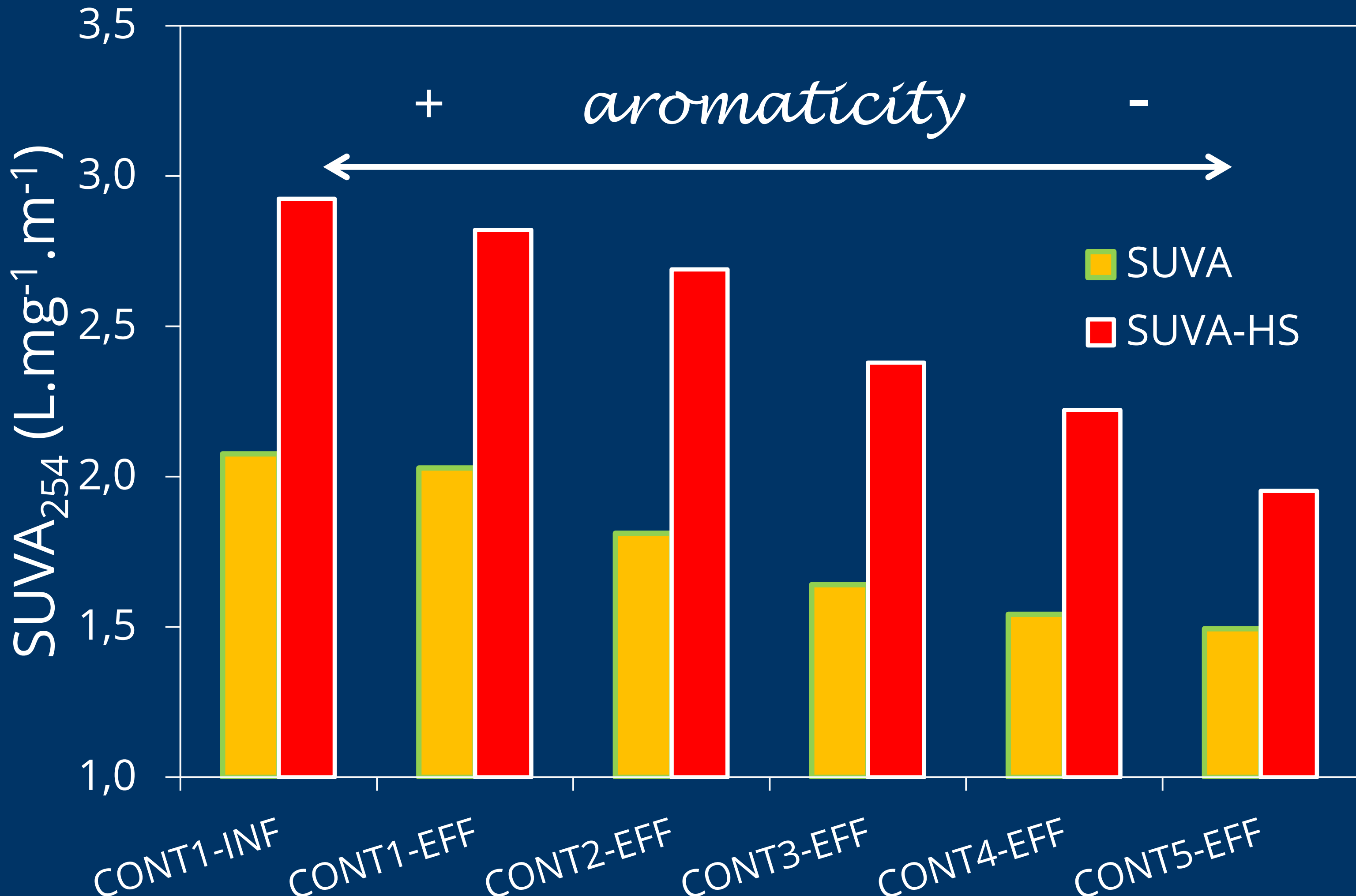
NOM composition

90 m³/h SIX pilot influent/effluent (13-12-13)



NOM composition

90 m^3/h SIX pilot influent/effluent (13-12-13)



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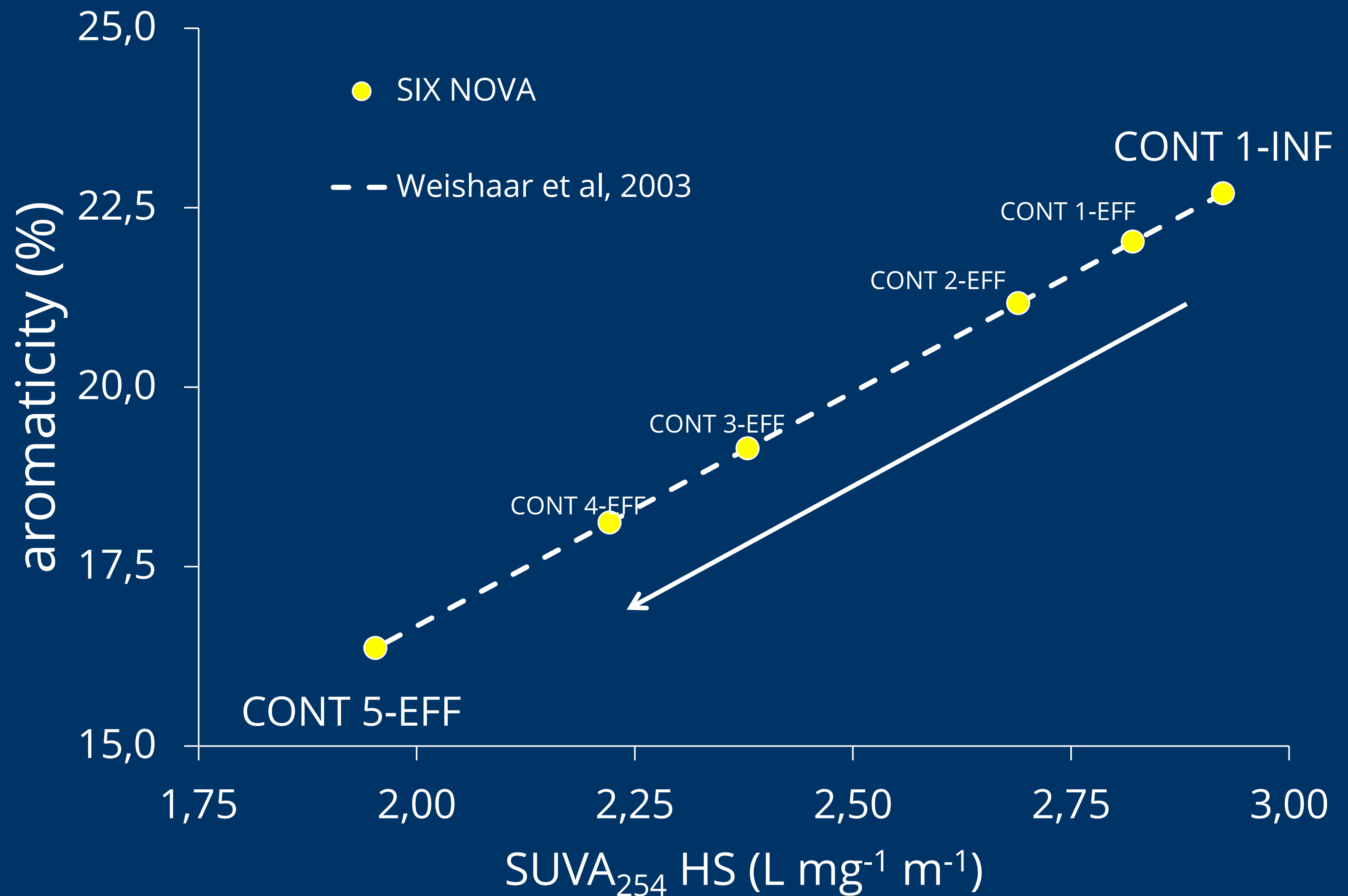
aromatic HS removal



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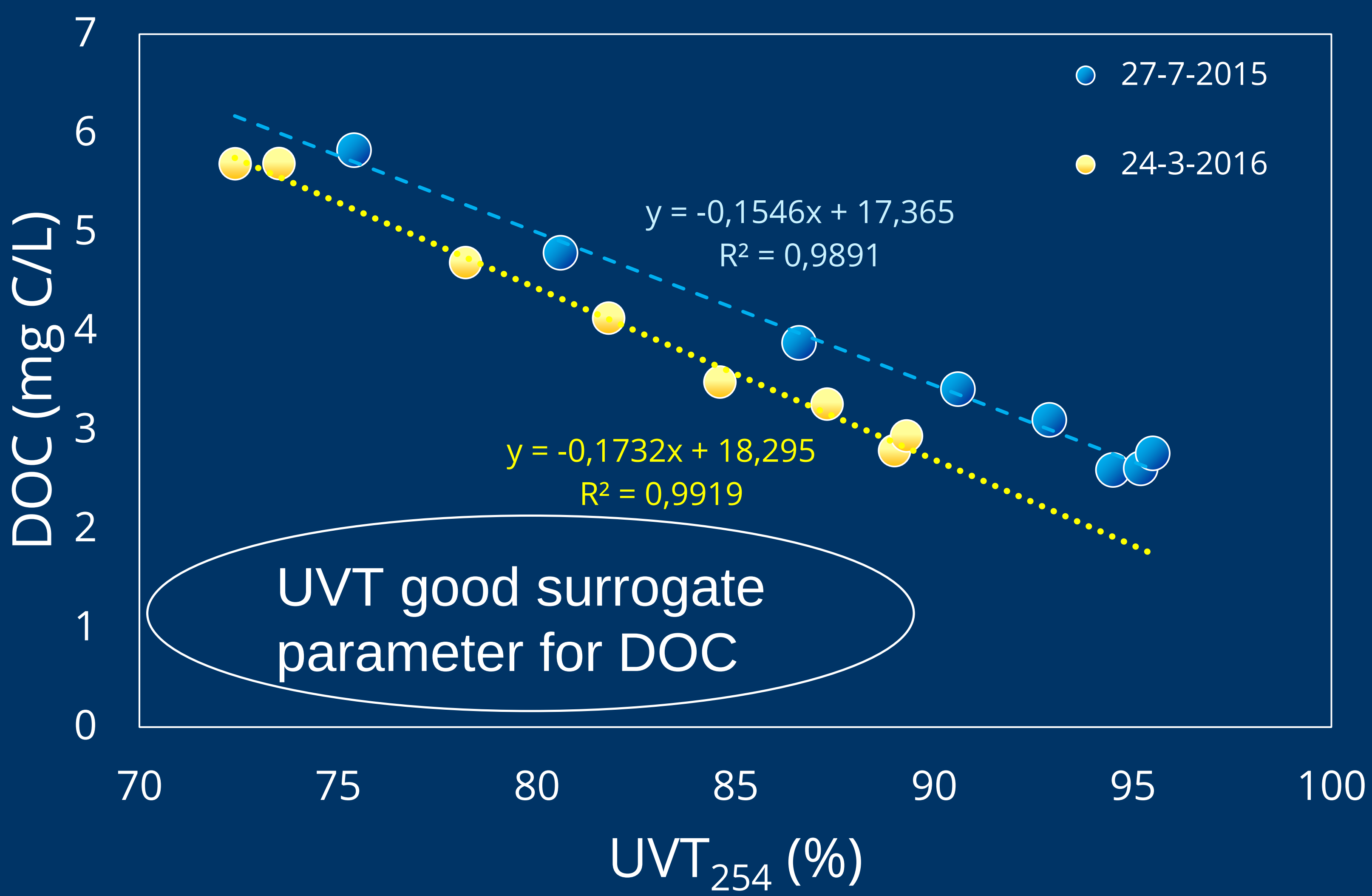
DOC(UVT)



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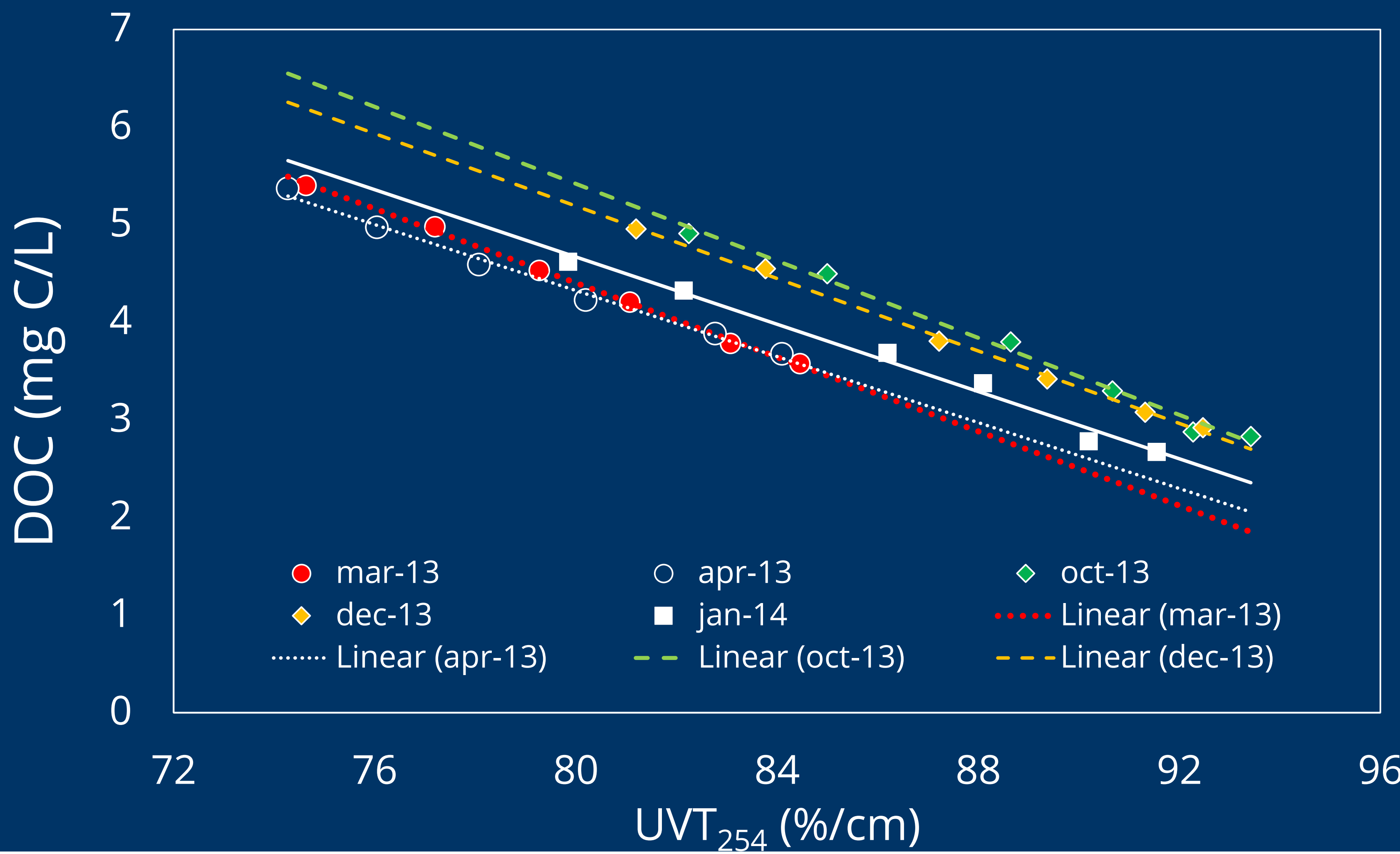
DOC(UVT) functions 2013



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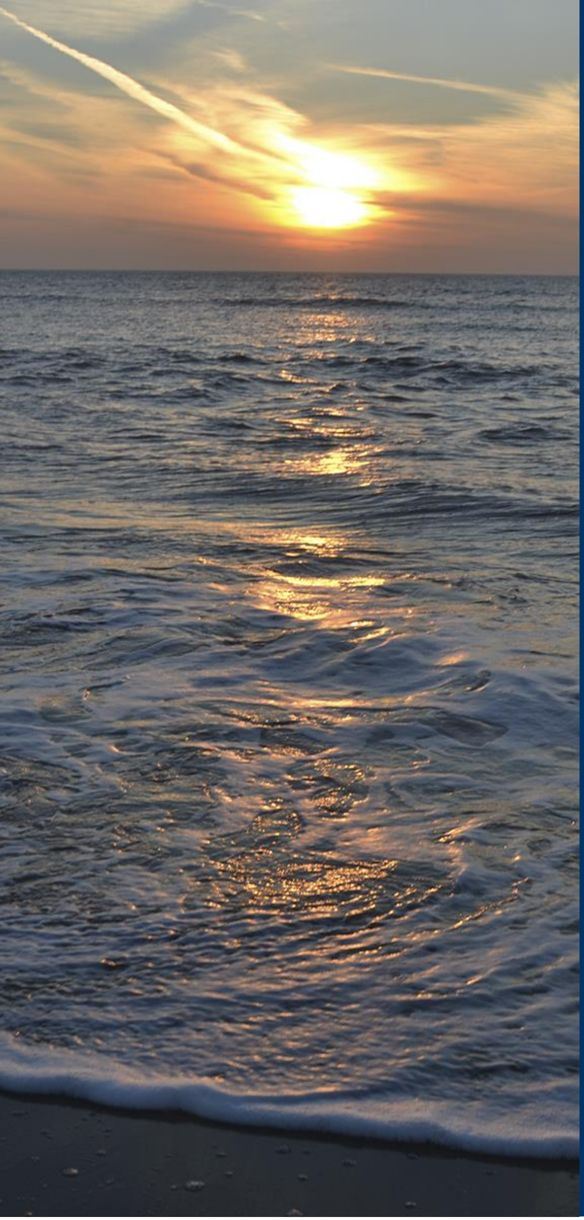

1. conclusions

NOM & UV absorbance

- Suspended Ion Exchange is capable of removing more “color” DOC (HA, FA) than (enhanced) coagulation;
- During IEX faster adsorption can be observed for more aromatic HS. lower aromatic HS have lower adsorption rates. For IJssel Lake water biolopymers are both non-chromophoric and (almost) non adsorbable.
- UVT is a suitable, ‘easy-to-measure’ , surrogate parameter for DOC, however:
- DOC(UVT) functions need to be re-calibrated regularly. Re-calibration frequency strongly depends on seasonal fluctuations in NOM composition of raw/IEX treated water.

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2. NOM removal kinetics

batch adsorption basic equations

$$c = a \cdot UVT + b \quad \Rightarrow \quad \frac{dc}{dt} = a \cdot \frac{d(UVT)}{dt}$$

1^{st} order adsorption kinetics acc. to Lagergren

$$\frac{dc}{dt} = -k.(c - c_e)$$

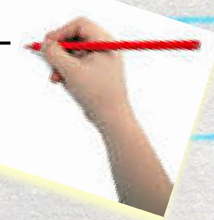
$$\frac{dUVT}{dt} = -k.(UVT - UVT_e)$$

completely mixed reactor kinetics

continuous flow model

single reactor mass balance:

$$c_{in} \cdot Q = c_{out} \cdot Q + V \cdot \frac{dc}{dt}$$



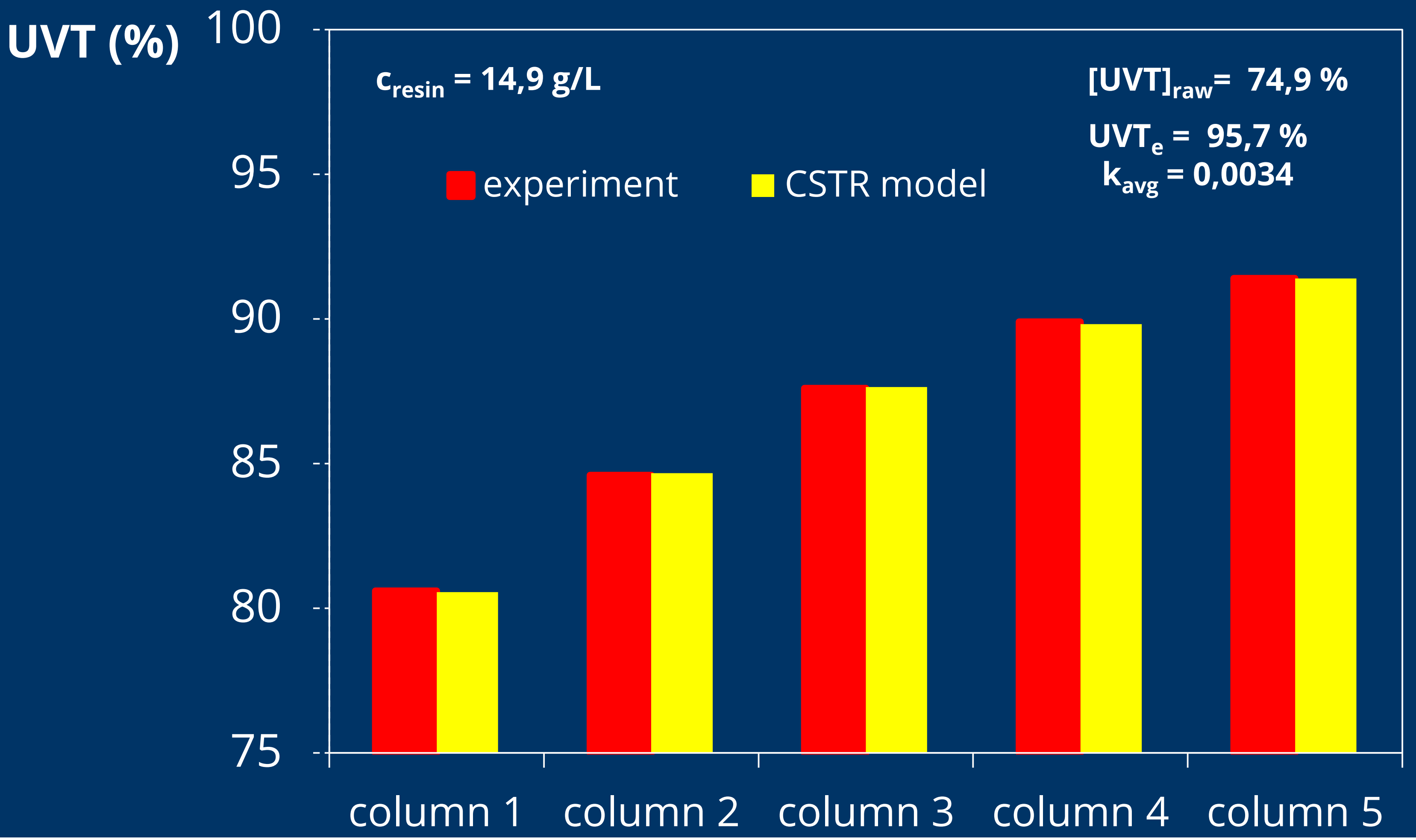
series of n completely stirred tank reactors (CSTR):

$$UVT_n = f(k, UVT_o, UVT_{eq}, t_{tot}, n)$$

$$UVT_n = \frac{UVT_o}{(1 + k \cdot t / (n))^n} + k \cdot \frac{t}{n} \cdot UVT_{eq} \sum_{k=1}^{n} \frac{1}{(1 + k \cdot t / (n))^k}$$

UVT adsorption Mini-SIX

February 15th 2012



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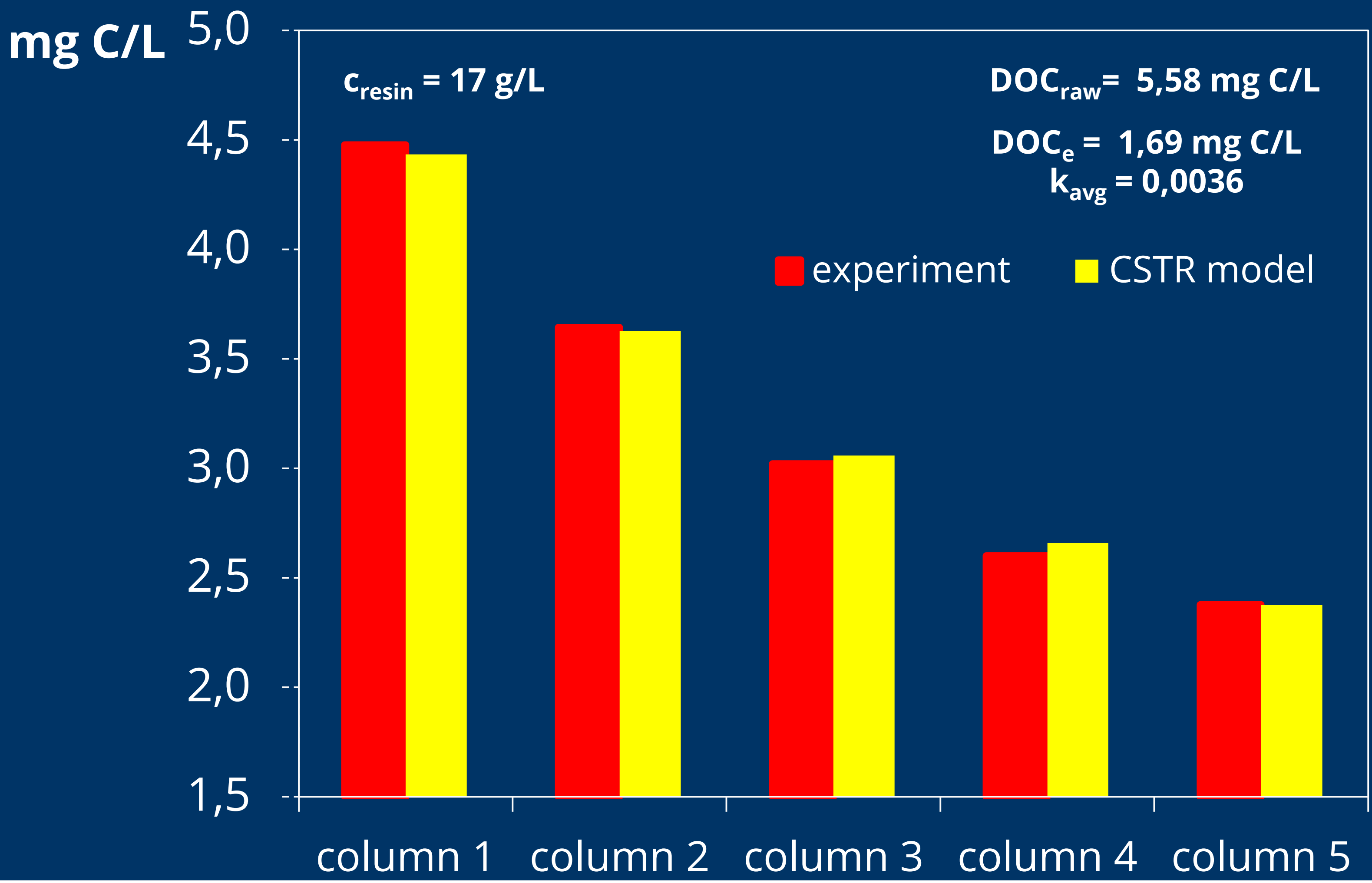
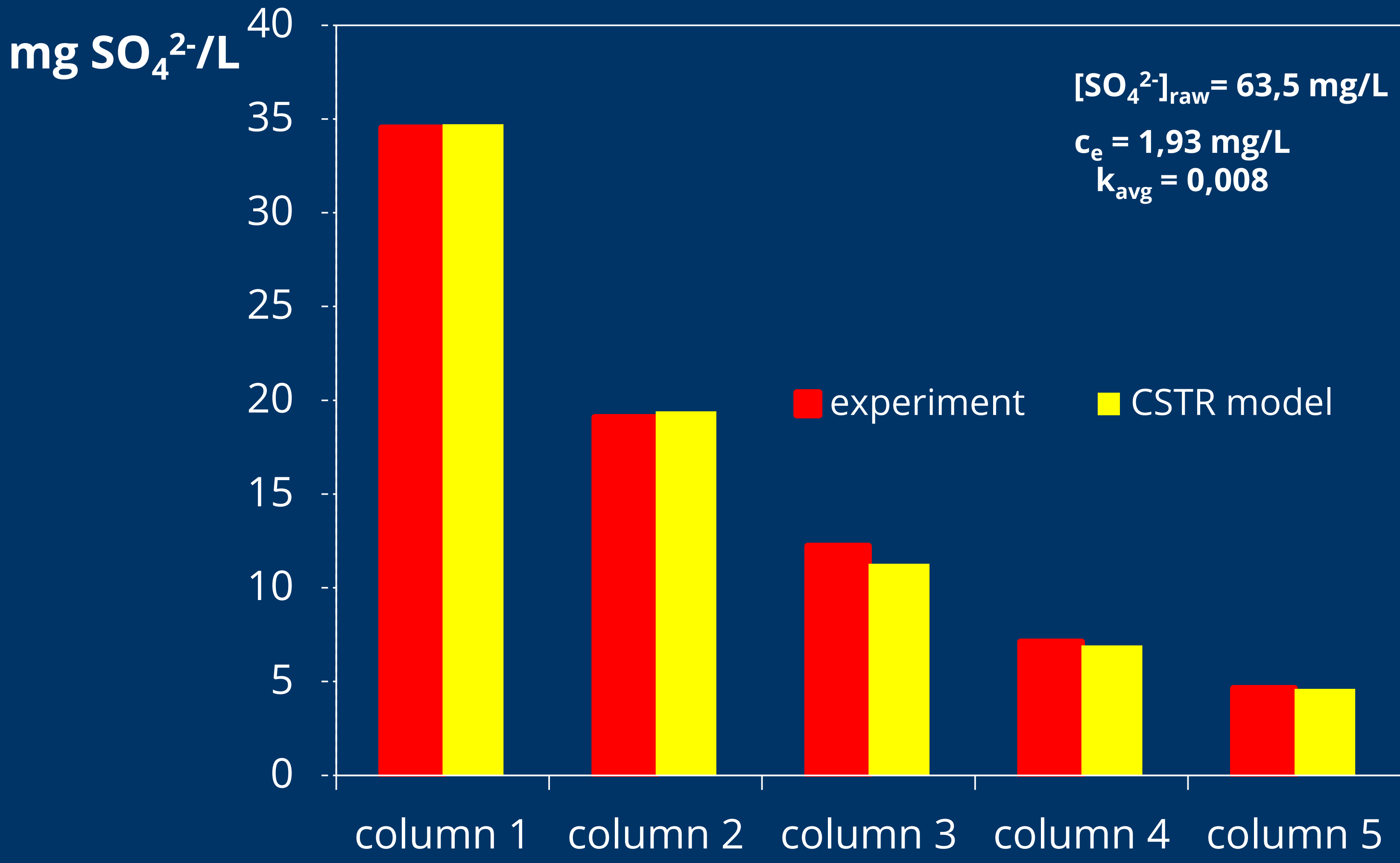
DOC adsorption Mini-SIX

February 22nd 2012



sulphate adsorption Mini-SIX

February 15th 2012



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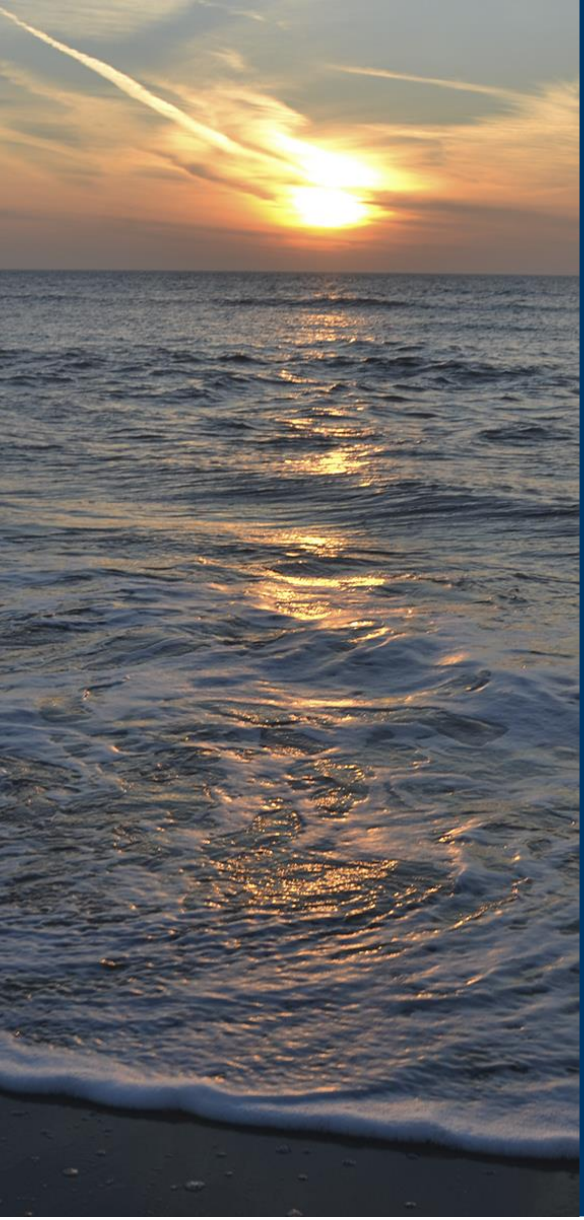

2. Conclusions

SIX adsorption kinetics

- Lewatit S 5128 non equilibrium adsorption can be satisfactory described according to a (pseudo) first order Lagergren differential equation;
- Each SIX reactor of the Andijk pilots can be regared as a Completely Mixed Stirred Tank Reactor (CSTR), which is one of the objectives of SIX, and thus:
- ‘Air lift loop’ principle is the preferred technique to suspend resin particles homogeneously

3. SIX pre-treatment options for Scottish, Scandinavian and Belgian Water treatment plants results preliminary lab & bench scale research

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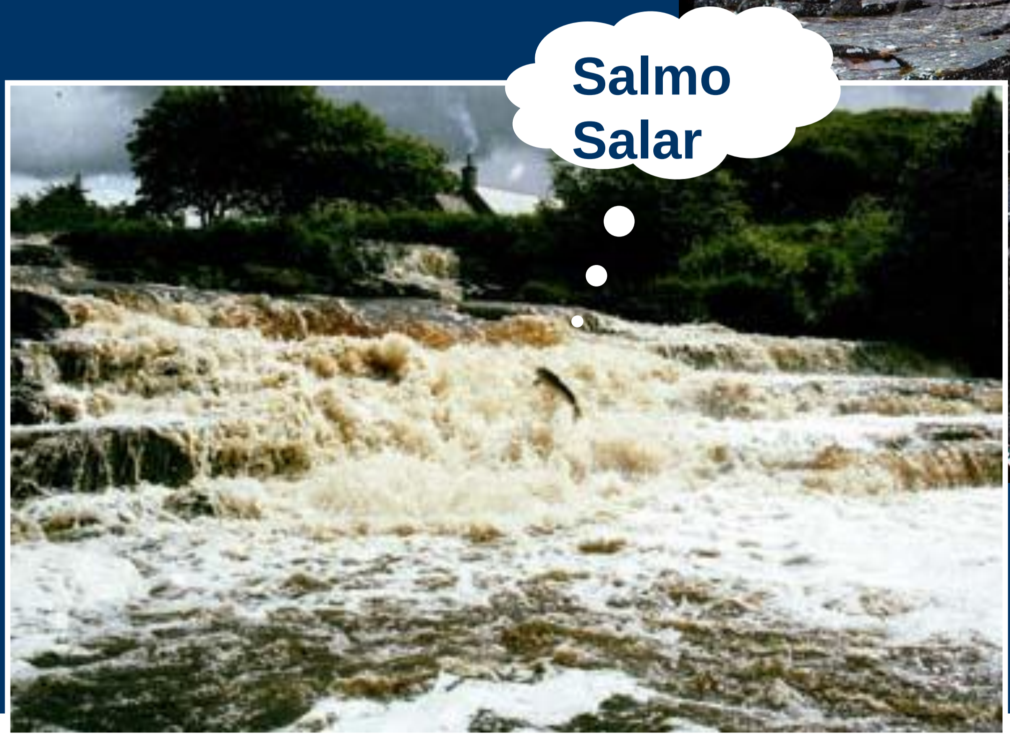
> 40 locations with ‘color’ problems

Black Water Falls (Ross-Shire)

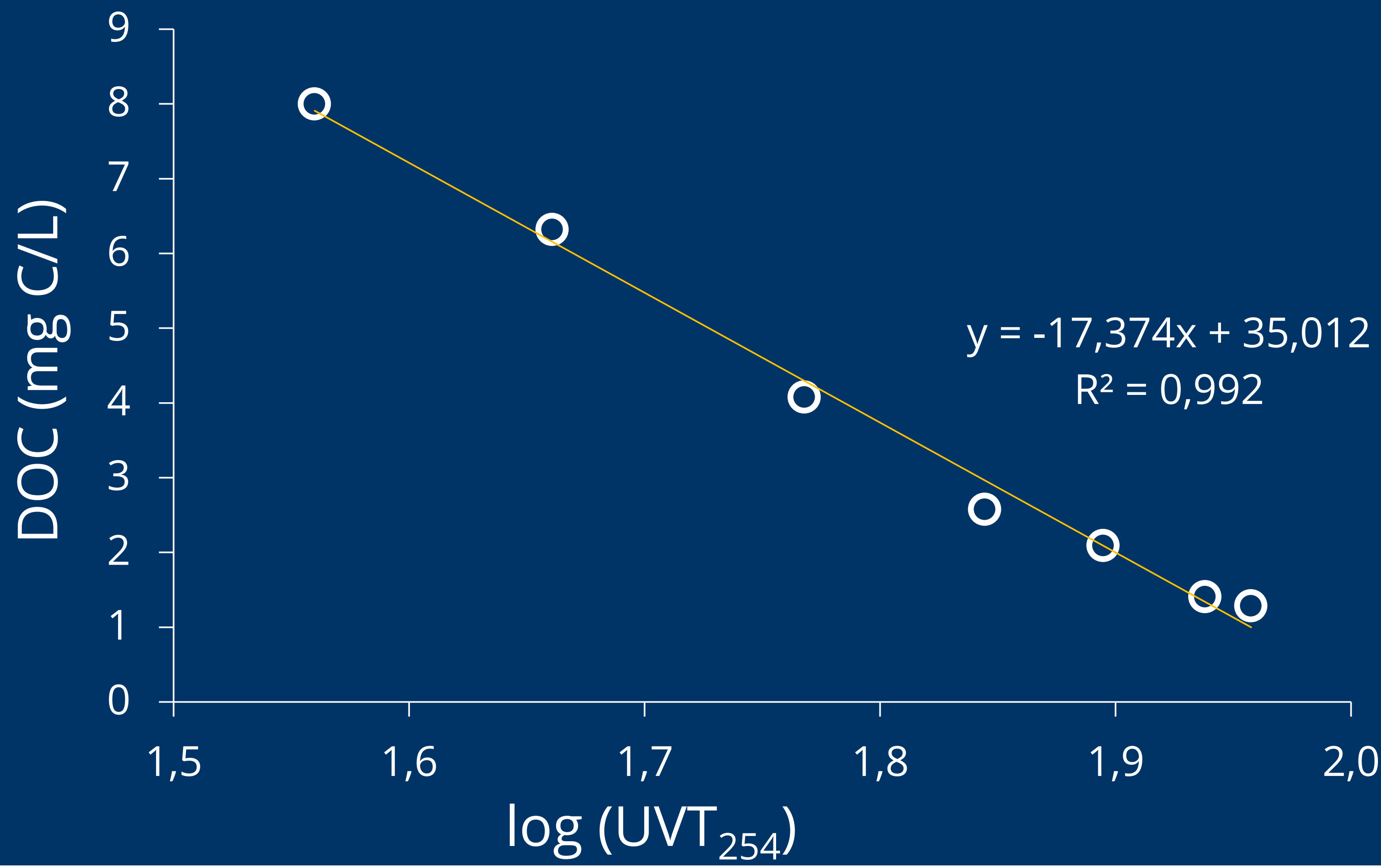


whisky or water (of life)?

test yourself!!

DOC-UVT correlation_Burncrooks

results derived from bench scale IEX experiments



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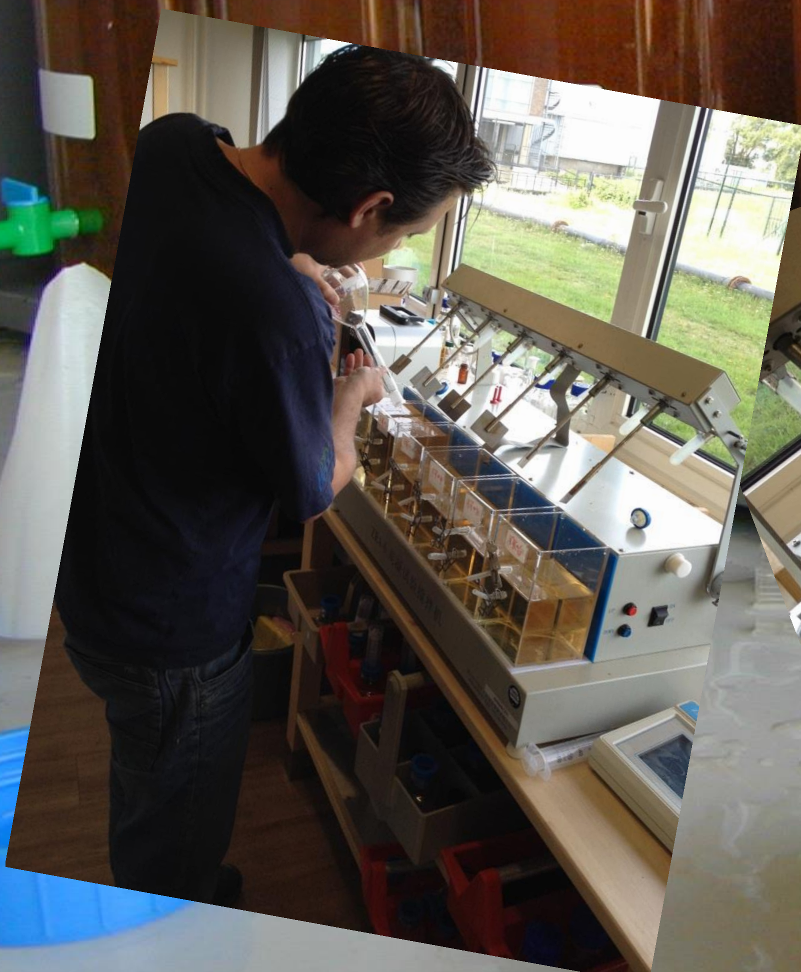
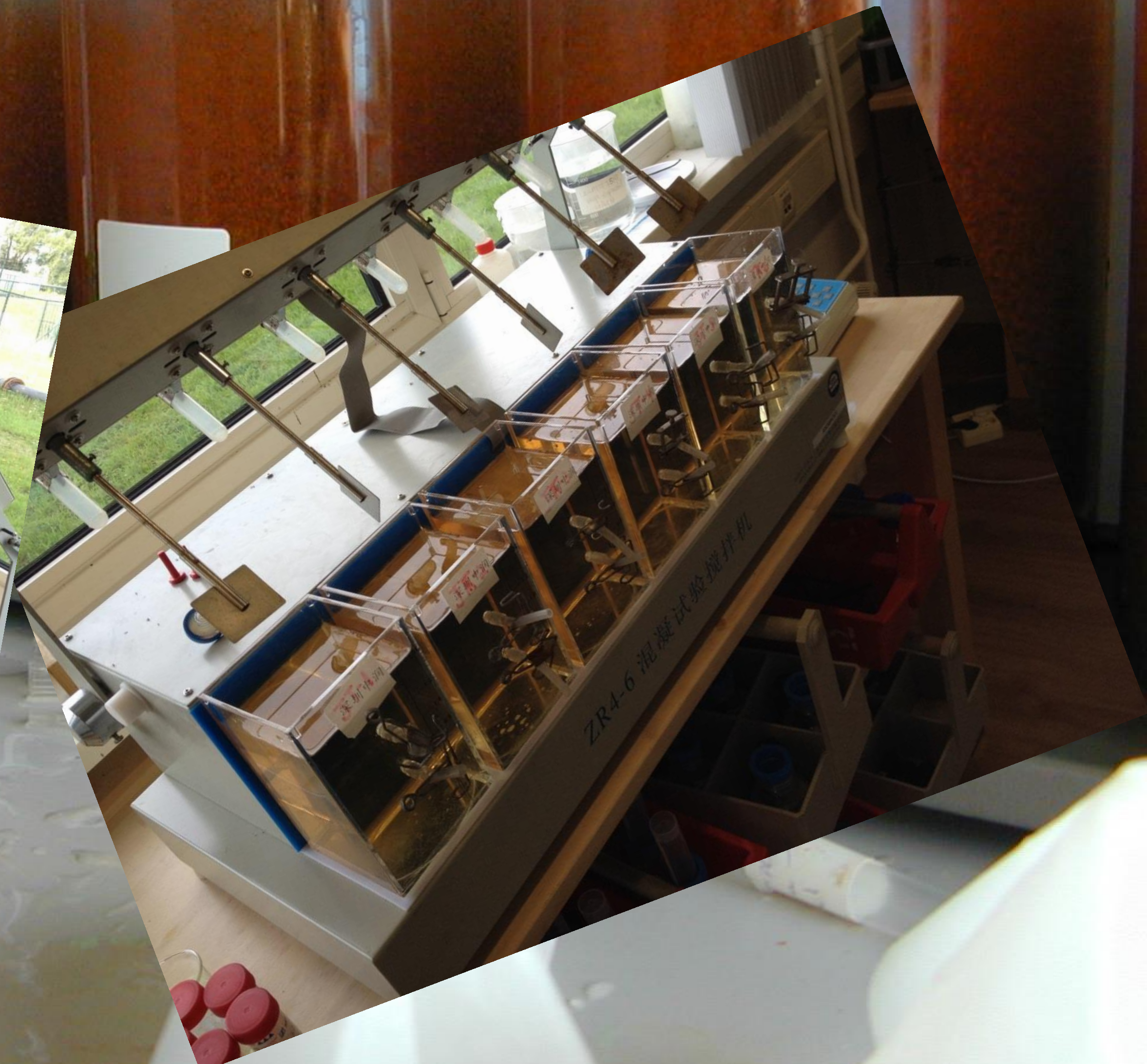
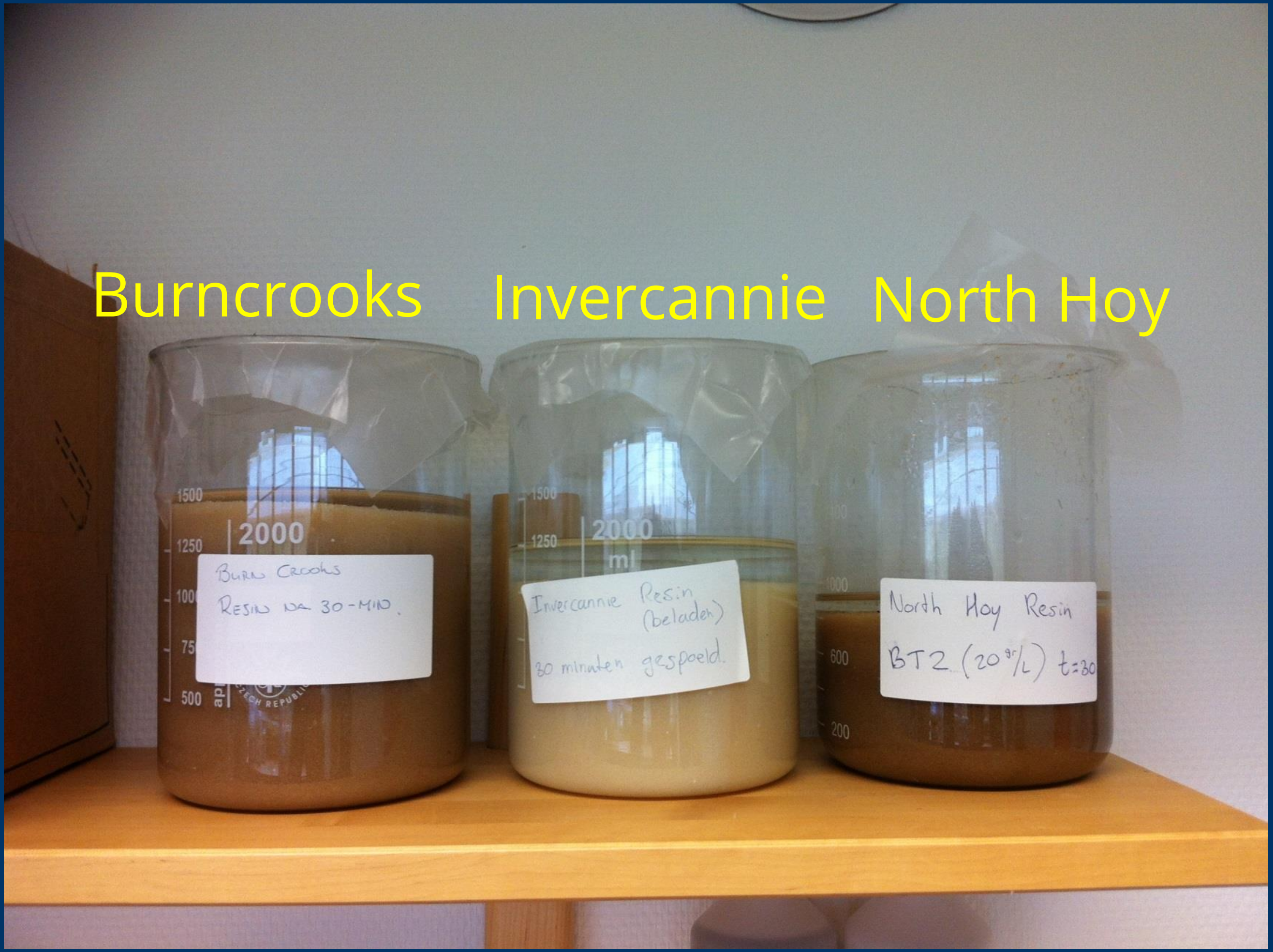
batch adsorption jar tests at Andijk

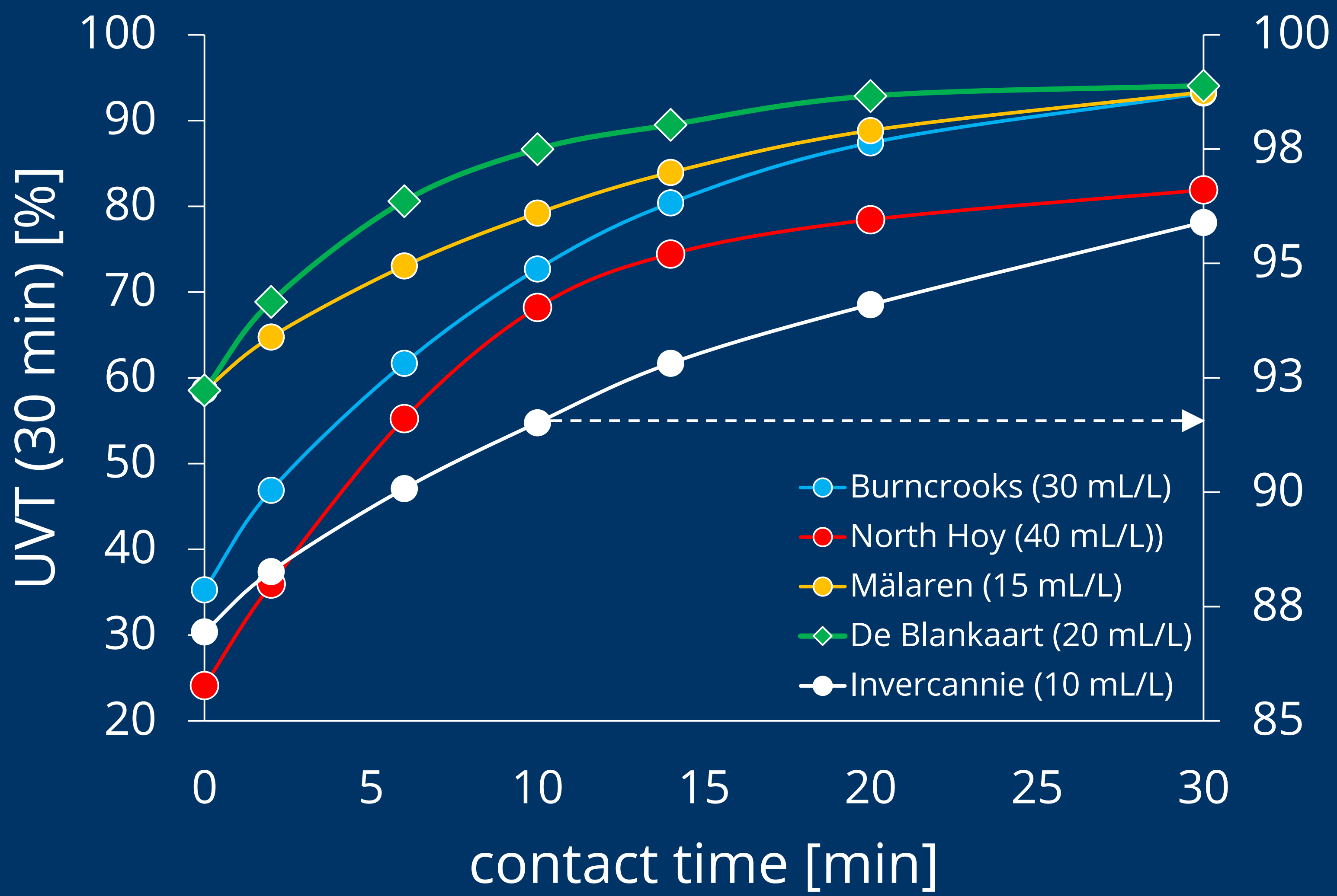




SW loaded resins



UVT after SIX treatment



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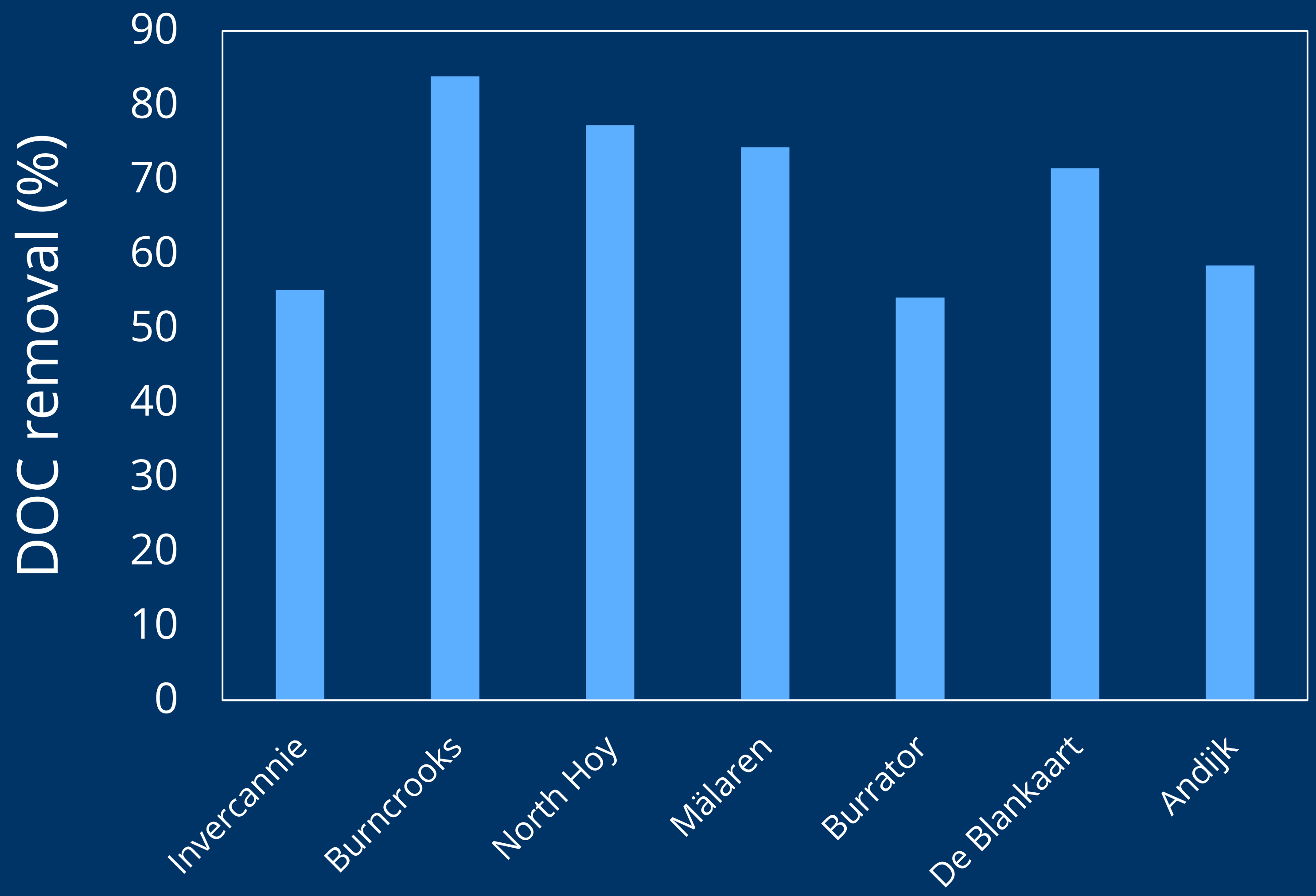
DOC removal different locations



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chloride exchange capacity various locations

Lewatit S 5128

SWTP	Company	IEX capacity meq/mL resin	DOC(0) mg C/L	UVT(0) %	Total Anion[1)] meq/L
Invercannie	SW	0,022	1,6	87,1	0,44
Burncrooks	SW	0,006	8,0	36,3	0,24
North Hoy	SW	0,016	14,0	24,2	0,60
Malaeren	Norrvat./Stockh.	0,084	8,5	58,6	1,40
De Blankaart	Watergroep	0,135	10,1	58,6	6,47
Andijk-pilot	PWNT	0,120	5,4	77,9	3,46

[1)] DOC excluded

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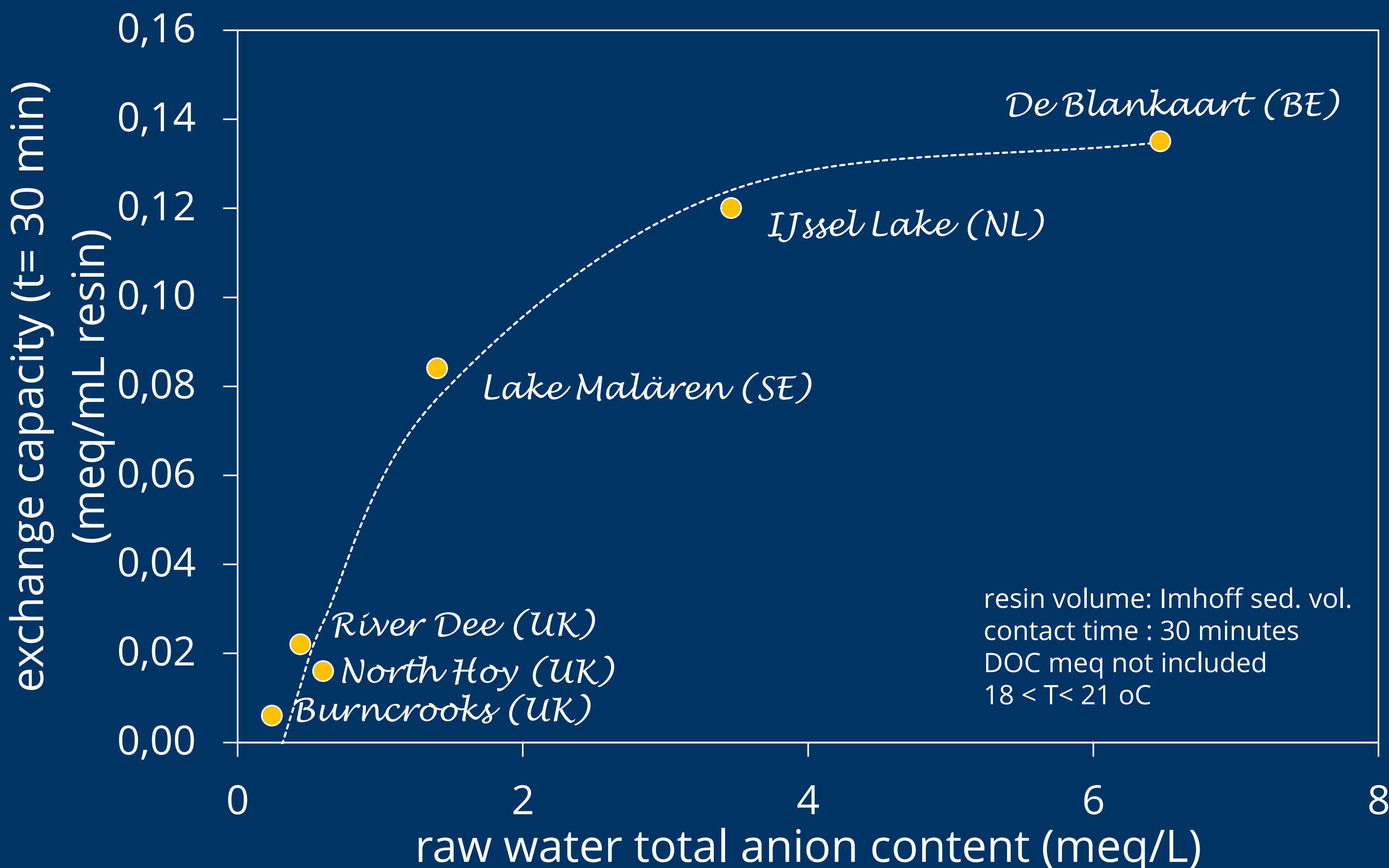
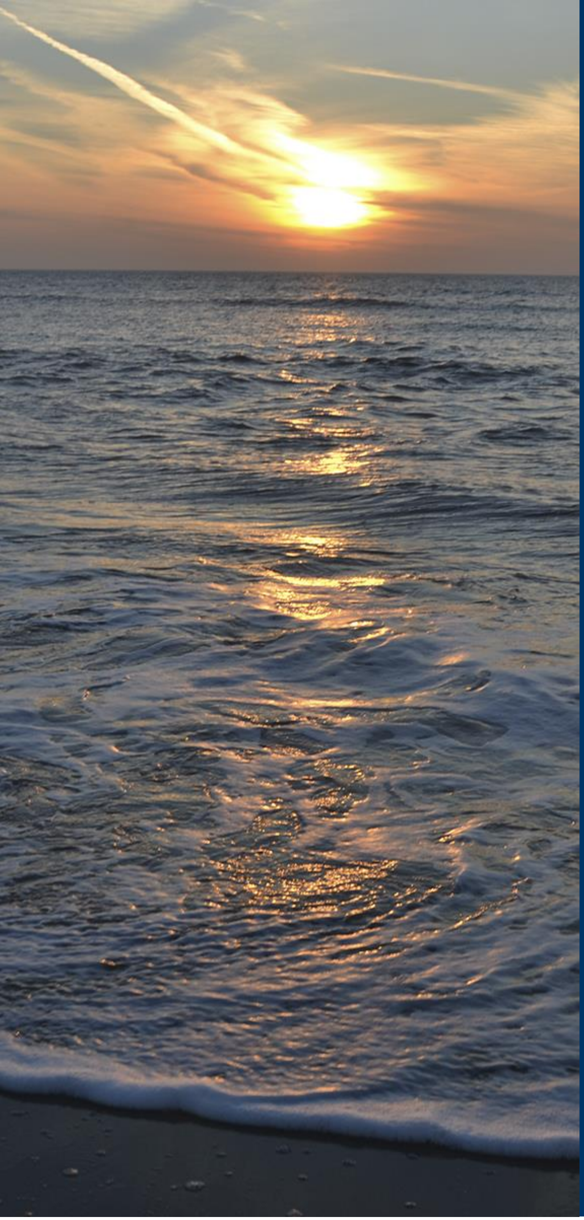
exchange capacity different locations





3. conclusions

DOC and color removal ‘peaty’ surface waters

- SIX is the appropeRiate pre-treatment for DOC/color removal, especially for typical “peaty” waters. Depending on raw water DOC/UVT:
  -) 60% < DOC removal < 90 %
  -) $10\ \% < \text{dUVT}_{254} < 50\ \%$;
- Total anion content has a major impact on resin exchange capacity, counter anion desorption and thus total salt demand during regeneration.

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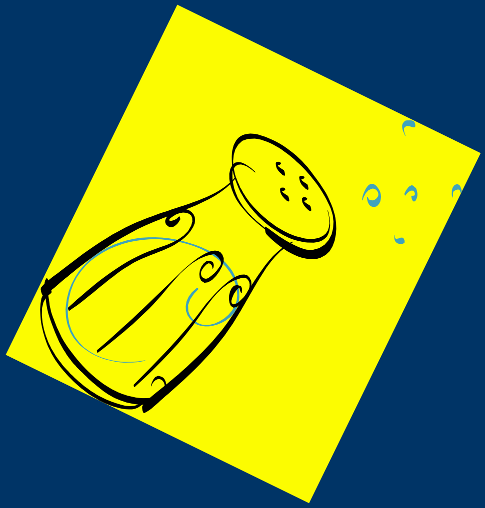
4. SIX® regeneration

fate of the chloride counter anion



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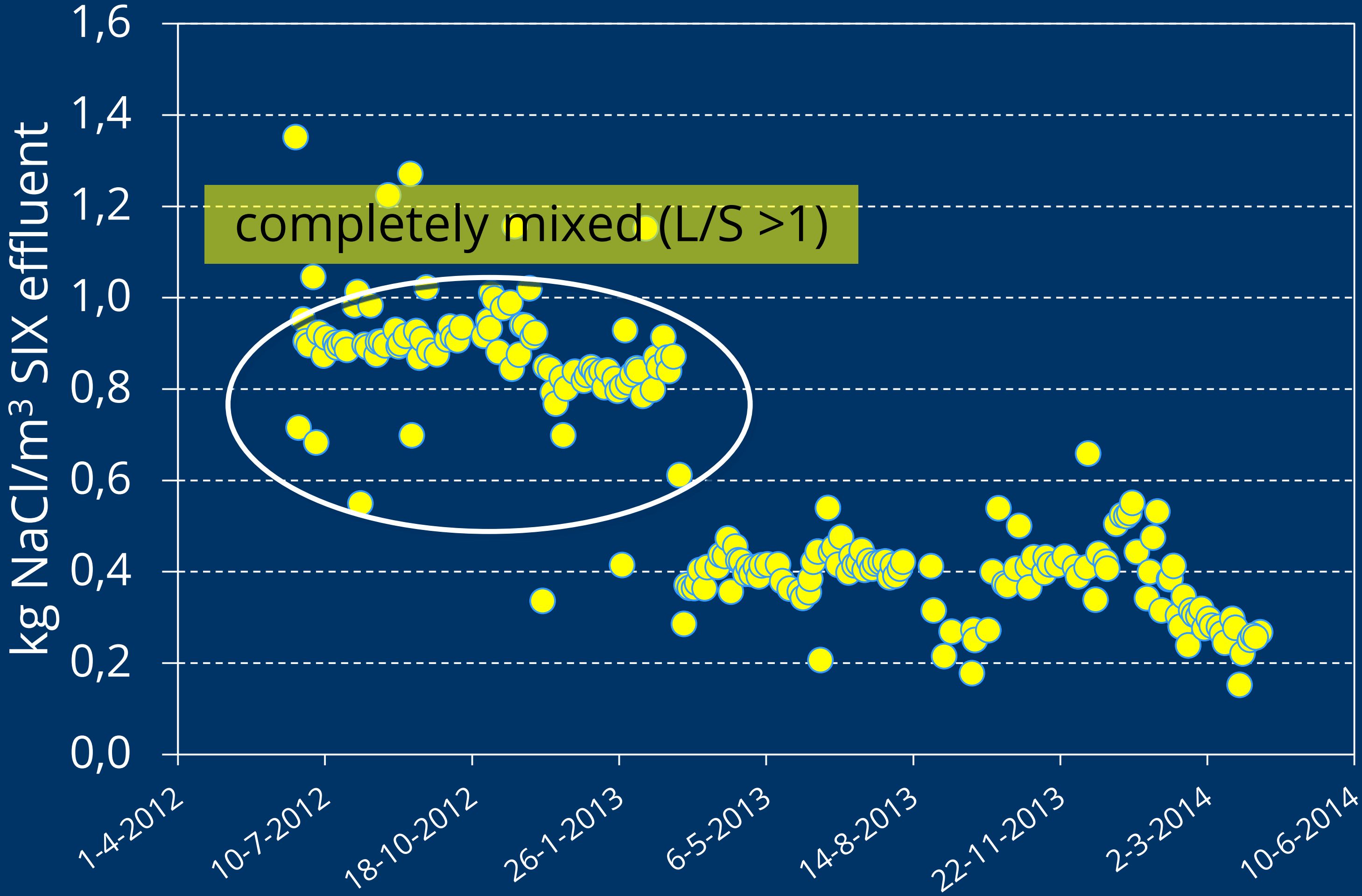
SIX® chloride demand

- dependent on adsorbed anions (SO_4^{2-}, HCO_3^-, NO_3^-) and NOM fractions (meq Cl/L)
- regeneration procedure efficacy
- target removal levels

Andijk SIX pilot salt use history



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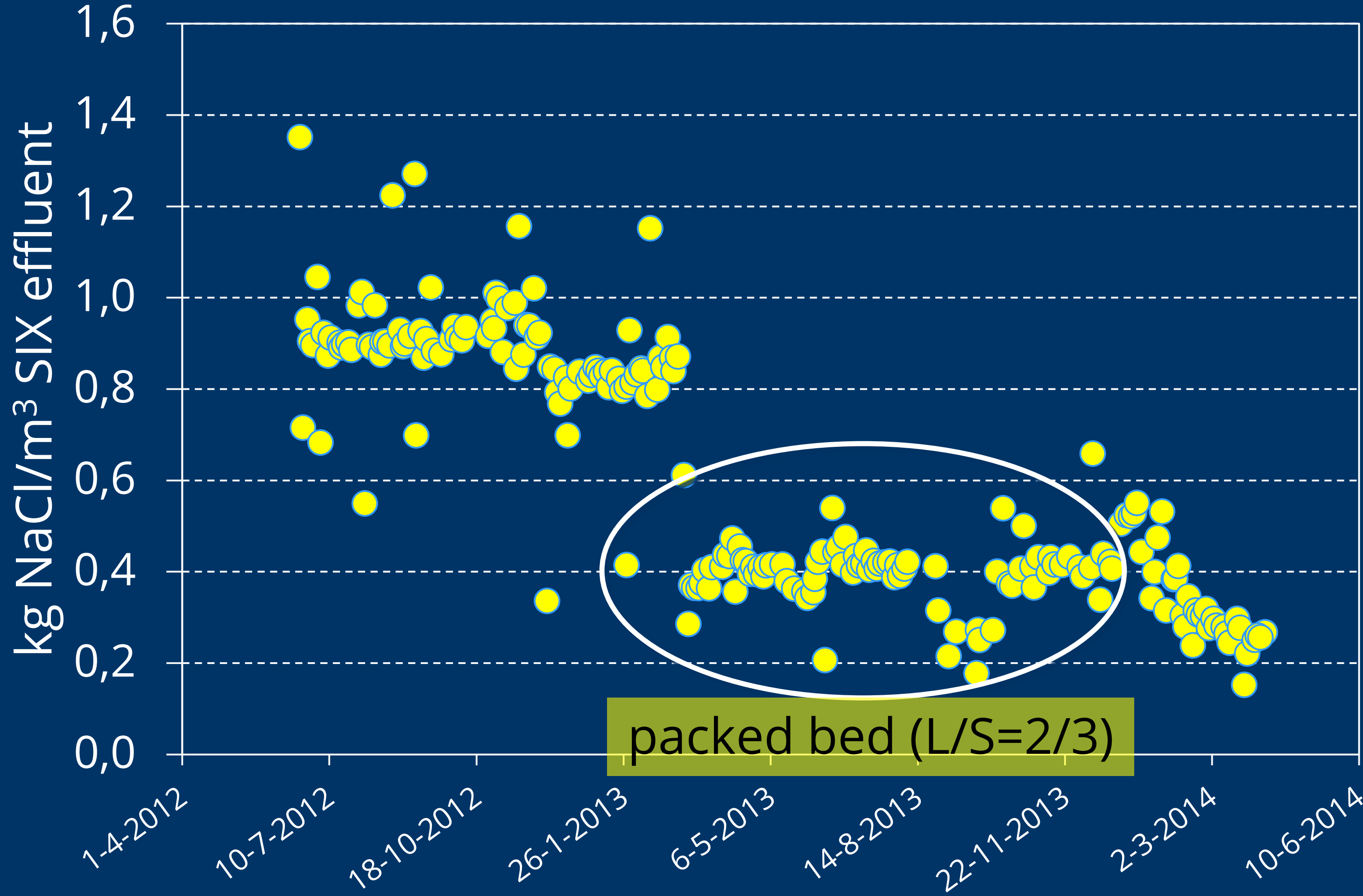
Andijk SIX pilot salt use history



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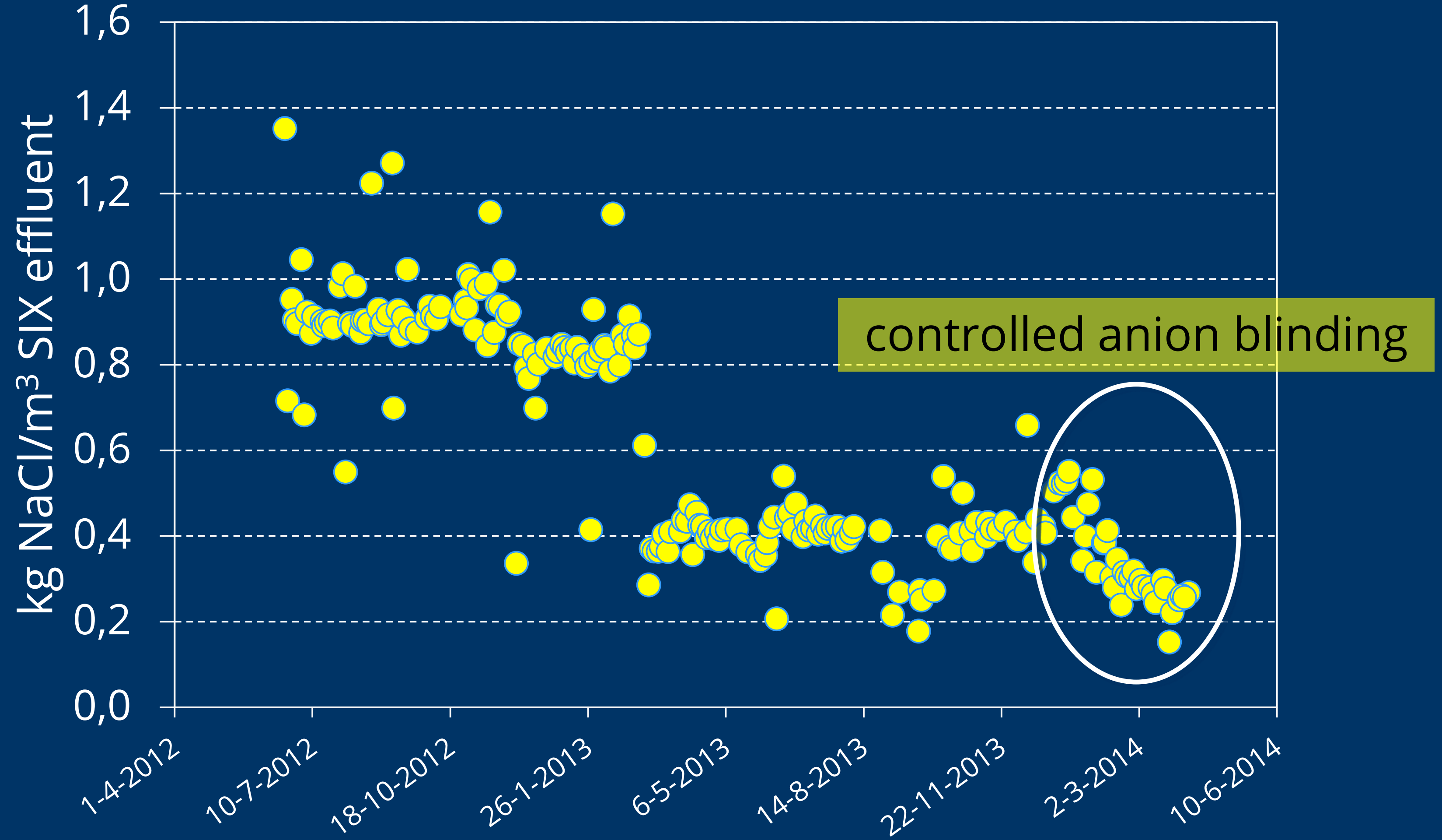
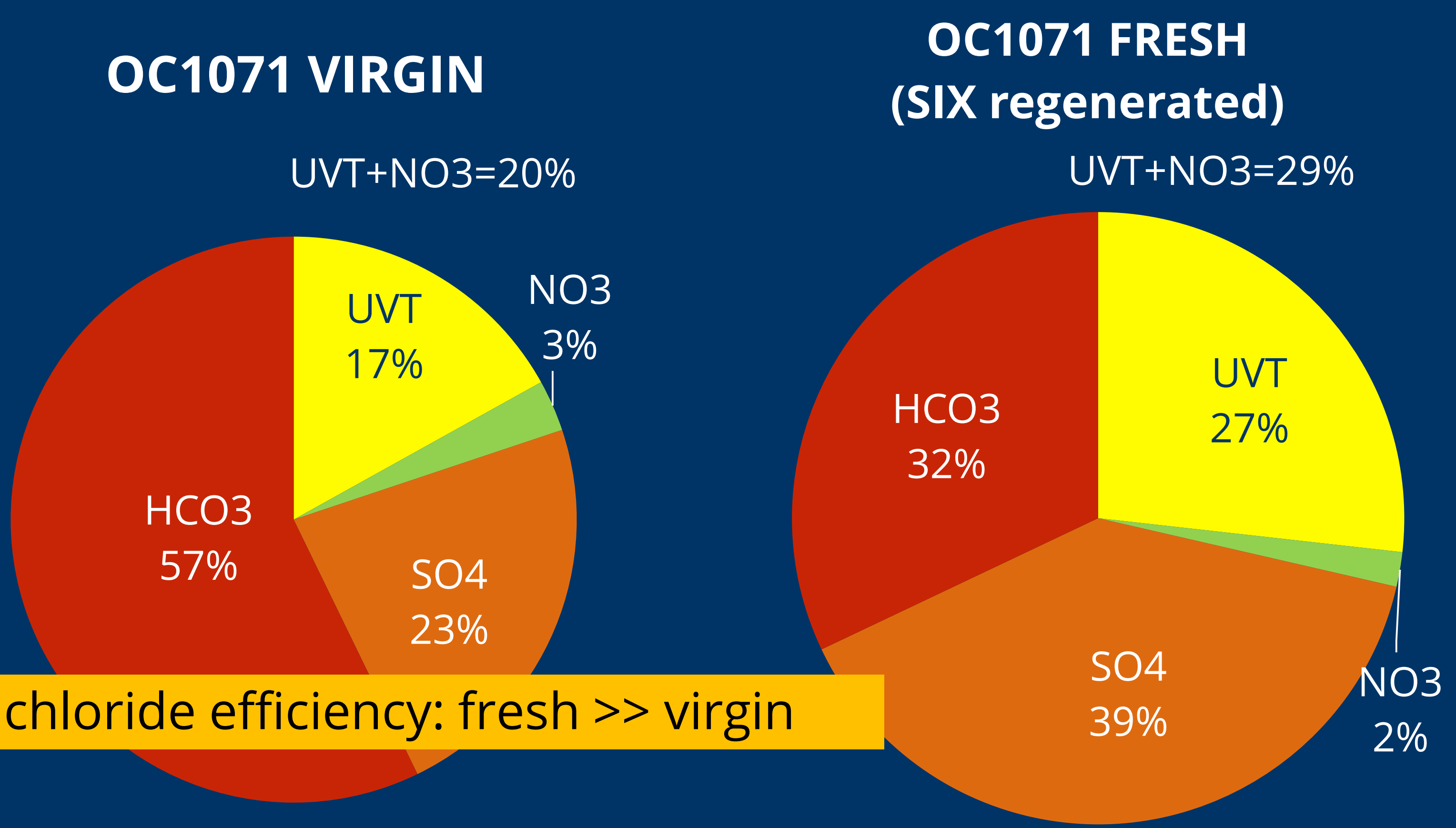
Andijk SIX pilot salt use history



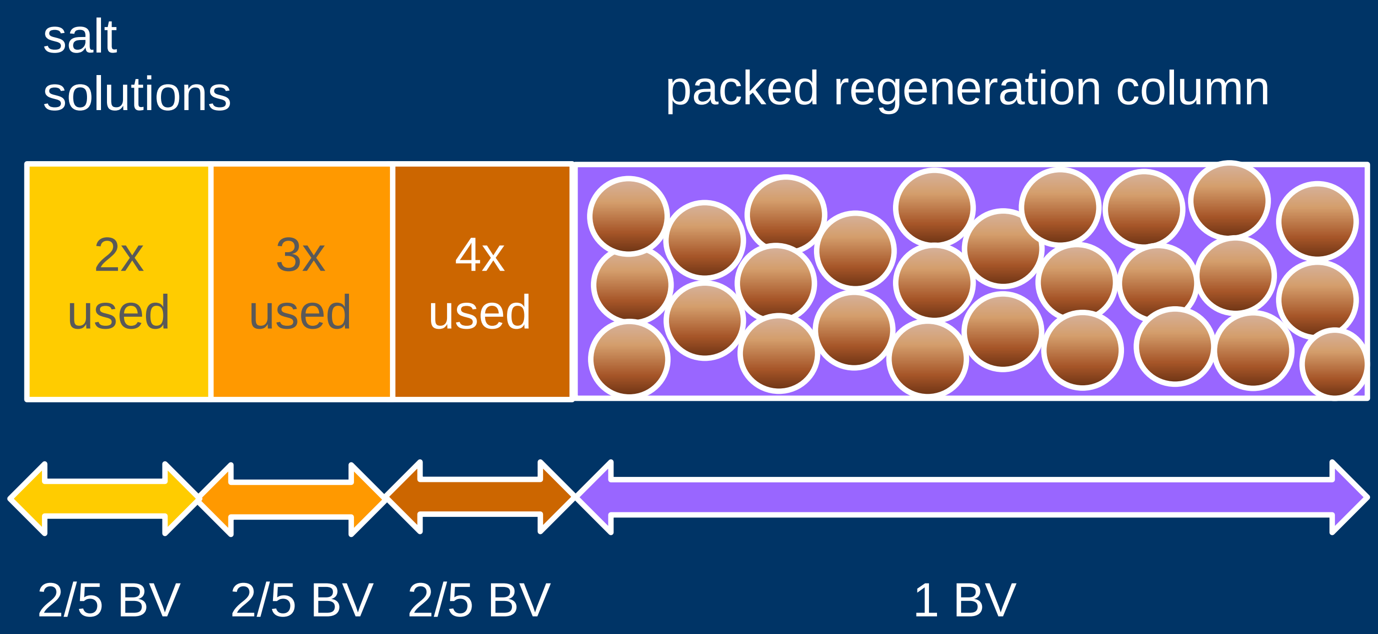
regeneration efficacy



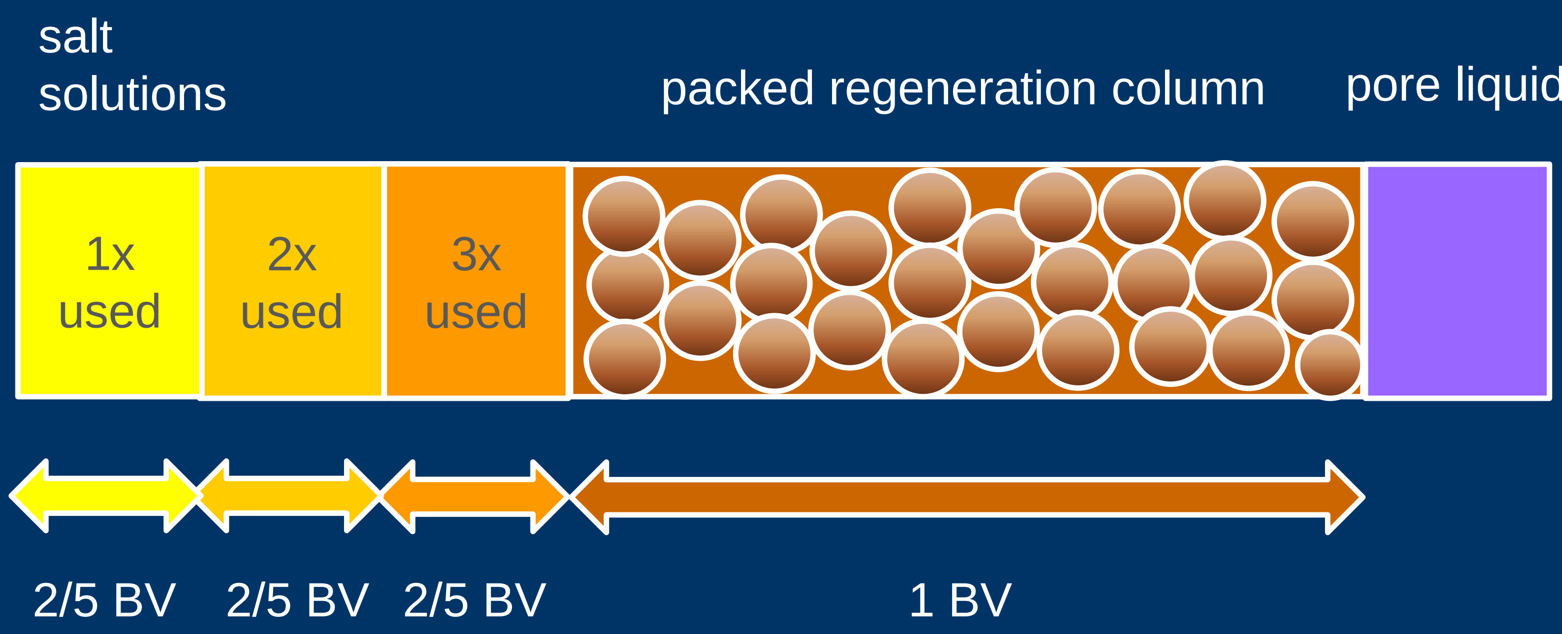
chloride efficiency: fresh >> virgin

comparison of fresh and virgin exchange OC1071 chloride use efficiencies at 16 g/L and 30 minutes

SIX regeneration principle



SIX regeneration principle



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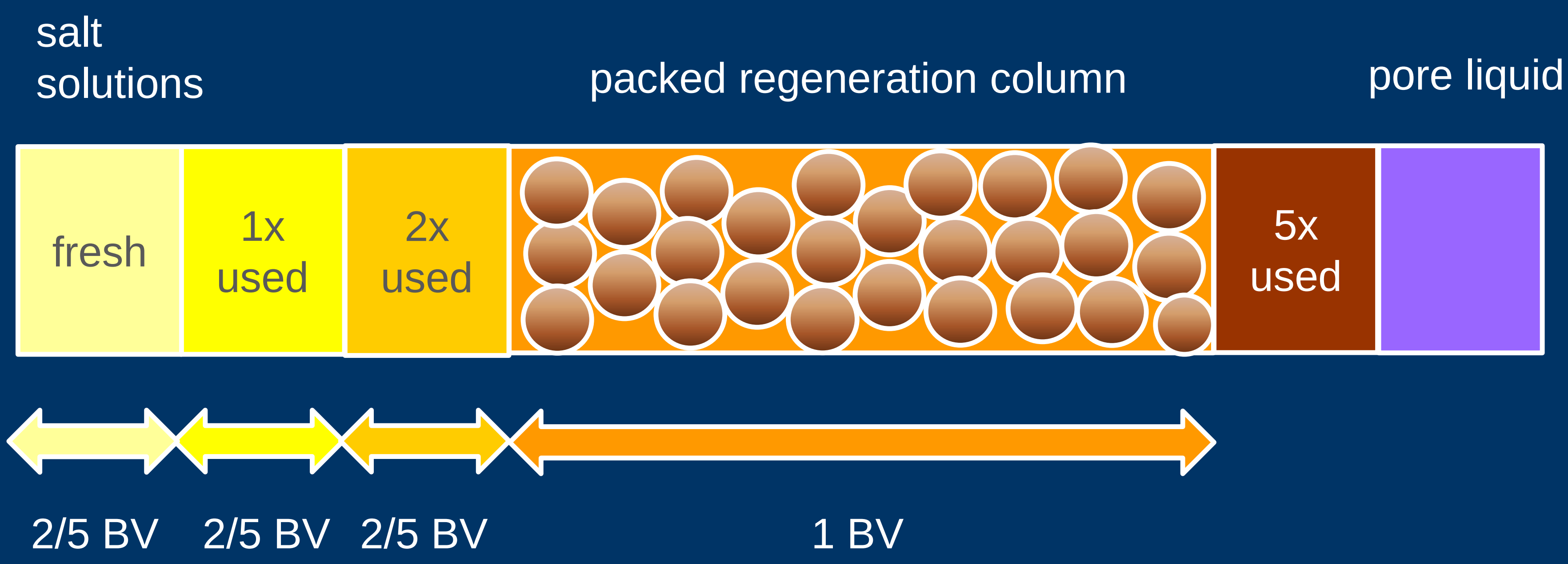
SIX regeneration principle



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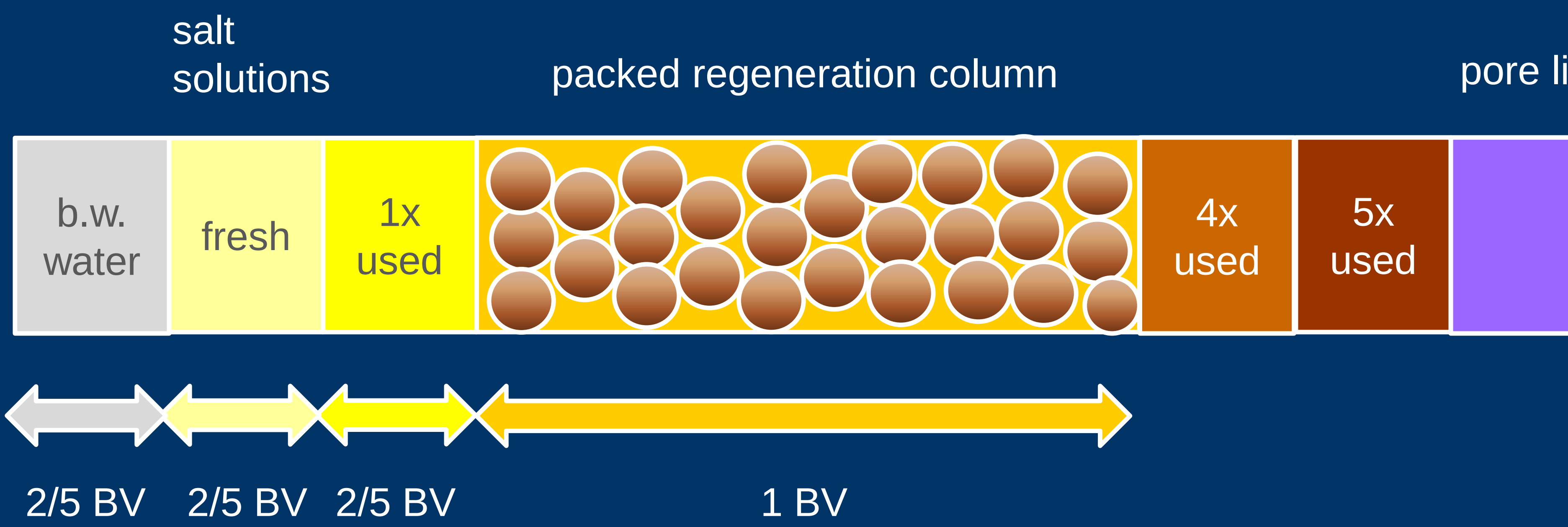

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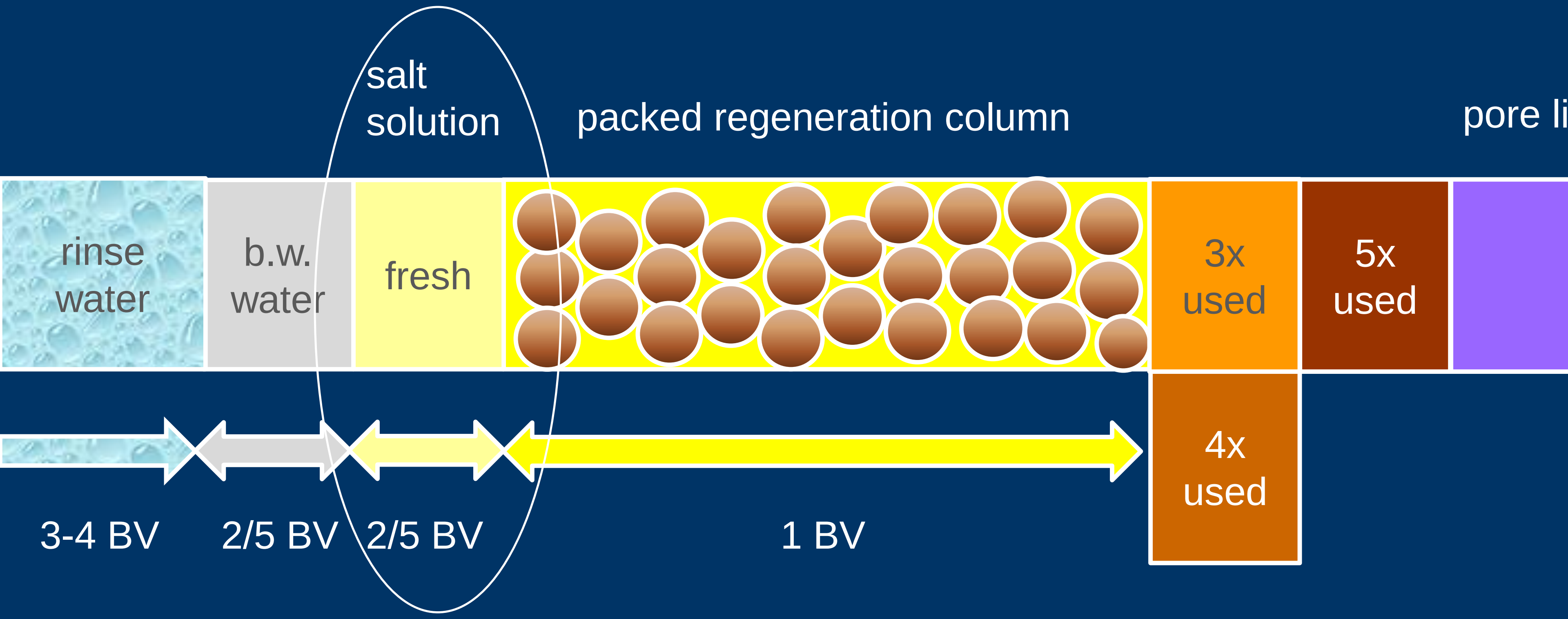

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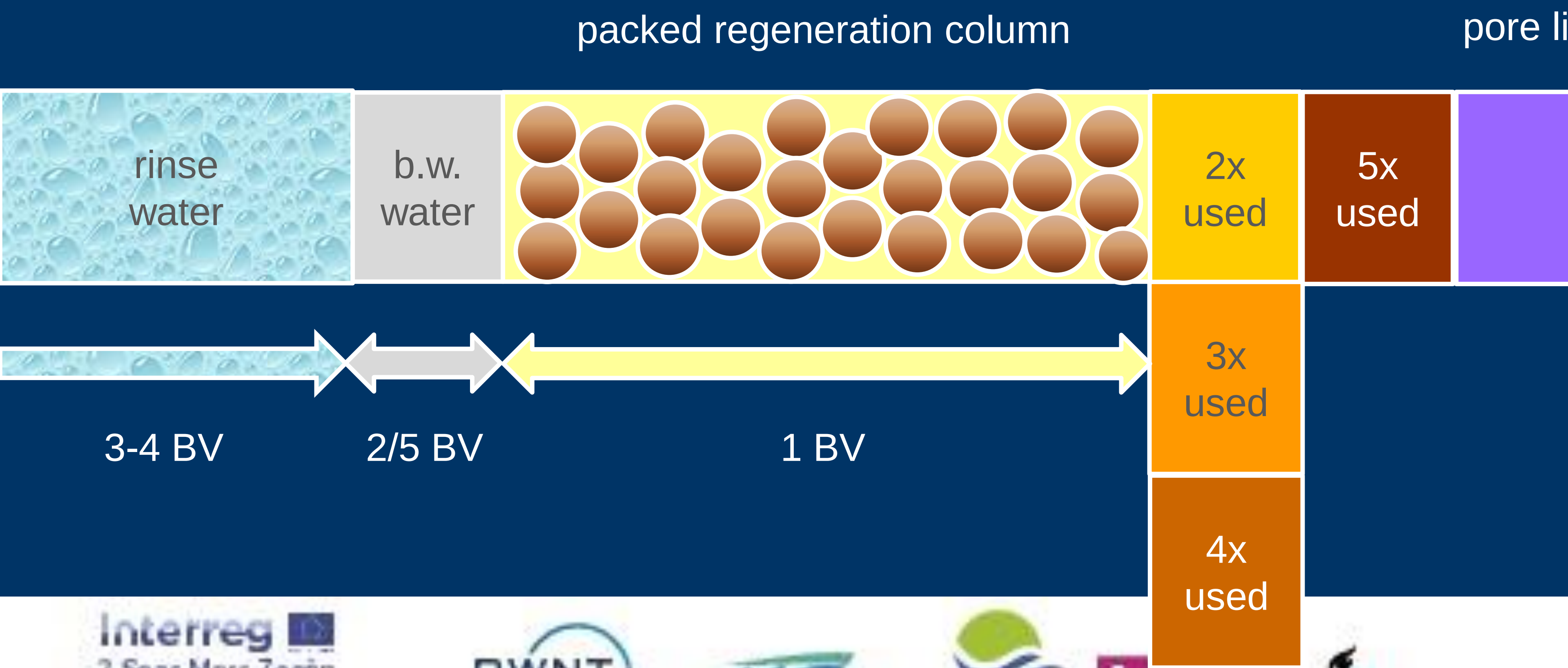

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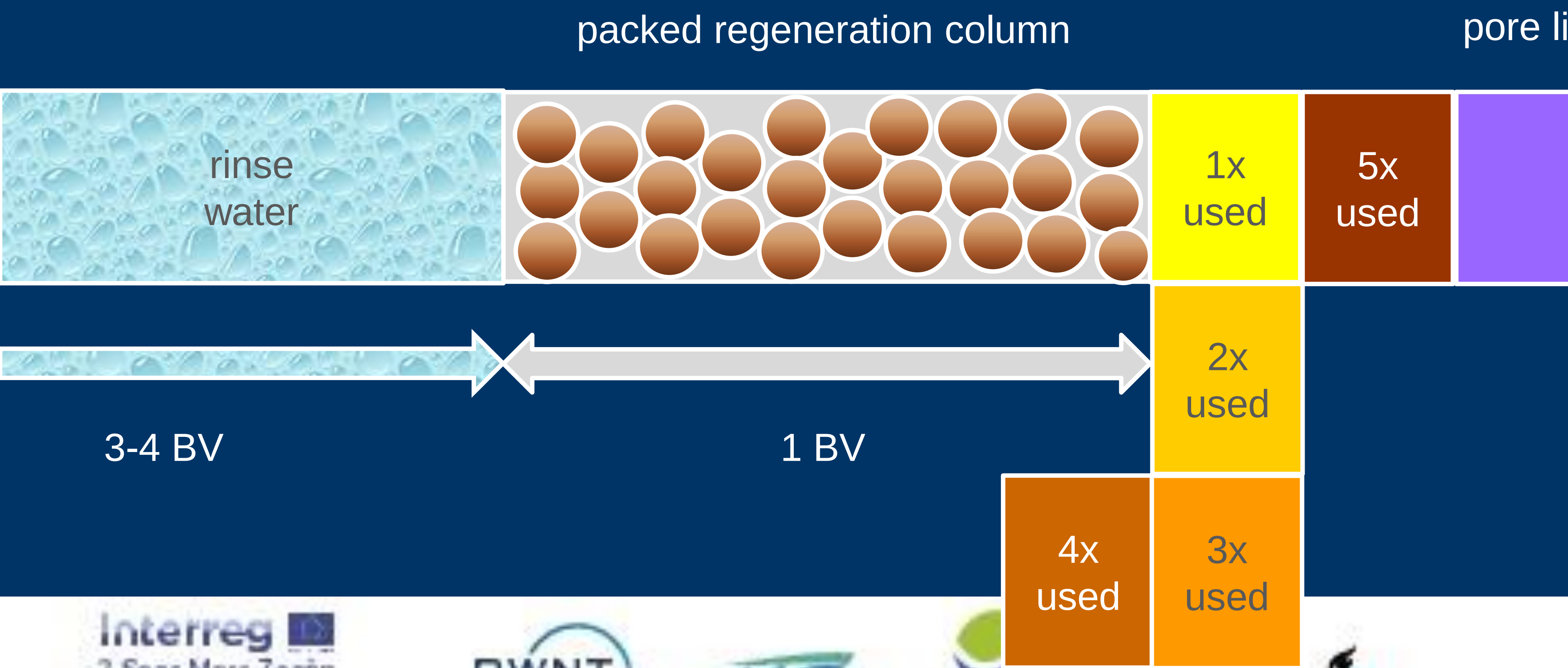
SIX regeneration principle



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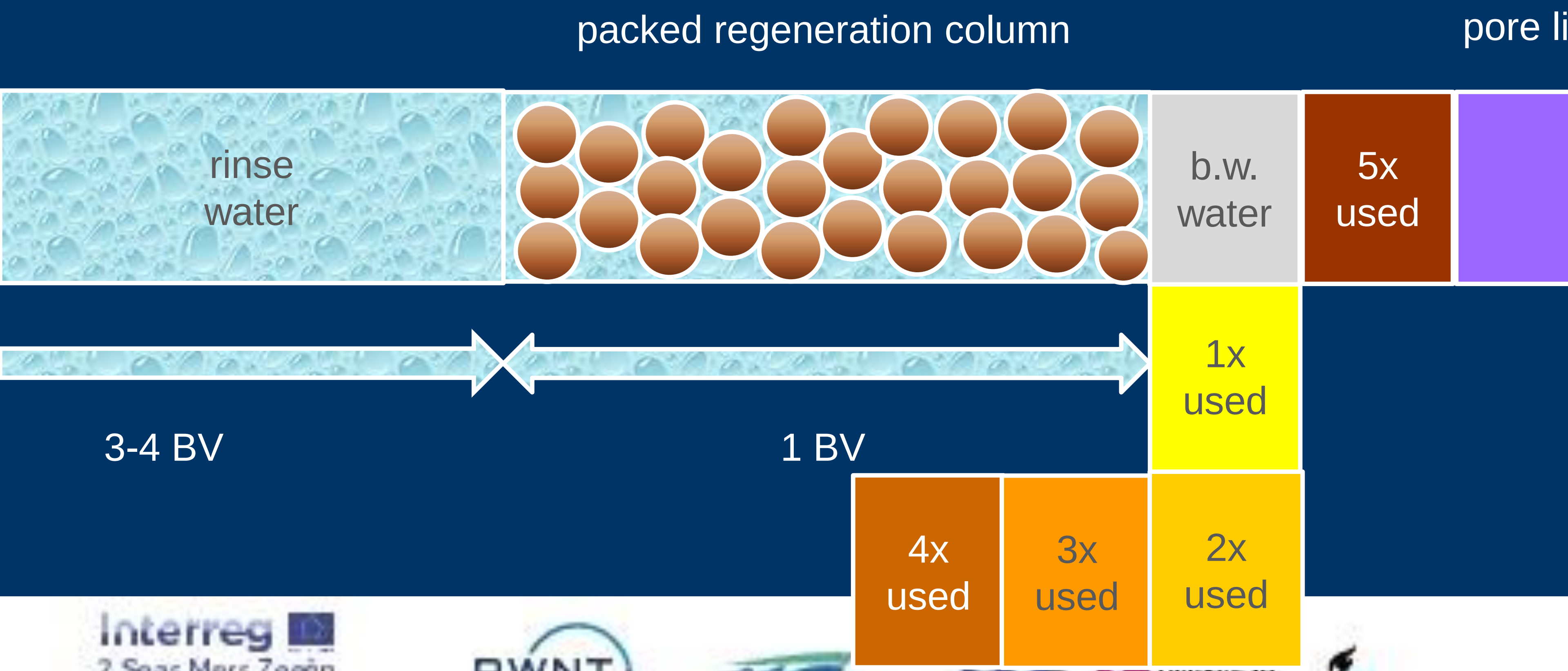
SIX regeneration principle



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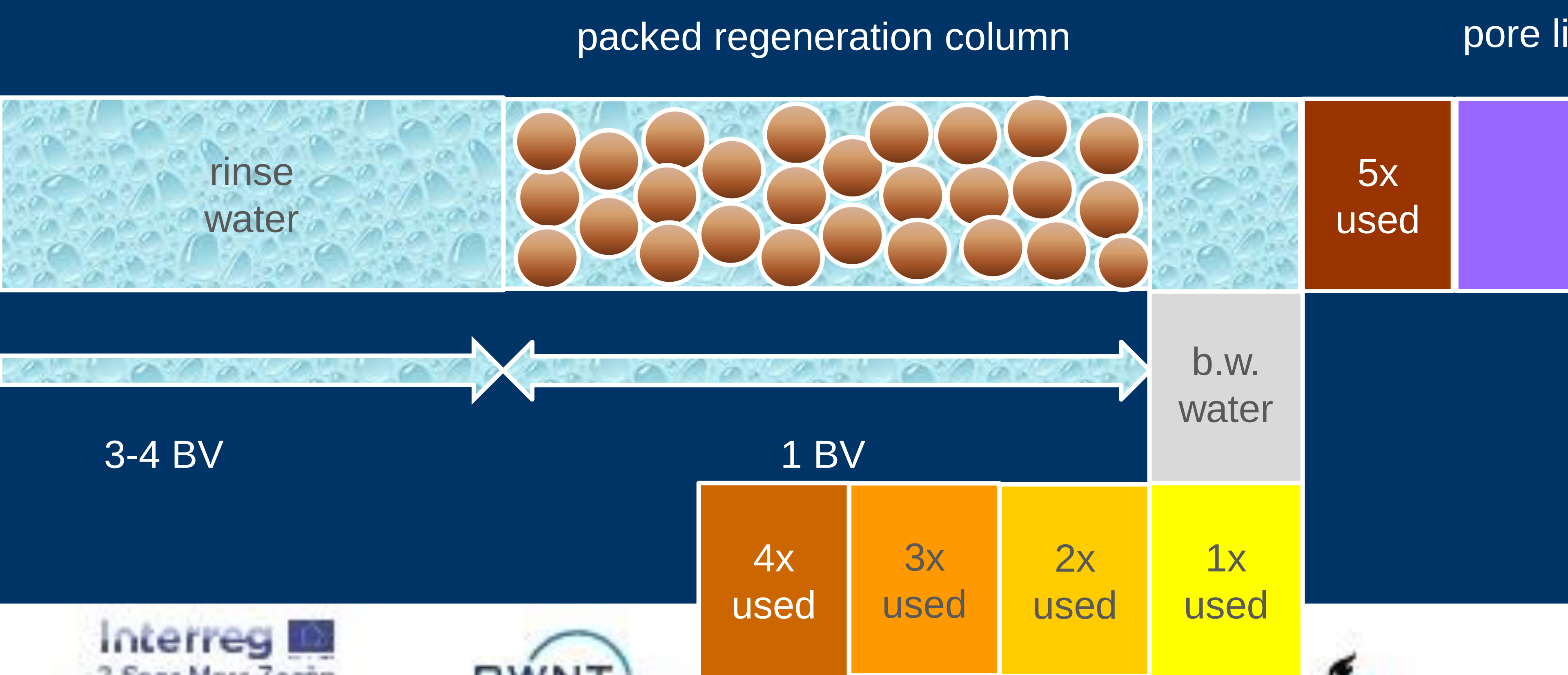

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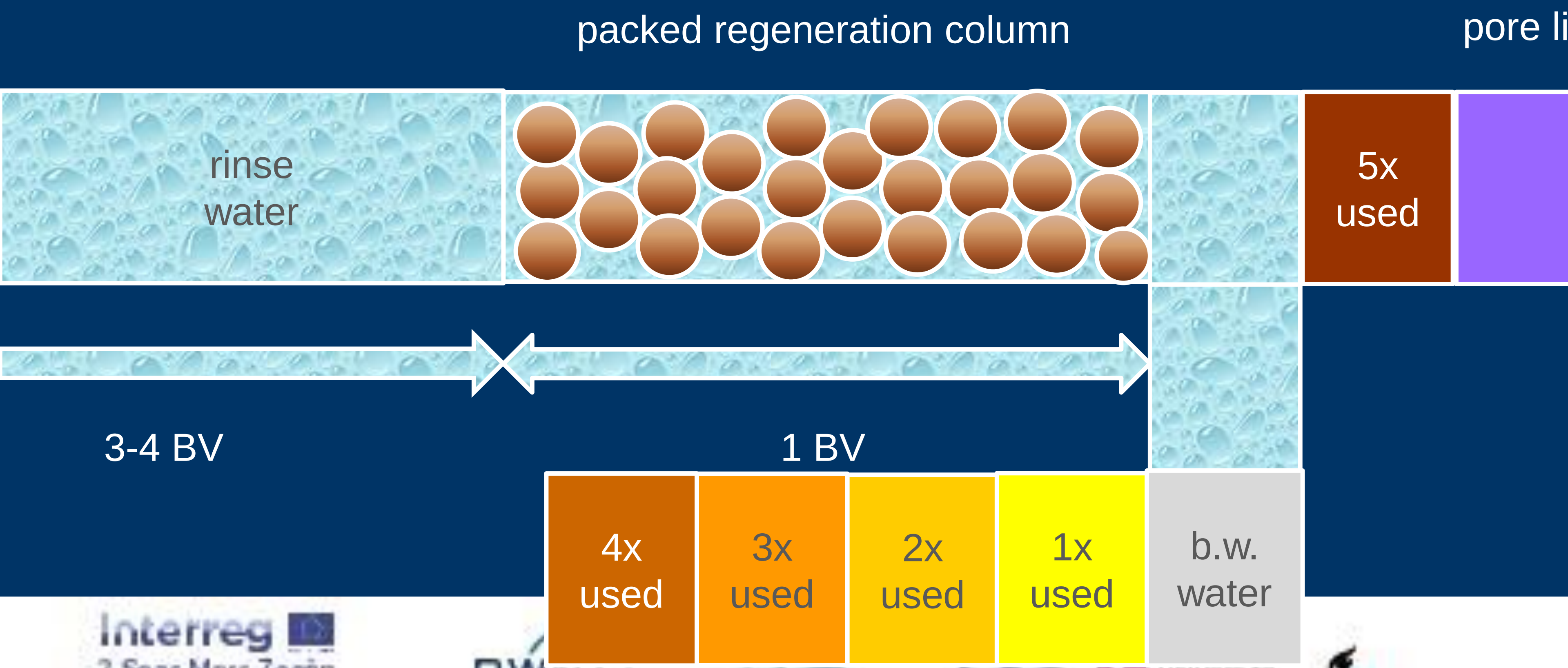

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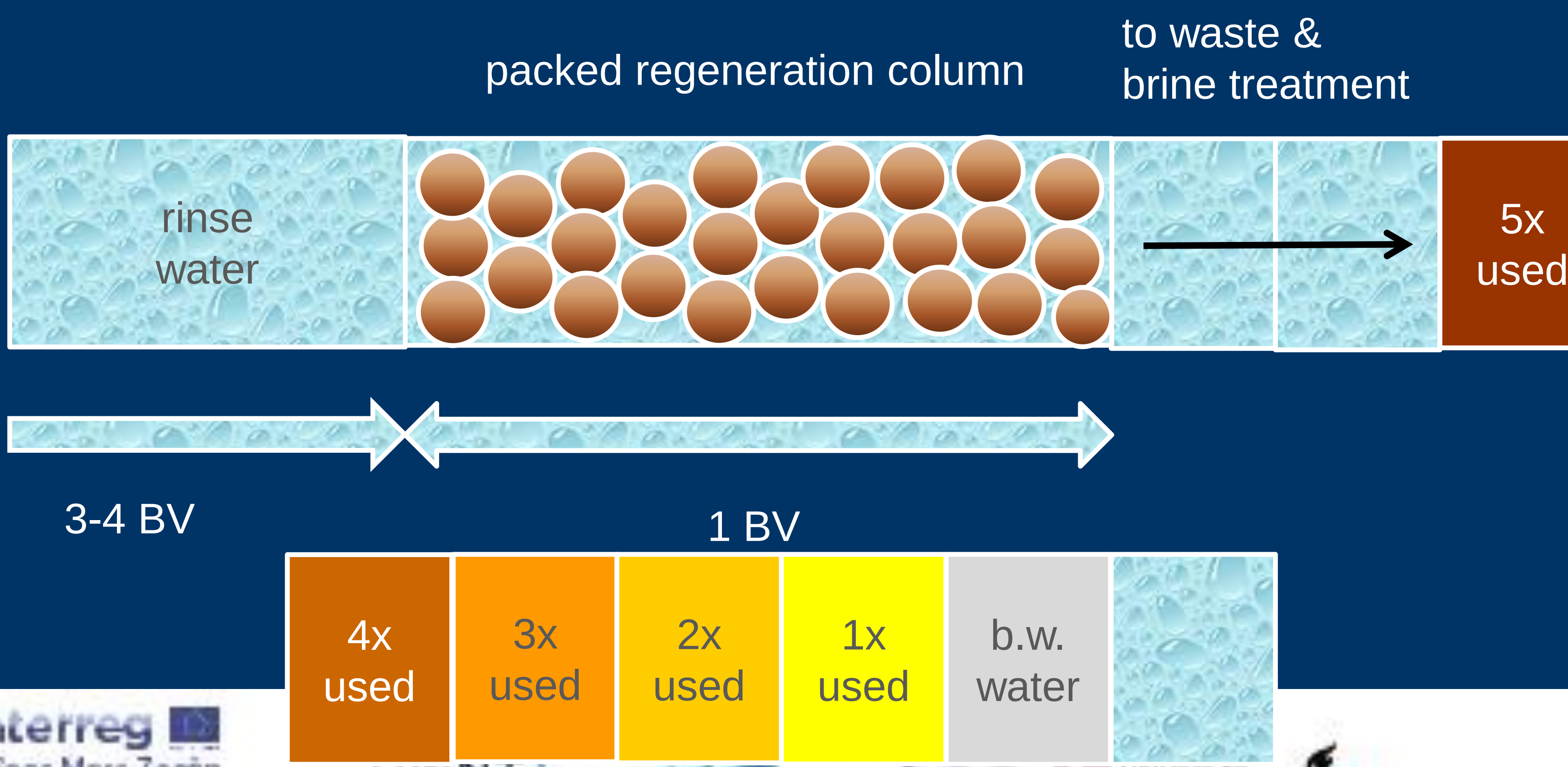

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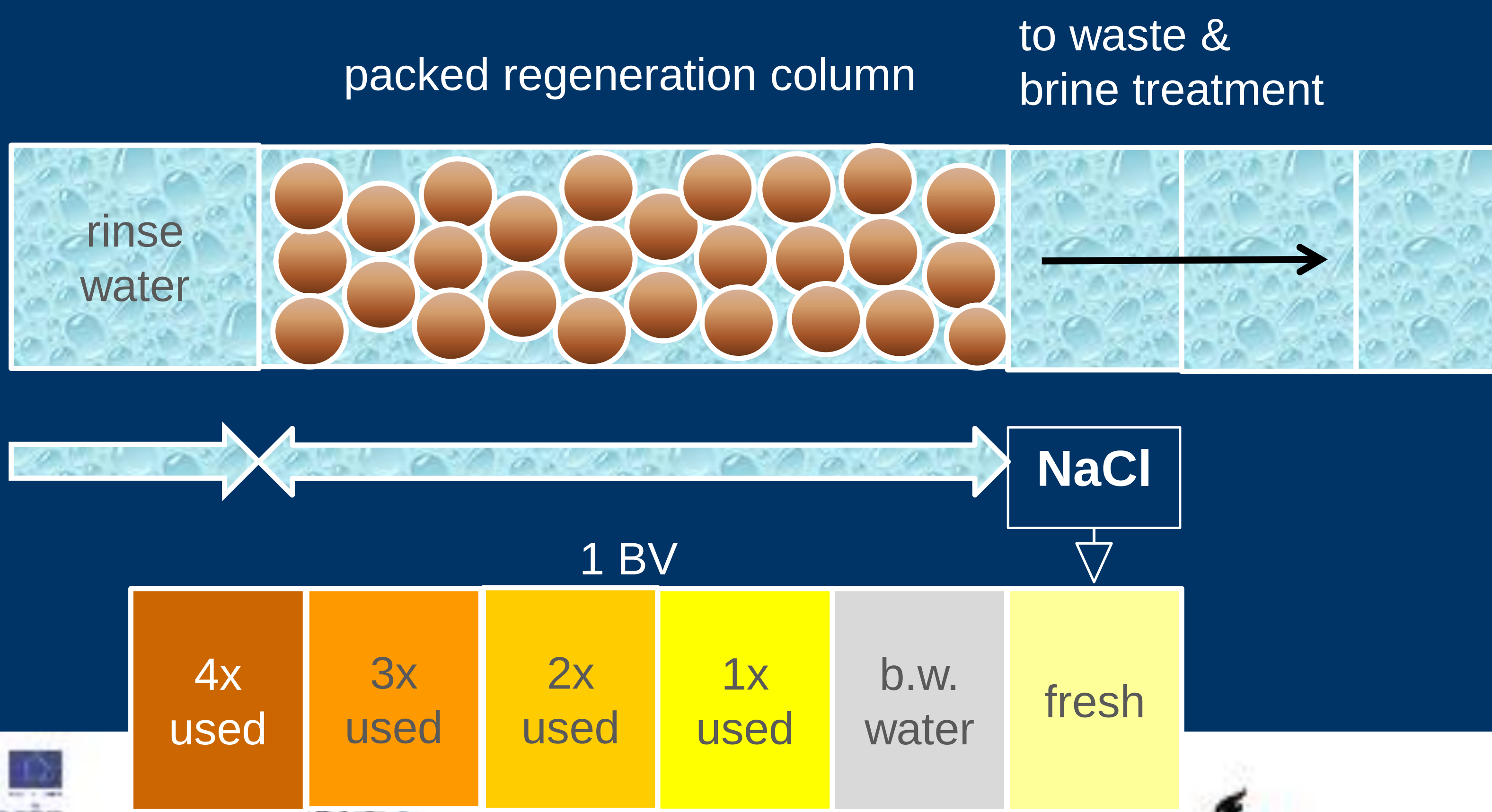

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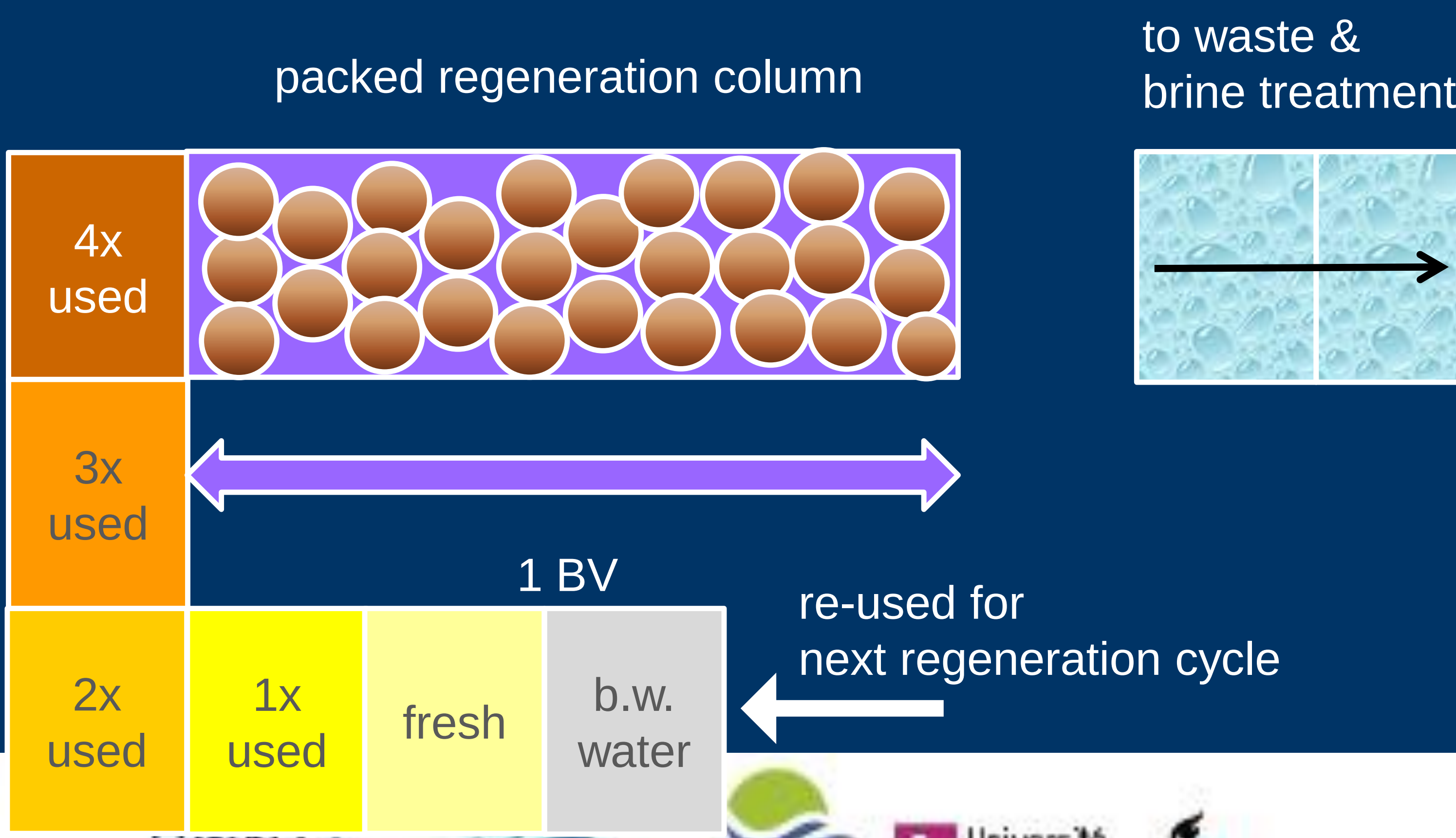

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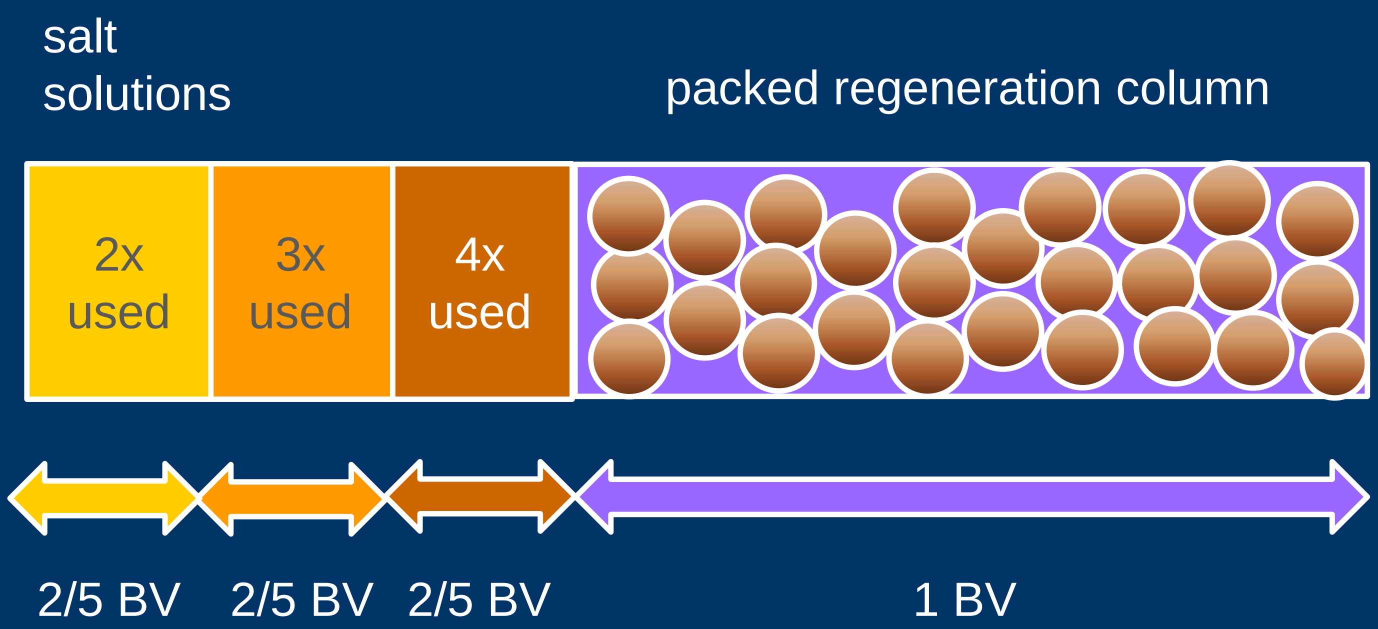

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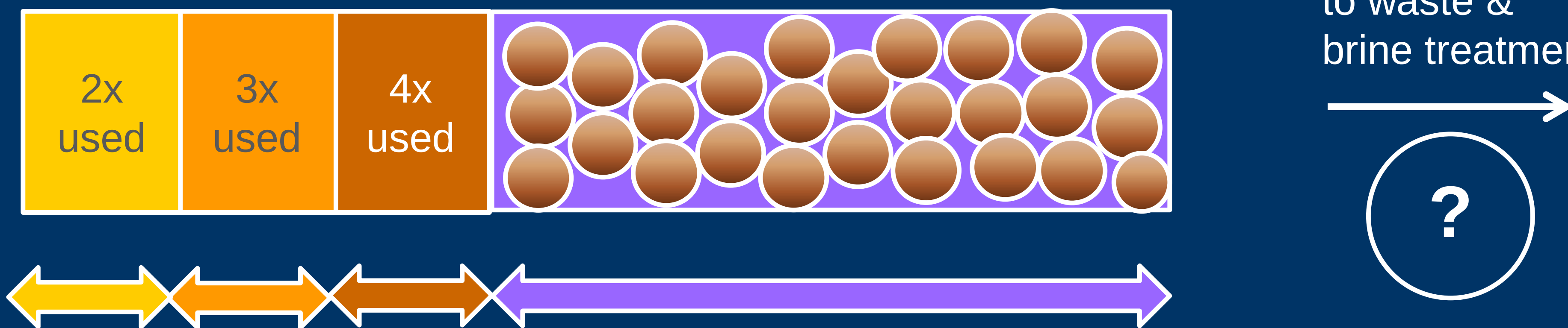
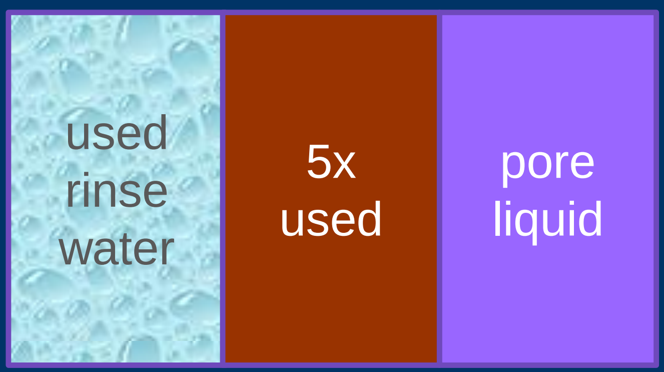


salt ejection profile

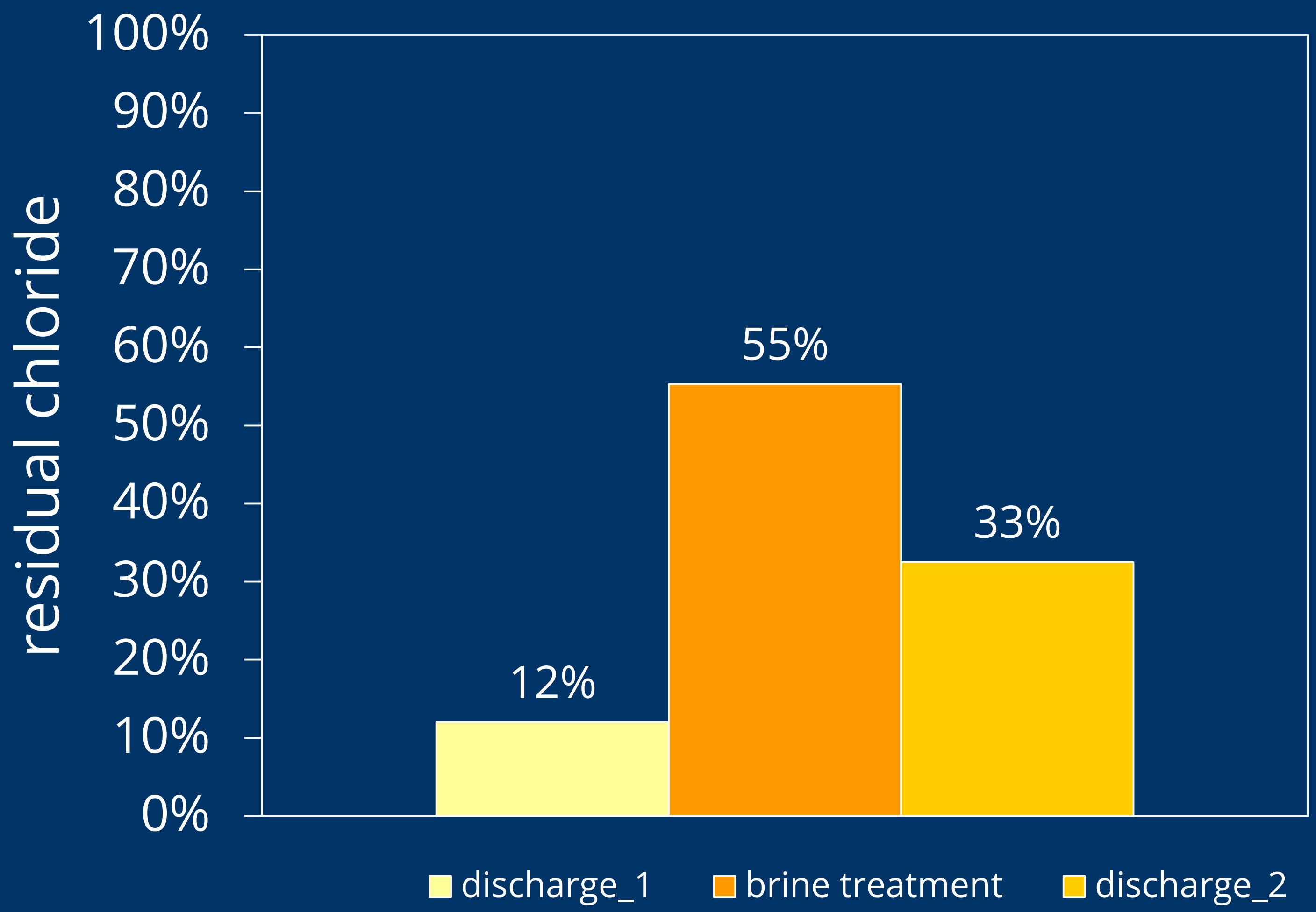
ideal plug flow



non ideal plug flow

chloride ejection profile

downflow regime



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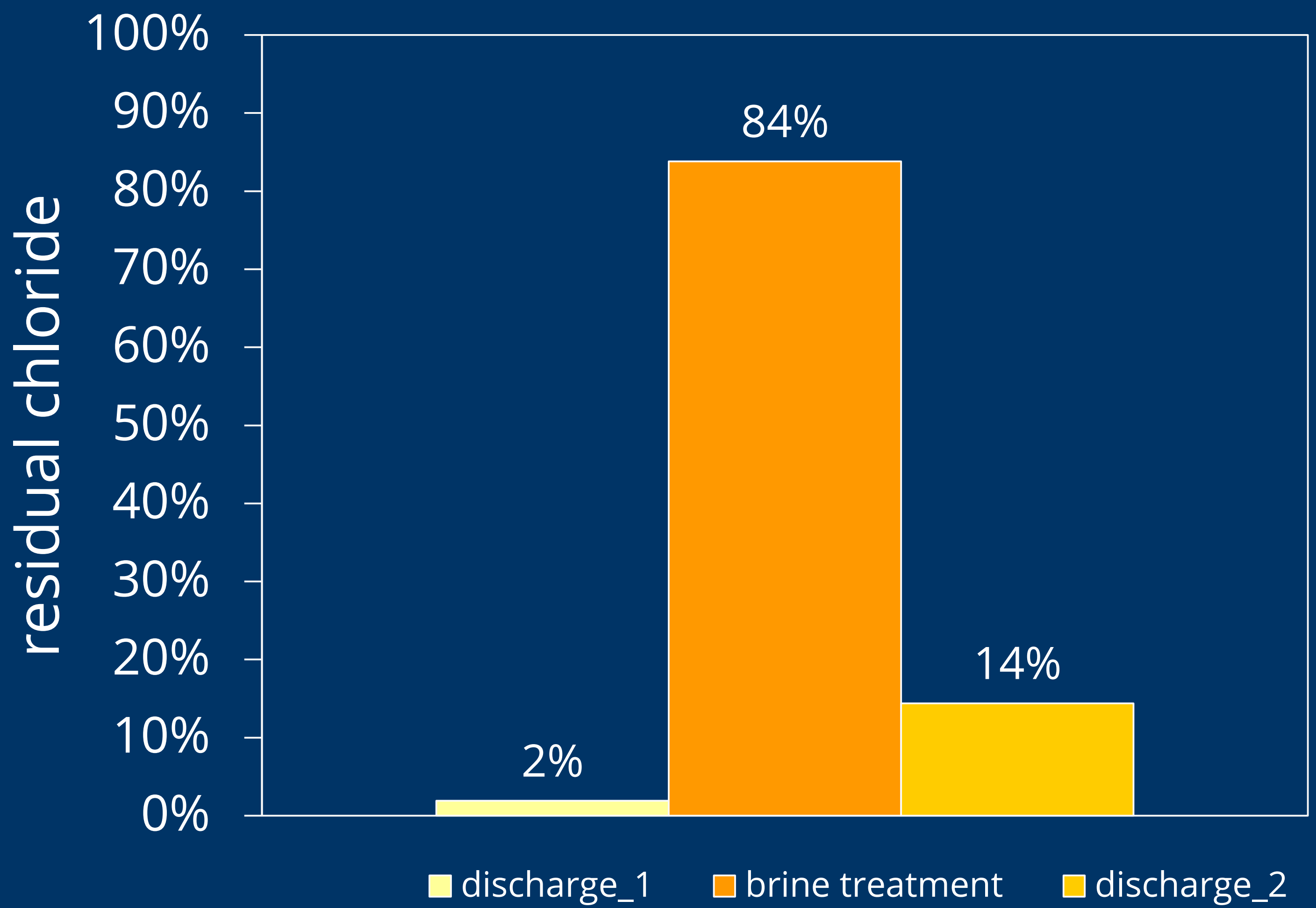
chloride ejection profile

upflow regime



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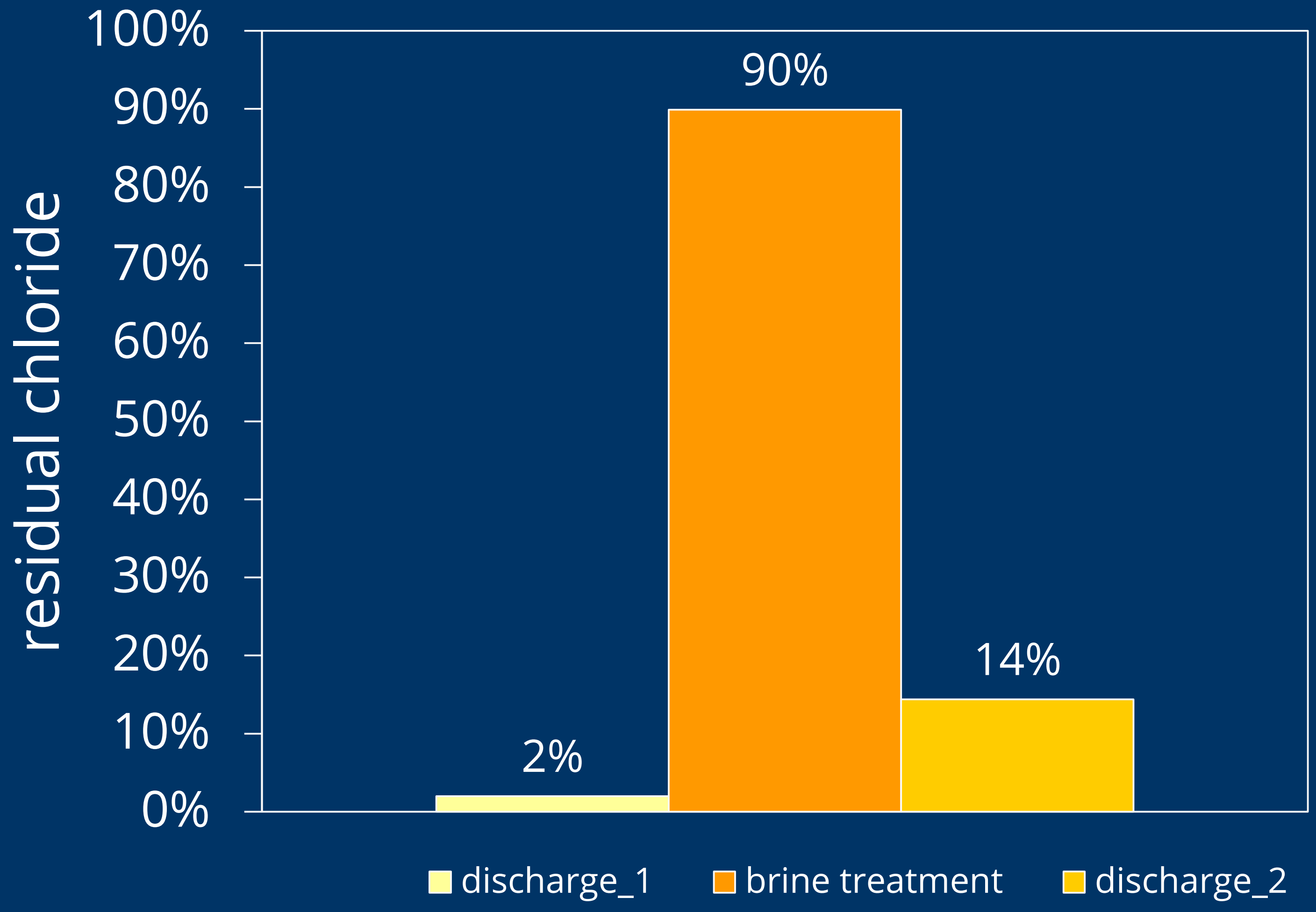
chloride ejection profile

upflow regime (salt solutions)/downflow (bw/rinsing)



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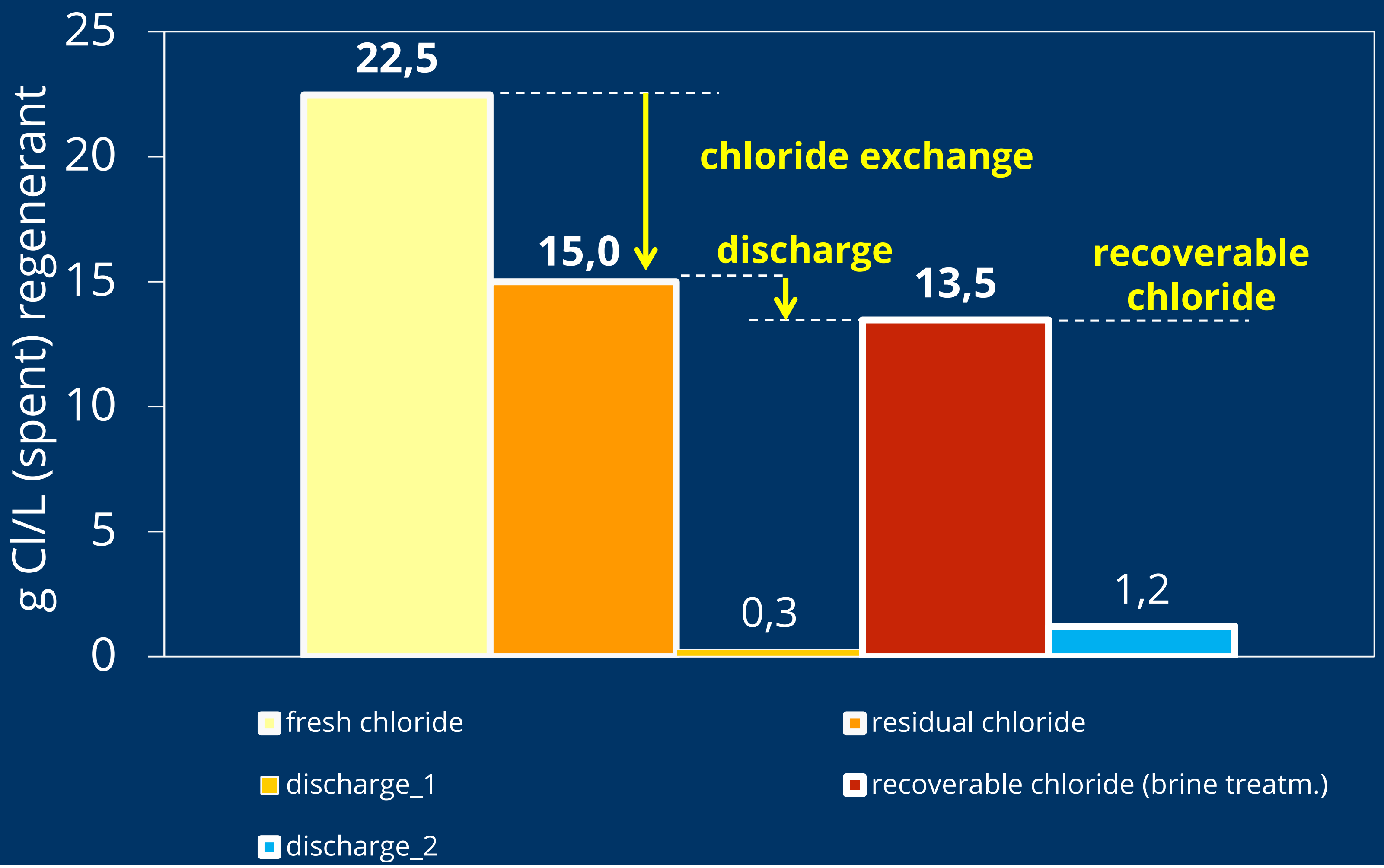
Andijk pilot chloride ejection profile

upflow (salt solutions)/downflow (backwash, rinsing)



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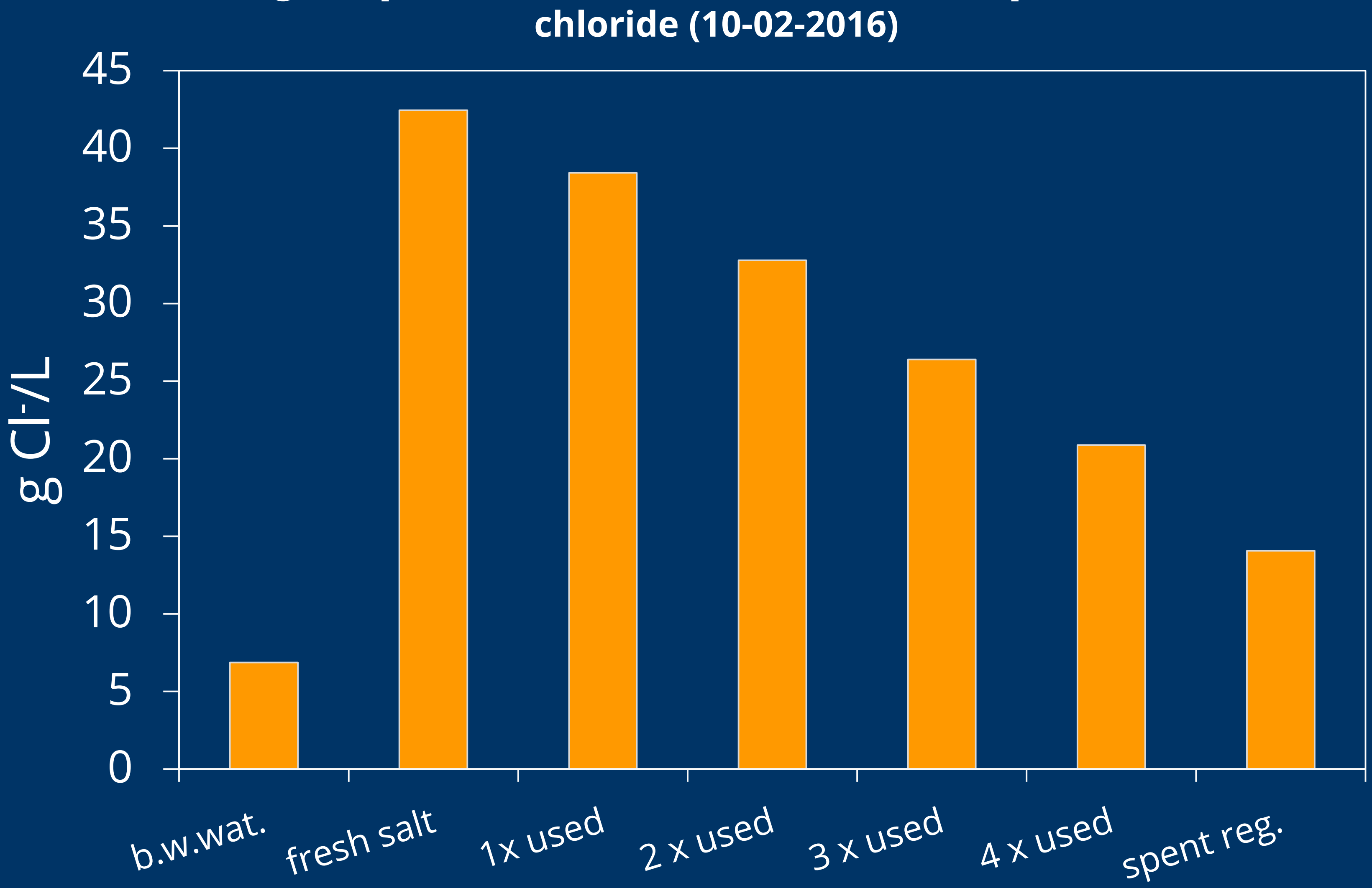
Andijk pilot brine composition



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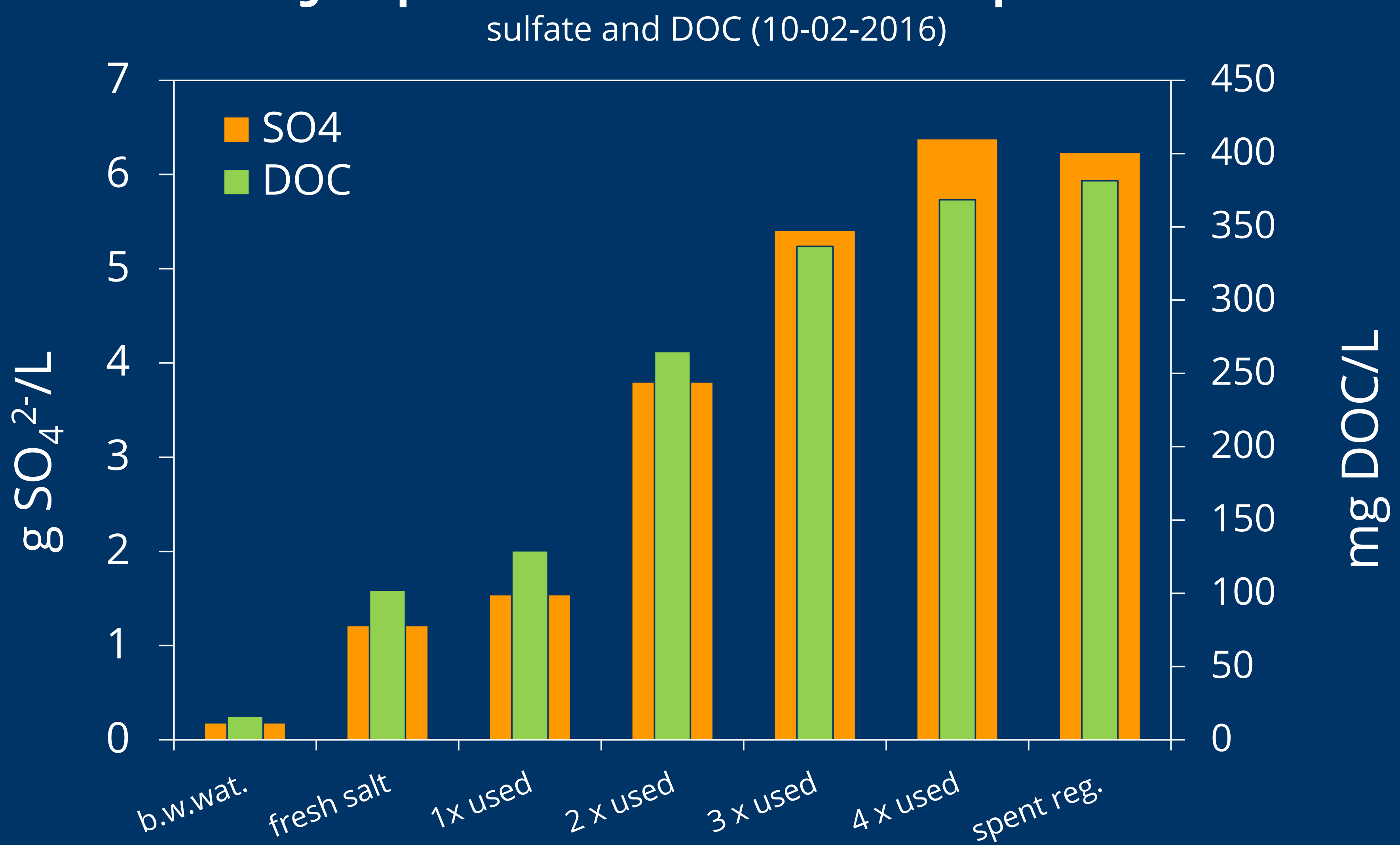
Andijk pilot brine composition



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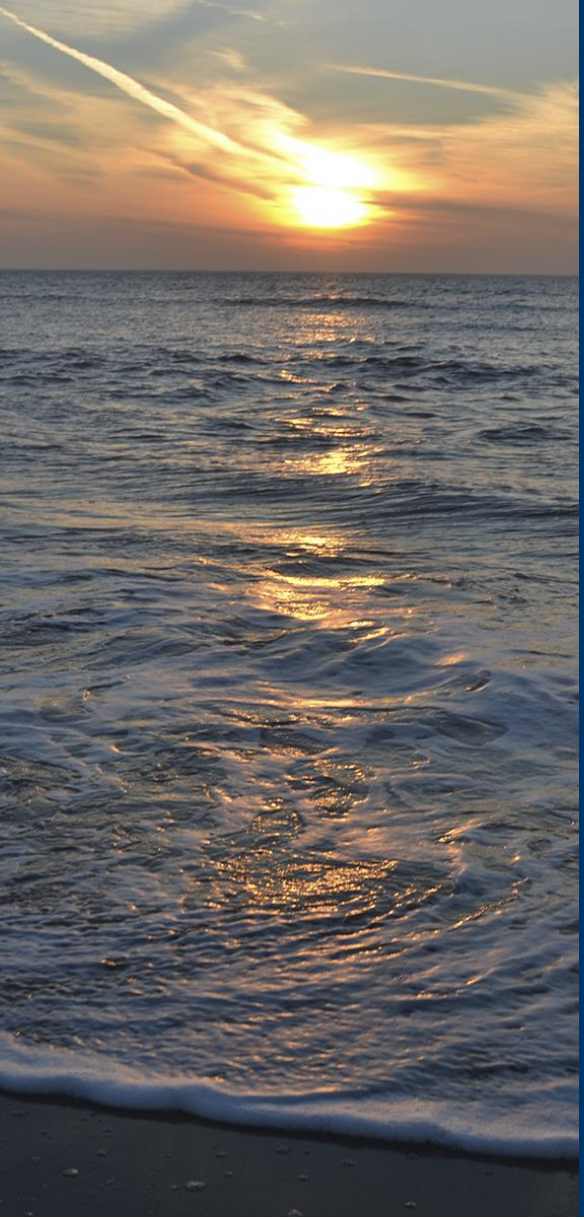

4. conclusions

regeneration regime optimization

- Lower L/S ratio's during regeneration result in more efficient use of the counter anion (Cl-), and thus:
- Packed Bed Regeneration is the preferred technique (L/S ≈ 2/3);
- Semi-counter-current regime (1-4 times used solutions) improves counter anion efficiency;
- Over-all salt demand can be further reduced by 'controlled anion blinding', i.e. more chloride is involved in the desorption of DOC;
- ~ 90% residual chloride still can be found in it's original spent regenerant volume (~ 2/5 BV) changing flow direction from upflow during regeneration to downflow during rinsing (optimum use of gravitation and differences in liquid densities).
- Regeneration regime optimization makes post-brine treatment more valuable

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