Particle Separation from Municipal Wastewater by Coarse Media Filtration

A Part of NTNU/XUAT Postgraduate Course

Wastewater As a Resource

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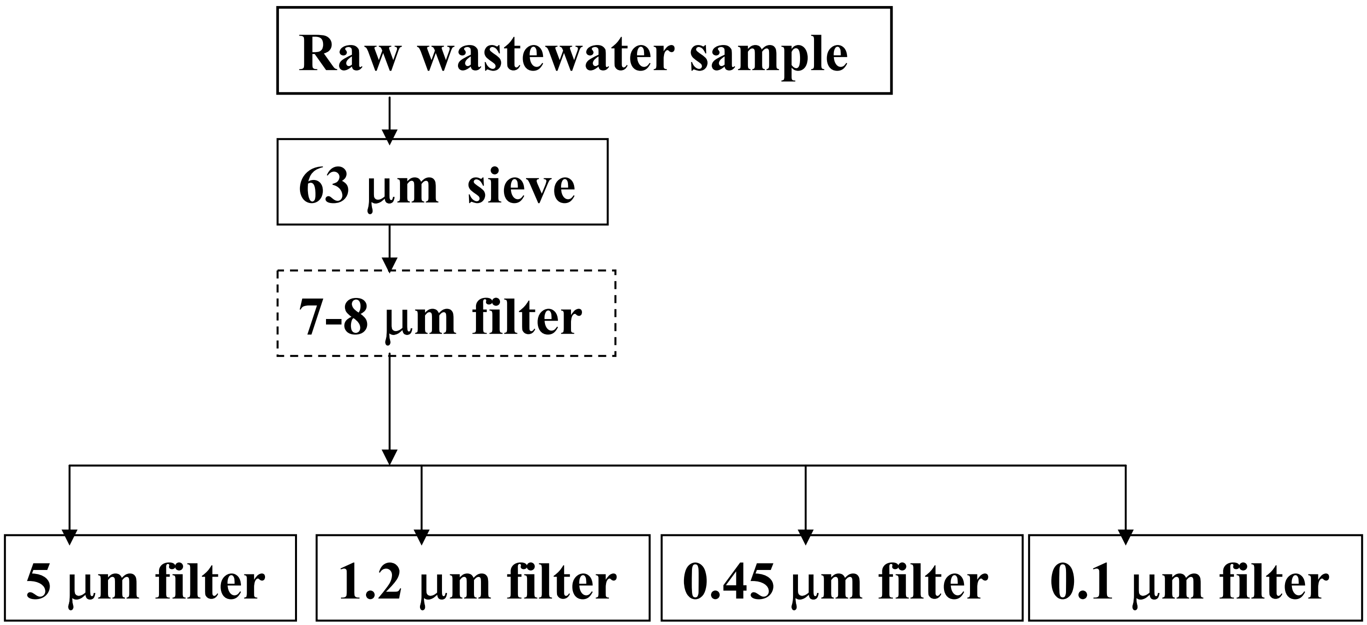
Main topics

- Wastewater characteriszation in municipal wastewater
- Wastewater treatment strategy
- Enhancement of particle separation and various processes
- Coarse media filtration of wastewater, tertiary, secondary, and primary
- Coarse media filtration for enhanced primary treatment
- High rate wastewater treatment schemes based on coarse media filtration

Wastewater characterisation—Fractionation procedure



(Adapted from van Nieuwenhuijzen 2002)

Wastewater characterisation—Fractions, particle sizes and analyzed parameters

Fraction	Particle size range	Analyzed parameters
Raw wastewater	Whole range	COD, BOD, N, P, TSS, Turbidity, T, pH, conductivity
Settleable-sd	>63 µm	
Suspended	5-63 µm	
Supra colloidal	1.2-5 µm	
Colloidal	0.45-1.2 µm	
Semi-dissolved	<0.45 µm	
Dissolved	<0.1 µm	

(Adapted from van Nieuwenhuijzen 2002)

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Average fractionated wastewater composition (from van Nieuwenhuijzen 2002 (The Netherlands))

Fraction / Parameter	Dissolved <0.1 µm	Supra Dissolved 0.1-0.45 µm	Colloidal 0.45-1.2 µm	Supra Colloidal 1.2-5 µm	Suspended 5-63 µm	Settleable >63 µm
TSS	-	-	-	-	52±18%	48±18%
Turbidity	-	-	7±4%	10±7%	62±17%	21±12%
BOD5	48±12%	-	-	14±6%	30±8%	8±4%
COD	36±10%	3±4%	2±2%	11±6%	27±11%	21±9%
Ntotal	83±25%	1±1%	3±3%	4±2%	5±3%	4±4%
Ptotal	53±18%	3±3%	3±1%	5±2%	30±12%	6±3%

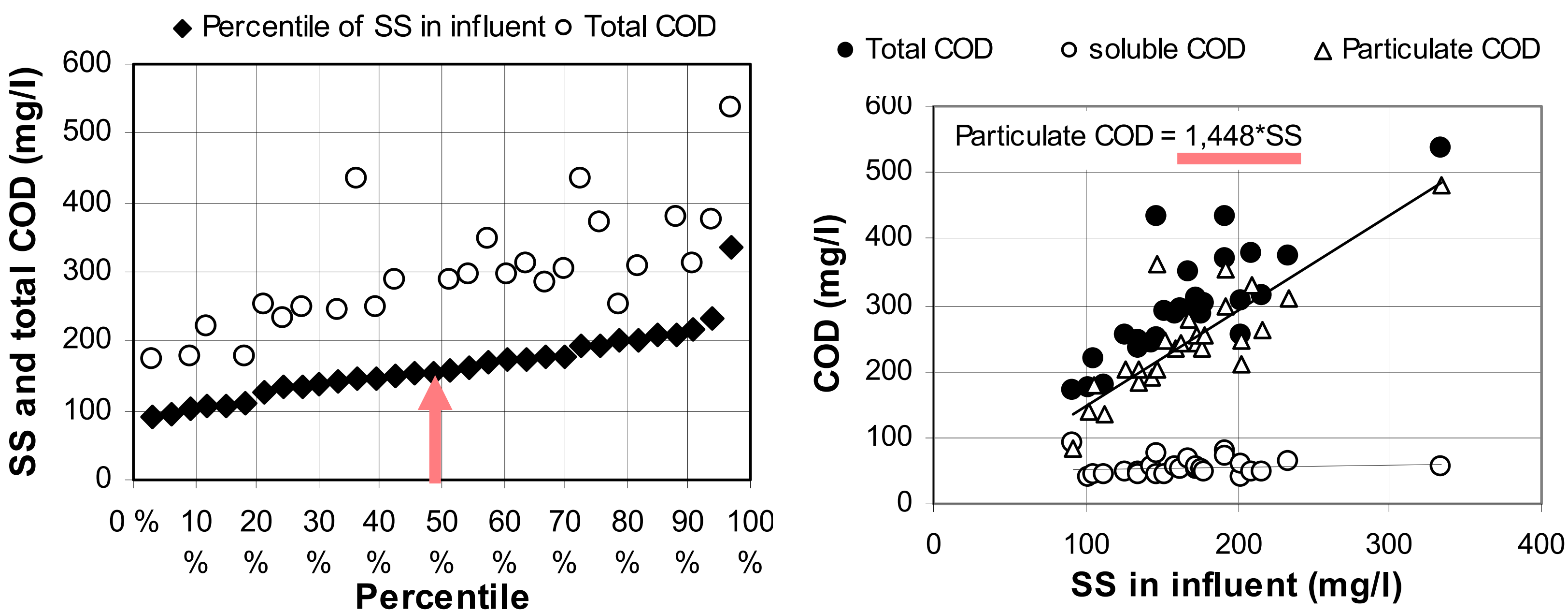
Average BOD/N ratios per fraction (after van Nieuhuijzen 2002)

Fraction / Parameter	Dissolved <0.1 µm	Colloidal material removed <0.45 µm	Settleable material removed <63 µm	Raw wastewater
BOD/N-average	2.4±1.34	2.3±1.49	3.6±1.91	4.1±1.80
BOD/N-dry weather flow	2.9±0.95	2.9±0.91	4.2±1.09	4.7±1.20
BOD/N-storm weather flow	0.9±0.58	0.8±0.59	2.0±0.61	2.4±0.44

Particulate COD and particulate N—A comparison

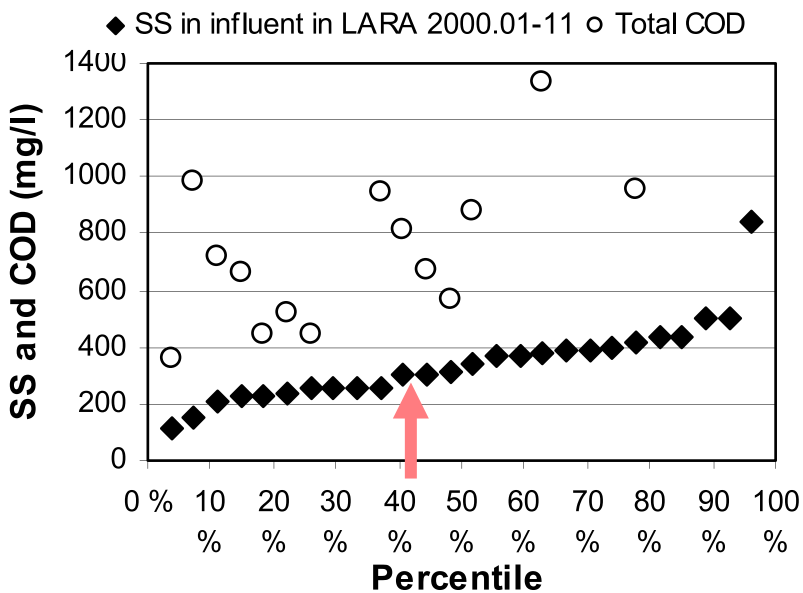
- Ødegaard (1999) and (2000): Averaged particulate COD is 69% of total COD in wastewater (Scandinavia). Particulate N is 32% of total N.
- Van Nieuwenhuijzen (2002): Average particulate COD is 64% of total COD in wastewater (Netherlands). Particulate N is 19% of total N.
- STOWA (1999): Particulate COD is 65-84% of total COD (also Netherlands).
- In France, 59-69% of total COD is particulate.
- Liao (2002): Domestic sewage 75-90% particulate COD; half inductrial 50-88% particulate COD (Norway).

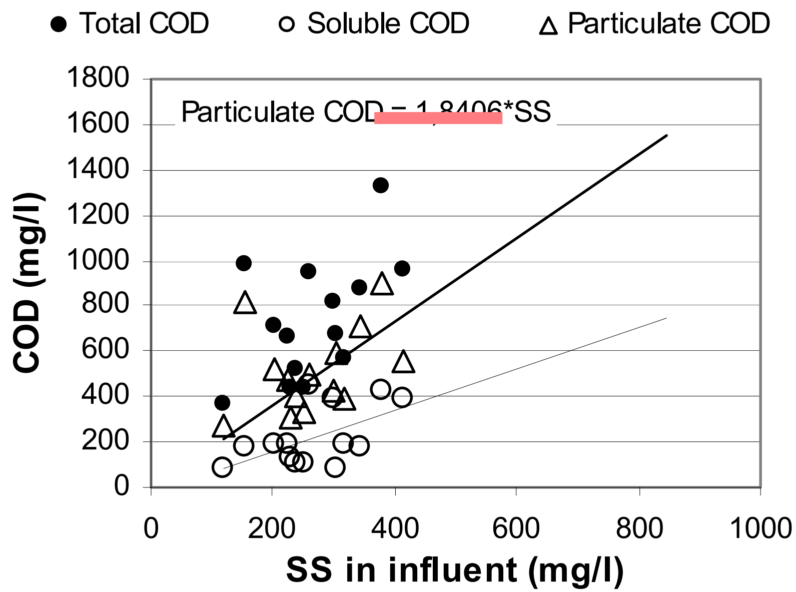
SS and COD in three wastewaters –
Høvringen Wastewater Treatment Plant (HØRA)



HØRA: Mountainous area, no industry, after 1.5 mm rotary sieving, 1998

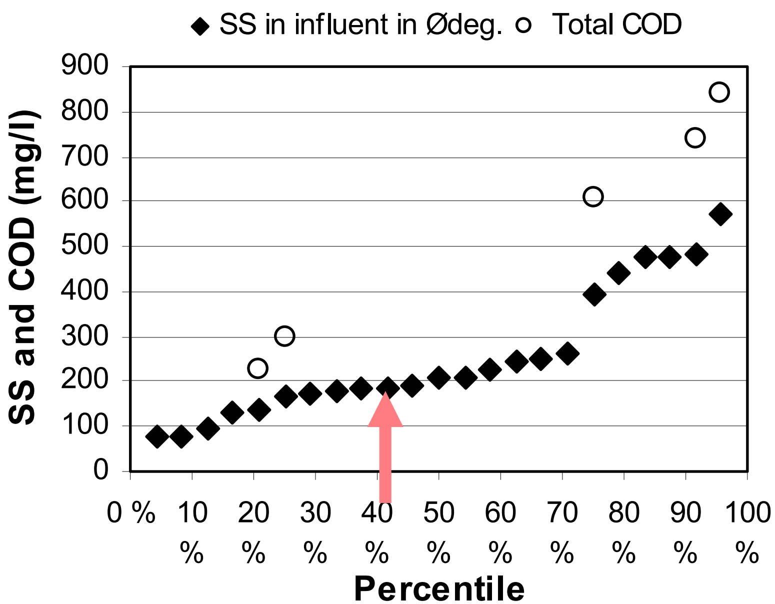
SS and COD in three wastewaters – Ladehameren Wastewater Treatment Plant (LARA)

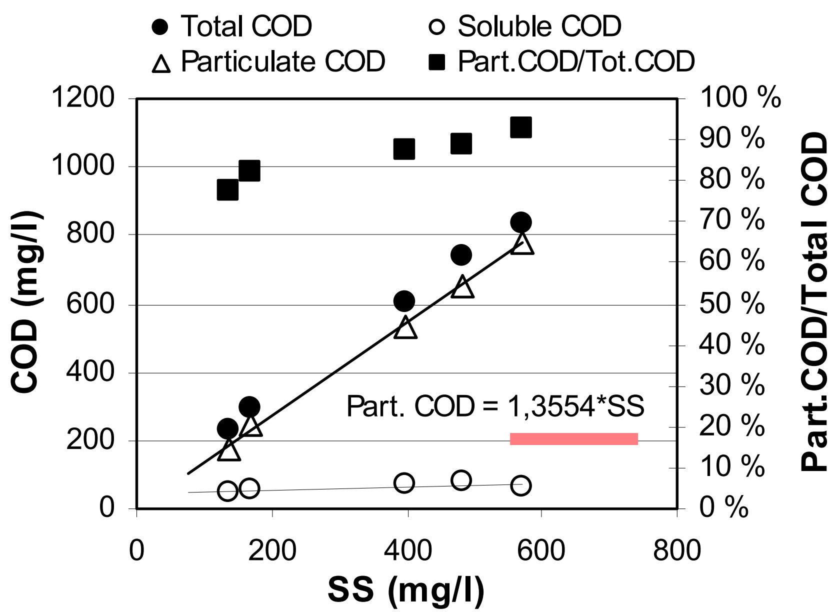




LARA: Mountainous area, half industrial, after grit chamber 1999-2000, much higher SS and COD, different particulate COD/SS ratio.

SS and COD in three wastewaters –The Ødegaarden Wastewater Treatment Experimental Hall





Ødegaarden: Domestic sewage, after primary settling, 2000-2001, similar to HØRA

Fractal settling properties of particles

- Particles in wastewater are fractal, the big particles are formed by principal clusters by Cluster-cluster model. The mass and the density of particles are power functions with non-integer powers. So does the settling velocity.
- Settling velocity is related by Andresen column settling method.
- Corresponding particle size distribution is measured by Coulter Particle Size Analyser LS230.
- Comparisons between two raw wastewaters and between two dosing conditions are made.

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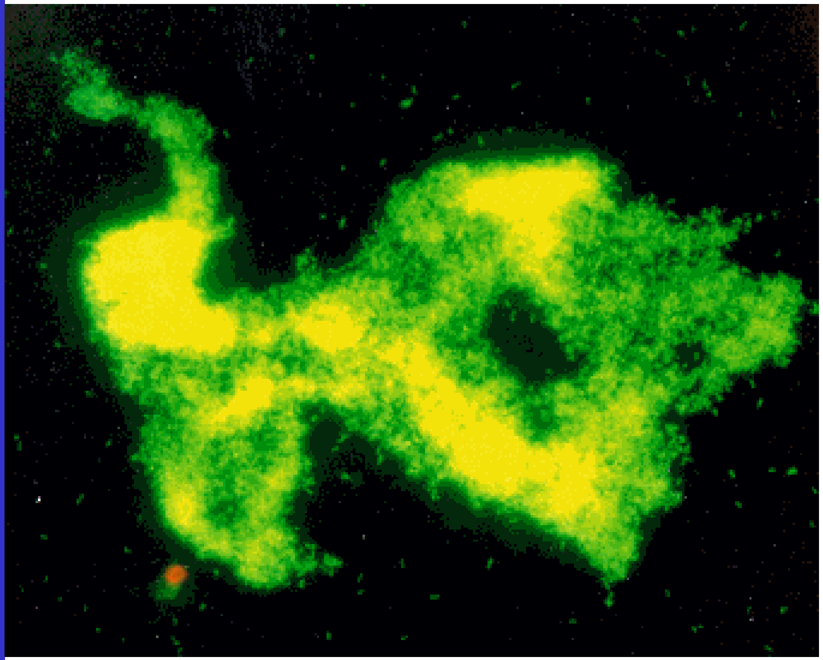
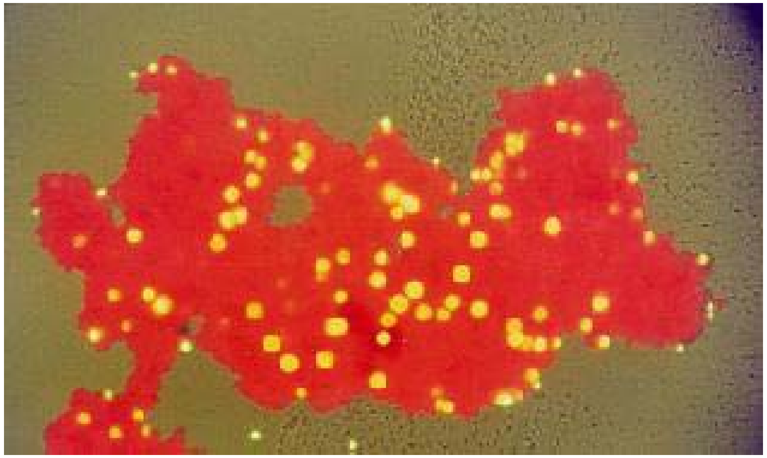
Fractal properties of particles—expressions

Property	Scaling relationship*
Solid volume--v	$v = \psi^{(D_3/3)} \xi_0 l_0^{(3-D_3)} l^{D_3}$
Encased volume--v_e	$v_e = \xi l^3$
Mass--m	$m = \rho_0 \psi^{(D_3/3)} \xi_0 l_0^{(3-D_3)} l^{D_3}$
Density--ρ	$\rho = \rho_0 \psi^{(D_3/3)} (\xi_0 / \xi)(l / l_0)^{(D_3-3)}$
Porosity--ε	$\varepsilon = 1 - \psi^{(D_3/3)} (\xi_0 / \xi)(l / l_0)^{(D_3-3)}$
Settling velocity--U	$U = \left[\frac{2g\xi_0}{a\rho_w \xi_2} \cdot (\rho_0 - \rho_w) \cdot \psi^{(D_3/3)} \cdot l_0^{(1+D_2-D_3)} \cdot v^{-b} \cdot l^{(D_3+b-D_2)} \right]^{[1/(2-b)]}$

Fractal particles—Logan's results

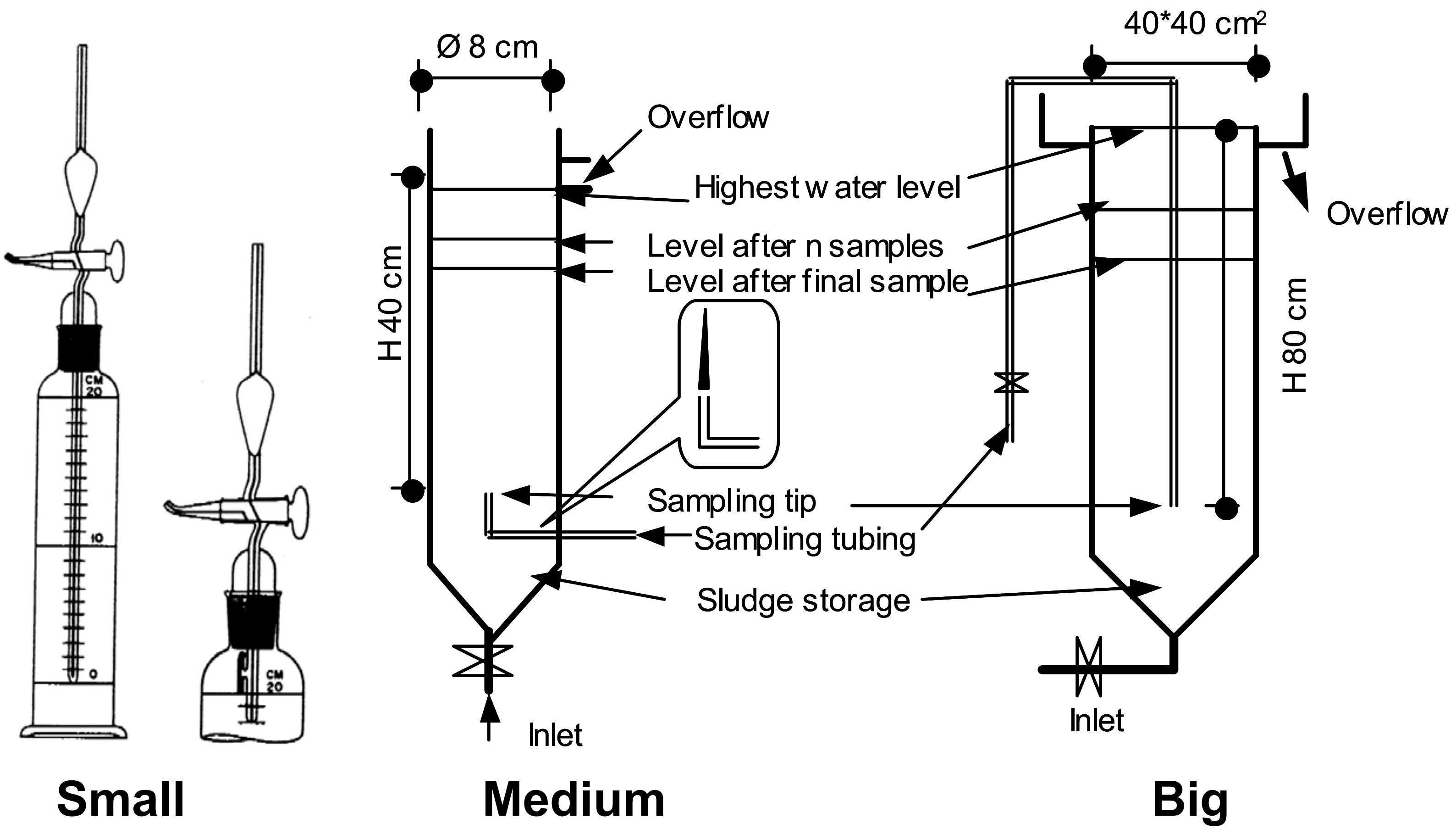


Bacteria flocs stained by acridine Orange and blue (left).

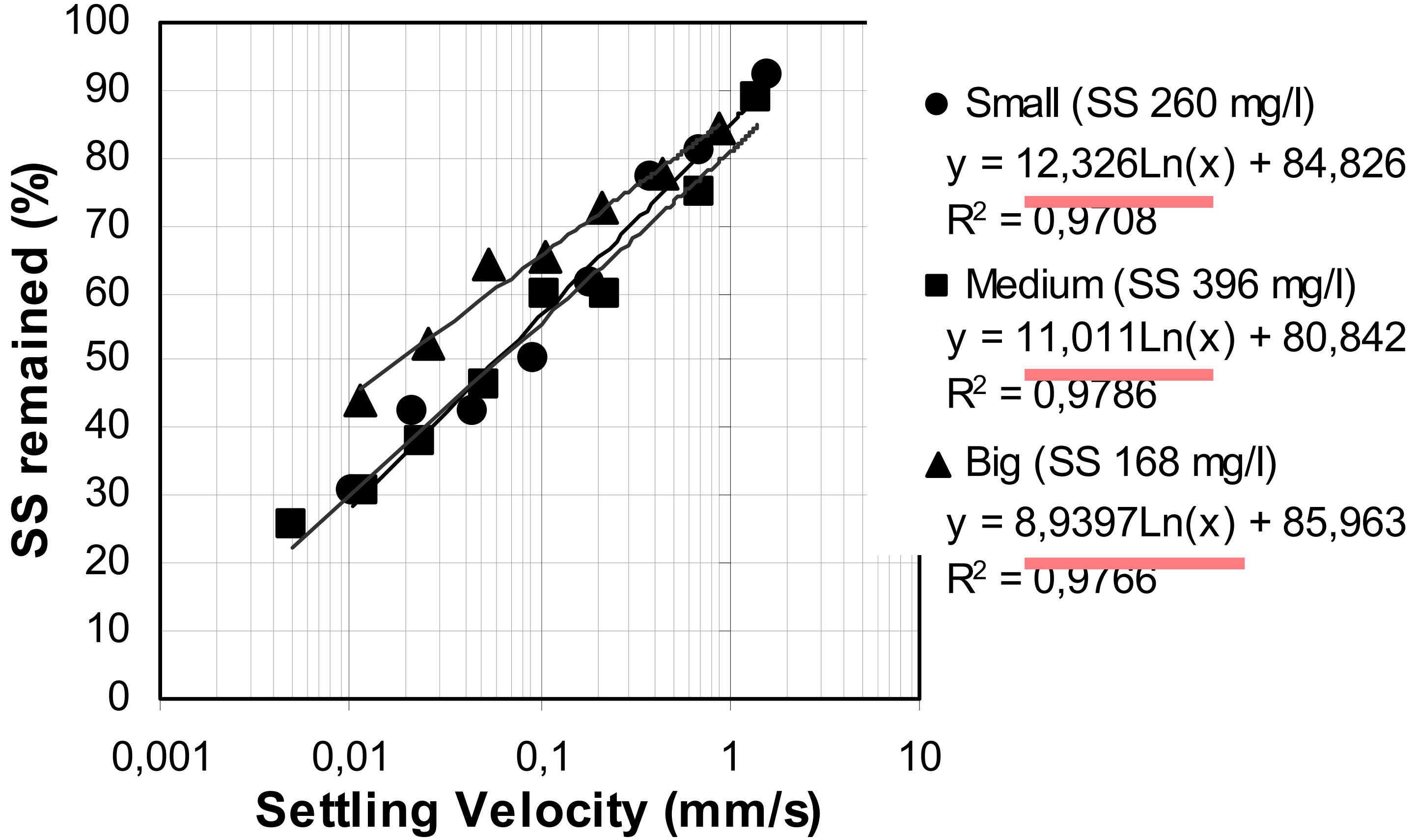


Read bead flocs coagulated with small Yellow bead (right).

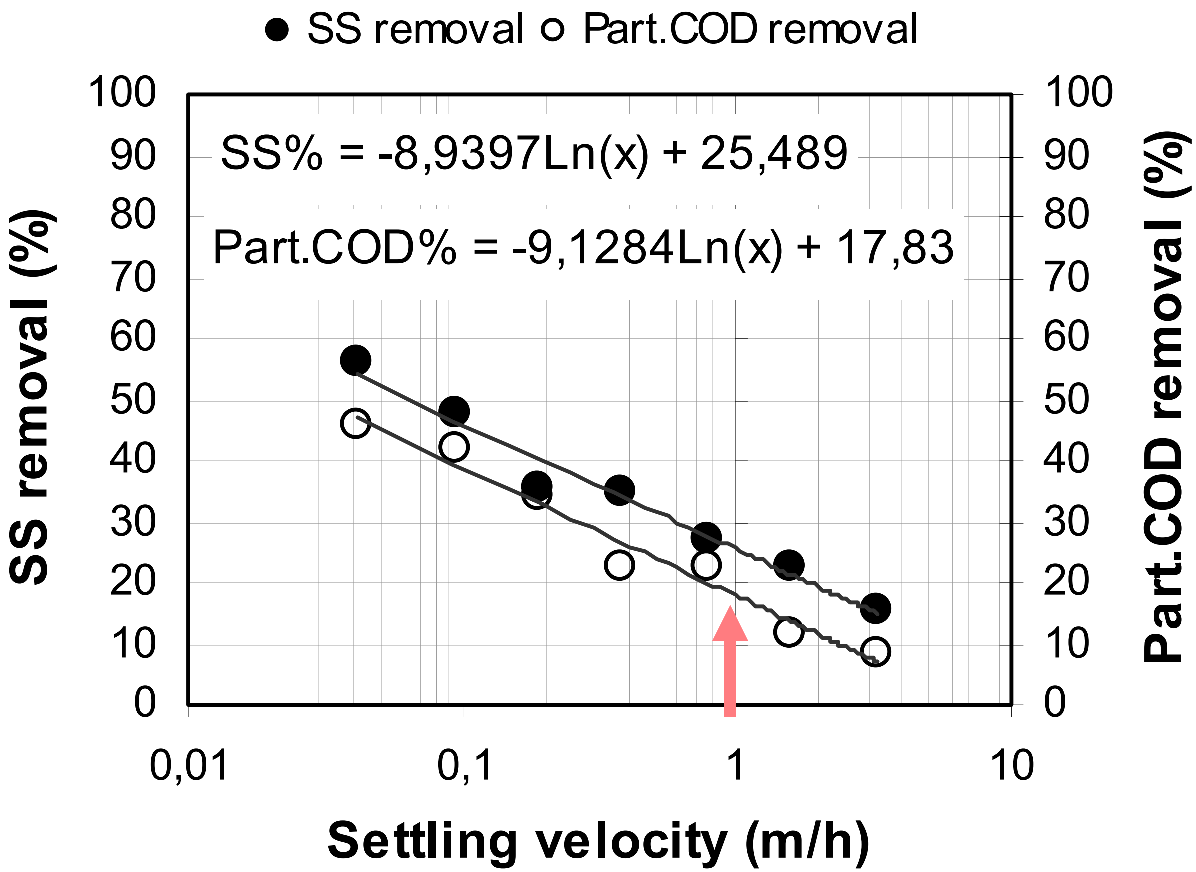
Andreasen’s fixed apparatus and the modified settling column



Comparison of three sizes of settling column

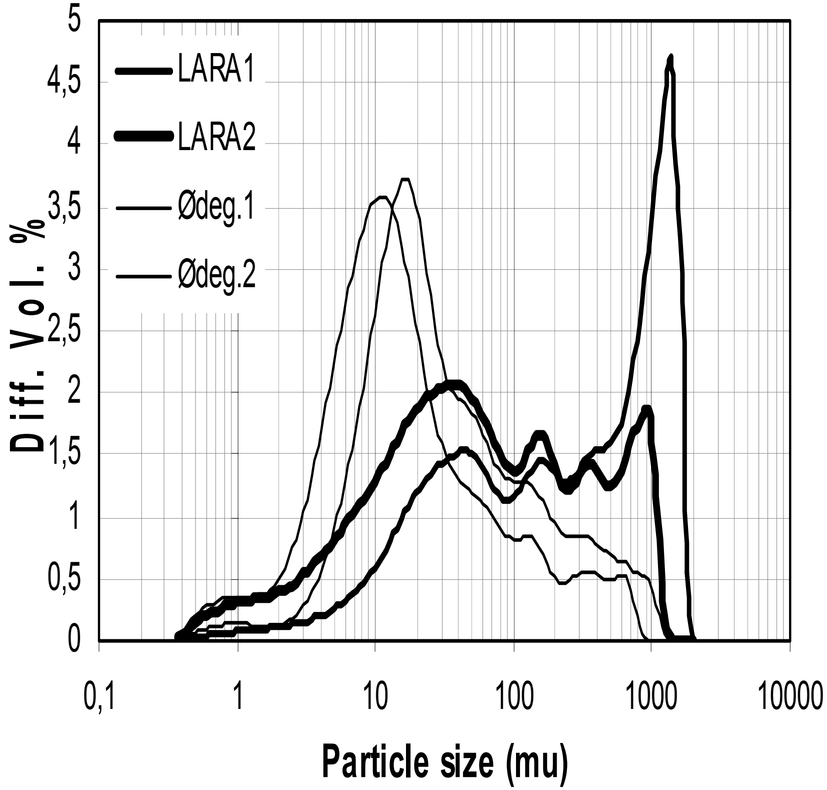


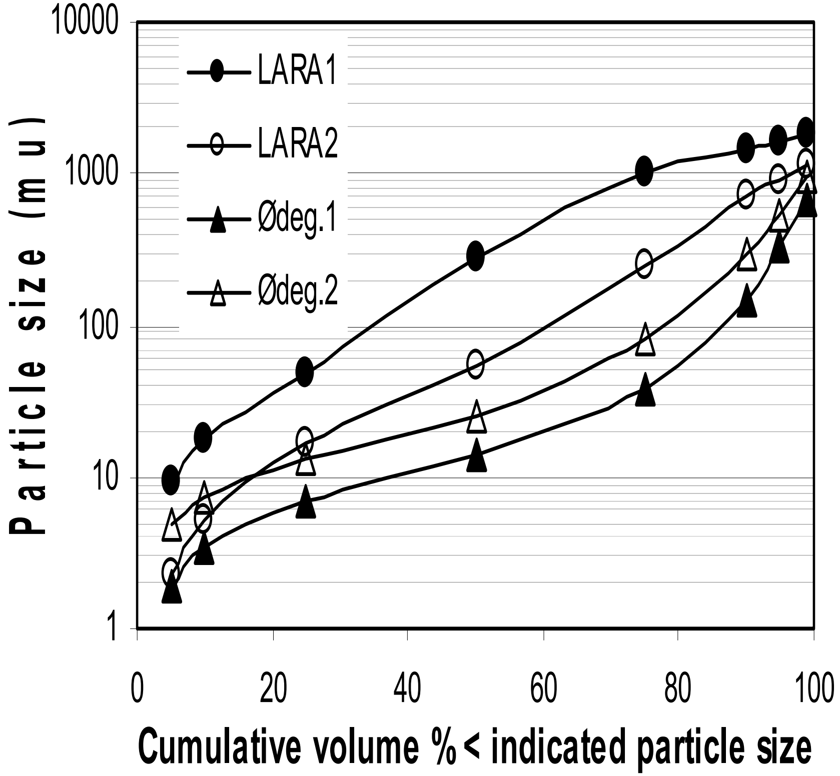
SS and particulate COD removal vs indicated settling velocity



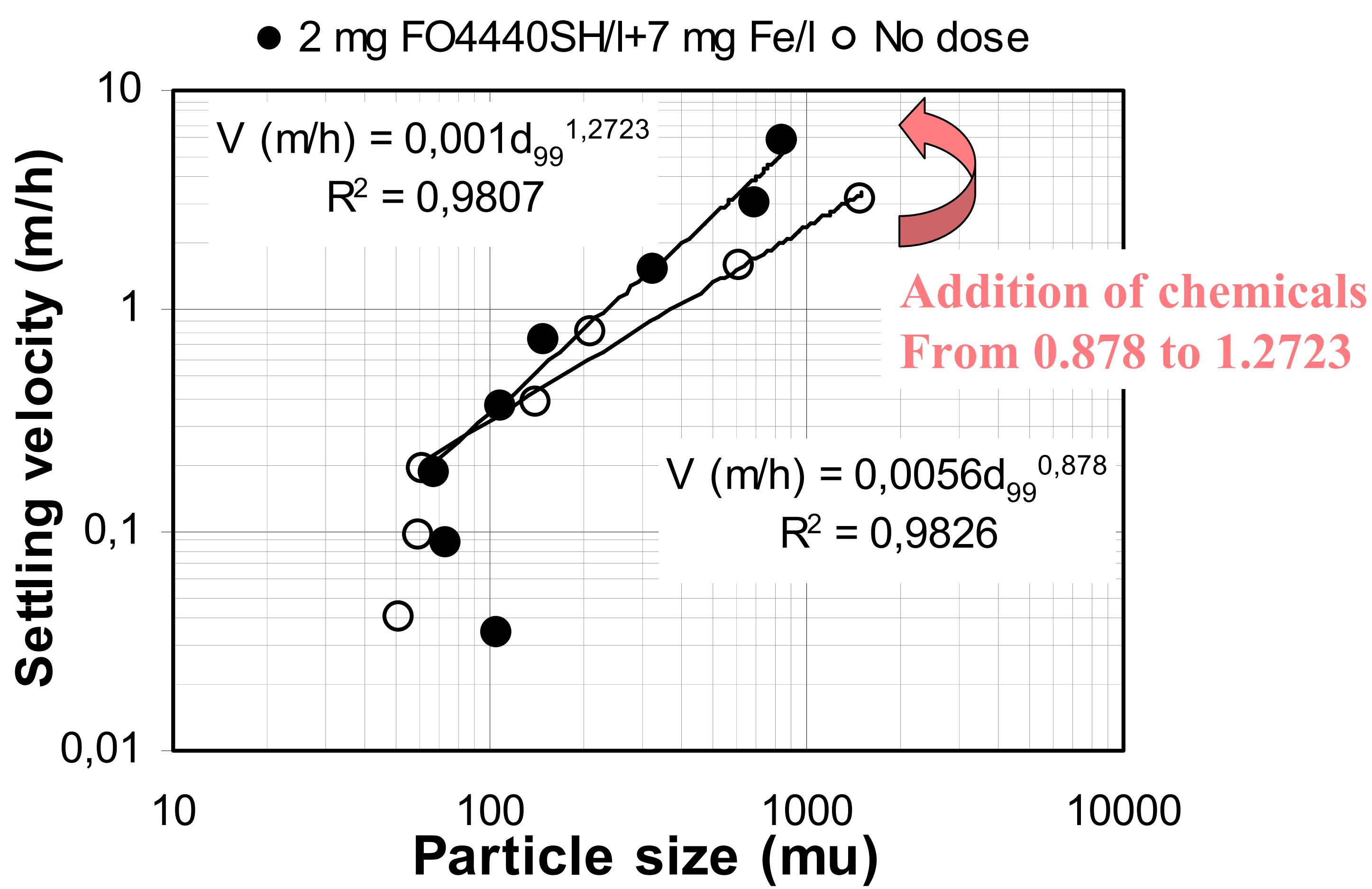
Particles are difficult to settle down because of low temperature and density

Particle size distribution of raw wastewater—A comparison

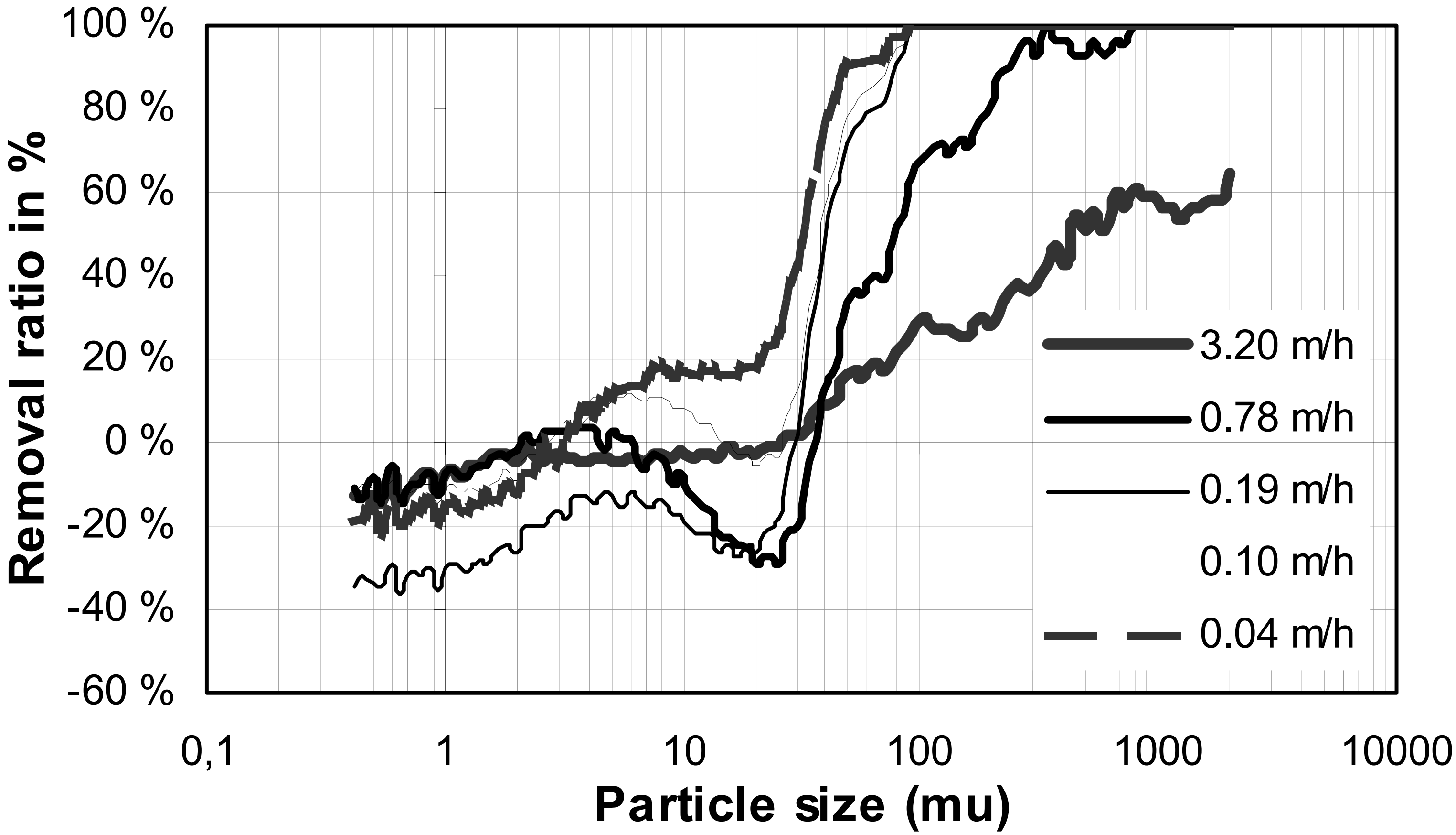




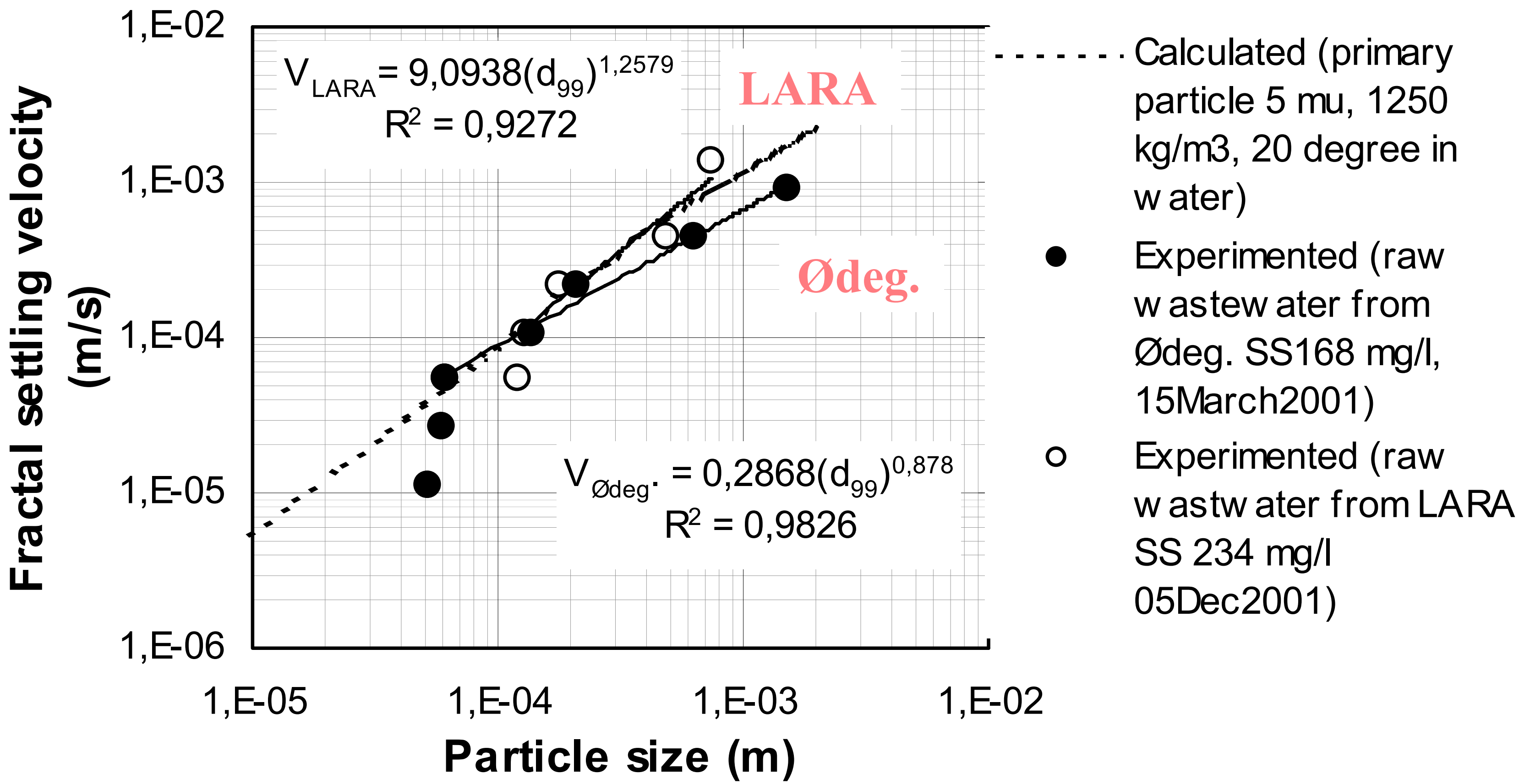
Settling velocity vs particle size—Effect of chemical addition



SS removal of various particles in settling column



Fractal settling velocity—comparison of two wastewaters

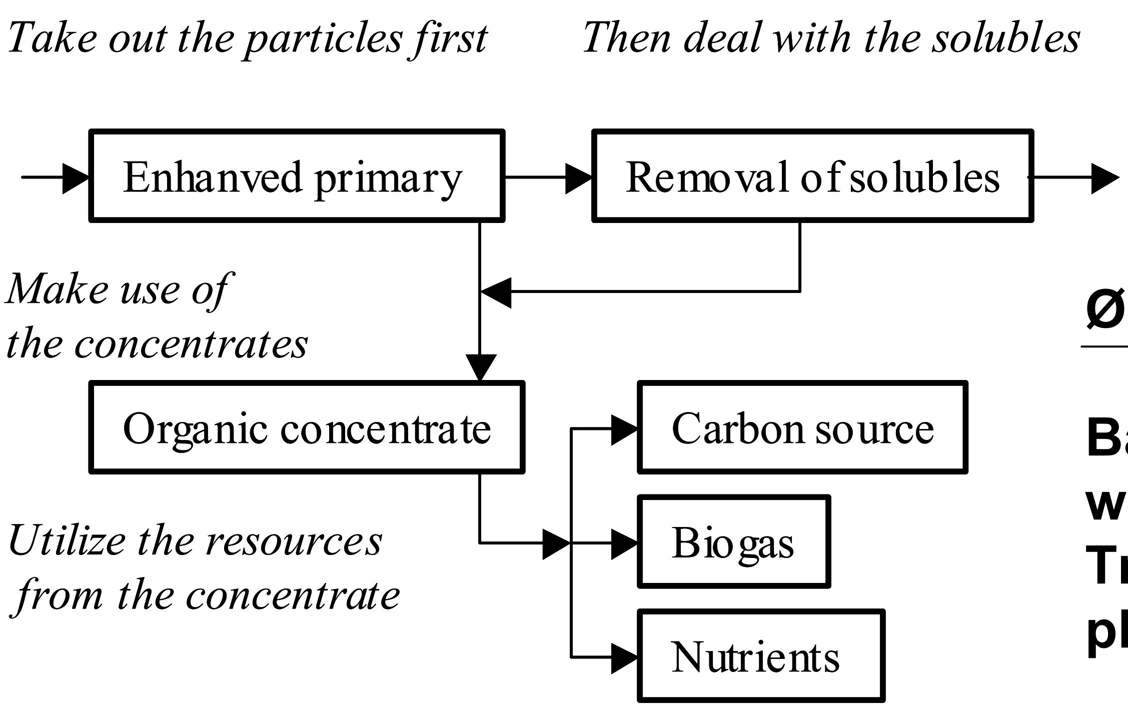


Wastewater characterisation—Main conclusions

- Contaminants in wastewater are largely related to particles (SS, COD, BOD, N and P, bacteria, virus, parasites, heavy metals, micropollutants, etc).
- Particles may be difficult to settle down (low temperature and density), therefore conventional sedimentation may not be effective.
- Particles are fractal in properties, indicating the complication of the issue of concern.
- Wastewater characterisation should be considered in determination of treatment technologies.

Wastewater treatment strategy

- Wastewater as resources: water, bio-energy, heat energy, biosolids, nutrients recovery.
- Particle separation as one of priorities.



Ødegaard (2000)

Basic wastewater Treatment philosophy

Approaches to enhance particle separation

- Changes in particle size and density: coagulation/flocculation, pelletisation, biosorption and bioflocculation (by sludge recycling), additions of heavy particles (magnetite or microsand or the like), addition of air-bubbles (dissolved air flotation).
- Application external attracting forces: Direct current electrical field, high-grade magnetic field, multiple gravitational field.
- Decreases in particle separation distances: Inclined plate/tube settling, deep bed filtration, membrane filtration.
- Combinations: contact (coagulating) filtration, ActiFloc process, SirlFloc process, coagulating dissolved air filtration, hydrodynamic separators, coagulation membrane filtration.

Comparison of several particle separation processes

- Pre-precipitation: (Ødegaard and co-workers) metal salts plus polymers, removal efficiencies: SS 92.9%, COD 77.5%, BOD7 83.7%, total P 95%; overflow rate:1-1.5 m/h (lab 7.5 m/h).
- ActiFloc process: (Guibelin et al 1994) Microsand 135 microns plus coagulant and flocculent, lammella settler up to 135 m/h, SS 80%, BOD 60%, P 80%.
- Hydrodynamic separator: (Andoh et al 1996) SS 60-90%, BOD 40-85%, P 40-95%, oil and grease 80-95%, total coliform 80-99%. Becker et al (2000) effluent 5 NTU and 20 mg TSS/l at 57 m/h.
- Dissolved air flotation: (Pinto Filho et al 2001) SS 74-95%, COD 70-89%, Turbidity 77-90%, P >90%, overflow rates: conventional DAF 5-7 m/h, DAF-filter 10-15 m/h, turbulent DAF 25-40 m/h.

Common: well controlled coagulation flocculation+high dosages

Coarse media filtration—Tertiary filtration

- Granular deep bed filters for tertiary filtation: (Task Committee on Design of Wastewater Filtration Facilities 1986) a well established process—

  Media/size (mm)/depth(m): Sand/0.4-0.6/0.25-0.3, Sand/1.0-1.2/0.6-0.9, Anthracite/0.8-1.0/0.5-0.6, S or A/1.4-1.6/0.75-0.9, S or A/1.6-1.8/0.9-1.1, S or A/2.0-2.4/1.25-1.5. Total head loss 2-4 m, water production per cycle 200-400 m3/m2, SS-in 30-70 mg/l, filtration rate 0.08-0.4 m3/m2/min (4.8-24 m/h), SS removal 70%.
- Variation of operation: HydroClear filter—shallow depth pulsed-bed sand filter; DynaSand filter—deep bed continuous backwash filter.

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Coarse media filtration-Secondary and primary effluent filtration

- Secondary filtration: (Sjøvold 1999, Von Vogt 2000, Ødegaard et al 2000) Media expanded clay aggregate (Filtralite) crushed in desired sizes, HC 1.5-4 mm/HC 1.5-6 mm, depth 1.2 m, filtration rate 5-12.5 m/h, MBBR effluent, SS 76-88%, COD 34-60%. (Ødegaard, Liao, and Hansen 2002) Kaldnes-Filtralite-Sand filter, Kaldnes media 11-24 mm/1 m, Filtralite 2.5-5 mm/0.5 m, Sand 1.2-2 mm/0.3 m, at 10 m/h and 2 mg/l polymer (high MW cationic), SS 90% effluent SS <15 mg/l, 20 m/h and 2 mg/l SS 85% effluent 25 mg/l, Sludge accumulation to 2-m head loss is 15-20 kg/m2-filterbed.
- Prmary effluent filtration: (Jimemez et al 1999) Mexico City, compressive Fuzzy synthetic media filter, effluent SS less than 30 mg/l, 1.02-1.3 Hleminth egg/l, SS 45%, filtration rate 21-87 m/h at head loss 10 m.

Coarse media filtration—primary treatment

- Primary filtration:

  Tanaka et al (1995)—ring shaped polypropylene net, porosity 90%, filtration rate 41.7 m/h, 2-3 mg/l cationic polymer, SS 80-90%, BOD5 44%, 2-m bed depth, head loss 0.2 m.

  Wessman (1997)—Kaldnes media K1, 1-m depth, filtration rate 25 m/h, SS 73% at no dose.

  Lerch (1998)—Kaldnes media, Star media, PS balls, PE discs in two stage filter, 30 m/h, SS 80-85% (no dose) or 90% (1.5 mg/l polymer).

  Ødegaard et al (1998)—Kaldnes K1 media, 1 m depth, SS 75-85% at filtration rate 5-15 m/h and no dose condition.

Coarse media filtration (CMF) for enhanced primary treatment (EPT)

- Rationales of enhanced primary treatment by coarse media filtration.
- Kaldnes media: media characterisation and bed configurations.
- Comparison of single media floating filters.
- Comparison of dual media filters and optimisation.
- Mutlimedia filters.
- Discussions
- Conclusions

Rationales of EPT by CMF

- Contaminants in wastewater are largely related to particles.
- Particles may be difficult to settle down (low temperature and density) in conventional sedimentation.
- Particles interfere biodegradation.

- Enhancement of particle removal is very beneficial to downstream biological treatment.
- Coarse media filtration is very effective and efficient for particle separation if proper media bed.
- Synthetic plastic media can be manipulated in many ways.

Problems → **Solutions**

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Kaldnes media: characterisation

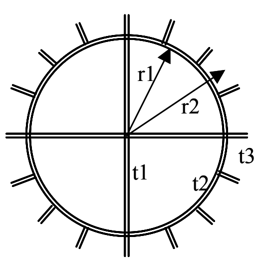
Two sizes K1 and K2 modified and two densities (950 and 1450 kg/m3) form four media K1L, K2L, K1H, and K2H.

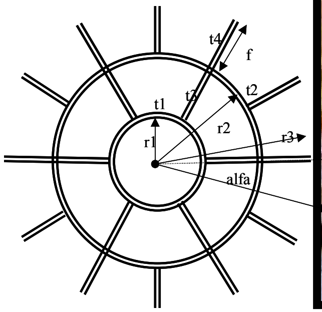
- K1: diam. 11*8 mm.

  A cylinder with a cross inside and 18 short (1mm) outer fins

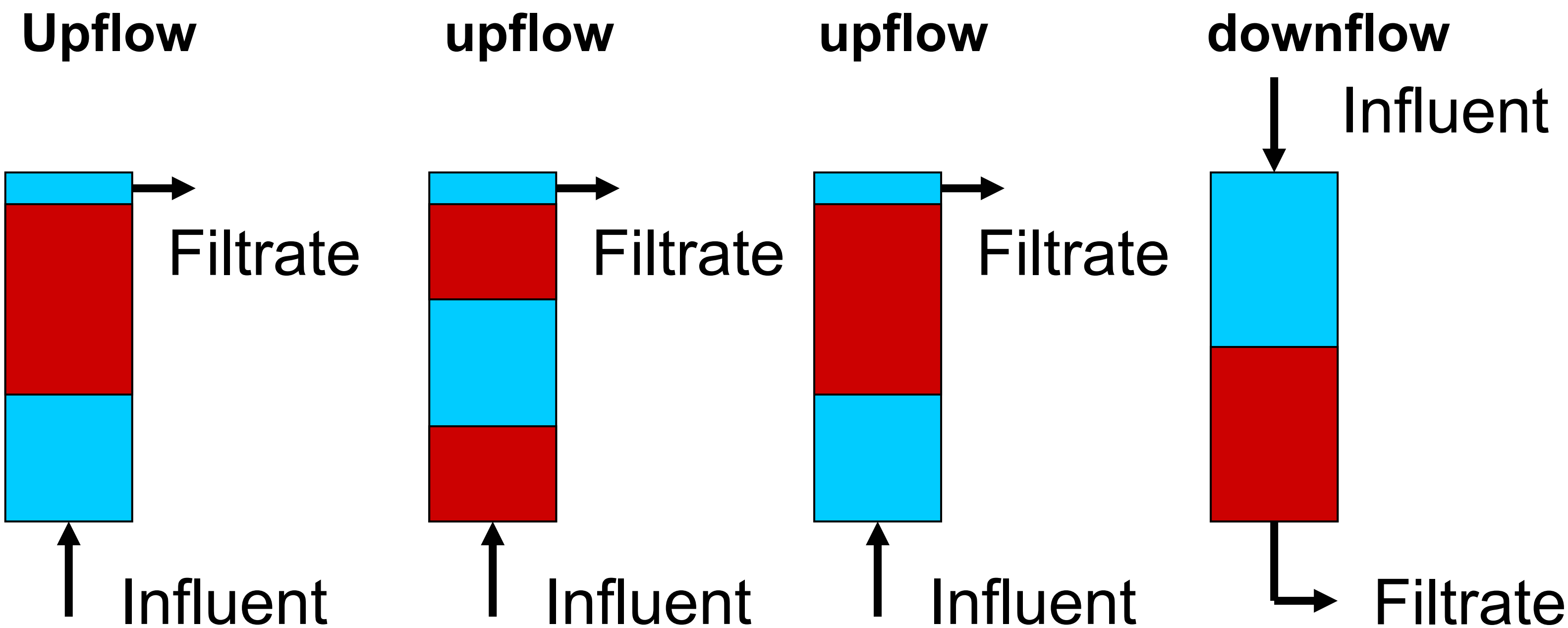
- K2 modified: diam.24*15mm.

  Two concnetric cylinders with partitioning and 12 long (5mm) outer fins.





Media bed configurations

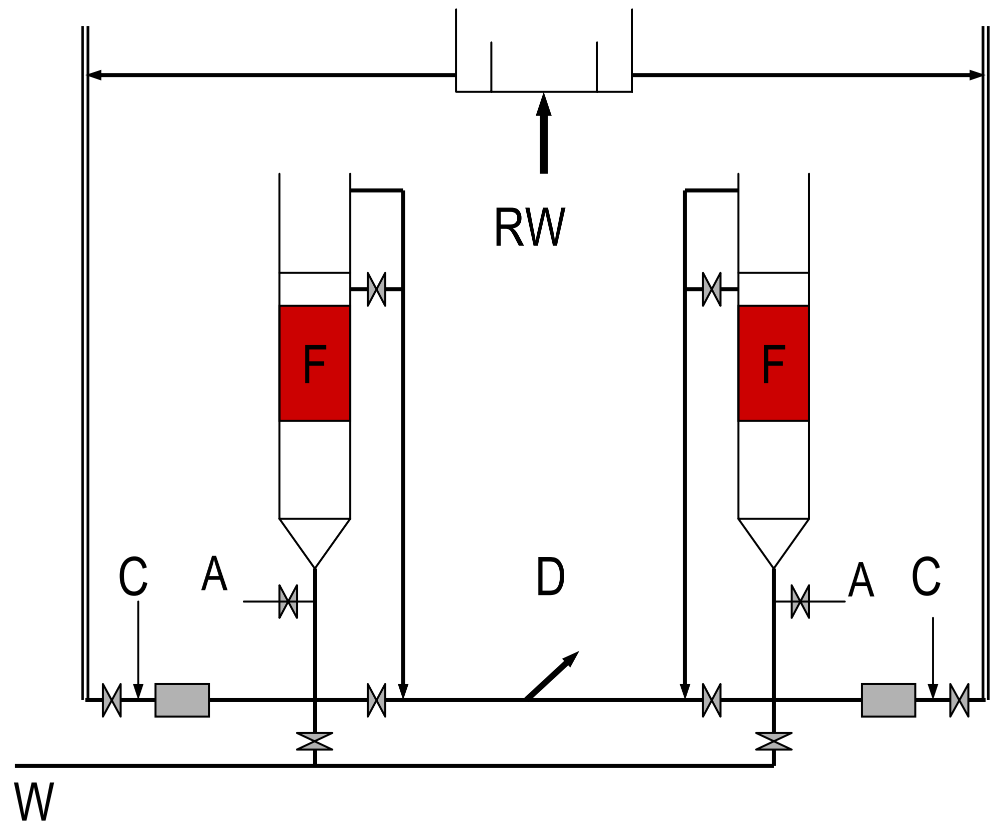


Single media	Dual media	Dual media	Dual media
K1L or K2L	K1L+K2H	K1L/K2L	K1H/K2H
1 m bed	0.5 m each	0.5 m each	0.5 m each

Porosity 0.8 in K1 bed and 0.86-0.9 in K2 bed

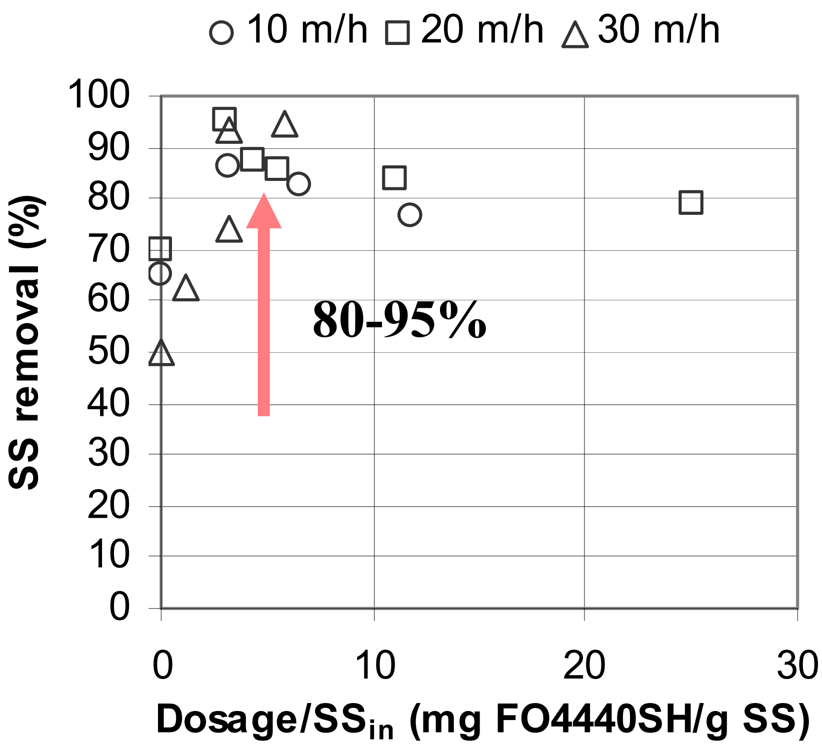
Comparison of single K1L and K2L media filters—Set-up

- **Set-up**—
  Ladehameren Wastewater Treatment Plant (LARA).
- **Raw wastewater**—
  SS: 414±261 mg/l
  COD: 713±294 mg/l
  SCOD: 202±122 mg/l.
- **Floerger FO4440SH**:
  High MW medium charge cationic polymer.

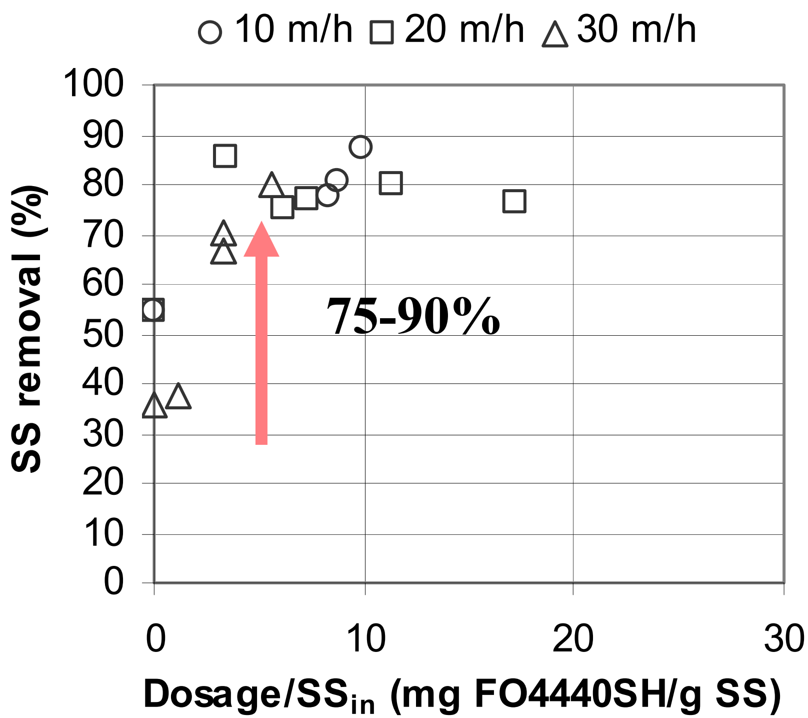


Comparison of K1L and K2L filters: SS removal (1)

K1L filter



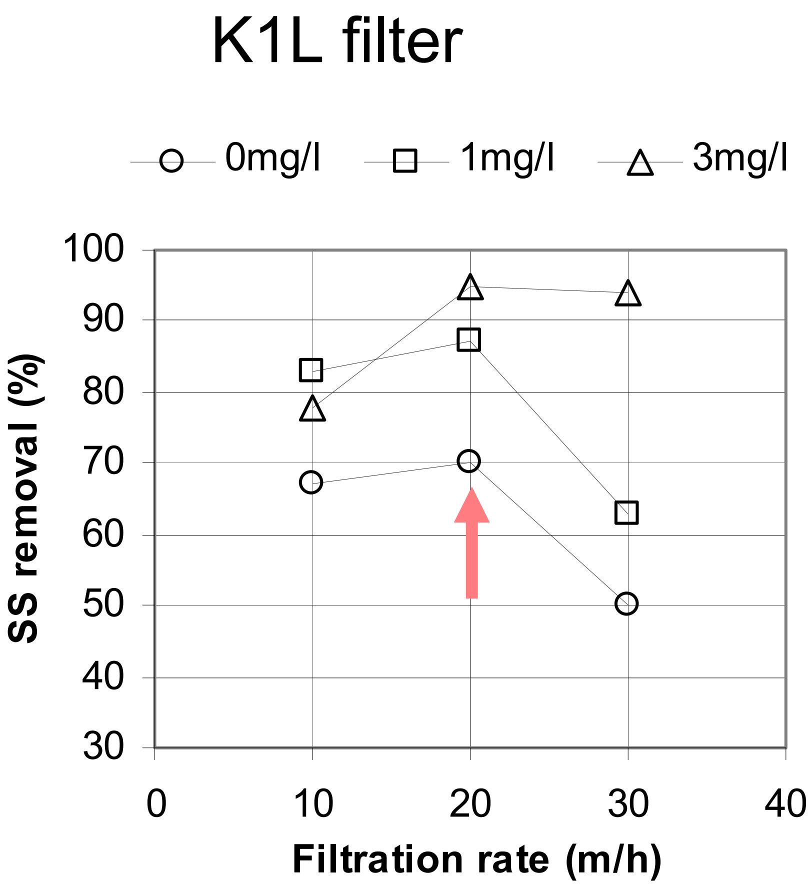
K2L filter

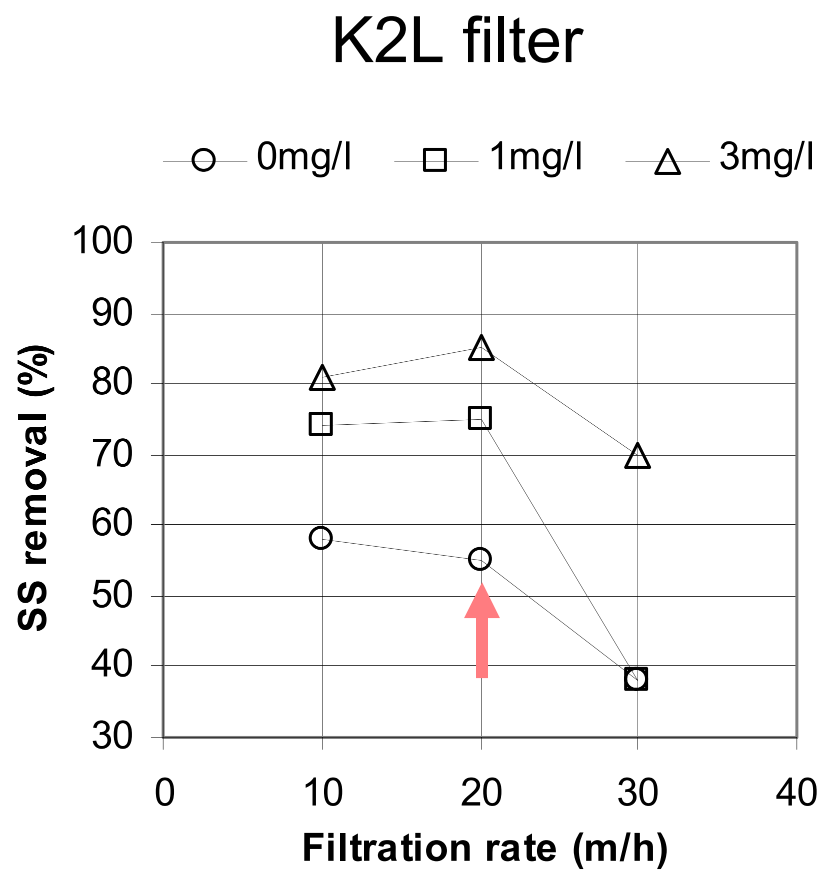


A critical dosage ratio of 5 mg FO4440SH/g SS equals to 1-2 mg FO4440SH/l at SS-in 200-400 mg/l, little influence of filtration rate.

No dose: K1L—65-70% up to 20 m/h, K2L—55% up to 20 m/h

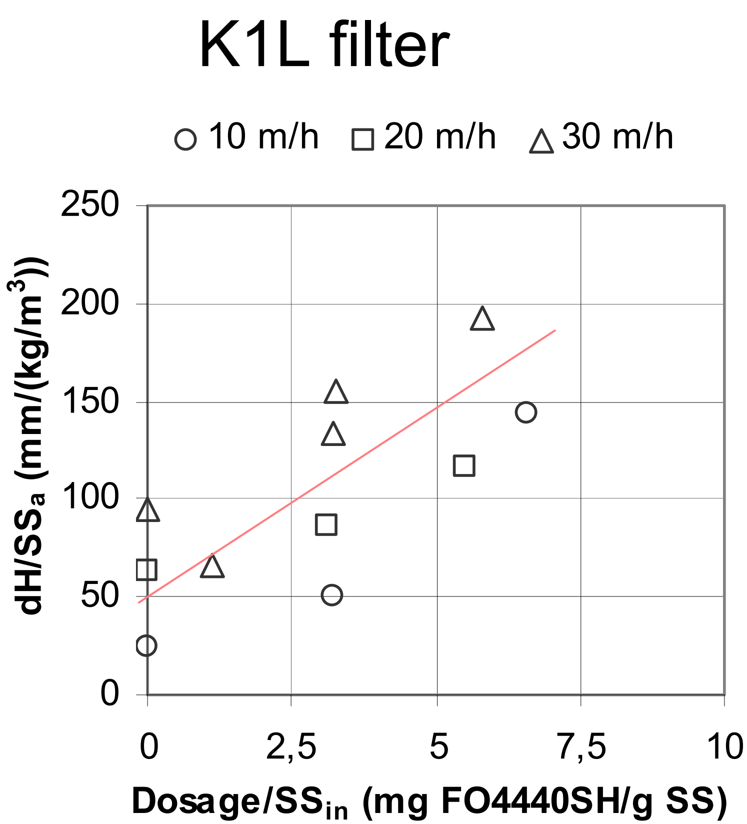
Comparison of K1L and K2L filters: SS removal (2)

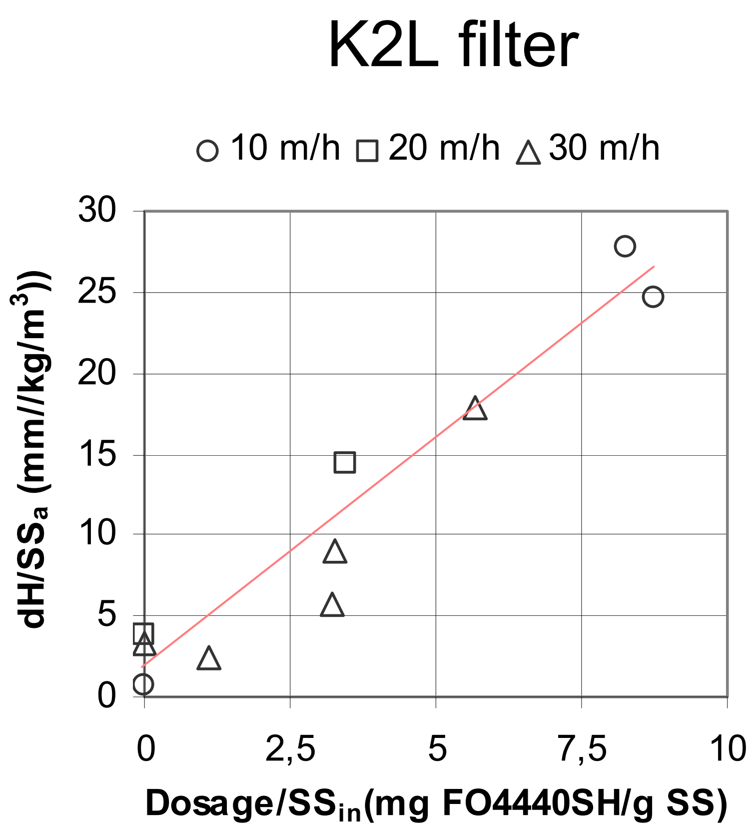




Addition of polymer compensates decreases in SS removal at high filtration. 20 m/h is a turning filtration rate, below this small influence on SS removal.

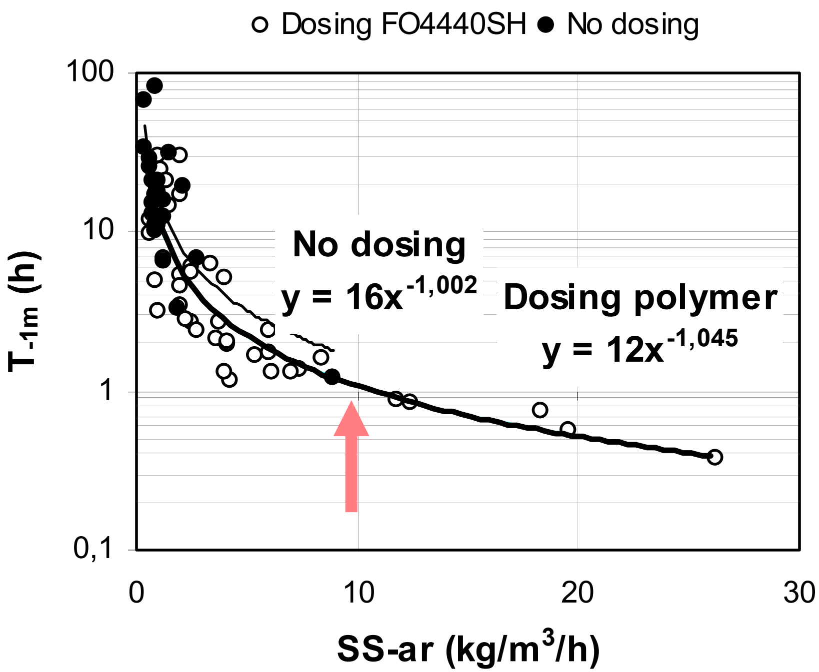
Comparison of K1L and K2L filters: Specific head loss

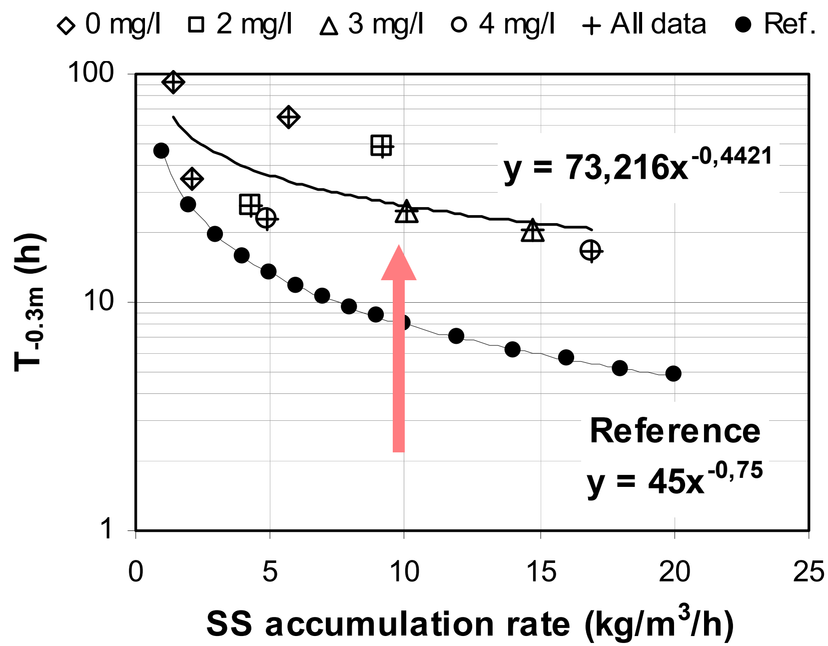




Specific head loss in K2L filter is only 1/10 of that in K1L filter.
Specific head loss strongly depends on dosage ratio.
Dosage ratio larger than 5 mg polymer/g SS has no benefit.

Comparison of K1L and K2L filters:





Length of filter cycle vs SS acc. rate in K1L filter (left) and K2L filter (right).

Comparison of K1L and K2L filters:

- K1L bed—small pores and quick clogging because of short outer fins.
- K2L bed—little clogging but breakthrough.
- Media—coarse enough to prevent clogging and fine enough for good
- Polymer and dosage—flocs just strong enough to withstand hydrodynamic
- A critical dosage ratio of 5 mg pol/g SS or 1-2 mg/l for SS in influent 200-
- Optimisation in media structure or in bed configuration is required for

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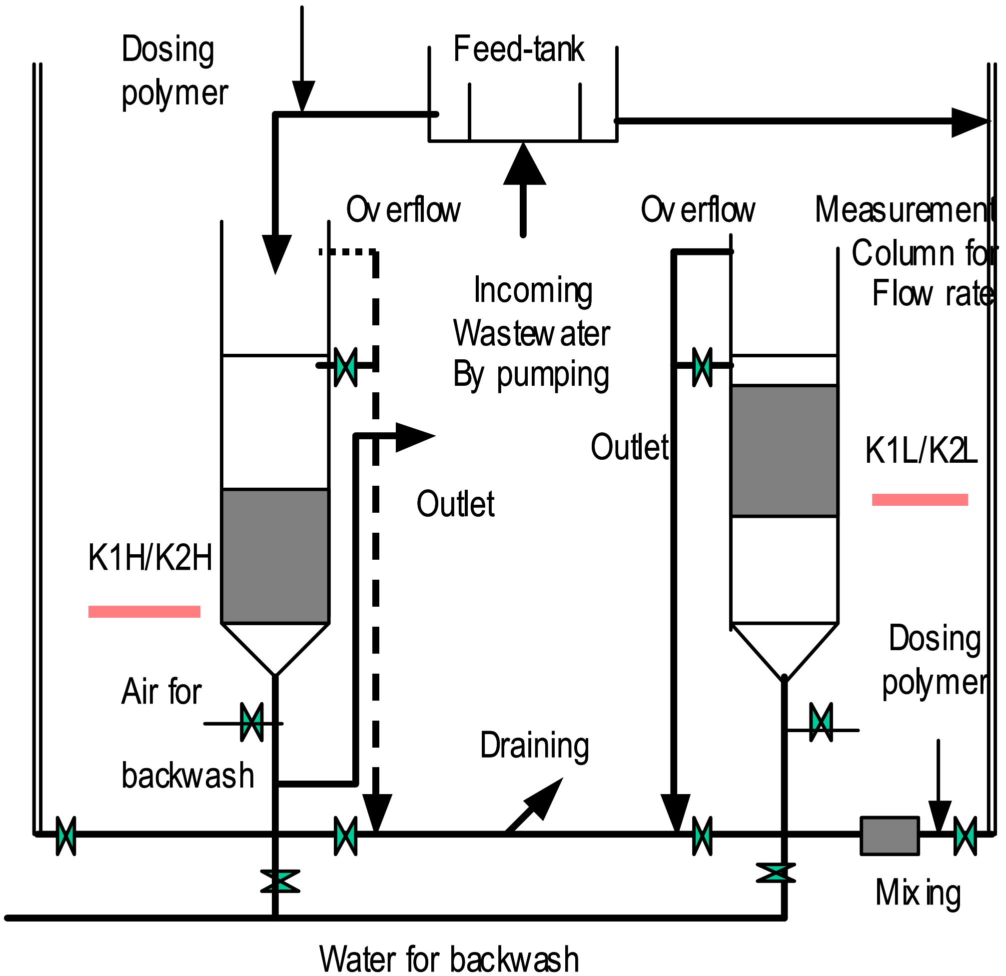
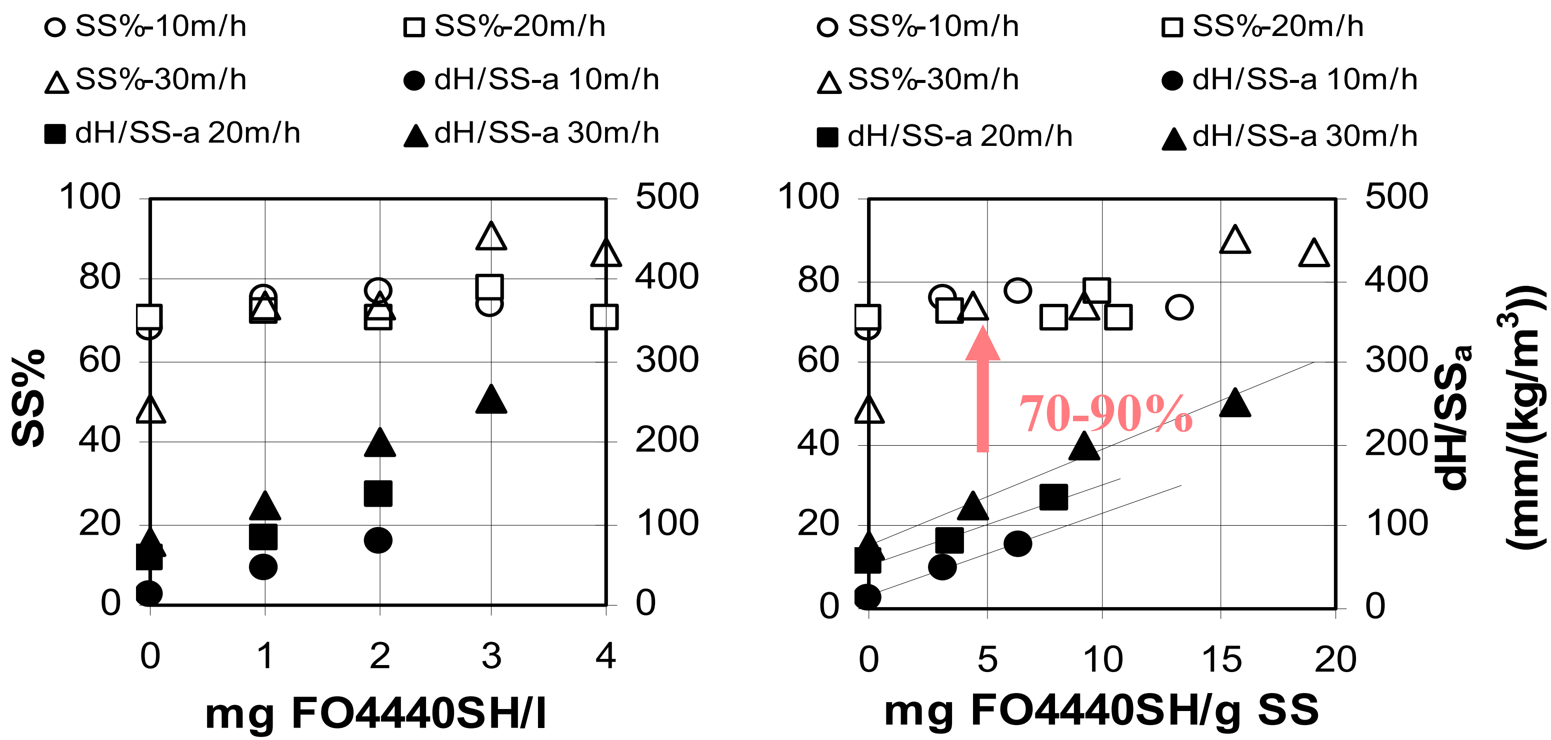
Dual media filters and optimisation: Set-

- SS: 246 ± 73 mg/l
- COD: 458 ±135 mg/l

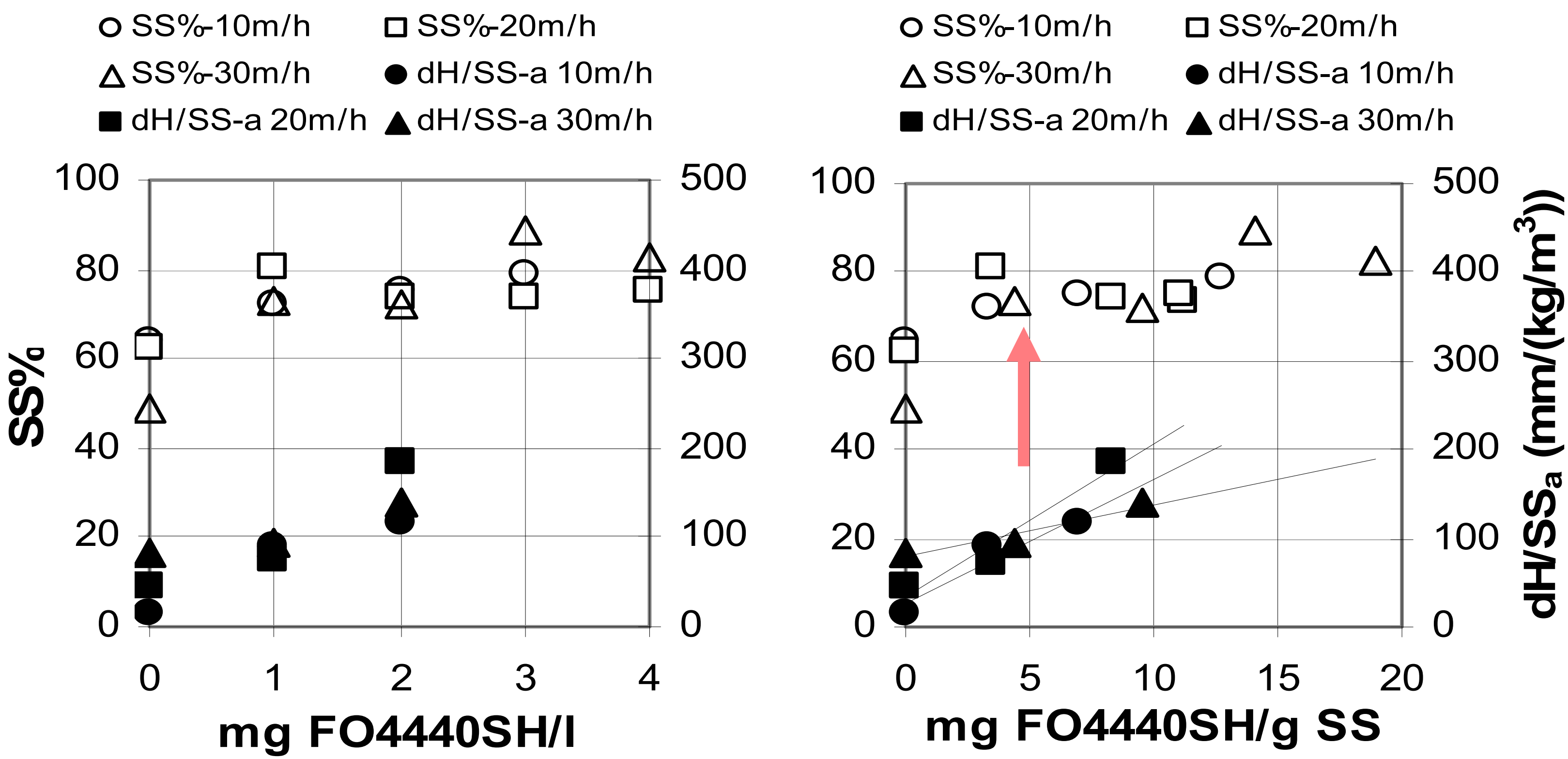


Dual media filters: The K1L/K2L filter



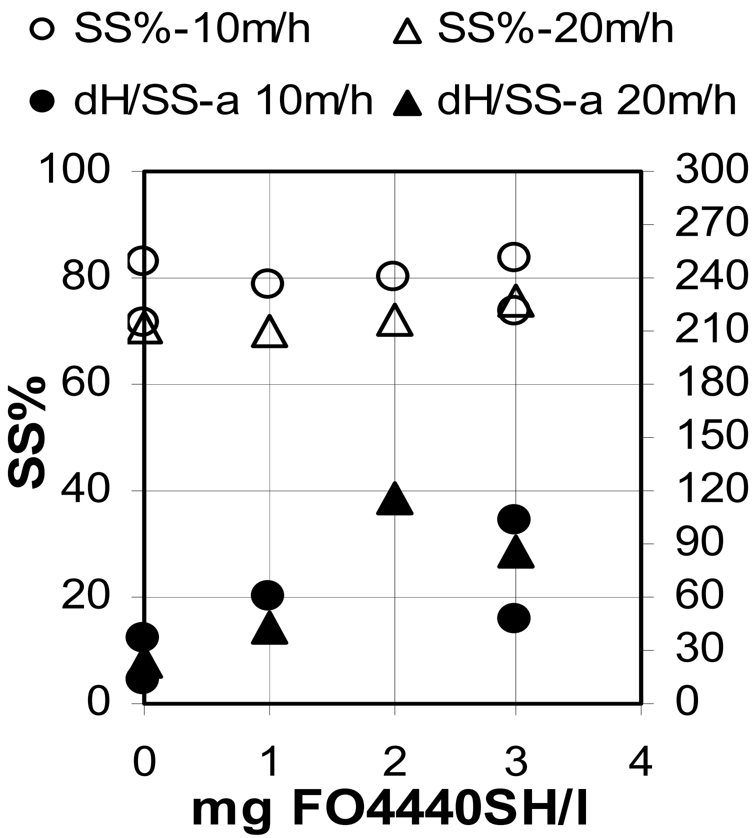
A critical dosage ratio of 5 mg pol/g SS is still there with SS removal of 70-90%. While no dose, around SS removal 70% is obtained up to 20 m/h. Specific head loss is 1/3 lower than in K1L filter.

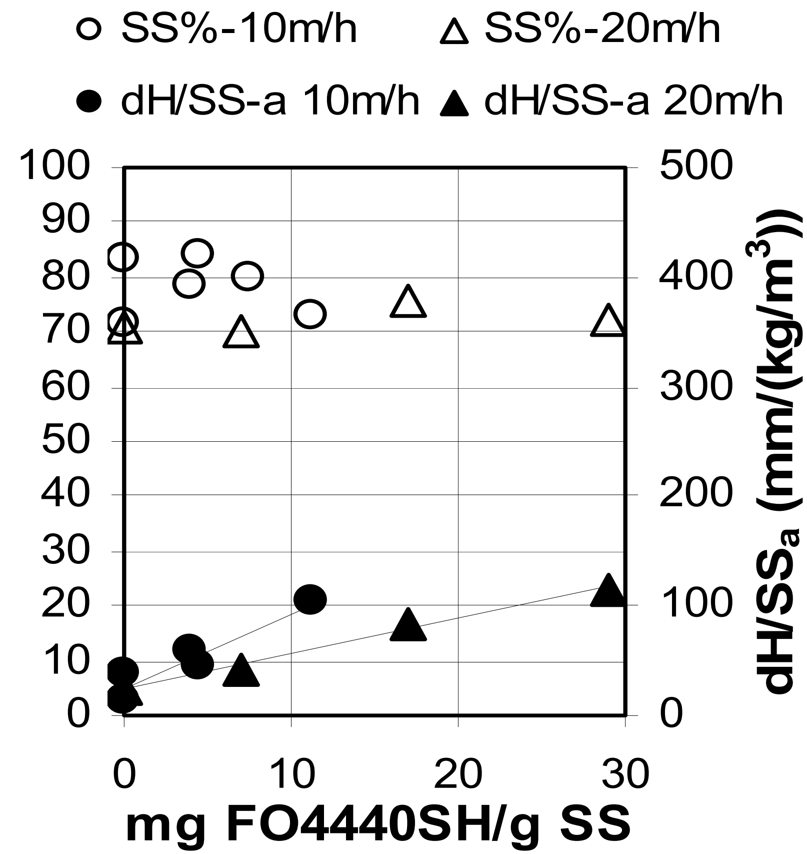
Dual media filters: The K1L+K2H filter



A critical dosage ratio of 5 mg pol/g SS is still there with SS removal of 70-90%. While no dose, around SS removal 65% is obtained up to 20 m/h. Specific head loss is 1/3 lower than in K1L filter with more variation. The K2H layer moves up.

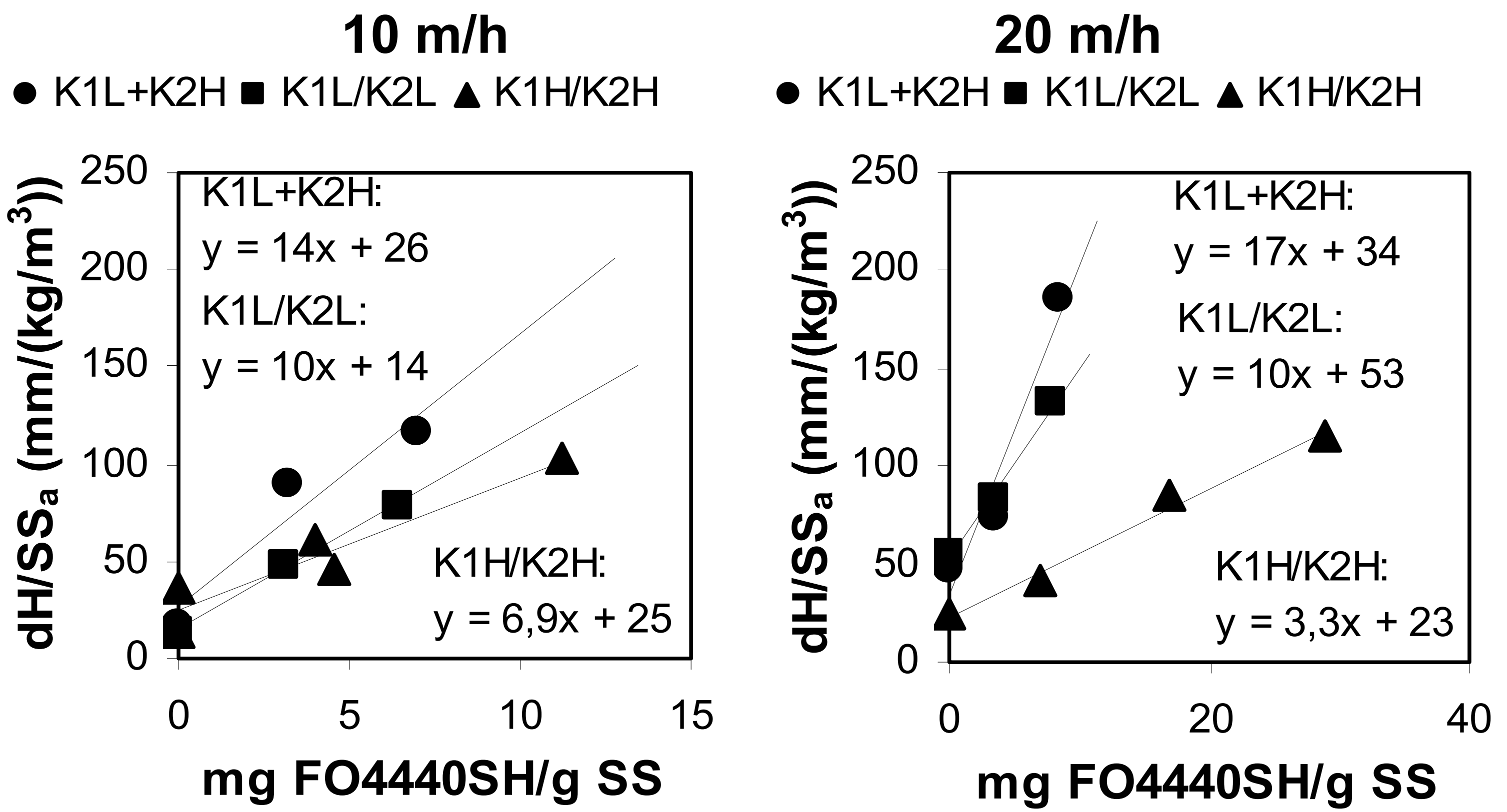
Dual media filters: The K1H/K2H filter





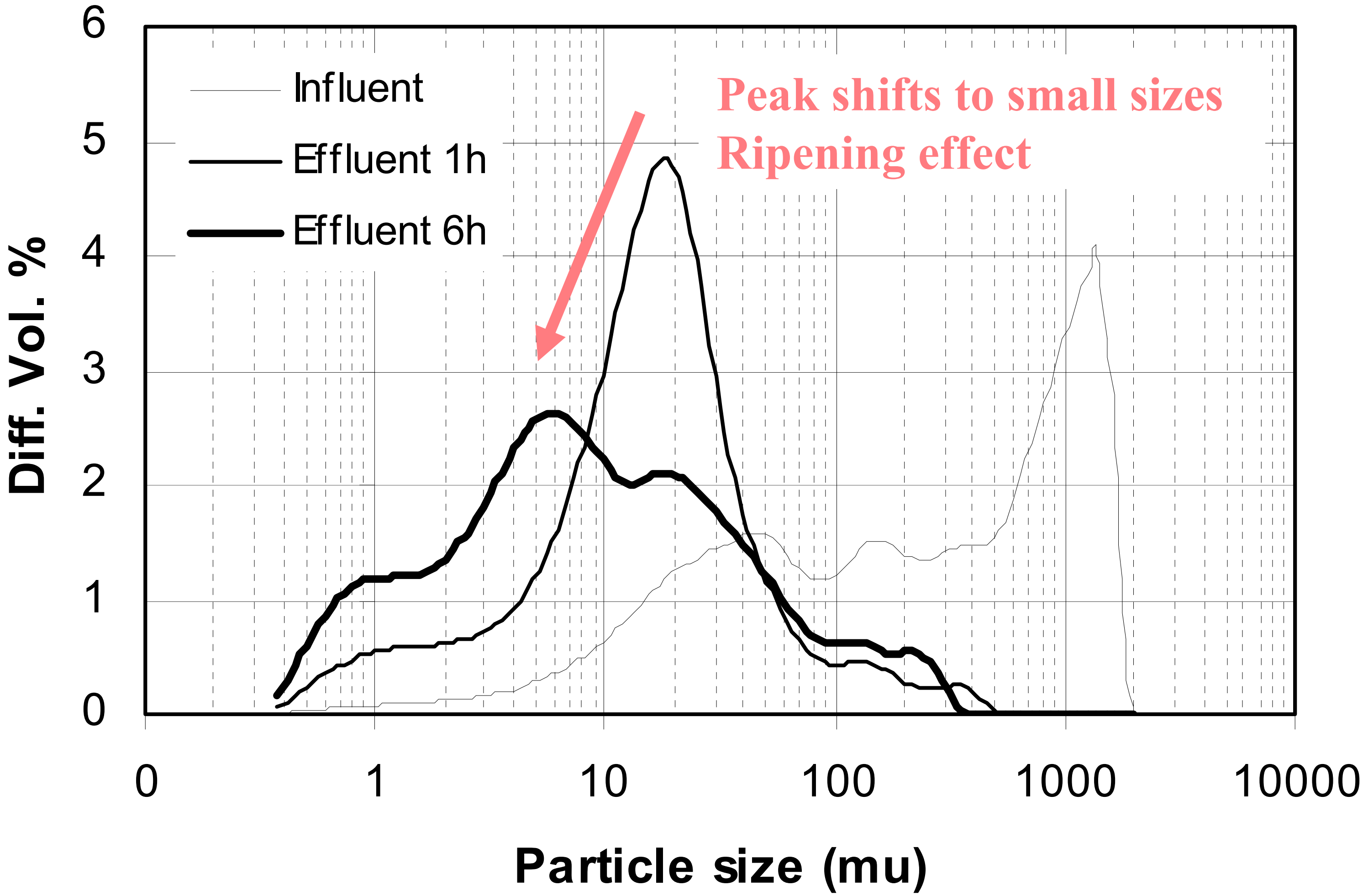
Similar SS removal compared with others, but much lower head loss.
!! Specific head loss is lower at higher filtration rate.
While no dose, SS removal of 70-85% is obtained up to 20 m/h.
A natural grading effect of media bed occurs, more K1H on bottom.

Dual media filters: A comparison of

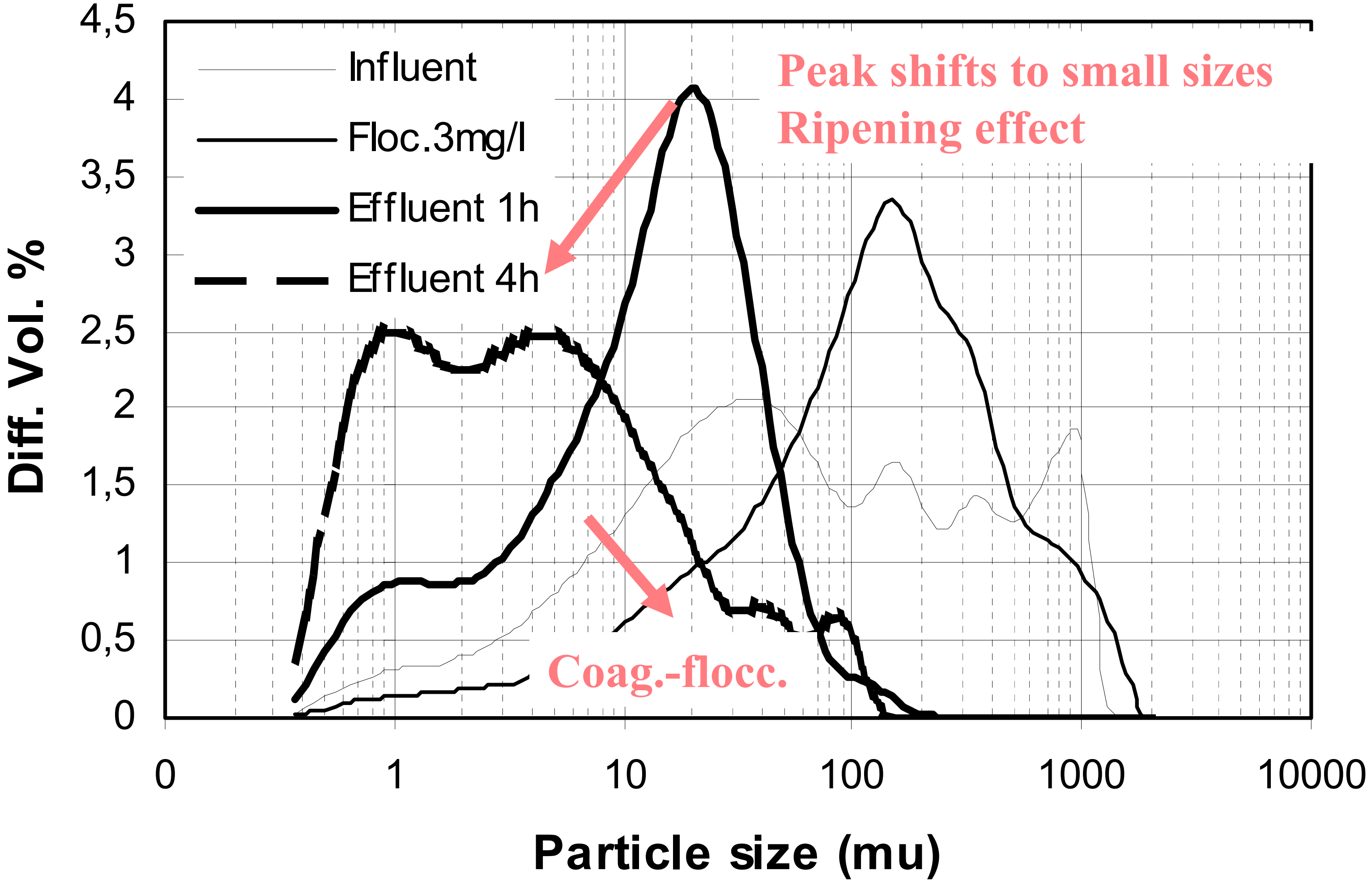


Different behaviours in specific head loss in three dual media filters reveal the influence of media bed configurations.

PSD changes in the K1H/K2H filter—10



PSD changes in the K1H/K2H filter—10

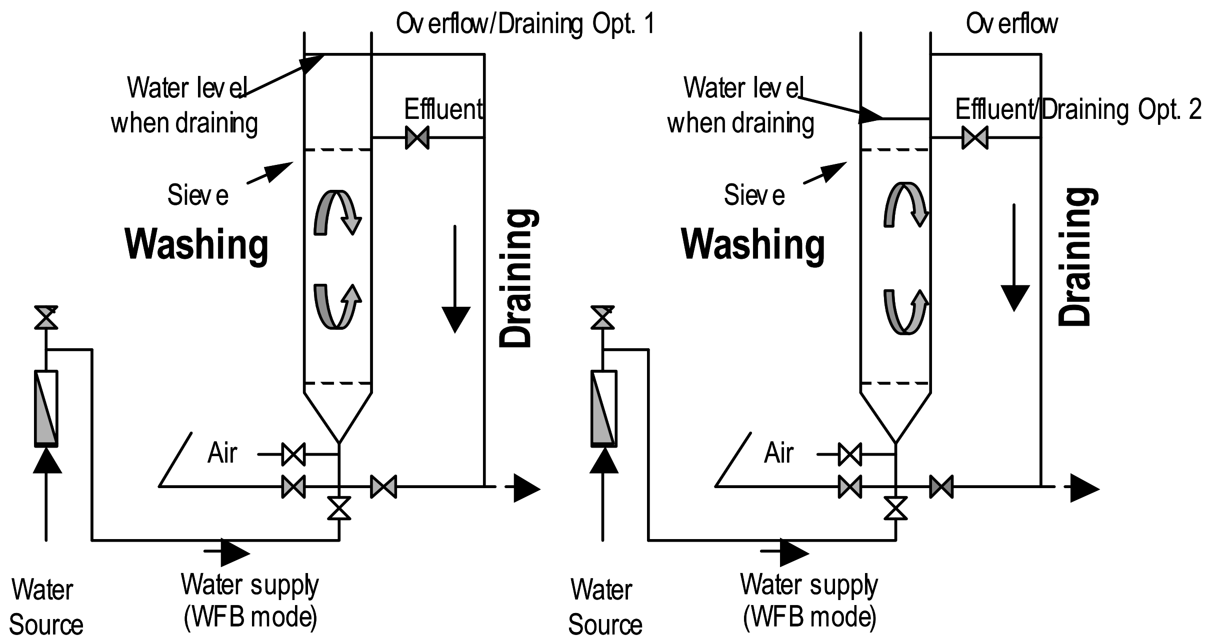


Dual media filters: A summary

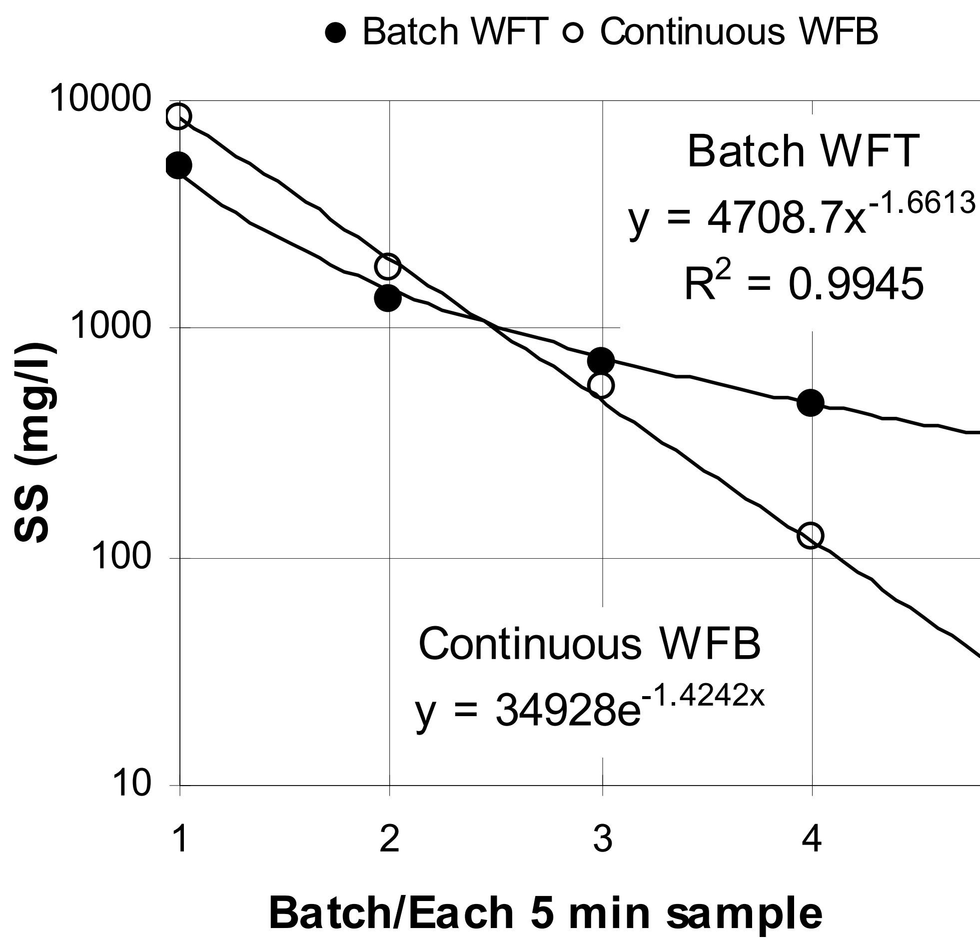
- There are lower head loss in dual media filters, epecially in the
- Although SS removal and head loss in the K1L/K2L and the
- The K1H/K2H filter is the best for the reasons of lower head loss,
- The K1L/K2L filter is also a good choice for its low head loss and high
- The K1L+K2H filter should be ruled out for its unstable peformance.

Backwashing: Single media filters

- Three backwash modes are compared: Batch mode Water supply from



Backwashing: The K1L filter



Comparison of two backwash modes at air and water flow rates of 90 and 31.5 m/h

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- The optimal backwash parameters: air flow rate 60 m/h, water flow
- The SS reduction versus water consumption follows exponential law.

$$C = C_0 e^{-kQ}$$

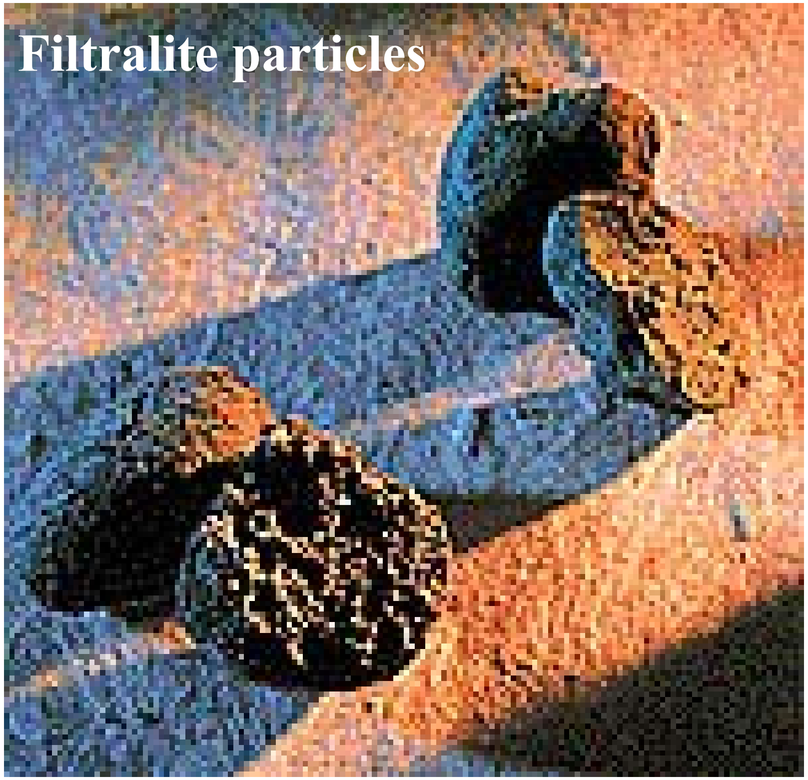
- Water consumption for SS reduction by 99% is 8.3 m3/m2.
- Optimal procedure: two-step procedure—A batch atep of air-loosing

Backwashing: Dual media filters

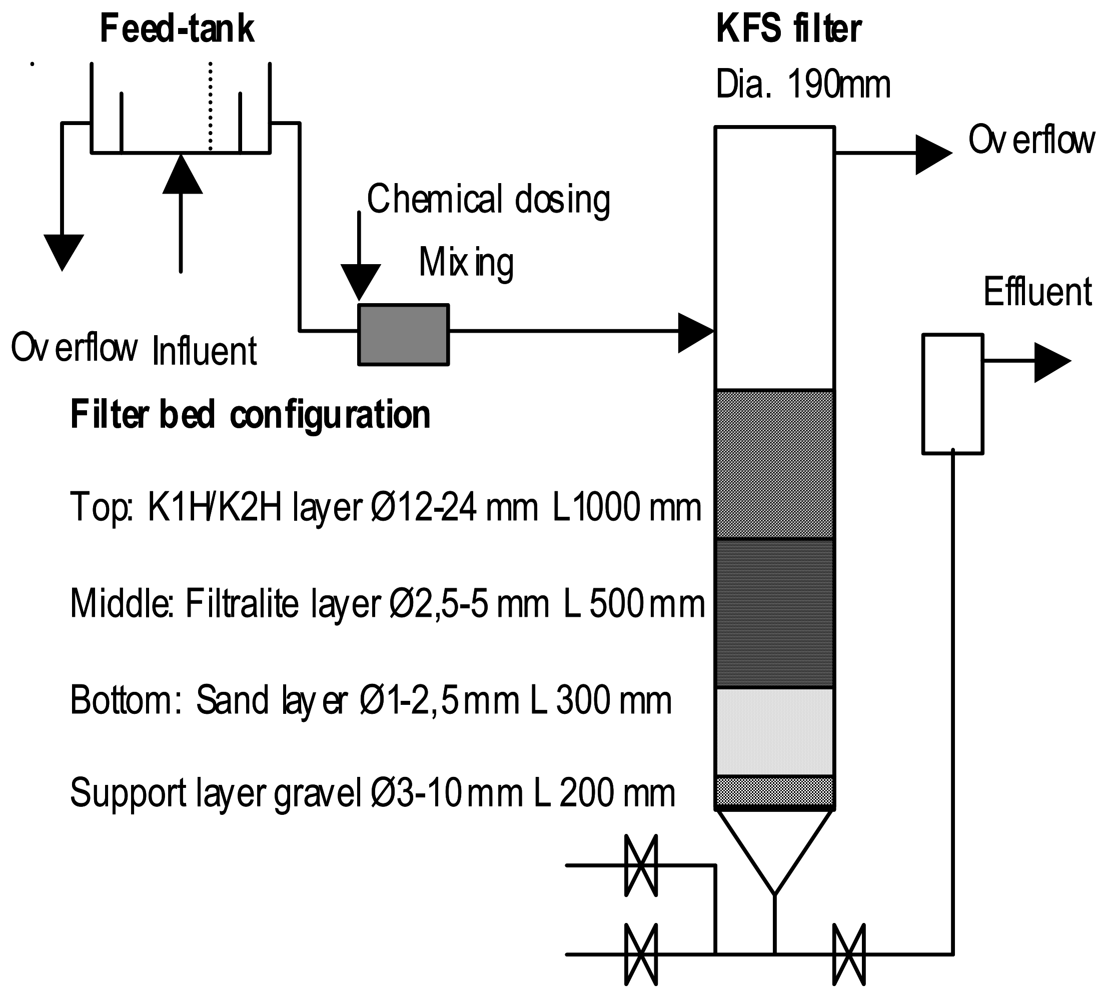
- Backwashing of the K1L/K2L and the K1L+K2H filters follow the
- Backwashing of the K1H/K2H filter uses continous mode with water
- Optimal backwash parameters for the K1L/K2L filter is air and water

Kaldnes-Filtralite-Sand (KFS) filter

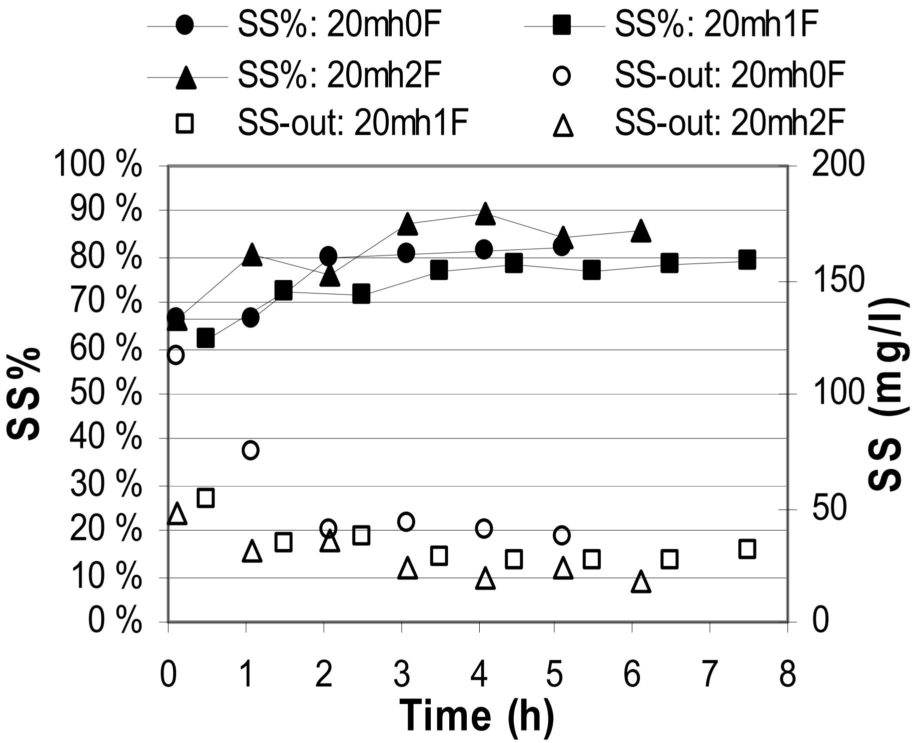
- Combination of the K1H/K2H
- Candidate granular media:
- Compatibility of media

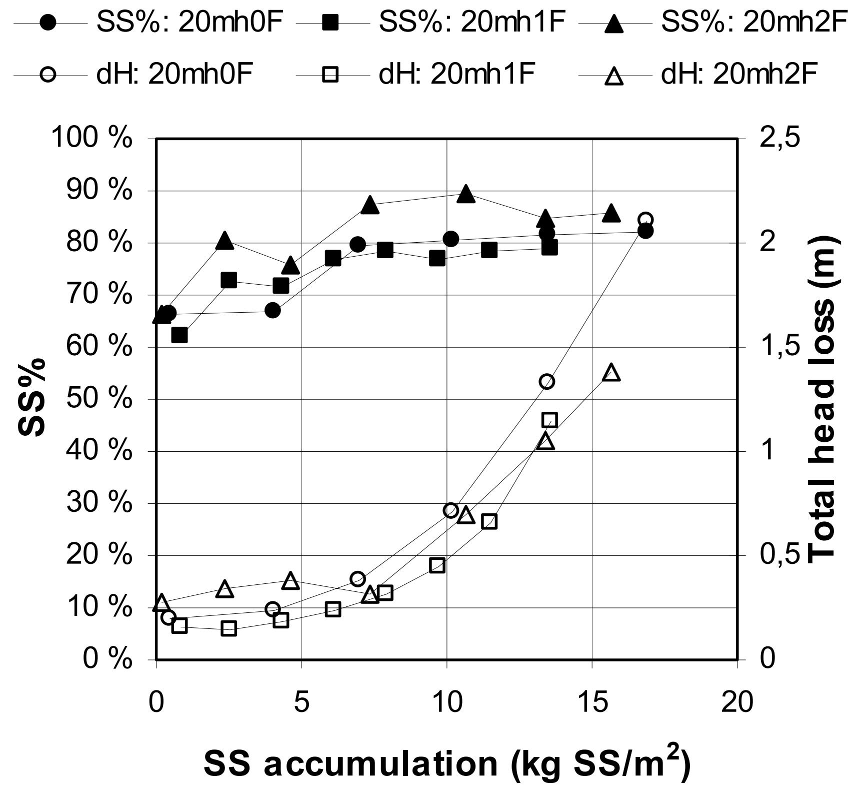


KFS filter: Set-up



KFS filter: 20 m/h



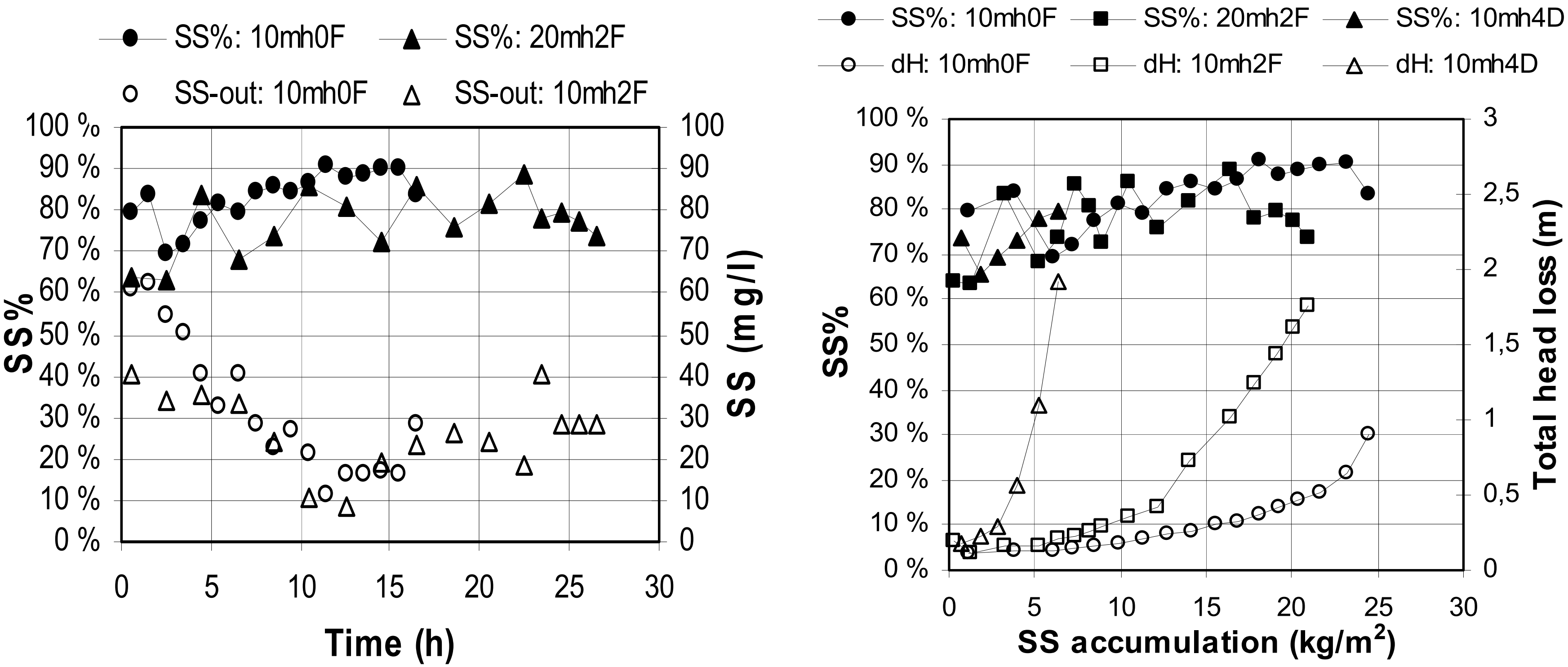


SS% and effluent SS vs time **SS% and head loss vs SS acc.**

Effluent SS 20-40 mg/l, SS% 80-90% (1-2 mg/l) or 70-80% (no dose)

SS accumulation up to 15-20 kg/m2 bed.

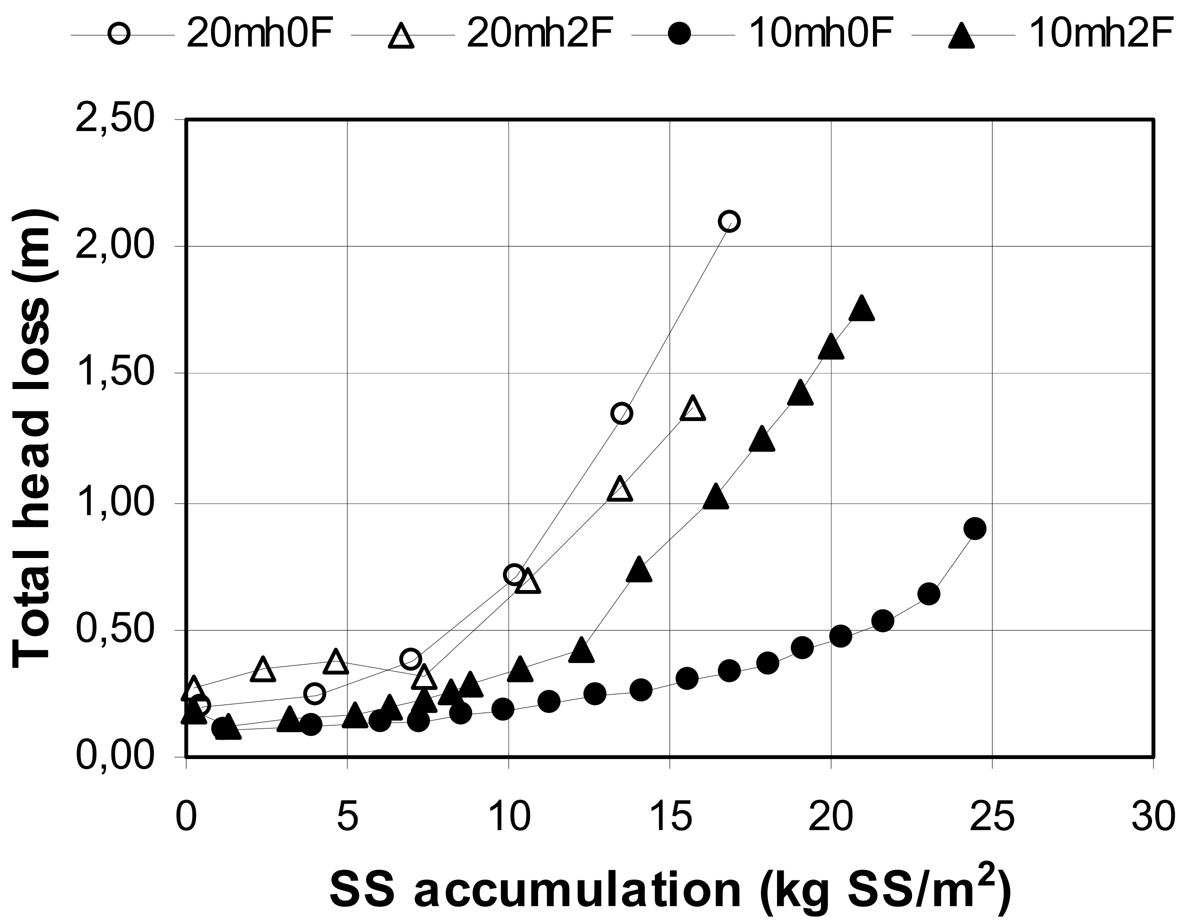
KFS filter: 10 m/h



SS% and effluent SS vs time **SS% and head loss vs SS acc.**

Effluent 20-30 mg/l, SS% 70-90%, SS accumulation 20-25 kg/m2 (0-2 mg/l high MW polymer) but 5 kg/m2 while 4 mg/l low MW polymer.

KFS filter: A comparison of head loss



Addition of polymer has less influence on head loss at higher filtration rate.

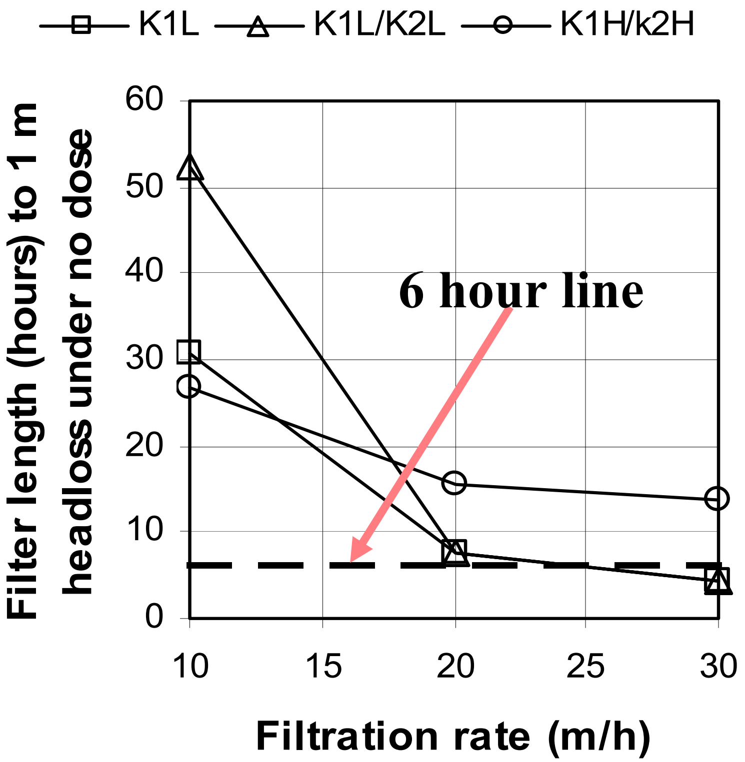
KFS filter: Further researches

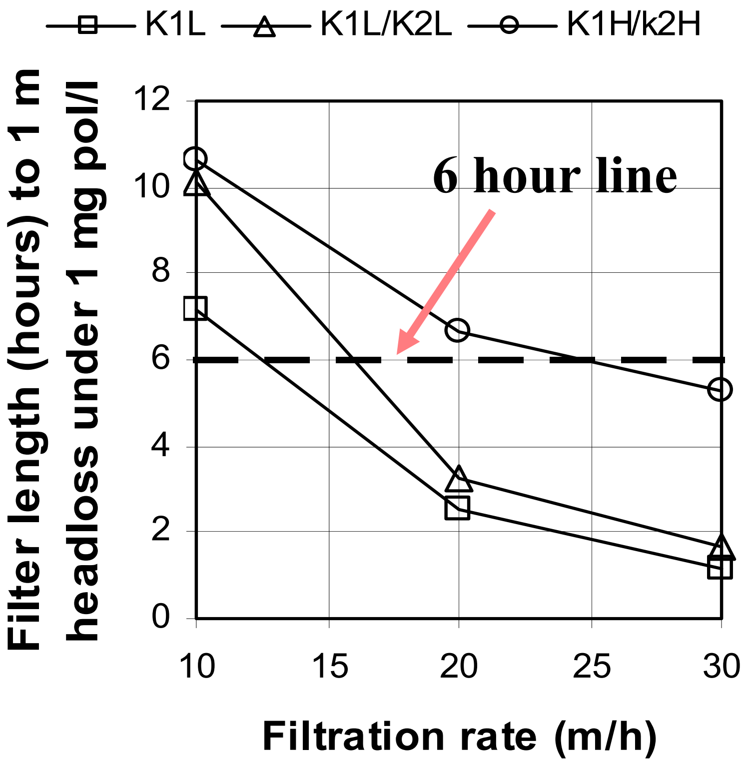
- Optimisation of media structure and bed configuration.
- Backwashing procedures.
- Possible application to secondary filtration and tertiary filtration.

Comparison of the K1L, the K1L/K2L, and the K1H/K2H filters

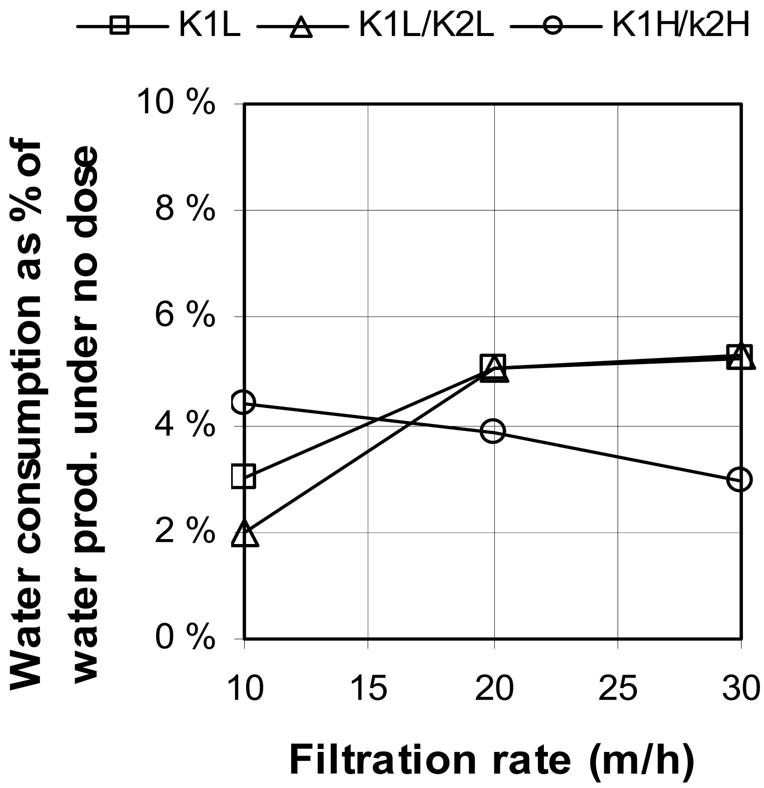
- The K1L, the K1L/K2L and K1H/K2H filters are feasible for enhanced primary treatment under different filtration rates and polymer dosages.
- According to previous results on SS removal and specific head loss in three filters under no dose condition and optimal dosage ratio, the backwashing properties, and the assumed influent SS concentration 200 mg/l, a prediction to filtration performances is made for a) length of filter cycle, water consumption for backwash, water production.

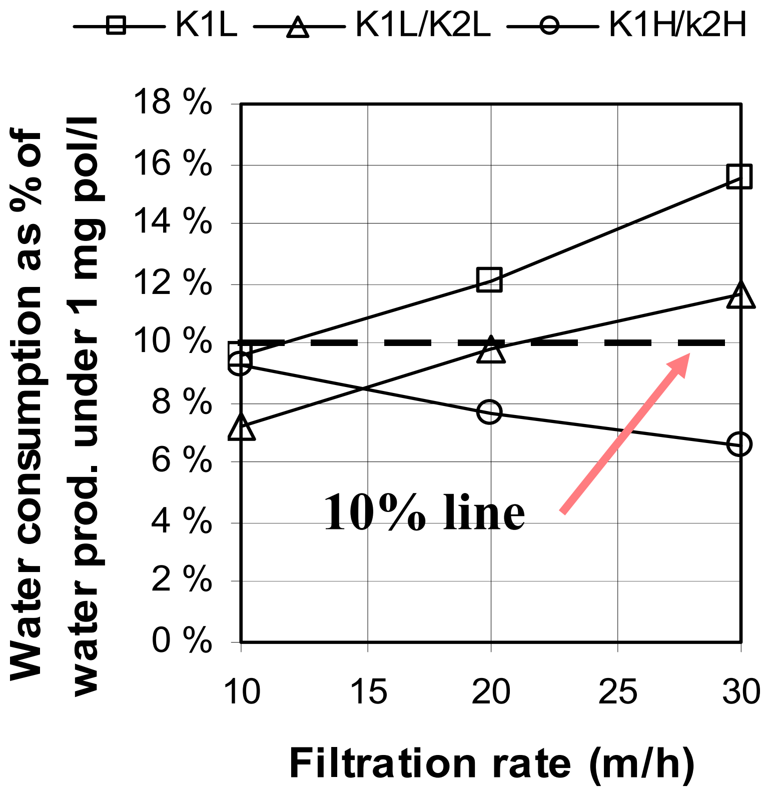
A prediction: Filter length to 1-m headloss



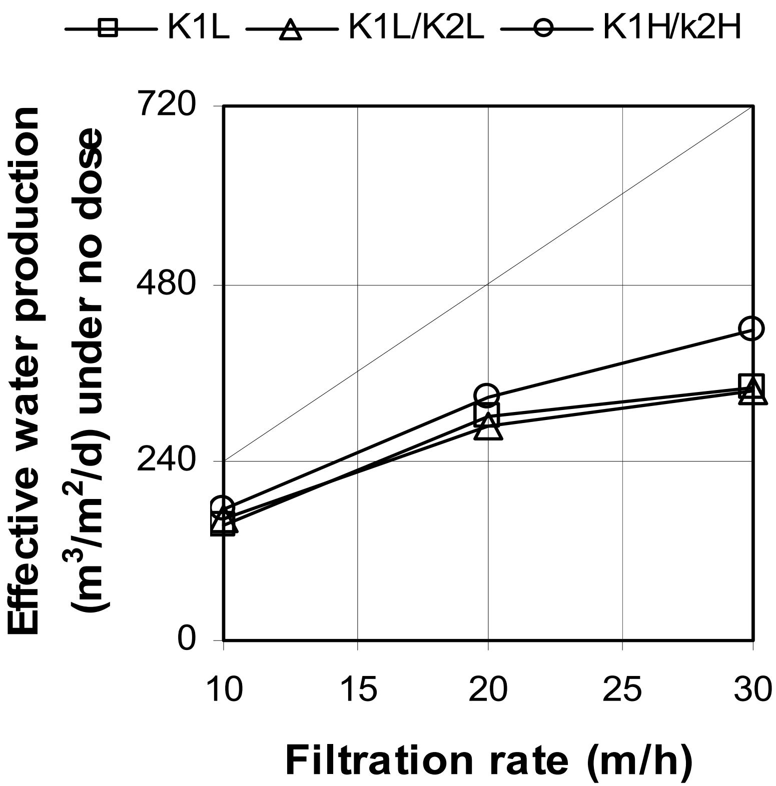


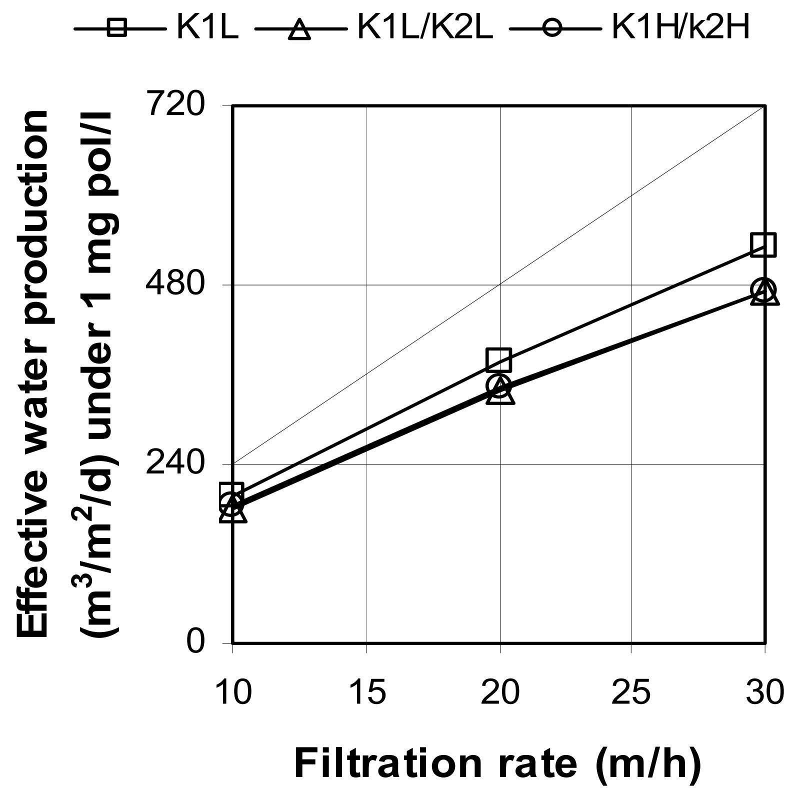
A prediction: water consumption for backwashing





A prediction: Effective water production





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Design suggestion for three filters—No dose condition

Parameters	K1L filter	K1L/K2L filter	K1H/K2H filter
Filtration rate	10-20 m/h	10-20 m/h	10-30 m/h
Air flow rate Water flow rate	30-60m /h 30-40 m/h	30-60 m/h 30-40 m/h	60-90 m/h 30-40 m/h
Expected SS removal efficiency	60-70%	60-70%	60-75%
Expected filter length to 1 m head loss	6-30 h	6-50 h	12-30 h
Expected water consumption for backwash	2,5-5%	2-5%	4-5,5%

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Design suggestion for three filters—Optimal dosage ratio

Parameters	K1L filter	K1L/K2L filter	K1H/K2H filter
Filtration rate	10-12 m/h	10-15 m/h	10-25 m/h
Air flow rate and water flow rate	30-60m /h 30-40 m/h	30-60 m/h 30-40 m/h	60-90 m/h 30-40 m/h
Expected SS removal efficiency	80-85%	70-80%	70-80%
Expected filter length to 1 m head loss	6-7 h	6-10 h	6-12 h
Expected water consumption for backwash	10%	7-10%	6-9%

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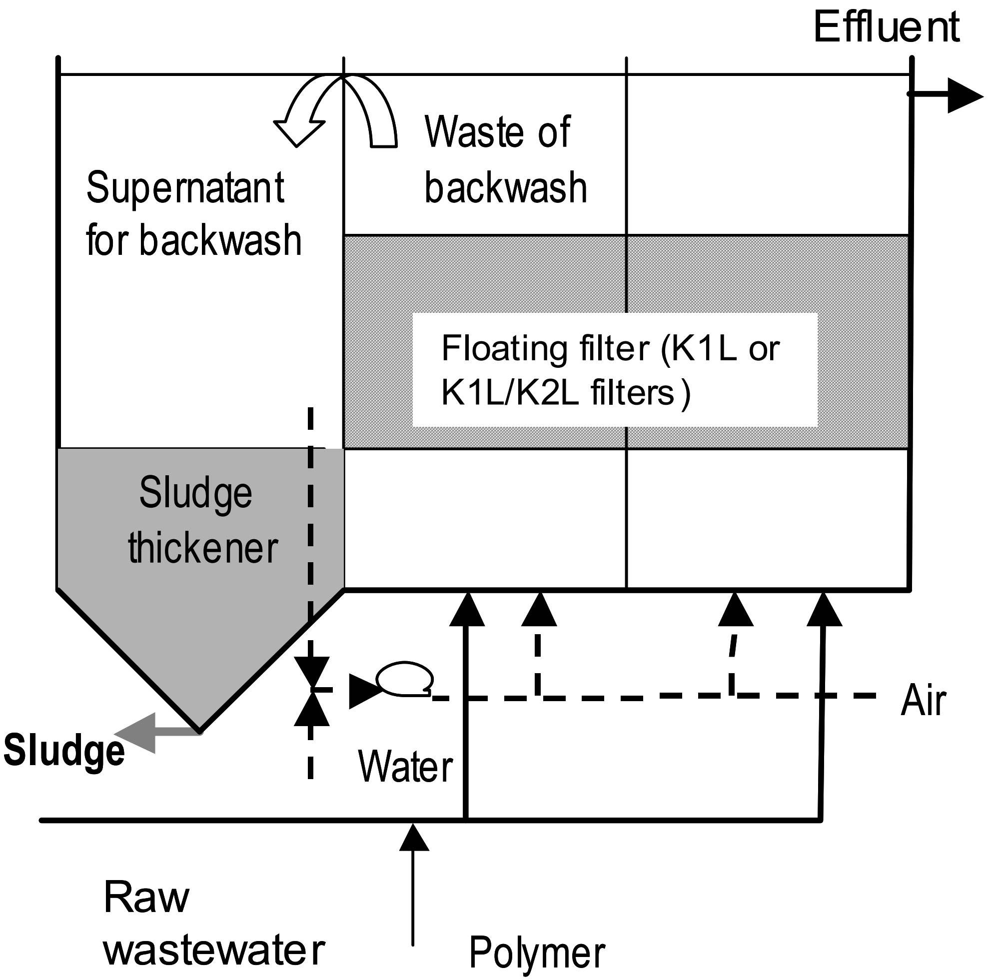
Upgrading of existing primary tank (1)

Floating filter is applied.

Part of primary tank as sludge thickener and the supernatant for backwash.

Water consumption is reduced significantly.

Similar way to upgrade circular tank.



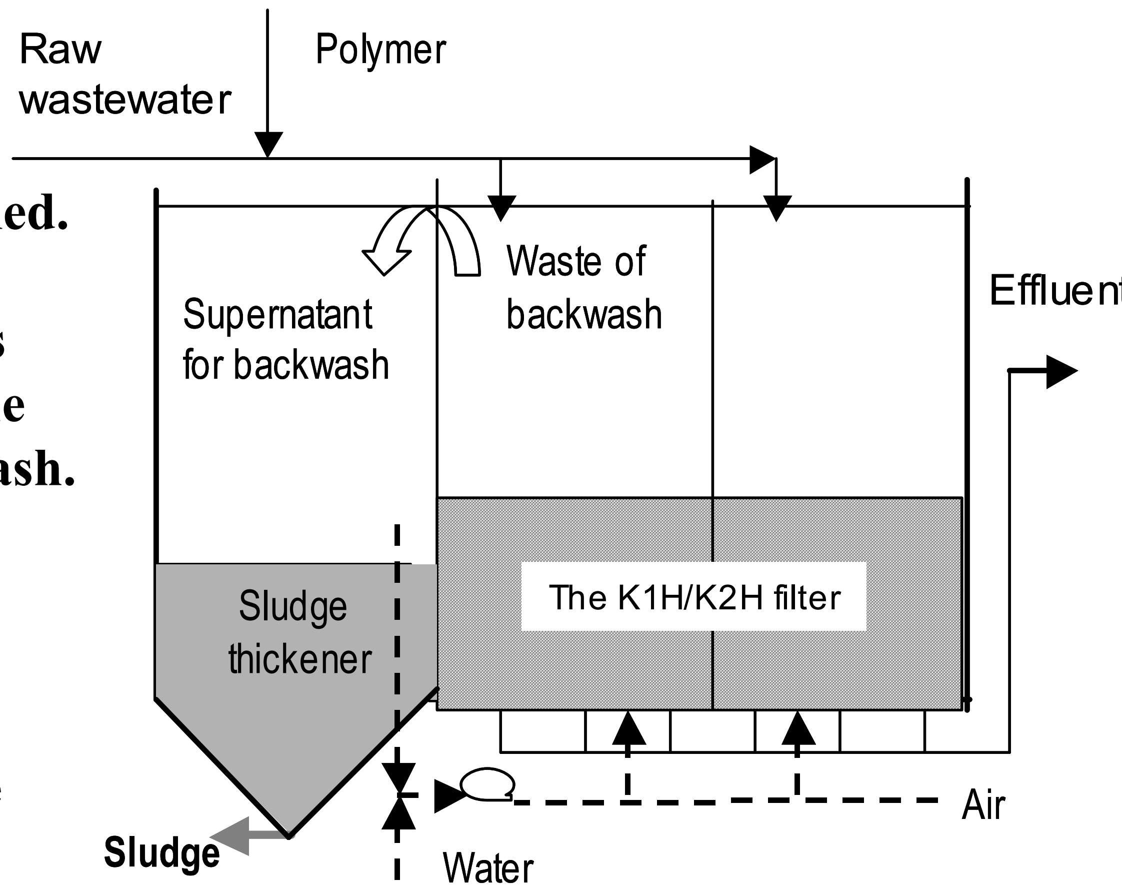
Upgrading of existing primary tank (2)

Downflow filter is applied.

Part of primary tank as sludge thickener and the supernatant for backwash.

Water consumption is reduced significantly.

Similar way to upgrade circular tank.



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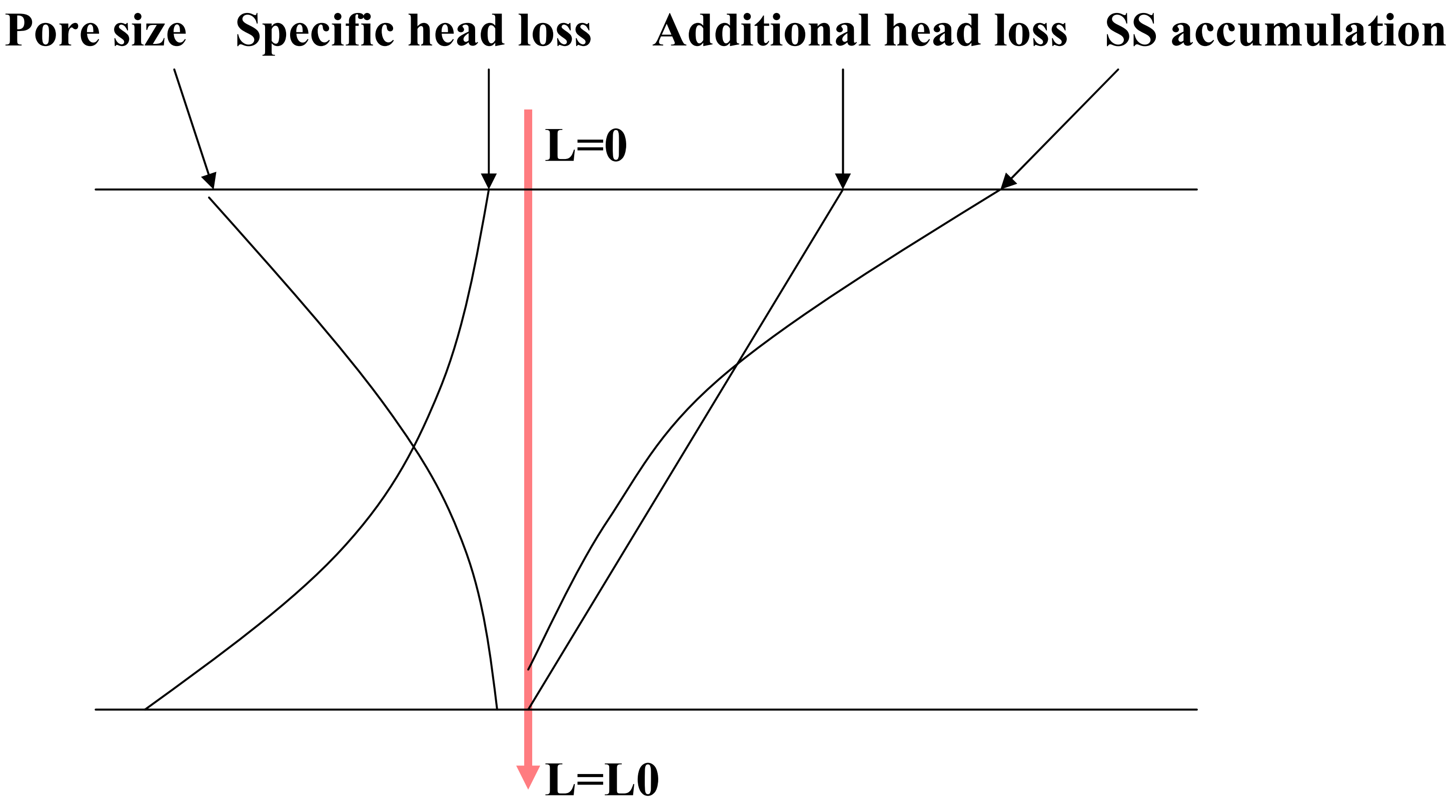
A conception of bed configuration optimisation for primary filters



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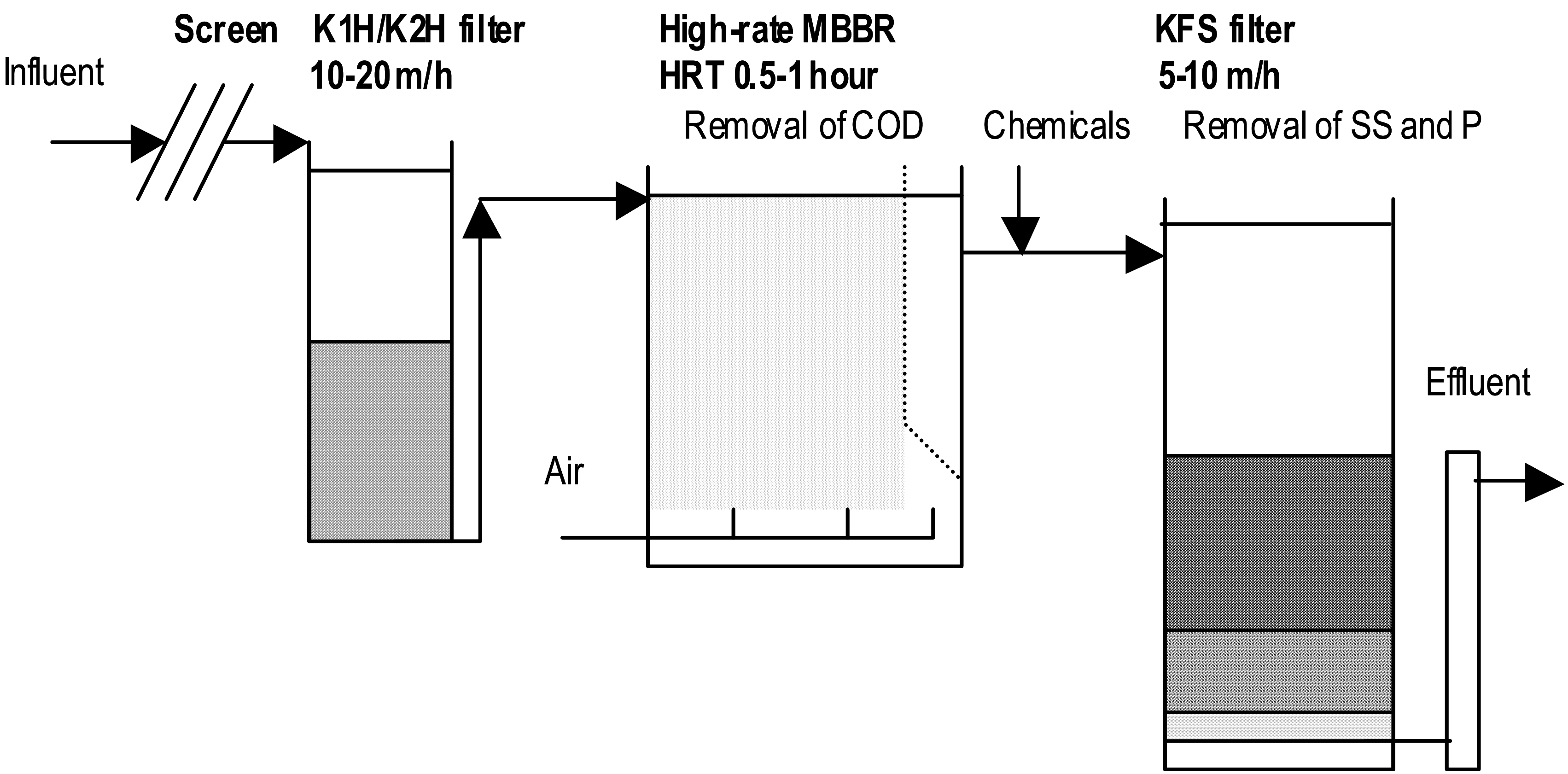
Filtration mechanisms in primary filters

- The dominating mechanisms are 1) sedimentation, 2)interception, 3) straining (sieving), 4) in-filter flocculation. The last three mechanisms become more significant with filtration time in a filter cycle.
- Detachment of previously deposited particles (clusters) occurs largely depending on addition of chemicals. Floc strength plays a great role in the extent of detachment.
- Detachment may occur as a spell of particles moving away from media surface like ”avalanche”.
- Wormholes develop very well in the first layers.
- Deposits are very permeable, implying the fractal properties need to be incoporated into interpretation and modeling of filtration process.

Conclusions of CMF for EPT

- Kaldnes based coarse media filtration was investigated and optimised.
- The K1L filter, the K1L/K2L filter,and the K1H/K2H filter were found to be feasible for primary filtration under different conditions.
- Media dimensions and structures had profound influences on filtration performances especially on head loss development.
- Combination of coarser and finer media into dual or multimedia filters was a direction for optimisation.
- High filtration performance at high filtration rate could be obtained under optimal filter bed configuration and dosage.
- Enhanced primary treatment by coarse media filtration makes the footprint of primary step very small with considerably lower organic and particle loadings to downstream steps.

High rate secondary treatment based on coarse media filtration



High rate tertiary treatment based on coarse media filtration