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Coarse Media Filtration – An Alternative To Settling In Wastewater Treatment

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ABSTRACT

In this paper coarse media filtration has been analysed as an alternative to the traditional settling in primary, secondary and tertiary treatment of wastewater. Various filter media configurations were evaluated for enhanced primary filtration. It was found that a dual media configuration based on Kaldnes biofilm media (K1 and $K2_{modified}$) were most suitable when taking both separation efficiency as well as filter run time into consideration. SS removal efficiencies of around 75 % were achieved in the dual Kaldnes primary filter at around 20 m/h without any chemical addition and around 85 % at low dosage (1-2 mg/l) of a high MW cationic polymer FO4440SH. In the latter case COD was removed by around 70 %. Further experiments were carried out on a multi-media Kaldnes-Filtralite-Sand (KFS) filter for enhanced primary treatment as well as for secondary filtration directly downstream a high-rate moving bed biofilm reactor, resulting in an extremely compact secondary treatment process. The secondary KFS-filter gave SS-removal efficiencies around 90 % (effluent SS < 15 mg/l) and filter run times of around 24 hrs at filtration rates of 10 m/h (sludge loading rates of around 1 kg /m^2h) when a small dose (2 mg/l) of polymer was used. It is also demonstrated that the primary filter may also be utilised as a pre-denitrification reactor. A dentrification rate of 1,5 kg NO_3-$N_{equiv.}$/m^3d was achieved when the filter was operated at a filtration rate of 5 m/h.

KEY WORDS

Particle removal, coarse media filtration, primary and secondary filtration, predenitrification

INTRODUCTION

In wastewater treatment one is to a large extent dependent on effective separation of particles and flocs in primary, secondary and tertiary separation steps. It is amazing that the settling tank is still the most favoured separation unit for various uses in wastewater treatment (primary, secondary, tertiary treatment) even though the settling tanks are very area consuming with overflow rates in the range of 1-3 m/h in conventional tanks. Lamella-sedimentation, flotation and filtration are being used to a certain extent, particularly in tertiary treatment, and microfiltration is slowly entering the field, but these more advanced particle separation processes are still totally outnumbered by the "good, old" settling tank. The future wastewater treatment plants will have to be more compact, however, because land space is becoming increasingly more costly (Ødegaard, 2000). This paper deals with an alternative particle separation process based on coarse media filtration. The main problem with traditional granular media filtration of wastewater is the rapid head-loss build-up. In the actual coarse media filter this is avoided by the use of a coarse plastic filter media resulting in very high porosity of the bed. In addition to slow head-loss build-up, the coarse media filter has much higher sludge retaining capacity than that of sand- or similar granular media filters. In the paper three different applications of coarse media filtration will be presented; for primary treatment, for high-rate secondary treatment and for tertiary treatment with nitrogen removal.

COARSE MEDIA FILTRATION FOR ENHANCED PRIMARY TREATMENT

Several experiments on primary filtration by the use of the Kaldnes biofilm carrier as filter media have been carried out earlier (Ødegaard et al, 1998, Liao and Ødegaard, 2001). A comparison of single Kaldnes-media floating filters were carried out in a set-up described by Liao and Ødegaard (2001), see fig. 1. The Kaldnes media, K1 and K2 (modified), made of polyethylene with density 0,95 g/cm^3, were evaluated in a floating media filter. A high MW cationic polyacrylamide polymer (Floerger, FO4440SH) was used in some experiments in order to evaluate the potential for enhancement of treatment efficiency

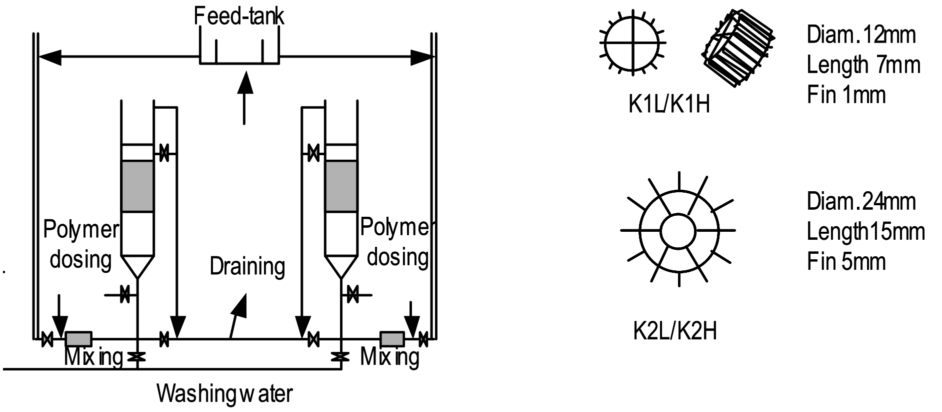

Figure 1 Experimental set-up for coarse media filtration and Kaldnes media (Liao and Ødegaard 2001)

In these earlier experiments, it was demonstrated that:

- the removal efficiencies were slightly lower in the K2 filters as compared to the K1 filters but the head-loss was much lower in the K2 filters
- a SS-removal efficiency of 60-70% could be achieved without using polymer at an overflow rate as high as 20-30 m/h
- a SS-removal efficiency as high as 75-95 % could be achieved at 20-30 m/h when adding the polymer
- the dosage of polymer needed was quite low and dependent on the SS in the influent. The recommended dosage was found to be around 5 mg polymer/$gSS_{influent}$ (1-2 mg/l for influent SS = 200-400 mg/l)

The fact that the K2 filter runs were normally terminated by breakthrough while the K1 filter runs were terminated by maximum head-loss, indicated that the combination of K1 and K2 media into dual media filters would make use of both advantages, high SS removal but yet rather low head loss. A new set of experiments (reported here) were carried out, in which combinations of the two Kaldnes media, K1 and K2, were used, now made in two different plastic materials, polyethylene with density 0,95 g/cm^3 (i.e floating – given the index L for light) and PVC with density 1,45 g/cm^3 (i.e. sinking – given the index H for heavy). The wastewater used was the raw wastewater taken after the grit chamber at Ladehammeren Wastewater Treatment Plant (LARA), Trondheim Norway in the same experimental set up as before (see fig. 1). The average and standard deviation of the raw water concentrations during the testing period for dual media filters were: 246 $\pm$ 73 mg SS/l, 458$\pm$135 mg COD/l.

Dual-media coarse filters for enhanced primary treatment

In the new set of experiments three different dual media filters were evaluated (see fig. 2d); the upflow $K1_{floating}$+$K2_{sinking}$ filter (K1L+ K2H), the upflow $K1_{floating}$/ $K2_{floating}$ mixed filter (K1L/K2L) and the dowflow $K1_{sinking}$/ $K2_{sinking}$ mixed filter (K1H/K2H). The results from these experiments are outlined in fig. 2 a-c. Head-loss is characterised by specific head-loss, i.e. headloss (in mm) developed over a filter run divided by the amount of sludge per filter volume accumulated over the same filter run.

The idea behind the upflow K2H+K1L filter was that the K2H part should accumulate most of the sludge while the K1L part should safeguard the removal efficiency. In fig. 2a it is indeed shown that the specific head-loss was low and comparable to that of the single K1 filter. The removal efficiency was about the same as in the single media K1 filter. Some degree of mixing between the two media after backwash was experienced. This lead to the upflow K1/K2 mixed filter (fig. 2d) in which floating media was used for both K1 and K2.

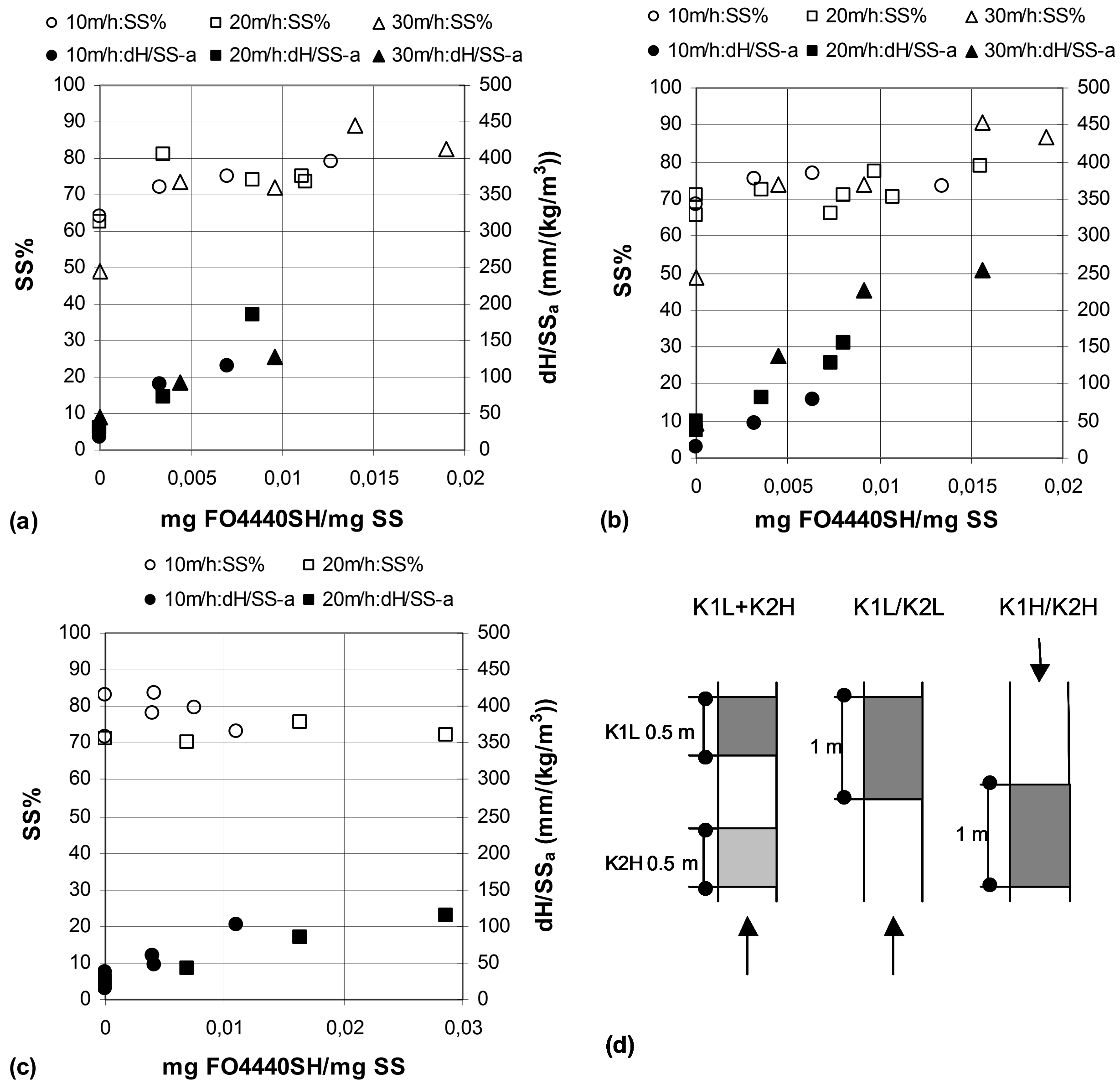

Figure 2. SS-removal (%) and specific head loss (mm/kgSS/m^3) in the (a) K1L+K2H filter, (b) K1L/K2L filter, (c) K1H/K2H filter, and (d) the bed configuration of three filters

The results with this filter (see fig. 2b) gave results very comparable to the K2H+K1L filter. It was observed during the experiments that the rising velocity of the K2L media was slightly lower than that of the smaller K1L-media, probably caused by the higher drag. It was decided to try also the sinking variant of the K2/K1 filter and it was observed that the filter was so mixed after backwash that the majority of the K2H was on top of the filter-bed and the majority of the K1H on the bottom, resulting in an coarse to fine media distribution in the direction of flow, which is ideal in a down-flow filter. Another interesting point that can be seen from fig. 2c, is that the specific head loss for the higher filtration rate (20 m/h) was not higher than that for lower filtration rate (10 m/h). This suggests that more even SS accumulation through the filter bed is achieved at the higher filtration rate caused by higher hydrodynamic forces that gives deeper particle penetration.

Based on these findings, it was decided to evaluate the potential of a new multimedia filter based on the idea that the major portion of the sludge should be separated in a coarse media filter section while a section of finer media should ensure good particle separation.

Kaldnes-Filtralite-Sand filter for advanced particle separation

The new multi-media filter, the Kaldnes-Filtralite-Sand (KFS) filter was designed as shown in fig. 3. It is a down-flow filter with a mixed, 100 cm K2H/K1H layer on top of a 50 cm expanded clay aggregate layer (Filtralite, density: 1,65 g/cm^3) with 2,5-5 mm grain size over a 30 cm sand layer (density: 2,65 g/cm3) with1-2,5 mm grain size. The support layer consists of gravel of 3-10 mm grain size. The coagulant could be dosed in an in-line static mixer. Enhanced primary treatment experiments were first carried out at filtration rates of 10-20 m/h with and without polymer dosing. During this period the raw wastewater in LARA plant was rather dilute and cold because of snow melting, with SS of 167±43 mg/l.

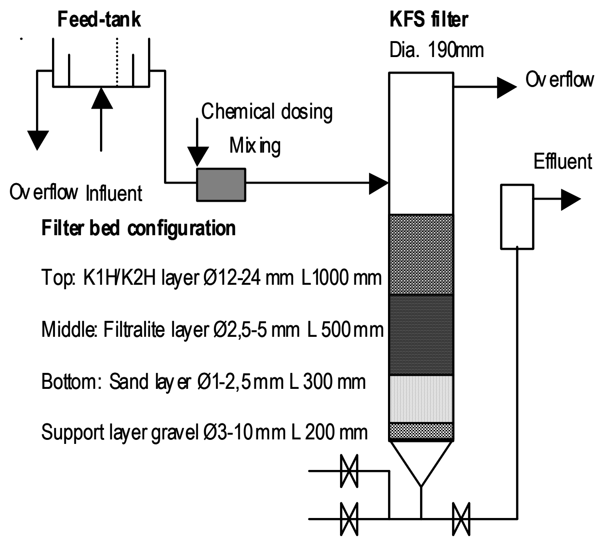

Figure 3 Experimental set-up and bed configuration of KFS-filter for enhanced primary treatment

In fig. 4 the SS-removal efficiency as well as effluent SS-concentration are shown versus filter run time at 10 and 20 m/h filtration rate and three different polymer dosages (0F-0 mg polymer/l, 1F-1mg/l, 2F-2mg/l). Even though the runs are not directly comparable because of variation in raw water quality, it is demonstrated that an effluent SS-concentration as low as 20-30 mg/l and a SS-removal efficiency of 80-90 % could be obtained at filtration rates as high as 10-20 m/h. The removal did not depend significantly either on filtration rate or on polymer dosage. The polymer dose improved removal efficiency slightly, but the main result of the polymer dosage was prolonged filter run time. A considerable filter ripening period was, however, experience, during which the separation efficiency was poorer.

It is demonstrated that filtration rate and polymer dosage influence mainly the headloss. The headloss development was mainly dependent on the amount of sludge accumulated and less on the polymer dosage. In the 20 m/h run, the filter run time until 1,5 m headloss was about 6 hrs while it was about 24 hrs at 10 m/h. The corresponding amounts of sludge accumulated were about 14 and 18 kg SS/m^2. The SS accumulation mainly occurred in the Kaldnes K2/K1 layer. These facts indicate that the Filtralite and sand layers played a less important role in the overall particle removal. The particles escaping the K2/K1 layer were so small that most of them also escaped the Filtralite and sand layers. This could probably have been remedied by increased polymer dosage in order to achieve more complete coagulation but this would be at the expense of a much higher head-loss build-up. It may be concluded, therefore, that the K2/K1 is more suitable for primary treatment and that the KSF filter should be more looked into as an alternative for secondary/ tertiary treatment.

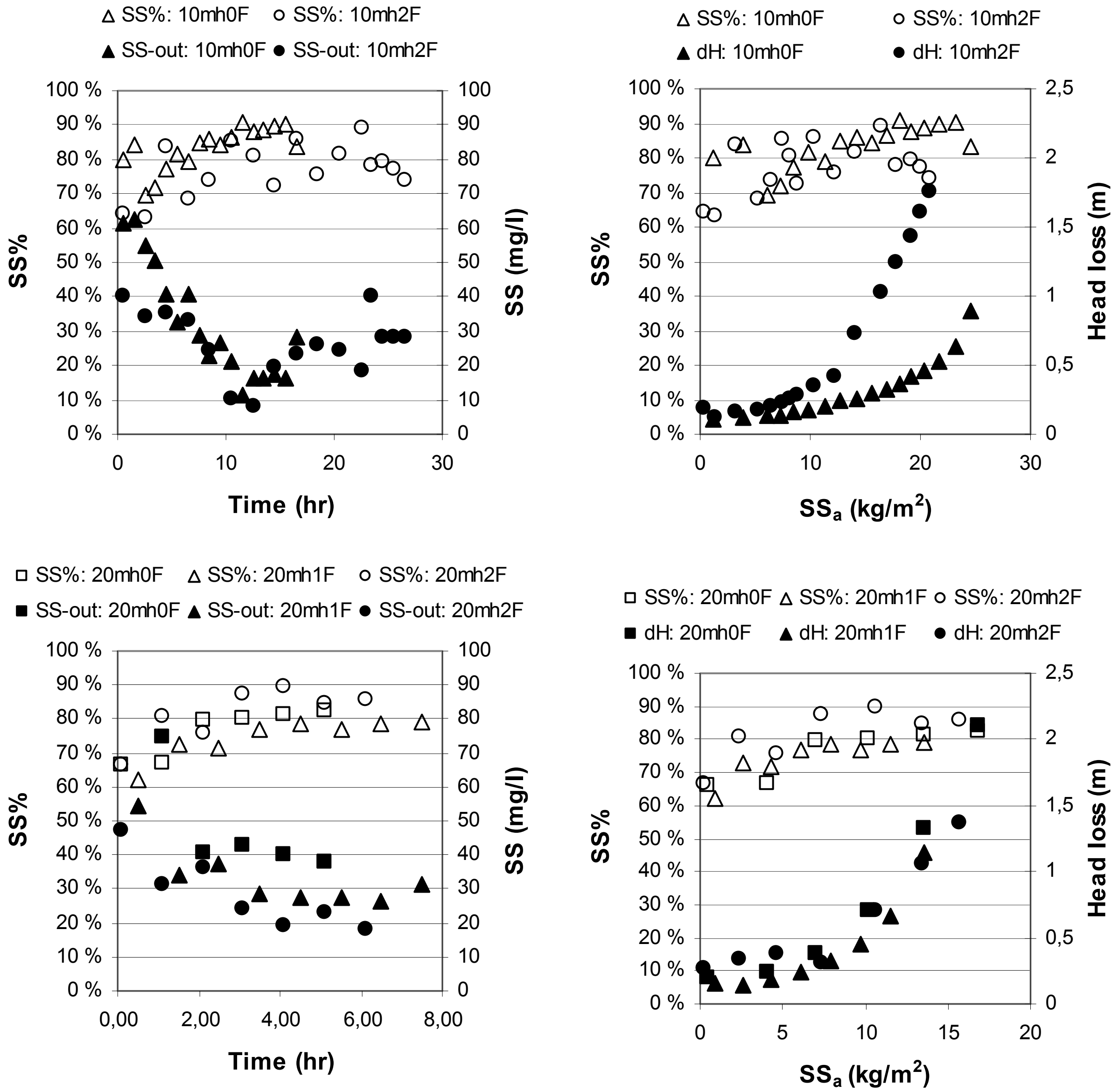

Figure 4. KFS filter performance at 10 and 20 m/h filtration rates and various dosages of polymer. Left: SS-rem. (%) and effl.- SS versus time. Right: SS-rem. (%) and head-loss (m) versus SS- accumul.

COARSE MEDIA FILTRATION FOR HIGH-RATE SECONDARY TREATMENT

A very compact secondary treatment alternative will be obtained when combining a high-rate moving bed biofilm reactor with a compact particle separation reactor (Ødegaard et al, 2000). It was decided to evaluate whether or not the KFS-filter could be used as the final separation step in such a process, see fig. 5.The fate of particles in biofilm reactors is not totally clear, but it is obvious that particulate matter to a far lesser extent is being degraded in a high-rate biofilm process than in a

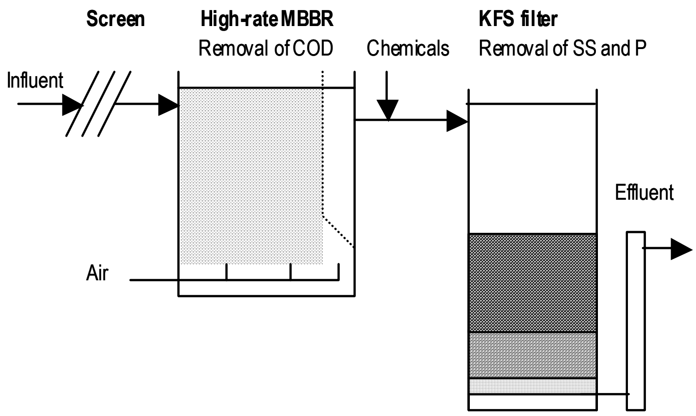

Figure 5. The high-rate secondary treatment system based on MBBR bioreactor and KFS filter

standard activated sludge process. When operating at such a high organic loading that the maximum COD degradation rate prevails, the COD-removal will primarily be due to consumption of soluble organic matter. The idea behind the high-rate Kaldnes moving bed biofilm process is that the biofilm is primarily supposed to deal with the soluble organic matter, while the coagulant is supposed to deal with the separation of the particulate matter, including colloids. Particulate COD, either entering the biofilm reactor with the raw water or produced in the biofilm reactor as a consequence of degradation of soluble COD, is supposed to be removed as suspended solid by KFS filter.

In order to test this system, a 1 m^3 moving bed biofilm reactor (MBBR) using K2 Kaldnes carrier (nominal media surface is 220 m^2/m^3 reactor volume) was started up at 30 min HRT two weeks before KFS filtration. Fig. 6 shows the filtration results at 10 m/h filtration rate at zero dosage, 2 mg polymer/l dosage and at 10 mg Fe + 2 mg polymer/l dosage.

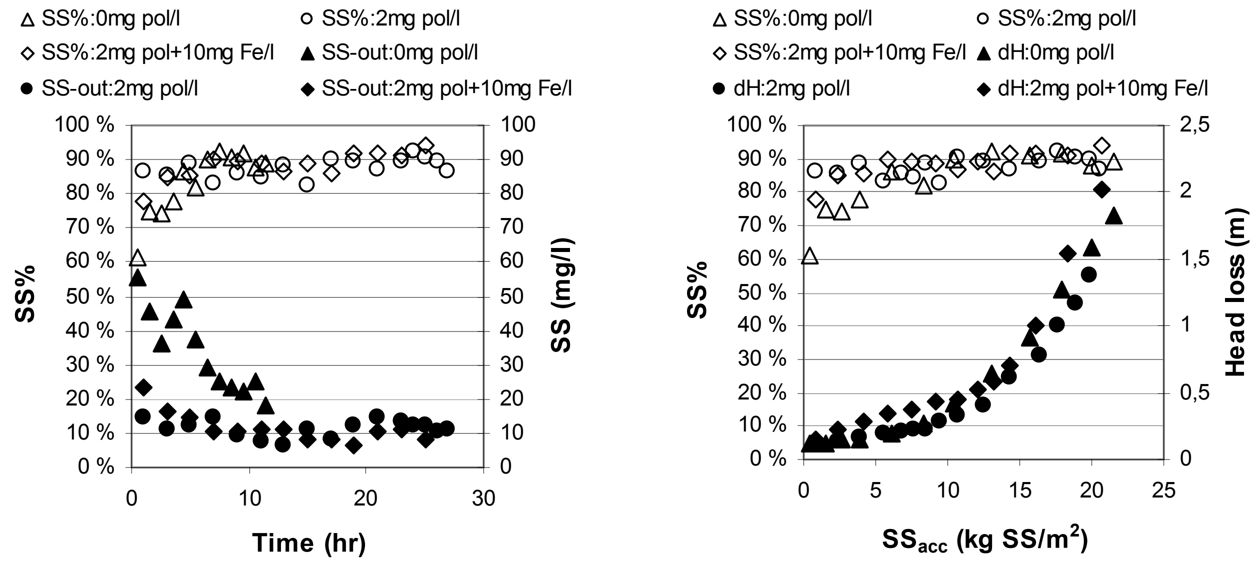

Figure 6 SS-removal (%) and SS in effluent versus time (left) and SS-removal (%) and head loss (m) versus SS accumulation (kg SS/m^2) (right) in KFS filter at 10 m/h after MBBR (secondary treatment)

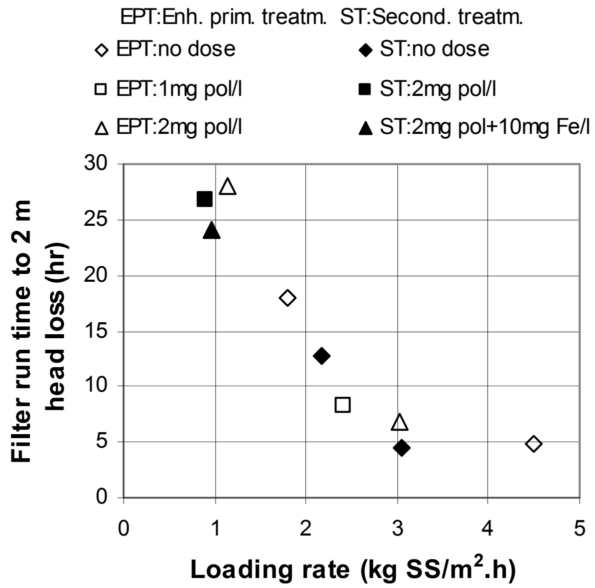

Figure 7. Filter run time (hr) to 2 m head loss versus SS loading rate (kg/m^2h)

The figure demonstrates quite clearly the benefit of the coagulant in this process. Even though there is a certain ripening period also when a coagulant is used, it is far less significant. In fact the results prove that the process should not be used without coagulant addition. The additional sludge caused by Fe-precipitation that will improve P-removal, results in a bit lower filter run time in order to reach a given headloss but the difference is not dramatic. The average SS-removal efficiency and effluent SS-concentration during the more than 24 hr filter run at 2 mg/l polymer dosage was > 90 % and 11 mg/l respectively, resulting in 20 $kgSS/m^2_{filter}$ accumulated sludge at about 1,5 m headloss. This is quite impressive and makes the KFS-filter an interesting separation reactor alternative for a high rate biofilm process. When operating at 20 m/h, the results were poorer with an average SS-removal efficiency of about 85 % and effluent SS-concentration of about 25 mg/l during the 6 hr filter run at 2 mg/l polymer dosage, resulting in 15 $kgSS/m^2_{filter}$ accumulated sludge at about 2,0 m headloss.

Filter run time is probably the most important design criteria for a filter like this and this may be determined based on the rate by which sludge is entering the filter and the necessary removal (i.e. the sludge accumulation rate). Figure 7 shows the filter run time to 2 m total head loss versus SS loading rate at various dosing scenarios and pre-treatments. It is interesting to see that there is a clear relationship independent upon dosing scenario and pre-treatment alternative, and consequently this curve can be used for design purposes. A 24 hours filter run time can be obtained at a SS loading rate of 1 kg/m^2h. 2 kg/m^2h gives 14 hrs filter run time and 3 kg/m^2h gives 6 hours.

COARSE MEDIA FILTRATION FOR TERTIARY TREATMENT

A very interesting and compact tertiary treatment method based on the coarse media filter idea, is shown in fig. 8. The K2/K1 Kaldnes primary filter is used both for primary separation as well as for pre-denitrification, a MBBR is used for nitrification and a KFS-filter is used for post-denitrification as well as for final particle separation. The idea here is that the particulate organic material that cannot be utilised as carbon source in a main-stream predenitrification process since it is not easily biodegradable, can be utilised in this scheme because it is caught by the filter and retained there for some time. Our hypothesis is that the denitrifiers in the filter will be able to utilise this organic material through hydrolysis. To a certain extent we believe that the same thing will happen in the post-filter and altogether this will reduce the carbon necessary as external carbon source. This process is now being evaluated, but we shall include some preliminary result (fig. 9) into the investigation whether or not the filters may be used as denitrification units parallel to being separation units at lower filtration rate such as 5 m/h.

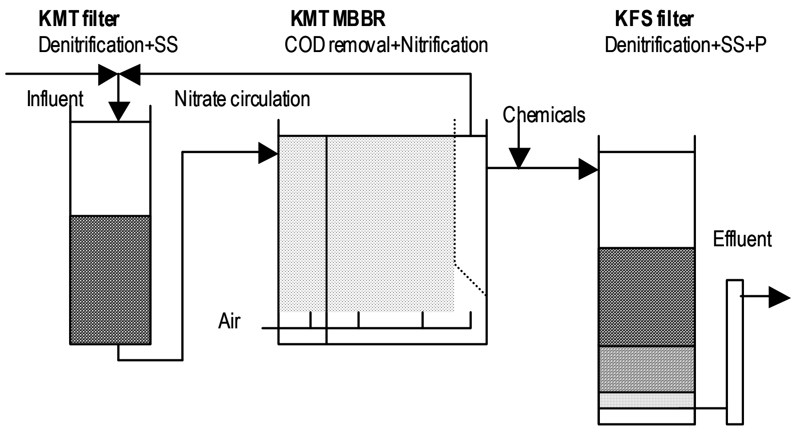

Figure 8. A high-rate tertiary treatment process based on MBBR and coarse filtration

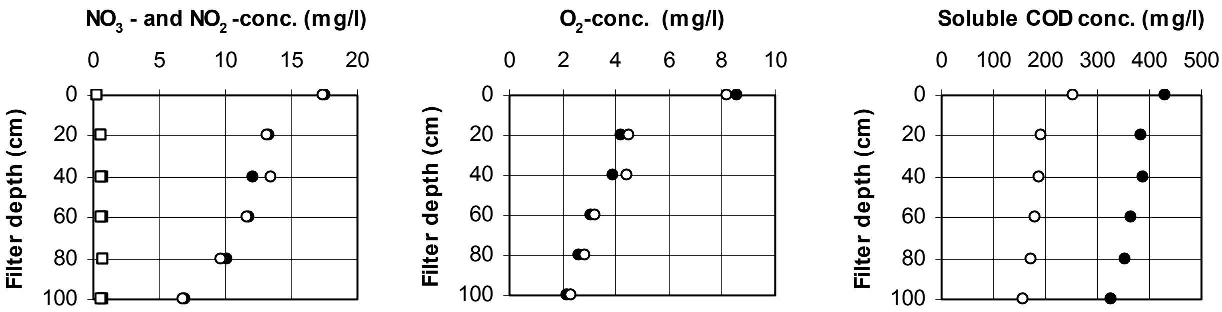

Figure 9. Concentration profiles down the 100 cm depth of the K2H/K1H primary filter

It is demonstrated in Figure 9 that the nitrate concentration in two different times (open and closed markers) was reduced from about 17,5 mg NO_3-N/l to about 7 mg NO_3-N/l at a soluble COD-consumption of about 100 mg COD/l and a O_2-drop of about 6 mg O_2/l. Then the denitrification rate is calculated as 1,5 kg NO_3-$N_{equiv.}$/m^3d. Compared to other experiences with denitrifying filters (Æsøy et al, 1998), these results are quite promising with respect to the potential of using the coarse media filters for denitrification as well as for particle separation.

CONCLUSIONS

It has been demonstrated in this study that coarse filters may favourably be taking over the role of settling tanks both in primary, secondary and tertiary wastewater treatment.

1. In primary treatment the dual media filters gave much higher SS removal efficiency and much higher overflow rates than those in primary settling tanks at no dose or low dose of polymer.
2. In secondary treatment the KFS filter gave 90% or higher SS removal or effluent SS less than 15 mg/l at proper combination of chemicals and filtration rate of 10 m/h.
3. It was demonstrated that the coarse dual media filters could be used as pre-denitrifying unit as well as particle separation when used in tertiary treatment. The denitrification rate recorded was 1,5 kg NO_3-N/m^3d.

ACKNOWLEDGEMENTS

The financial support for this study that was received from the Norwegian State Education Funds, Kaldnes Environmental Technology AS, and Optiroc AS is highly appreciated.

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