Coarse Media Filtration for Enhanced Primary Treatment of Municipal Wastewater

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Abstract
In these experimental studies enhanced primary treatment in coarse media filters has been evaluated. The coarse media used in the filters have been plastic carriers normally used for moving bed bioreactors, a Kaldnes carrier K1 with density < 1 g/cm^3 (K1L) and a bigger carrier K2, that was used both in a lighter, floating (K2L) version and a heavier, sinking one (K2H). The results demonstrated that media characteristics influenced significantly on filter performance. The dosing of a high MW and high charge cationic polymer was, however, found to have an even greater effect on treatment efficiency and especially on head loss development. Both filters were found to be feasible for enhanced primary treatment at high filtration rates (20-30 m/h) especially when dosing low dosages (1-3 mg/l) of polymer. The combination of two media into dual media filter might take the advantages of both. Further experiments were carried out on a dual media filter consisting of lighter K1L media and heavier K2H media. It was indeed found that the K1L+K2H up-flow filter resulted into better performances in terms of water production when an optimised backwash procedure was taken into account.

Keywords
Coarse media filtration; municipal wastewater; primary treatment

INTRODUCTION

Wastewater treatment is to a very large extent a matter of particle separation. This is a result of the fact that most of the pollutants in wastewater exist on particulate or colloidal form or are transformed to this form in the course of the treatment process (Ødegaard, 1998). Particle separation is in primary wastewater treatment plants normally carried out by settling. With the overflow rates normally used in primary settling tanks (2-3 m/h) around 50 % of the suspended solids and 30 % of the organic matter are removed. While there has been considerable research focusing on downstream and final particle separation, very little has happened in the area of primary treatment even though considerable cost savings can be achieved by enhancing this treatment step.

Primary treatment may be enhanced by dosing a coagulant (metal and/or cationic polymer) to the water before settling. This will result in improved removal efficiencies of many parameters since such a large fraction of the pollutants (organic matter, bacteria and viruses and organic and inorganic micro-pollutants) are associated with colloidal and suspended matter (Ødegaard 1998, Mels and Nieuwenhuisen 2000). Still, however, relatively low overflow rates have to be used, resulting in spacious plants. Another high rate alternative (overflow rates in the range of 10-30 m/h) that has emerged over the last years is coarse media filtration with or without pre-coagulation (Okubo, et al 1990, Coma 1991, Mouri and Niwa 1993, Ishibashi et al 1993, Tanaka et al 1995, Lerch 1998, Ødegaard et al 1998 and Caliskaner et al 1999).

In these experimental studies enhanced primary treatment in coarse media filters has been evaluated. The coarse media used in the filters have been plastic carriers normally used for moving bed bioreactors. The experiments have focused on parameters that will have impacts on the cost effectiveness on the process, i.e. efficiency, filtration rates, polymer dosages, backwash procedures and water production in a whole.

EXPERIMENTAL

Experimental studies on the comparison of floating filters and dual media filter were carried out at Ladehammeren Wastewater Treatment Plant (LARA) in Trondheim, Norway with the experimental set-up and filter media shown in Fig. 1.

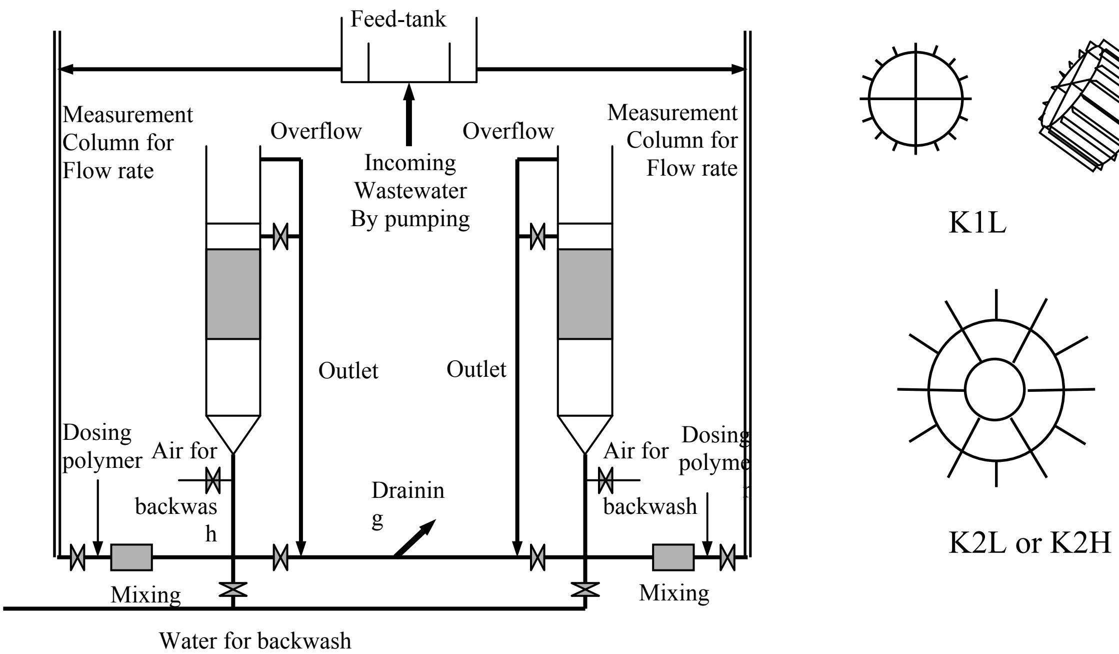

Fig.1 The set-up of the pilot-plant and the shapes of the Kaldnes media K1L and K2L or K2H

The set-up consists of two filter columns, each of 500 mm in diameter and of 2000 mm in effective height for filtration. Two different shapes of biofilm carriers were used. K1 is the standard biofilm carrier used in the Kaldnes moving bed biofilm process. It is made of polyethylene and has density of 950 kg/m^3 (K1L). The other carrier K2 was made for these experiments. It was made in two versions, one floating based on polyethylene (K2L, density 950 kg/m^3) and one sinking, made of PVC (K2H, density 1,45 kg/m^3). For K1L and K2L floating filters, one meter of each media was filled in each column in which wastewater was led from the feeding tank, through flow measurement columns, dosing point of polymer to the up-flow filters. For the K1L+K2H dual media filter, half a meter of K1L and K2H media each were filled in one column, forming a 1-meter gap between the two media because of the difference of density.

The K1L media is shaped like a cylinder of 10 mm in diameter, 7-8 mm in length, with an inner cross and 18 short fins (1 mm wide), as shown in Fig. 1. The thickness of the cylinder and cross walls is between 0.5-1 mm. The K2L and K2H media have two concentric cylinders with diameters of 5 mm and 14 mm partitioned by six inner walls, and 12 outer fins of width of 5 mm were added on the outer side. The total diameter is 24 mm and the length is 15 mm.

A cationic polymer with high molecular weight (MW) and high charge density (Floerger FO4440SH) could be dosed to the water through an in-line static mixer. After the termination of each filter run, determined either by a preset head loss (1 m) or by an obvious breakthrough, the filters were cleaned by an optimised procedure of two steps. Firstly the whole content of the filter column was aerated and mixed resulting in scouring and detachment of the trapped sludge that was subsequently drained out of the column. This batch cleaning step lasted for 3-5 min. Thereafter air and water was introduced from the bottom of the filter and the wash water was drained out of the column through the overflow at the top. This continuous cleaning step lasted for 10-15 minutes.

The porosities of the filter beds of K1L and K2L (or K2H) media were measured to be 0,80 and 0,86 respectively. Although the porosity of the two media beds is similar, the distribution of pore sizes in the media bed is quite different. In the K1L filter bed, the media is closely packed because of the short outer fins, while in the K2L or K2H filter bed the media are loosely packed because of the longer outer fins. It was anticipated, therefore, that the K2L or K2H filter bed would result in much less head loss than the K1L filter bed.

Raw wastewater characteristics varied largely during the experiments. In the period of comparison of K1L and K2L filters, SS in influent to filters was 414±261 mg/l. COD and SCOD were not measured in this period. Lower SS of 246±77 mg/l in influent occurred in the following period on experiments of K1L+K2H filter. COD and SCOD were measured in this period as 713±294 mg/l and 202±122 mg/l, respectively.

Firstly, a series of experiments were arranged in order to compare K1L and K2L media filters under filtration rates of 10, 20, and 30 m/h and dosages of the cationic polymer at 0, 1, 2, 3, and 4 mg/l. After the comparison of K1L and K2L filters, experiments were then carried out on the K1L+K2H dual media filter under the same conditions. Data on SS in the influent and effluent of the filters were measured with 0.5 or 1 hour interval. Some samples were also measured on COD and SCOD concentration. The head loss development through the filter beds with time was also recorded.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Comparison of K1L and K2L filters

Averaged SS removal. It is demonstrated in Figs 2a – 2d that for K1L and K2L filters a SS removal above 80% (sometimes above 90%) could be achieved at an optimal dosage of polymer, while a maximum of about 70% in K1L filter and 60% in K2L filter could be reached without polymer addition. Fig.2a - 2b show that the dosage ratio of 5 mg FO4440SH/g SS seemed to be the optimal one.

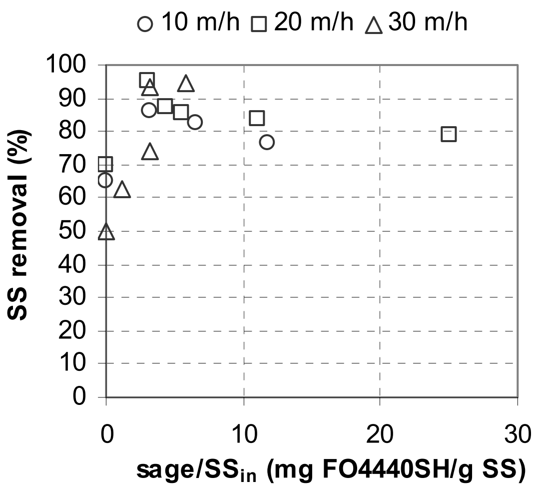

Fig. 2a. SS removal in K1L filter

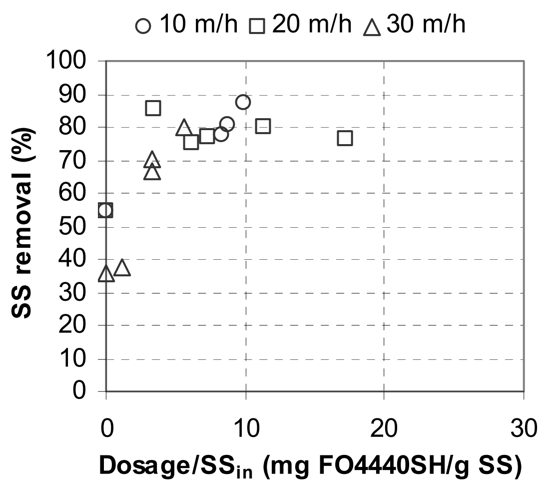

Fig. 2b. SS removal in K2L filter

This optimal value, 5 mg FO4440SH/g SS, results in dosages of 1mg/l at 200 mg SS/l in influent and 3 mg/l at 600 mg SS/l, demonstrating that the polymer consumption is quite low. Although the design of the two media is quite different, the SS removal is less different. There is, as expected, the tendency that the SS removal decreases with increasing filtration rate, even though this relationship is not so clear. It is demonstrated in Fig 2c and 2d that reduced efficiency at higher rates could be compensated for by increased polymer dosage. But as long as the polymer dosage was higher than 2 mg/l or above (for the K1L filter), the filtration rate did not seem to play a very significant role for the SS removal throughout the range of experiments. The similar effect was experienced with the K2L filter for dosages higher than 3 mg/l.

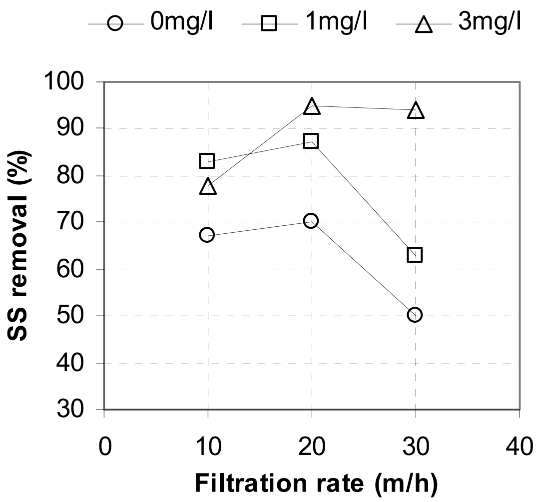

Fig. 2c. SS removal in K1L filter

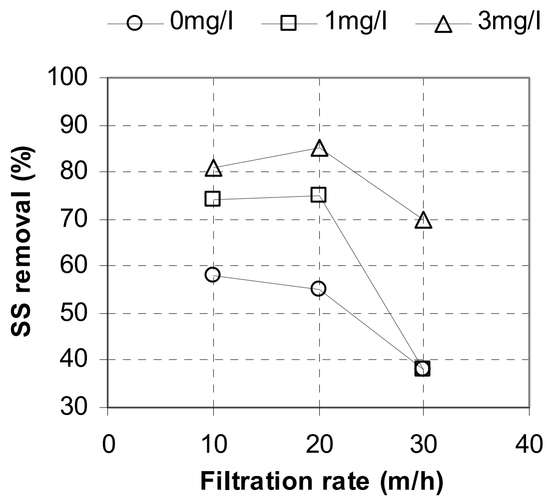

Fig. 2d. SS removal in K2L filter

Specific head loss dH/SS_a. The specific head loss (mm/(kgSS/m^3)) is defined as the head loss (mm) developed during a filter run divided by the sludge accumulation per unit volume of filter (kgSS/m^3). There is a dramatic difference in the specific head loss between the K1L and the K2L filters. As shown in Fig. 3a and 3b, dH/SS_a increases with increasing specific dosage for both filters. It is demonstrated, however, that the specific head loss for the K2L filter is on average (5-25 mm/(kg/m^3)) only about 1/10 of that for the K1L filter (50-200 mm/(kg/m^3)), indicating a dramatic difference in sludge accumulation capacity. In the K2L filter, the preset 1-m total head loss was difficult to reach before an obvious breakthrough because of the low specific head loss.

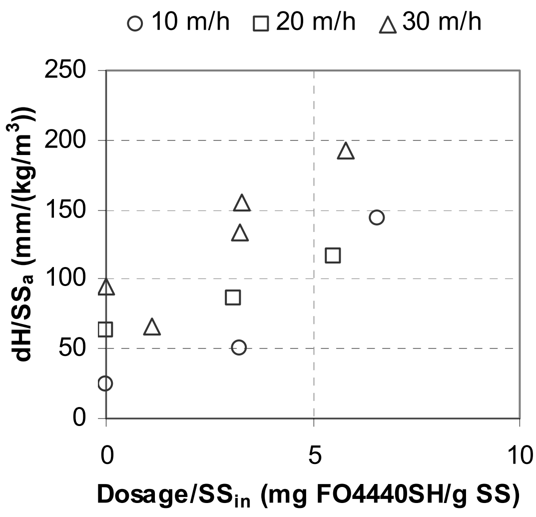

Fig. 3a. dH/SS_a in K1L filter

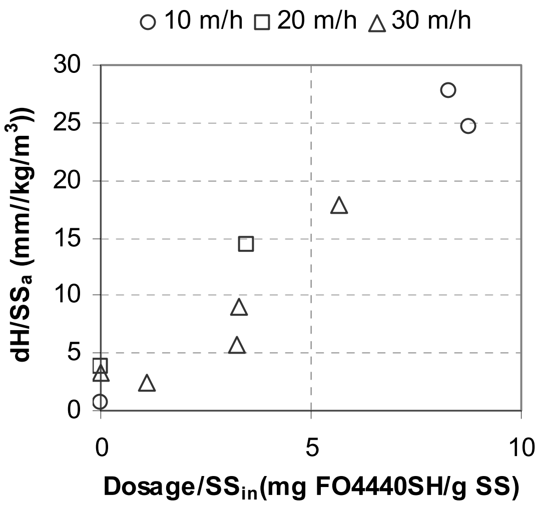

Fig. 3b. dH/SS_a in K2L filter

From these observations it can be assumed that a blocking effect of deposit contributes considerably to the head loss development in the K1L media filter, especially when polymer is dosed to form strong flocs. The relationship between dH/SS_a and dosage ratio is clearly demonstrated. The filtration rate has much less influence on head loss development than dosing polymer, implying that choosing a proper polymer is much more important than choosing a lower filtration rate, when one is aiming at controlling the head loss development. High specific head loss results in short length of filter run time and consequently low water production (high consumption of water for filter cleaning). One should, therefore, be aiming at filters with relatively coarse media operated at high rates and relatively low polymer dosages. This will require optimisation of filter media configuration in the bed as e.g. indicated in the K1L+K2H dual media filter.

Water production WP and Effect Water Production WP_e. Water production per unit filter area per day, WP, reflects the capacity of filtration process by considering the water consumption for filter cleaning. Fig. 4a and 4b demonstrate that, increasing filtration rate from 20 to 30 m/h does not bring any advantages in the K1L filter (especially at polymer dosages above 2 mg/l), but in the K2L filter this would still have good perspectives. So even though the finer media results in higher treatment efficiency, it may not be more preferable because the much faster head loss development results in more frequent filter cleaning and consequently higher operation cost. The straight lines in Fig 4a and 4b illustrate the theoretical maximum water production when the ideal condition of no cleaning and 100 % SS removal would exist. The distances between data points and this line demonstrate the loss of capacity of the filters for the backwash. It is noted that a maximum of head loss in K2L filter, 300 mm instead of 1000 mm preset value, was assumed to calculate the water production.

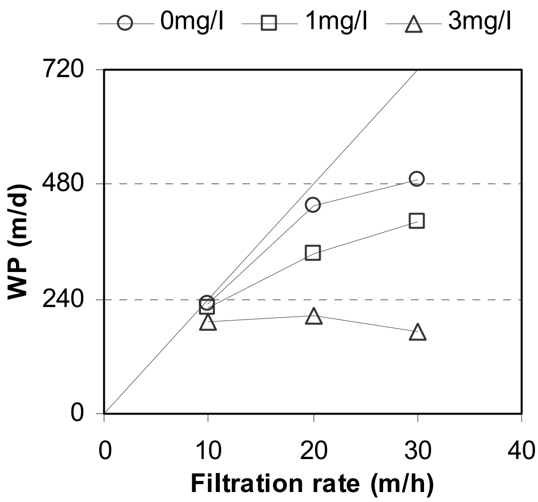

Fig. 4a. WP in K1L filter

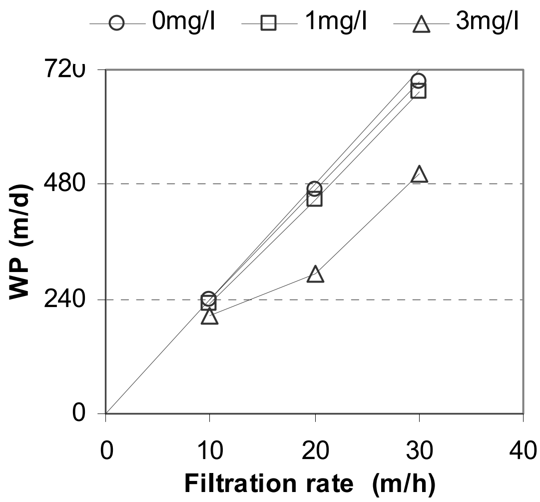

Fig. 4b. WP in K2L filter

In the optimisation of filtration processes it is often a compromise between high WP and SS removal. So in order to consider the overall capacity of a filter, a parameter coined as the effective water production WP_e, was defined as the product of water production WP and the SS removal efficiency (%). Analyses (not shown in figures) demonstrate that in the K1L filter dosing polymer of 3 mg/l or more resulted in lower effective water production than dosages of 0 – 2 mg/l. It also demonstrates that filtration rate over 20 m/h did not produce higher WP_e. While in the K2L filter, the dosage of polymer 2 mg/l seemed to be most favourable, but it seems that higher filtration rates than 20 m/h could still be beneficial in this filter.

Experimental results of the K1L+K2H dual media filter

It is quite clear that the combination of K1L media and K2H media to form a dual media two-layer filter may make use of the advantages of both media but get rid of their drawbacks. The experimental results of K1L+K2H filter are demonstrated in Figs. 5-8.

Averaged SS removal. As shown in Fig. 5 - 6, there is still an optimal range of dosage ratio over influent SS concentration at around 5 mg FO4440SH/g SS. Lower than this value, the SS removal decreases a lot, while above this the SS removal may keep at a higher level between 75% to 90%. Because of different wastewater characteristics in this period of experiments, the SS removal may not be able to directly compare with that in K1L and K2L filters. The same trend of compensation of SS removal at higher dosages of polymer with respect to higher filtration rates is also clearly demonstrated. SS removal is even increased with filtration rates for dosage of 3 mg/l, implying that the greater in-filter flocculation may contribute to this effect.

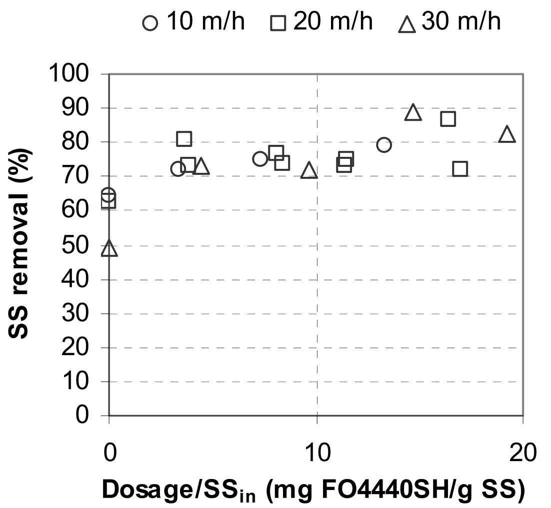

Fig. 5. SS removal in K1L+K2H filter

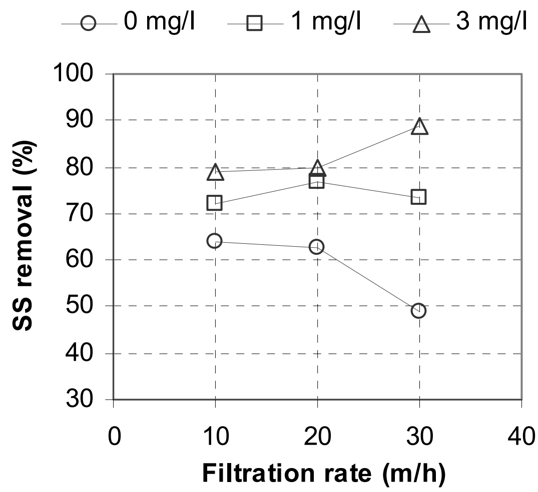

Fig. 6. SS removal in K1L+K2H filter

Specific head loss dH/SS_a and water production. As expected from the analysis, the specific head loss in K1L+K2H filter was decreased by a large extent compared to that in K1L filter. Nearly half of specific head loss is resulted by combining K2H media with K1L media into this dual media filter, shown in Fig. 7. The specific head loss seems to increase at a greater rate at the lower range of dosage ratio 0 - 5 mg FO4440SH/g SS.

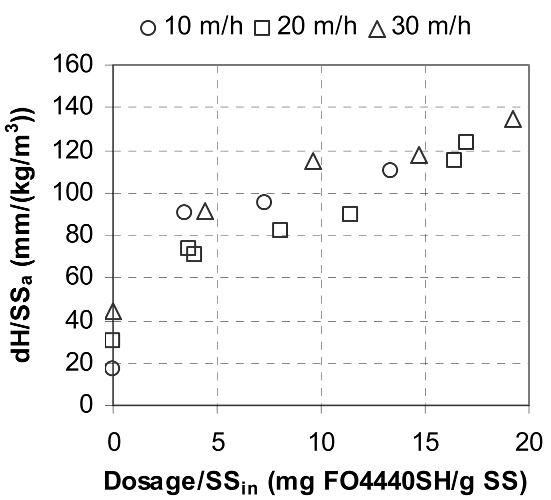

Fig. 7. dH/SS_a in K1L+K2H filter

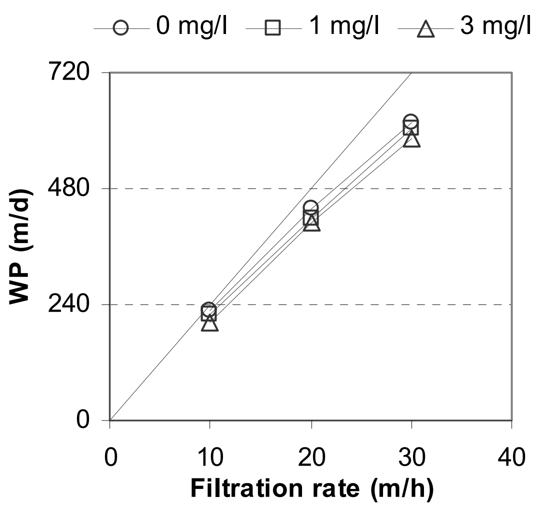

Fig. 8. WP in K1L+K2H filter

Combining the much lower specific head loss with rather similar or somewhat lower SS removal in K1L+K2H filter, the water production is much higher in this K1L+K2H filter than that in K1L filter as indicated in Fig. 8. Rather small difference on the water production at different dosages reveals that this filter has much broader application.

Discussions

Optimisation of coarse media filters for enhanced primary treatment is a matter of balancing filter media and bed configuration selections, filtration rate and chemical dosages in view of the removal efficiency needed and the costs accepted (determined by size of filter, energy for filter cleaning and costs for polymer). Because of the characteristics of particulate substances in raw wastewater or after grit chambers, the media size in coarse media filters must be large enough to prevent clogging and rapid head loss development. On the other hand it must be fine enough to give acceptable removal efficiencies. The advantage of K2L media over K1L media is the big pores and even pore size distribution even after a long time of operation during the filter run. The porosity of the filter bed itself does not make big difference. It is the ability of the filter to avoid clogging in the first layers that is important.

The combination of two media into dual media filter reveals the big potential to optimal bed configuration in order to decrease head loss considerably with acceptable SS removal. The choice of proper coagulant is also among the most important aspects for the success of primary treatment by filtration. The use of high MW and high charge cationic polymer as coagulant is proven to be a suitable one. There is still much work to do, however, in order to optimise the coagulation after the proper filter media and configurations are optimised. Experimental studies on other filter bed configurations (e.g. K1L/K2L dual media filter and K1H/K2H dual media filter) and combinations of different polymers to optimise the filtration performance will be reported elsewhere.

While it was focused on the SS removal in the experiments, the relationship between SS removal and COD and particulate COD removal has also been investigated. It was found that100% removal of SS corresponds to 90 - 100% removal of particulate COD removal and 70 - 90% removal of total COD. This may mean that 90% removal of SS in these filters results in 81 - 90% removal of particulate COD and 63 - 81% removal of total COD. So the COD loadings to the downstream biological steps were reduced to a large extent after coarse media filtration, further resulting in considerable savings on space and energy in wastewater treatment plants.

CONCLUSIONS

The following conclusions can be drawn from the results and analyses above.

1. Kaldnes carrier based coarse media filtration for primary treatment has been demonstrated to give SS removal up to 80-90% at a low dosage (ca 2 - 3 mg/l) of a high MW, high charge density, cationic polymer and high filtration rates (typically 20 m/h in single media filter and 20 - 30 m/h in dual media filter). The removal efficiency without polymer dosing was lower (60-70 %) and lower filtration rates had to be used for optimal efficiency. The optimal polymer dosage was found to be 5 mg FO4440SH/g SS.

2. The difference of structure of the plastic filter media in the smaller K1L and the larger K2L had a dramatic influence on the performance of filtration, especially on head loss development. Big and even pore size distribution in the packing of media bed resulted in much less head loss.

3. Both K1L and K2L media were found to be feasible for enhanced primary treatment under preferable conditions. The filter cycle in the K1L media filter was found to terminate by head loss while the K2L media filter by breakthrough.

4. By comprehensively evaluating the treatment efficiency and capacity, K1L media filter seems optimally to be operated at a filtration rate of around 20 m/h and at a polymer (cationic polymer FO4440SH) dosage of around 1 - 2 mg/l. While The K2L filter is preferably operated at dosages of 1 - 3 mg/l and filtration rates of 20 - 30 m/h.

5. The combination of K1L and K2H media into the dual media filter demonstrates the great advantages in much lower specific head loss and much larger water production under broader range of dosages of polymer, therefore indicating that the optimisation of coarse media filtration for enhanced primary treatment should follow this way to find out the optimal filter media and bed configuration and the consequent coagulation.

6. The COD loadings were reduced to a large extent under high filtration rates (20 - 30 m/h) and low dosages of polymer (1 - 3 mg/l), indicating further space and energy savings in the biological steps in wastewater treatment plants.

REFERENCES

Caliskaner O., Tchobanoglous G. and Carolan A. (1999). High-rate filtration with a synthetic compressible media. *Water Environmental Research*, **71**(6), 1171-1177.

Coma J., Jabbouri A., Grasmick A., and Elmaleh S. (1991). Intensive primary-treatment of urban waste-water. *Wat. Sci. Tech.,* **24**(7), 217-222.

Ishibashi T., Fujii M., and Katsuura H. (1993). Filtration process using filter media made of fibre. *Proc. 6th World Filtration Congress*. Nagoya, Japan, May 18-21, 1993, 111-114.

Lerch A. (1998). *On the development of high rate deep bed filtration unit for sewage treatment.* Diploma thesis, Gerhard-Mercator Univ.

Mels A. R. and van Nieuwenhuijzen A. F. (2000). Cationic organic polymers for flocculation of municipal wastewater –Experiments and scenario study. In: *Chemical Water and Wastewater Treatment VI*, Hahn Hoffmann and Ødegaard (eds.), Springer Verlag Berlin-Heidelberg, 23-33.

Mouri M. and Niwa C. (1993). Pilot plant studies on filtration of raw sewage using floating filter media and multiple filter column inlets. *Wat. Sci. Tech*., **28**(7), 143-151.

Okubo Y., Itoh T. and Miki K. (1990). Development of a new domestic wastewater treatment system using an up-flow filter for raw wastewater. Preprint of poster-papers, IAWPRC-Biennial Conf., Kyoto, Japan, 29. July-3. Aug., 1990, pp. 299-302.

Tanaka Y., Miyajima K. and Funakosi T. (1995). Filtration of municipal sewage by ring shaped floating plastic net media, *Water Research*, **29**(5), 1387-1392.

Ødegaard H.(1998). Optimised particle separation in the primary step of wastewater treatment. *Wat. Sci. Tech.*, **37**(10), 43-53.

Ødegaard H., Ulgenes Y., Brevik D., and Liao Z.(1998) Enhanced primary treatment in floating filters. In Hahn, H.H., Hoffmann, E. and Ødegaard, H.(eds): Chemical water and wastewater Treatment V SpringerVerlag Berlin Heidelberg, New York, 149-162.