CHEMICAL REHABILITATION OF RAPID SAND FILTER AT KLAGSHAMN WWTP IN MALMÖ
KEMISK REKONDITIONERING AV SANDFILTER PÅ KLAGSHAMN ARV I MALMÖ


Dimitrova, I.; Dabrowska, A.
VA SYD, Box 191, 201 21 Malmö, Sweden

Abstract
At many wastewater treatment plants (WWTPs), rapid sand filters are used as polishing step before the wastewater is released to the recipient. Thus, after time, the media gets clogged and the filters are regularly backwashed. In case of poor backwashing, the next filtration cycle will begin with an inefficient filter. Agglomerates of media grains, flocculation chemicals, biosolids and fats can lead to appearance of "mud balls". "Mud balls" can grow rapidly and form cracks, increasing the local filtration rates or causing increased head loss and, consequently, destroy the filter. In such cases, rehabilitation of filter media is needed. Replacing the old media is a costly and time consuming procedure. In this paper, different chemical cleaning methods are compared with the aim to find a procedure that can be applied in a full scale without negative impact on the recipient or on the main process. Ten percent solution of sodium hydroxide has shown good impact on media characteristics and can solve problems with "mud balls". Applied in full scale, the method has four to five time lower cost compared to replacement of the filter media.

Sammanfattning
Vid många ARV används snabba sandfilter som poleringssteg innan avloppsvattnet släpps ut till recipienten. Filtrering följs av backspolning, som initieras antingen efter utlöpt gångtid eller på inställt tryckfall. Ineffektiv backspolning leder till att filtermaterialet inte blir rent. Agglomerat av mediekorn, flockningskemikalier, partiklar och fett kan leda till att ”mudballs”, geléartade fasta agglomerat, bildas och snabbt växer sig större. ”Mudballs” kan orsaka sprickor i filterbädden, som ökar de lokala filtreringshastigheterna eller orsakar tryckförluster, vilket förstör filtret. I dessa fall behövs rekonditionering av filtermaterialet. Byte av filtermaterial är en kostsam och tidskrävande procedur. I denna artikel jämförs olika kemiska rengöringsmetoder, som syftar till att hitta ett förfarande som kan tillämpas i fullskala utan negativ påverkan på recipienten eller huvudprocessen. Tio-procentig lösning av natriumhydroxid har visat sig ha god potential och kan kringgå problemen med ”mudballs”. I fullskala kräver metoden fyra till fem gånger lägre ekonomisk insats jämfört med byte av filtermaterialet.

Key words: Rapid sand filter; chemical rehabilitation; mud balls; costs

Introduction

Sand filter clogging

At many WWTPs, rapid sand filters are used to remove suspended solids before releasing the wastewater into the recipient. The end of the filter run is reached when the head loss increases and the media gets clogged. The procedure of backwashing normally begins with applying an air source followed by washing with water through nozzles from the bottom of the filter. Pre-treatment of the influent with coagulants and/or flocculants can contribute further to accumulation of suspended solids, media and metal precipitates, decreasing the backwashing performance. If the filter media is not restored to a clean state, the next cycle begins with clogged media and the accumulation of deposits increases for each new cycle. This creates agglomerates, so-called "mud balls", these can grow and form inactive filtration zones where the water velocity increases, resulting in a high filtrate turbidity and shortened running time for the filter (Tchobanoglous et al, 2003). In such cases, the filter is no longer efficient and the media and the nozzles need to be replaced or rehabilitated. Such replacement is a costly and time consuming procedure, therefore the aim of this study is 1) to find a chemical method for rehabilitation that can be applied in full scale and 2) to compare the costs for the two methods.

The full scale plant

The Klagshamn WWTP, in Malmö, is treating a flow of about 22 000 $m^3 d^{-1}$. Phosphorus is mainly reduced by pre-precipitation, which is supplemented by a post-precipitation in the sand filter are when needed. The biological treatment is accomplished in an activated sludge process (ASP) with nitrification and in a moving bed biofilm reactor (MBBR) for denitrification with dosage of ethanol as carbon source. In the final step, the filtration takes place in a dual-media filter (Mases et al, 2010). The filter facility is divided into five filters with an area of 44 m^2 each, equipped with 2200 backwashing nozzles (S10 1"ww, 0.7mm) on the bottom of each unit. The dual media consists of 0.6 m sand (1.2– 2.0 mm) and 1.2 m Filtralite®Clean MC (2.5–4.0 mm). The design capacity is calculated to 3.0 kg SS m^{-1} and the operating time is 24 h. The cleaning procedure is initiated by excessive head loss or when the predetermined running time is reached.

In 2017, ineffective backwashing cycles due to problems with backwashing pumps were observed. The specific bio deposits, accumulated in the filter media became difficult to remove by backwashing. In a period of a few weeks, these bio deposits in the filter bed had grown and built larger "mud balls". In addition, a gelatinous layer of deposit was observed on the surface of the filter. Microscopic observation could determinate these substance as extracellular polymeric substances (EPS), a complex of high-molecular-weight polymers excreted by microorganisms, produced from cell lysis and absorbed organic matter from the wastewater (Sheng et al, 2010). Extracellular polymeric substances can occur for many reasons, but generally their appearance can be associated with stress in biological systems. The most known producers of EPS in wastewater are *Zooglea*, which require only low levels of nitrogen to function, which, in turn enables them to thrive under nutrient deficient conditions (Jenkins et al, 2005). The conditions described above were observed in the filter at Klagshamn, e.g. lack of nutrients in presence of biodegradable organic matter. The sand particles covered with a layer of EPS have lower density than the clean grains and can escape out during backwashing, which in the long run results in loss of media (Haarhof et al, 2008; Bhosale et al, 2013).

Replacement of filter media and nozzles

The most effective, but also the most costly method to repair a filter is to replace the filter media and the nozzles. The clogging of the nozzles is a result of hard precipitation of the influent with coagulants (e.g. iron chloride). This method has a large economic impact, including costs for new media, nozzles, rent of machines for replacement of the media and costs for the disposal of the old one, summing up the total cost for one filter unit in size with the filter of Klagshamn at about 300 000–350 000 SEK. Note that the labour costs for the maintenance time of about 5–7 days is not included in the calculation.

Chemical rehabilitation of filter media

Chemical remediation often involves chemicals that are potentially or directly hazardous for the recipient and if large amount of these are returned back to the main process, the biological step and later the recipient will be damaged. Chemical cleaning, based on the use of different biocides or oxidizers, e.g. chlorine, ozone, peroxide, aluminium compounds, and formaldehyde, gives a good result (Bhosale et al, 2013), but is not suitable for in-situ cleaning procedures. For this purpose, other chemical such as sodium hydroxide and acids can potentially be used and neutralized before discharge in the mainstream process. In this study, different concentrations and combinations of sodium hydroxide, hydrochloric acid and sulphuric acid and different treatment time, were tested in laboratory scale with the aim to compare the different methods and to find one suitable procedure that can be applied in full scale.

Methods

Laboratory test

Filter media sampled from five places from one of the filters was mixed for laboratory tests. To ensure accuracy of the results, three sets of samples, with weight of about 20 g were treated by different methods (different chemical solutions and time). An overview of the methods can be seen in Table 1. To remove specific deposits from the media, the samples were initially flushed with distilled water, then dried at 105° C for 4 h. After performing the cleaning procedure according to Table 1, the samples were again flushed with distilled water, dried at 105° C for 4 h and weighed. The final weight of the samples were compared with the initial weights.

Full scale test

The cleaning method, tested in laboratory scale with best deposit reduction result was chosen to be applied in full scale. To ensure representative sampling, the procedure of chemical rehabilitation began with backwashing of the filter. Grab samples from five different places from the filter, on depths between 15 and 50 cm were collected and mixed. The samples were analysed according to Swedish Standard method SS 028113 for DS and VS.

Results and discussion

Laboratory tests

The weight loss (in percentage) by the different treatment methods is presented in Table 2. Greater reduction of the mass of the sample indicates that larger part of the deposits could have been dissolved from the media, i.e. the more efficient the method.

The results for the base, the two acids and combinations of them, are presented in Figure 1. Greatest reduction of biosolids (0.75–7.73 % weight loss) was achieved in batch 1 to 6, using sodium hydroxide as solvent. The reduction correlates with the concentration and the length of the treatment time applied. Furthermore, insignificant reduction of about 1 % was achieved when using acids (both hydrochloric acid and sulphuric acid) and the reduction did not improve by using more concentrated solutions or longer treatment time (batch 7–18). For the tests using combinations of base and acid, (batch 19–26), the maximum treatment time was limited to 4 hours divided in two parts, equal for each chemical substance. The reduction for these batches using combination of chemicals was as good as the results using a base

Table 1. *Overview of the methods tested in the laboratory.*

Number of the batch	Type of chemical	Concentration (%)	Treatment times (h)
1–6	NaOH	5, 10	1, 2, 4
7–12	HCl	5, 10	1, 2, 4
13–18	H_2SO_4	5 ,10	1, 2, 4
19–26	Combination of NaOH + HCl and NaOH + H_2SO_4	5, 10	1, 2, 4

Table 2. *Result from the laboratory tests.*
All values are presented as an average value from the three samples together with the standard deviation.

Number of the batch	Description			Weight loss (%)	Number of the batch	Description			Weight loss (%)
	Tests with one chemical					Tests with combination of chemicals			
1	5 %	NaOH	1 h	0.75 ± 0.11	19	5 %	NaOH	1 h	2.30 ± 0.25
2	5 %	NaOH	2 h	2.24 ± 0.25		5 %	HCl	1 h	
3	5 %	NaOH	4 h	5.78 ± 0.28	20	5 %	NaOH	2 h	2.97 ± 0.05
4	10 %	NaOH	1 h	1.63 ± 0.20		5 %	HCl	2 h	
5	10 %	NaOH	2 h	3.70 ± 0.22	21	10 %	NaOH	1 h	1.93 ± 0.01
6	10 %	NaOH	4 h	7.73 ± 0.56		10 %	HCl	1 h	
7	5 %	HCl	1 h	0.79 ± 0.10	22	10 %	NaOH	2 h	3.25 ± 0.05
8	5 %	HCl	2 h	0.62 ± 0.03		10 %	HCl	2 h	
9	5 %	HCl	4 h	0.46 ± 0.07	23	5 %	NaOH	1 h	1.57 ± 0.12
10	10 %	HCl	1 h	0.60 ± 0.06		5 %	H_2SO_4	1 h	
11	10 %	HCl	2 h	0.45 ± 0.01	24	5 %	NaOH	2 h	1.66 ± 0.02
12	10 %	HCl	4 h	0.70 ± 0.05		5 %	H_2SO_4	2 h	
13	5 %	H_2SO_4	1 h	0.32 ± 0.04	25	10 %	NaOH	1 h	2.20 ± 0.20
14	5 %	H_2SO_4	2 h	0.26 ± 0.00		10 %	H_2SO_4	1 h	
15	5 %	H_2SO_4	4 h	0.10 ± 0.00	26	10 %	NaOH	2 h	2.78 ± 0.16
16	10 %	H_2SO_4	1 h	0.08 ± 0.04		10 %	H_2SO_4	2 h	
17	10 %	H_2SO_4	2 h	0.42 ± 0.02					
18	10 %	H_2SO_4	4 h	1.09 ± 0.03					

for 2 hours, but less efficient in comparison to the reduction when treating the media with base for 4 hours. Clearly, it can be seen that sodium hydroxide (batch 1 – 6) is a suitable option for cleaning chemical and the reduction of the deposits in the sand increases with concentration and treatment time, Figure 2 a) and b). Plausible method suitable for application in full scale could be chemical cleaning with sodium hydroxide.

Full-scale application

As mentioned above, the backwashing water from the filter is collected in an equalization basin before returning to the inlet of the plant and the main process. To clean the media of one filter, 30 tonnes of sodium hydroxide (10 % solution) are needed to cover and to soak the sand media. Returning that amount of sodium hydroxide back to the main process would damage the biological step due to increased pH value and due to the fact that the autotrophic ammonia-oxidizing bacteria are known to be highly sensitive to high pH (Henze et al, 2000). Therefore, neutralisation of the sodium hydroxide solution with equal molarity of acid (e.g. hydrochloric acid) is needed.

The cost for the chemicals, based on the use of 30 tonnes sodium hydroxide (10 % solution) and 30 tonnes hydrochloric acid (10 % solution) is estimated to about 70 000 SEK and the time for maintenance – about 8 h.

The procedure of chemical rehabilitation in full scale began with a shutdown of the filter and starting a backwash cycle, then the media was soaked with 10 % solution of sodium hydroxide for 4 h.

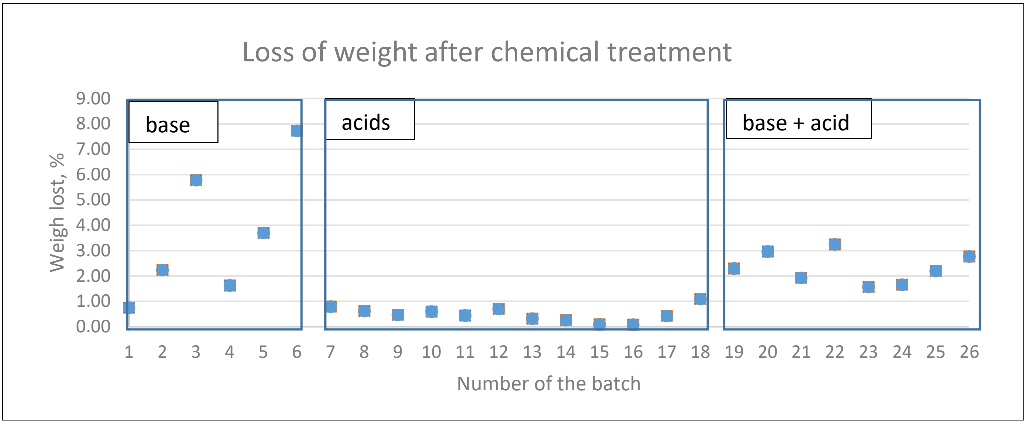

Figure 1. *Results from the different batches, divided by the active substance used for dissolving the deposits.*

The calculated amount of hydrochloric acid needed for the neutralization of the sodium hydroxide was released directly in the filter and the blowers were started for few minutes to mix both chemicals. Due to the limited volume of the equalization basin, the neutralization took place directly in the sand filter. To ensure that the neutralization was successful and before returning the backwash water into the main process, a "short" backwash program (using only one of the three backwashing pumps) was initiated. The pH value of the backwash water collected in the equalization basin, was monitored. The whole rehabilitation cycle ended with a complete backwash cycle including air and water before getting the filter back in operation.

Four mixed grab samples from five different places in the media were analysed before and after the rehabilitation was done. The reduction of the dry solids (DS) and the volatile part of DS (VS) were analysed (Figure 3).

After performed rehabilitation, the DS of the filter media increased from 67.9±0.78 % to

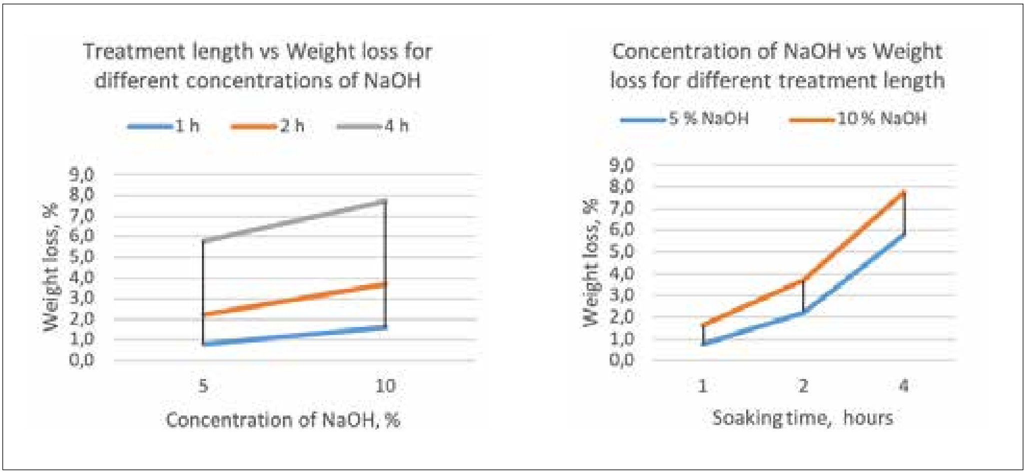

Figure 2. *The relationship between the concentration of sodium hydroxide and the reduction of the solids in the media (a) and the relationship between the soaking time and the reduction of the solids in the media (b). Relationships plotted as correlation between the parameters.*

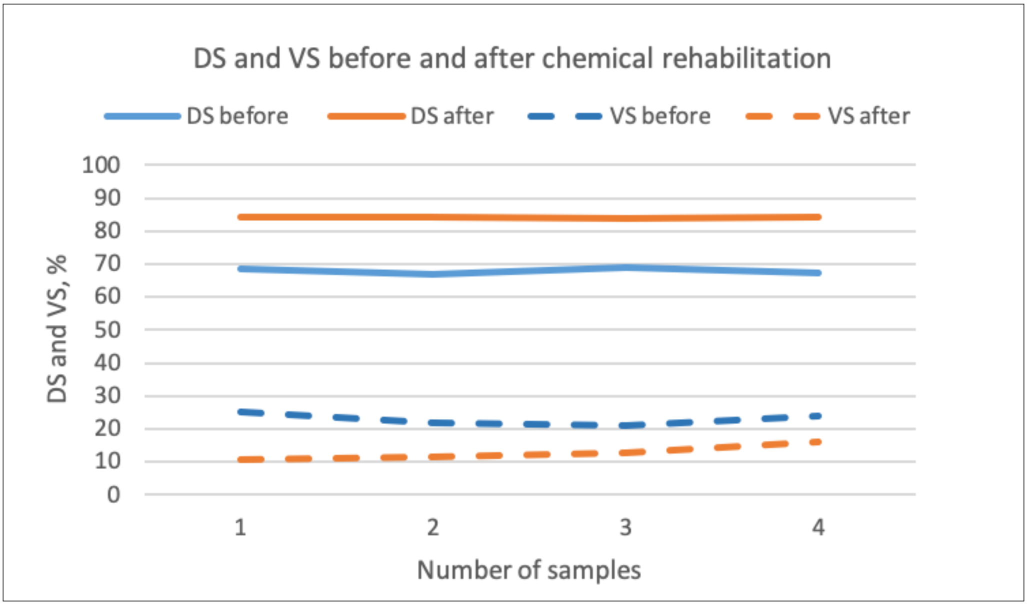

Figure 3. *DS and VS before and after rehabilitation of the media in the full scale filter.*

84.0±0.47 % and the weight loss was calculated to 12.4±0.45 % based on the DS values. The increscent of the DS can be explained by the fact that the biomass accumulated in the media captures water and the DS content of the media with high level of bio deposits is lower in comparison to the pure media. As expected, the VS calculated as a percentage of the DS also changes after the treatment. The decrease from 22.8±2.1 % to 13.8±2.9 % is due to reduction of the solids on the grains and dissolution of the volatile part of the deposits; expressed as weight loss the value of 13.05±0.46 % was been calculated. It is important to remember that even if the VS decreases with 8 % units (22.8±2.1 % to 13.8±2.9 %), the media can not be characterized as fully clean as the VS for clean media is less than 1 %. In this case, the amount of 30 tonnes sodium hydroxide (10 % solution) was calculated as the amount needed to cover the media, taking into account the volume of the sand filter and not the amount of the deposits accumulated in the media. As such practical limitations exist, the possible solution will be to repeat the rehabilitation procedure if the results after chemical treatment are not considered to be satisfactory.

Since biologically active filters are important for the overall reduction of nutrients in the wastewater treatment plant, the evaluation of the cleaning procedure should not only focus on the organic deposits left in the media, but rather on the overall filter function and the running time.

As the running time depends on both the clearness of the media as well the turbidity of the influent, in this case a comparison between periods with similar load and accumulation degree for the filter before and after the treatment were done, showing that for an accumulation degree of 1–3 kg SS d^{-1} the running time before chemical rehabilitation was established to 8–12 h and after – to 20–24 h.

Conclusions

Chemical rehabilitation of the filter media can remove organic deposits, such as "mud balls" and biofilm on the grains of the filter media. Different chemical solutions, one base and two acids, as well as different treatment time has been tested in laboratory scale, showing that soaking the media with 10 % sodium hydroxide for 4 hours results in reduction of the weight with 7.73±0.56 %. Different concentrations of acids did not have any remarkable impact, and the reduction was established to about 1 % weight loss. As the time of the treatment procedure and the concentration of the chemical were increased, the reduction of the deposits in the media increased. In some cases, when the backwash water needs to be returned to the main process, neutralization with acid to prevent a sudden raise of pH in the following treatment steps is recommended. In this study, a chemical rehabilitation base on a combination of 10 % sodium hydroxide for 4 hours followed by neutralization with 10 % solution of hydrochloric acid resulted in weight loss (solids removal) of 12.43 ±0.45 %, based on the DS values.

In-situ chemical cleaning methods are four to five times lower in cost than replacement of the media and less time-consuming compared to ex-situ methods of rehabilitation. However, since hazardous chemicals are used, the procedure of cleaning with caution, taking into account the conditions of the main process and the configuration of the filter facility.

Future work

The long lasting effects of the procedure, as well as the limitations of the method (e.g. maximum reduction of bio deposits) should be studied further.

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