Improvement of Drinking Water Plant Treatment

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Abstract: **-** Surface waters may contain a large number of undesirable compounds, which have to be removed in order to produce drinking water. In addition, depending upon the origin of water sources, certain biological pollutants may be present, such as algae, and especially the harmful cyanobacteria, which may present adverse health impacts. Several parameters can affect the efficiency of drinking water treatment plants, such as the type and configuration of subsequently applied treatment processes, the mass loading (flow rate), the presence of other co-existing pollutants etc.
In this paper, the operation of a large drinking water treatment plant was examined, located in Thessaloniki (N. Greece), and the efficiency of coagulation/ sedimentation and filtration processes were studied, regarding the removal of pollutants, which include organic matter, turbidity, solids and algal content. Various conventional coagulants were investigated for the removal of suspended solids and organic matter, using two alternative treatment schemes: coagulation/sedimentation, followed by sand filtration and direct filtration (i.e. without prior sedimentation), using for the experiments a depth filter (around 1 m), treating up to 380 m^3/h water (i.e. large-scale experiments). The operation of sand filter was evaluated using a single layer (sand only) and a double layer filter (sand: 60 cm, anthracite: 40 cm) and their performance was assessed in terms of removal capacity and head-loss build-up. Furthermore, the effect of influent pre-ozonation on the subsequent coagulation potential of drinking water was studied, while specific effort was given to the elimination of harmful algae.

Key-Words*:* **-** Depth filtration, direct filtration, dual media filter, water treatment plant

1 Introduction

Efficient production of drinking water from natural surface waters is a complicated process, where a wide variety of parameters have to be considered, such as the specific composition of raw water, the type and the configuration of applied treatment processes, the design parameters etc. Usually, the undesirable fraction of natural surface waters, which have to be removed, consists of the suspended (or colloidal) solids and of the natural organic matter (NOM). NOM usually comprises from particulate matter, such as algae cells or bacteria, as well as of dissolved organic matter (humic/fulvic acids) [1].

The conventional methods for removing these undesirable constituents (and colloids) generally include coagulation-flocculation, sedimentation, and depth filtration through granular media [2]. The aim of these methods is the aggregation of the solids and colloids to form settlable flocs, which can be removed easily in the settling basin. Depth-filtration through specifically used granular media (sand, anthracite, etc.) and active carbon are commonly used as polishing processes, whereas the application of other processes, such as ozonation and chlorination can also contribute to the removal of organic matter and the disinfection of water. These processes are employed in the drinking water treatment plant of Thessaloniki, Greece, receiving raw water from Aliakmon River; the flow diagram of the plant is given in Fig. 1. The capacity of this plant is around 150.000 m^3/d.

The efficiency of water treatment plant processes and the quality of water are examined in different points and controlled by the use of online meters and regular laboratory tests. Online measurements comprise of pH, conductivity, turbidity, temperature,

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residual aluminum and ozone concentrations, flow rate and dosages measurements. All these online values can be monitored, recorded and controlled electronically in a system called S.C.A.D.A. (Supervisory Control and Data Acquisition). The standard laboratory tests include also measurements of pH, conductivity, turbidity, suspended solids, and residual aluminum and ozone concentrations, as well as the determination of inorganic (asbestos, iron and manganese) and organic (pesticides, TOC) content. Algal and microbial content determination is also necessary. Algae can cause problems during the filtration process (quick fouling), besides they are potentially harmful for human health.

compared to the operation of a common sand filter bed. Dual-media filter beds are considered more effective than single ones, because such a filter can function as a progressive sieve, which can trap the larger solids at the top (anthracite) and the smallest particles deep within the bed (sand layer) [3]. This maximizes the solids holding capacity of bed in comparison with a mono-medium filter bed, substantially reducing the respective backwashing times in great extent.

The performance of direct depth-filtration was studied in this work, aiming to the optimization of plant operation and the reduction of the associated costs. The term direct filtration describes a turbidity

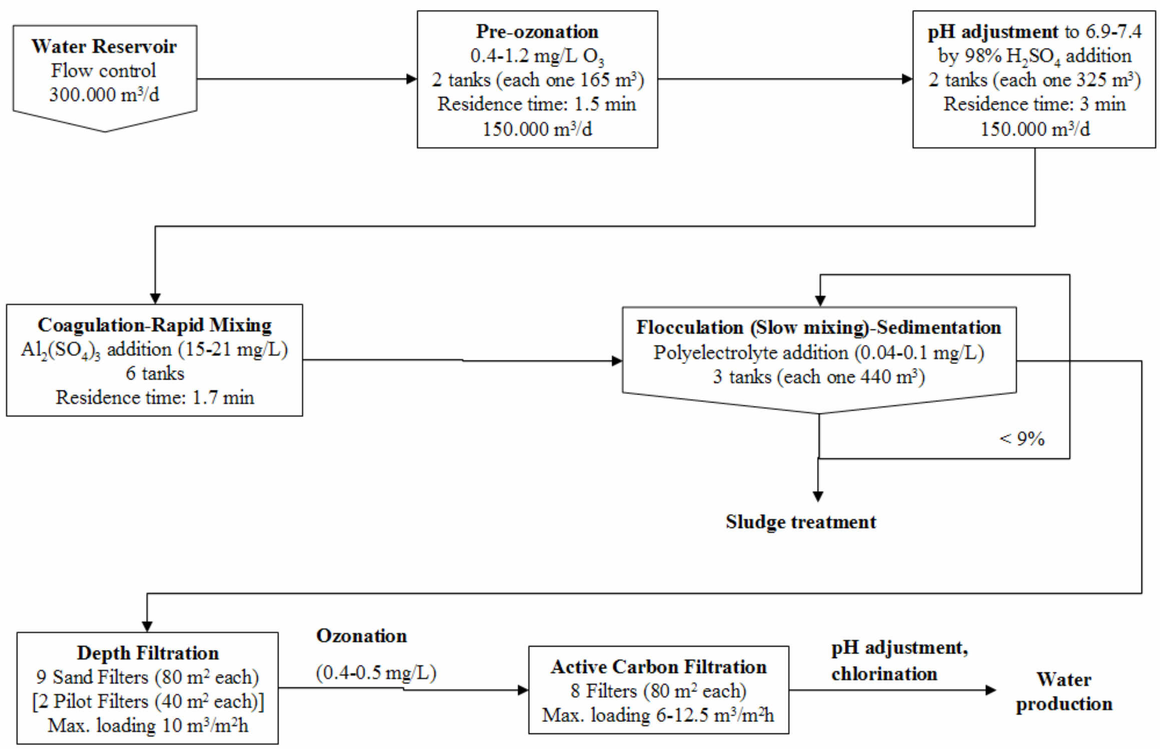

Fig. 1. Flowchart of basic processes in the drinking water plant treatment.

2 The aim of the study

In this paper, the operation of drinking water treatment plant of Thessaloniki was examined in order to investigate the efficiency of alternative applied techniques during the filtration process. Initially, filtration was studied through a dual-media filter bed, composed of a coarse layer of crushed anthracite coal (40 cm, D_{10}= 1.0-1.1 mm) over a layer of finer sand (60 cm, D_{10}= 1.4 mm) and it was

removal process, but without the application of separate flocculation and settling steps. With this method the coagulation/flocculation of raw water occurs immediately before, or within the feed water of filter. Direct filtration is considered suitable for surface waters with low turbidity, as well as for multi-medium filter beds, such as anthracite-sand filter, because in this case the influent must be of low turbidity and it is necessary to have a larger grain diameter (as anthracite) in order to decrease head loss [2].

Also, alternative chemical agents, such as Poly-Aluminium Chloride (PACl) can be applied as coagulants. According to the literature, PACl coagulant is regarded as more effective, than the commonly used aluminium sulphate (abbreviated as alum), because of the lower dosage requirements, the better performance at low temperatures (i.e. below 10 ^{o}C), the increased coagulation/flocculation rates, and the lower sludge volume production [4].

The evaluation of efficiency of the aforementioned technologies was accomplished, taking into account the removal of pollutants, which include organic matter, turbidity, solids and algal content. The ultimate aim of this study would be the investigation of the optimization of treatment methods, which can offer savings in terms of plant size, capital cost, and energy cost, as well as time saving and higher water production.

3 Experimental

All the large-scale experiments were conducted using two pilot filter beds of the water treatment plant of Thessaloniki. The operation of pilot beds was compared with the operation of a mono-layer filter bed. The surface area of pilot filters is half of the others (i.e. 40 m^2 and 80 m^2, correspondingly). The total depth of mono- and the dual-media filter beds is about 100 cm. The inlet flow rate of the pilot filter is the half than that of the other filters (i.e. about 375 m^3 h^{-1} against 750 m^3 h^{-1}), therefore to achieve the same filtration rate (about 9.4 m h^{-1}). The rest operation conditions are described separately in the following paragraphs.

3.1 Dual-bed filtration

After the adjustment of pH to 6.9-7.2, the coagulant (alum) addition (at concentrations between 1.7-2.5 mg Al/L), and the polyelectrolyte addition (0.065-0.11 mg L^{-1}) in the flocculator basin, the water was directed from the sedimentation tank to the filtration beds. All these operational conditions are the same for the experimental, as well as for the other filter beds.

The optimization of filter beds operation was investigated by performing online measurements of pH, conductivity, temperature, turbidity and head loss. Moreover, regular samplings of raw and of treated water (i.e. before and after filtration) were took place in order to check the aforementioned online measurements, as well as to determine the residual aluminum concentration and the absorbance at 254 nm, which is considered as an indication of NOM content.

3.2 Direct filtration

Direct filtration consists of a sequence of processes, such as pre-ozonation, pH adjustment and coagulant and polyelectrolyte addition, followed finally by filtration. The mixing of the chemicals was occurred in the 80 m pipe (diameter= 20 cm), which was used for the by-pass of flocculator-sedimentation tank. Filtration was conducted in the pilot sand filtration bed. The depth of the sand layer was set to 100 cm. Grain size distribution tests showed that the effective size (D_{10}) was 1.4 mm, whereas the uniformity coefficient (D_{60}/D_{10}) was in the range of 1.75 to 1.79. According to the literature for depth (1 to 2 m) sand filters, an effective size in the range of 2 to 4 mm and a uniformity coefficient in the range of 1.3 to 1.8 are recommended [5]. Direct filtration experiments were evaluated as mentioned before in the previous section. At this phase, various inorganic coagulants will be examined, other from alum, such as Poly-Aluminum Chloride (PACl).

4 Results

4.1 Dual-bed filtration results

The operation of dual-media filter bed lasted at least 3 months, in order to obtain statistically important experimental data/results. Finally, after some modifications of operational conditions of the filter bed, such as the flow rate and the duration of backwashing and the exact depth of the sand filter bed, the optimization of dual-bed filtration was achieved.

The daily average values (online and laboratory) of turbidity in the inlet and outlet of filter beds are presented in Fig. 2. Firstly as it can be seen from Fig. 2, there is good similarity between the online and the laboratory obtained data. Secondly, the filtrated water of the double-layer bed presented slightly increased turbidity values, in comparison with the single bed, during the first weeks of operation. This observation was predictable, as it is known that filter beds need a specific period of preliminary operation time in order to function properly. During this time, as the filter bed was backwashed repeatedly, the grain size of filtration medium was shifted towards the recommended more effective one and the ultra-fine fraction was gradually removed. Thus, after some months of operation (about 2.5 months) and a slight modification in the depth of sand layer (i.e. it was increased around 5-7 cm), it can be seen that the two filter beds produce a water of the same high quality.

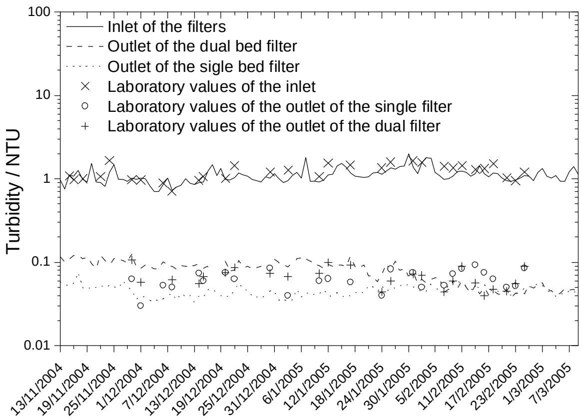

Fig. 2. Turbidity of water in the inlet and the outlet of the filter beds.

In Fig. 3 the absorbance at 254 nm (NOM indication) for the raw water, as well as for the filtrated water from the two compared filters is presented. These results show a significant dependence between NOM content of the raw and the filtrated water. Furthermore, due to the presence of anthracite and the resulting sorption, the respective values of UV_{254} were found lower in the case of dual bed filtration, when compared with the single bed.

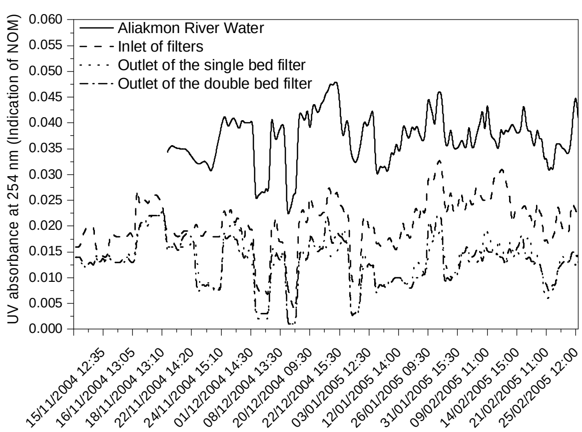

Fig. 3. Absorbance at 254 nm of raw and filtrated water.

Table 1 contains the statistics evaluation of various physicochemical parameters, which were examined during the investigation of dual-bed filtration. It must be noted that the residual aluminum concentration of filtrated water is much lower, than the upper permissible legislative limit of 200 μg Al/L for potable water.

A typical diagram of the pressure drop within the filters at various times during a filter run is illustrated in Fig. 4. It can be seen clearly that the filtration cycle of dual-media filter lasts about 3 to 4 times more, than the respective time of the single bed filter. Particularly, it was estimated that the average duration of filtration cycle of the double bed is about 74 h, whereas the average filtration cycle of the single bed is only 18 h.

Table 1. Average values and standard deviation of online and laboratory measurements, regarding the operation of filter beds.

Online and laboratory measurements	Mean Value	Standard Deviation
pH (online) at the inlet of filter beds	7.07	0.16
Lab value pH at the inlet of filter beds	7.11	0.10
Inlet turbidity, NTU (online)	1.11	0.32
Lab inlet turbidity, NTU	1.22	0.30
Outlet turbidity of dual-bed filter, NTU (online)	0.08	0.05
Lab outlet turbidity of dual-bed filter, NTU	0.07	0.03
Outlet turbidity of single bed-filter, NTU (online)	0.05	0.03
Lab outlet turbidity of single-bed filter, NTU	0.07	0.02
Residual Al conc. at the inlet of filters, μg L^{-1}	482	160
Residual Al conc. at the outlet of single filter, μg L^{-1}	28	9
Residual Al conc. at the outlet of dual-filter, μg L^{-1}	25	10

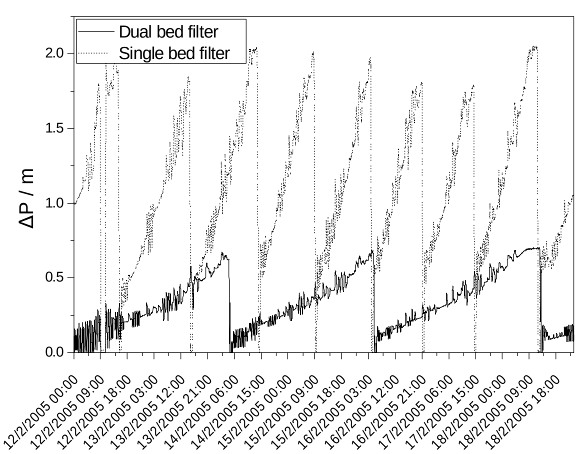

Fig. 4. Pressure drop development in the two filter beds.

The larger filtration cycle of dual-bed filter constitutes the most significant advantage in comparison with the single bed. It was computed that the water production of the dual bed could be about 10% higher, in comparison with the single bed. Furthermore, energy cost savings can be also obtained, because of the reduced usage of the pumps for the backwashing of dual filter.

4.2 Direct filtration results

Until the writing of this manuscript few experimental results of the direct filtration process were obtained. The large-scale experiments started in the pilot sand filtration bed. Initially, the effect of coagulant dosage without the addition of the polyelectrolyte was study. The selected dosages of alum were 0.1, 0.3, 0.5, and 0.7 mg Al/L. With the small dosages (0.1 and 0.3 mg Al/L) the duration of filtration cycle was slightly reduced, but the filtrated water presented rather high (unacceptable) turbidity (about 0.5-1.0 NTU). With the higher dosages (0.5 and 0.7 mg Al/L) the turbidity of filtrate was decreased to about 0.1 to 0.2 NTU, but the filtration cycle was reduced significantly to 4 hours (between backwashings). The addition of polyelectrolyte was examined at concentrations of about 0.01 to 0.03 mg L^{-1}. A combination of alum and polyelectrolyte addition at concentrations of 5 mg Al/L and 0.03 mg L^{-1} correspondingly resulted to improved results, regarding the turbidity of the filtrated water (about 0.1 to 0.2 NTU) and the filtration cycle (5-7 hours).

The rapid clogging of beds during the direct filtration is known from the literature [2, 3]. However, using a dual filter bed (such as the coal-sand filter), it is expected that the direct filtration will be more successful. Also, the addition of PACl coagulant may increase further the efficiency of filtration process.

5 Conclusion

Summarizing, in this paper the operation of a double-layer filter bed (anthracite and sand) was compared with a single-layer bed of sand. The experimental results proved that the quality of effluent water was similar for the two beds, regarding the turbidity and NOM removal, as well as the residual aluminum concentration. However, the double-bed was superior to the single bed, as the filtration cycle of the former can last about 3 to 4 times more. The 10% higher water production of the dual bed and the lower energy consumption for the backwashing can contribute considerably to the total production of water in the treatment plant, as well as in the cost energy savings. Finally, the direct filtration process is expected to be successful, especially with the use of dual filter bed, thus reducing treatment time and operational costs.

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References:

[1] Aromaa A., *Comparing Alum and Ferric Salt in Surface Water Treatment*, University of Oulu, 2000

[2] Ching-Jung Chuang and Kun-Yan Li, Effect of Coagulant Dosage and Grain Size on the Performance of Direct Filtration, *Separation and Purification Technology*, Vol.12, 1997, pp. 229-241.

[3] Weber W.J., *Physico-chemical Processes for Water Quality Control*, Wiley-Interscience, 1972.

[4] Duan J. and Gregory J., Coagulation By Hydrolysing Metal Salts, *Advances in Colloid and Interface Science*, Vol.100-102, 2003, pp. 475–502

[5] Amini F. and Truong H.V., Effect of Filter Media Particle Size Distribution on Filtration Efficiency, *Water Qual. Res.*, Vol.33, No.4, 1998, pp. 589-594.