

Optimization of Compressible Medium Filter for Secondary Effluent Filtration

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Abstract Several innovative filtration technologies have been developed in the last two decades to decrease the backwash requirements, to increase the water production efficiency, and to improve the operational and design conditions. The Compressible Medium Filter (CMF) also known as the “Fuzzy Filter” involves the use of a synthetic compressible fiber (polyvaniladene) porous material as the filtering medium instead of conventional granular material. The optimization of the CMF operation is discussed in this paper. Both the CMF removal performance and backwash water ratio (BWR) increase significantly as the medium compression ratio (MCR) is increased. The optimum MCR (for turbidity removal purposes) is the minimum MCR that results in the required degree of turbidity removal to prevent excessive BWR. The optimum MCR for the filtration of conventional activated sludge secondary effluent (for wastewater reuse application) increases from approximately five percent to 25 percent as the average influent turbidity increases from 4 NTU to 7 NTU. The filtration model developed for CMF application can be used to predict the optimum MCR curves for different and more complex filtration conditions. Chemical requirements are also eliminated or minimized with the CMF technology by increasing the MCR when the influent conditions get worse.

Keywords Compressible medium filter, filtration optimization, fuzzy filter, secondary effluent filtration

Introduction

Several innovative filtration technologies (Furuya et al., 2005; Dayton, 2006; Knapp and Tucker, 2006) have been developed in the last two decades to decrease the backwash requirements, to increase the water production efficiency, and to improve the operational and design conditions. The Compressible Medium Filter (CMF) technology involves the use of a synthetic compressible fiber (polyvaniladene) porous material as the filtering medium instead of conventional granular material (Caliskaner et al., 1999). An individual compressible filter medium ball is approximately 30 mm in diameter (see Figure 1). The CMF has also been designated as the “Fuzzy Filter” because of the appearance of the material. The optimization of the operation of the CMF is discussed in this paper.

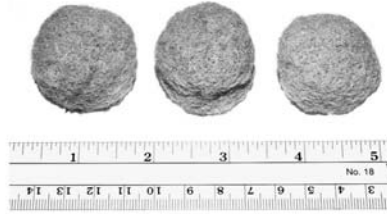


Figure 1 Compressible filter medium

Background

The CMF has two unusual properties; (1) the filter medium is highly porous and (2) the medium is compressible. These two uncommon properties of the new filter medium are unique and potentially offer significant advantages over existing filtration technologies employing incompressible solid filter mediums. Unlike conventional filters, it is possible to optimize the performance of the CMF by adjusting the medium properties (i.e., collector size, porosity, and depth). The properties of the medium can be adjusted by altering the degree of the medium compression in response to the changing influent conditions (e.g., influent turbidity, total suspended solids, particle size distribution) and the desired effluent quality. The filter medium is retained between two perforated plates (see Figure 2); the medium compression ratio (MCR) is changed by adjusting the position of the upper movable plate (compression plate). The average MCR is calculated by the use of following expression:

$$\text{Medium compression ratio} = 1 - \frac{\text{compressed medium depth}}{\text{uncompressed medium depth}} \quad (1)$$

For example, to compress the medium 40 percent, the compression plate is lowered until the medium thickness is 460 mm when the initial uncompressed medium depth is 760 mm.

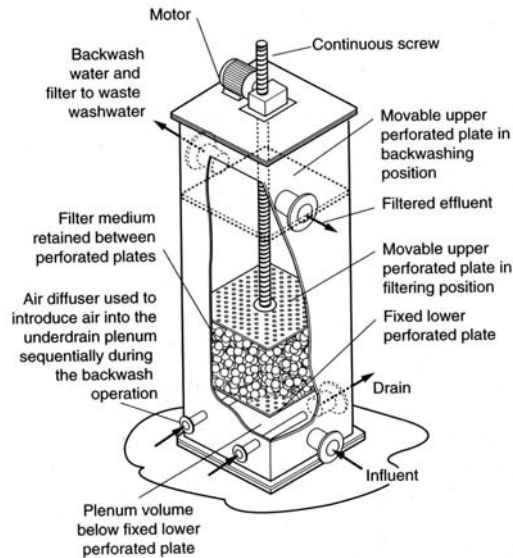


Figure 2 Schematic diagram for the operation of the compressible medium filter

Methodology

The CMF performance evaluation was conducted at filtration rates from 205 to 1230 L/m²•min and with MCRs from 0 to 40 percent to determine the optimum operational conditions. The experiments conducted at 820 L/m²•min will be discussed in this paper. The medium properties such as the porosity, collector size (size of the interstice), and depth all decrease with the increase in the applied MCR. The properties of the filter medium as a function of the MCR are presented in Table 1.

Table 1 Properties of the compressible filter medium at different medium compression ratios

Medium Compression Ratio, %	Porosity, %	Medium Depth, mm	Effective Collector Size, mm
0	90	760	0.44
15	88	650	0.38
30	86	530	0.23
40	83	460	0.17

The parameters used to analyze the filter performance include turbidity, total suspended solids (TSS), and particle size distribution. Turbidity measurements were performed continuously by using two Hach Model 1720C low range process turbidimeters. Turbidity measurements of the grab samples for comparison and confirmation purposes were made with a Hach Model 2100 P turbidimeter. Total suspended solids measurements were conducted according to Method 290 D outlined in Standard Methods (American Public Health Assoc., 1995). Particle size distribution can be obtained via several techniques reported in the literature (Mueller et al., 1967; Rickert and Hunter, 1978; Gibbs, 1982; Li and Ganczarczyk, 1985; Durst, 1985). Sieving, the most conventional of all the particle size analysis techniques, was used in this study. The experimental procedure is almost the same with TSS analysis except the use of several filters with different pore sizes in series. Filters with pore sizes of 60, 20, 5, and 0.8 µm were chosen for this study.

Results and Discussions

The results of the experiments performed at a filtration rate of 820 L/m²•min to determine the optimum MCR are presented in this section. The discussions related to the optimum filtration conditions are also presented below.

Effect of Medium Compression Ratio on the Removal Performance

The filtration experiments conducted at MCRs of 0 percent and 30 percent are presented in Figure 3 and Figure 4, respectively. The average effluent turbidity was observed to be less than 2 NTU for both experiments. Similar experiments at MCRs of 15 percent and 40 percent were also conducted (Caliskaner, 1999). An average effluent versus influent turbidity analysis has been performed to compare the filter turbidity removal performance at the MCRs mentioned above, and to determine the influent turbidity value that can be filtered without exceeding the effluent requirement. These experiments were conducted without the use of chemicals. The increase in the removal efficiency due to the increase in the MCR is depicted in Figure 5. Greater influent turbidity values can be handled as the degree of the compression increases. As seen in Figure 5, the effluent turbidity is around 1.5 NTU for influent turbidity values of approximately 3.2 NTU, 5.5 NTU and 7 NTU at MCRs of 0 percent, 15 percent and 30 percent, respectively.

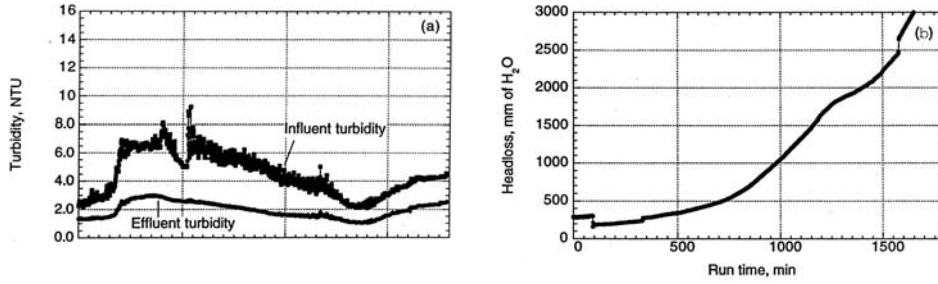


Figure 3 Filtration of activated sludge effluent at a filtration rate of 820 L/m²•min, an initial bed depth of 760 mm, and 0 percent bed compression: (a) influent and effluent turbidity data versus time and (b) headloss development versus time

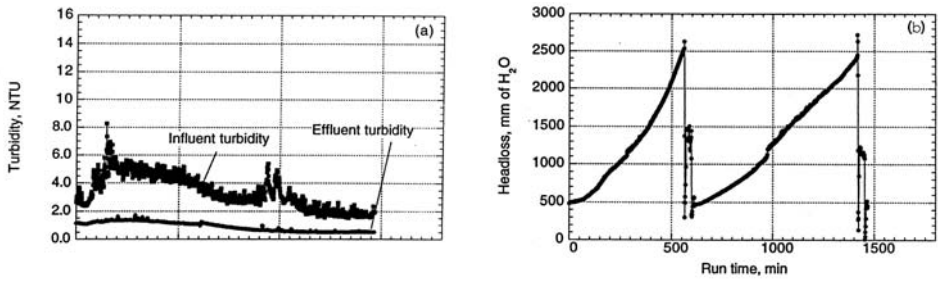


Figure 4 Filtration of activated sludge effluent at a filtration rate of 820 L/m²•min, an initial bed depth of 760 mm, and 30 percent bed compression: (a) influent and effluent turbidity data versus time and (b) headloss development versus time

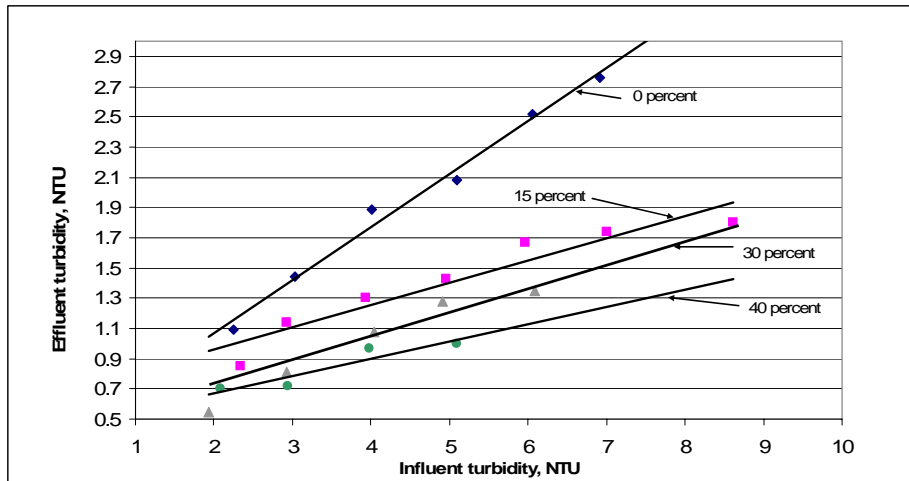


Figure 5 Average influent versus effluent turbidity values at a filtration rate of 820 L/m²•min for MCRs between 0 percent and 40 percent

Effect of Medium Compression Ratio on Backwash Water Ratio

The other important consideration to evaluate and optimize the performance of the filtration operation is the quantity of the backwash water used relative to the amount of water processed. The typical backwash water ratio (BWR) is between one percent and five percent for CMF, which is significantly less compared to the BWR ratios of six percent to 15 percent for most conventional secondary effluent filters (Metcalf & Eddy, 2003).

The experiments were terminated for backwashing either after approximately 24 hours of operation (for medium maintenance purposes) or when the medium headloss development reached the maximum allowable level of 2540 mm. The filtration run time decreases as the MCR increases because the headloss development increases with the MCR. As seen in Figure 3 and Figure 4, the filtration run time was approximately 30 hours and ranged between 10 and 15 hours for MCRs of 0 percent and 30 percent, respectively.

Secondary effluent is used for backwashing with the CMF technology. The complete backwash cycle takes approximately 30 minutes, and the backwash flow rate is 410 L/m²•min. The observed BWR values are plotted as a function of MCR in Figure 6. As seen in Figure 6, the BWR increases as the medium compression increases. The BWR increased approximately 2.5 times from 1.1 percent to 2.8 percent as the MCR was increased from 0 percent to 40 percent.

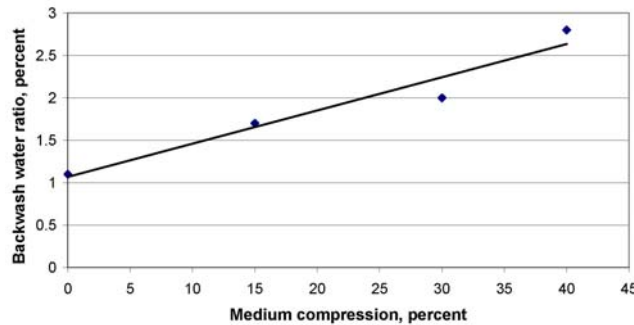


Figure 6 Backwash water ratio as a function of medium compression at a filtration rate of 820 L/min-m²

Determination of Optimum Medium Compression Values

As illustrated in Figure 5, turbidity removal increases as the MCR is increased. The BWR also increases as the MCR increases (see Figure 6). The optimum MCR (for turbidity removal purposes) is therefore defined as the minimum value of the MCR that results in the required degree of turbidity removal to prevent excessive BWR (i.e., to prevent excessive headloss development across the filter medium).

The optimum medium compression curves for average influent turbidity values from 3 NTU to 7 NTU are presented as a function of the target effluent turbidity values in Figure 7. One common application of CMF is to produce an average effluent turbidity of 2.0 NTU to comply with the requirements specified in the Title 22 wastewater reuse criteria (Calif. Admin. Code, 1978). A target effluent turbidity of 1.6 NTU can be used for the design and operation of the CMF to include a safety factor of 20 percent. The optimum operational MCRs are presented in Table 2 for the target effluent turbidity value of 1.6 NTU. The optimum MCR increases from approximately five percent to 25 percent as the average influent turbidity increases from 4 NTU to 7 NTU.

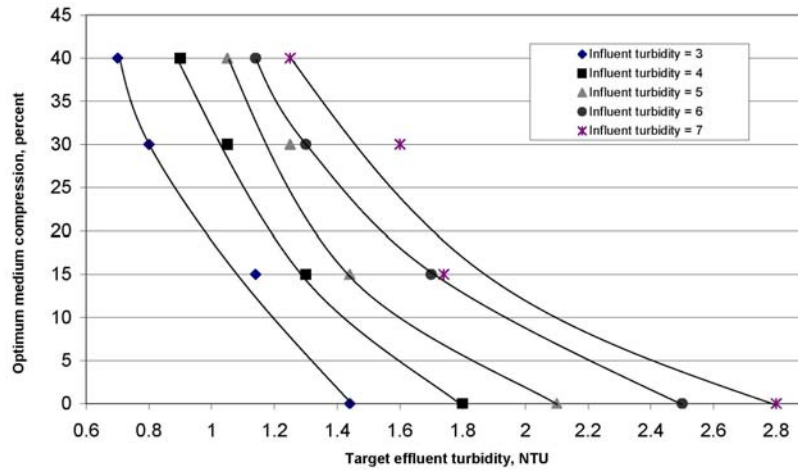


Figure 7 Optimum medium compression curves as a function of influent and target effluent turbidity values at a filtration rate of 820 L/min-m²

Table 2 Optimum medium compression levels at different influent conditions for the filtration of conventional activated sludge secondary effluent for wastewater reuse

Average Influent Turbidity, NTU	Optimum Medium Compression, %
3	0
4	5
5	10
6	18
7	25

In Table 2, the optimum operational MCRs are given for typical particle size characteristics of conventional activated sludge secondary effluent that is taken from a municipal type wastewater treatment plant. The optimum compression ratio is also a function of the particle size and characteristics and specific filtration purposes. The particle size distribution from an extended aeration system or from a trickling filter system is different than the conventional activated sludge secondary effluent used in this study. For example, the optimum MCR would be 30 percent to maximize the removal performance if the suspension is composed of large particles (e.g., larger than 60 μm in size) as increasing the compression ratio beyond 30 percent does not have a positive effect on the particle removal efficiency but increases the BWR (i.e., rate of headloss development) significantly. On the contrary, 40 percent medium compression is selected to maximize the particle depth removal efficiency if the suspension is composed of particles very small in size (e.g., less than 5 μm in size). Because of the variations in filtration conditions for different applications, filtration modeling has engineering significance especially for the CMF because of the additional filtration parameter which is the MCR. A new predictive model has been developed to describe the filtration performance of the CMF and to predict the optimum MCR. The model developed for heterodisperse suspensions and variable influent conditions (turbidity and hence TSS), can be used to predict all possible phases of filtration (i.e., ripening, constant removal, and breakthrough). The following hyperbolic type second order nonlinear partial differential equation was derived to model the CMF:

$$\frac{\partial^2 C}{\partial a \partial x} - \frac{1}{C} \frac{\partial C}{\partial x} \frac{\partial C}{\partial a} + \frac{V}{\sigma_{\max}} \lambda C \frac{\partial C}{\partial x} - \frac{1}{\lambda} \frac{\partial \lambda}{\partial a} \frac{\partial C}{\partial x} = 0 \quad \text{Eq. 2}$$

Where, C = Concentration of particulate material (TSS in wastewater), M/L³
t = Filtration time, T
x = Medium depth in the direction of the flow, L
σ_{max} = Maximum specific deposit, M/L³
λ = filter coefficient, L⁻¹
V = Approach filtration velocity, L/T

The development of Equation 2 and verification of the model are presented somewhere else (Caliskaner and Tchobanoglous, 2005). The model is used to predict the optimum medium compression curves (as in Figure 7) for different and more complex filtration conditions.

Optimization of Chemical Addition

Chemical addition is typically the only operational adjustment for filters with fixed medium properties to obtain the desired effluent quality when the influent conditions get worse. The CMF technology has the potential of eliminating or minimizing the chemical addition by increasing the MCR when the influent conditions get worse. From the results presented in this study (see Figure 5) it can be concluded that for a medium compression value of about 15 percent, the average effluent turbidity will be less than 1.6 NTU for influent turbidity values of up to approximately 6 NTU. Medium compression ratio is increased (i.e., to between 30 and 40 percent) to maintain the average target effluent turbidity value of 1.6 NTU (without chemical addition) when the average influent turbidity increases up to between 8 NTU and 9 NTU. The elimination of the requirement of a chemical for high filter influent turbidity values by simply adjusting the MCR is a significant advantage with respect to both wastewater treatment plant (WWTP) effluent limitations (e.g., for aluminum and iron) and chemical cost requirements. Chemical requirements are minimized as the chemicals become necessary only at very high secondary influent turbidity values (e.g., higher than 9 NTU).

Conclusions

The conclusions drawn from the results discussed in this paper are summarized below.

- (1) Both the CMF removal performance and BWR increase significantly as the MCR is increased. The turbidity removal performance was observed to increase almost 100 percent as the MCR was increased from 0 percent to 40 percent. The BWR was also observed to increase approximately 250 percent as the MCR was increased from 0 percent to 40 percent. The optimum MCR (for turbidity removal purposes) is therefore defined as the minimum value of the MCR that results in the required degree of turbidity removal to prevent excessive BWR.
- (2) The optimum MCR for the filtration of conventional activated sludge secondary effluent (for wastewater reuse application) increases from approximately five percent to 25 percent as the average influent turbidity increases from 4 NTU to 7 NTU.
- (3) Optimum medium compression values change for different filtration conditions and applications. The new filtration model can be used to predict the optimum medium compression curves for different and more complex filtration conditions.

- (4) The CMF technology has the potential of eliminating or minimizing the chemical addition by increasing the MCR when the influent conditions get worse. Chemical requirements are minimized as the chemicals become necessary only at very high secondary effluent turbidity values.
- (5) The BWR is an important design and operational criterium for the entire WWTP as the backwash reject water is returned to the head of the WWTP (e.g., headworks, primary influent, or secondary influent). Therefore, optimized design and operation of the CMF results in directly related optimized conditions for all of the treatment facilities downstream of the backwash water return location. The BWR of the CMF technology is typically five to ten percent less compared to granular type filtration technologies. From the results presented in this paper, it can be concluded that the BWR can further be reduced one to two percent by the optimization of the CMF operation resulting in significant capital and operational cost savings.

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