FILTRATION OF EFFLUENTS FOR MICROIRRIGATION SYSTEMS

J. Puig-Bargués, J. Barragán, F. Ramírez de Cartagena

ABSTRACT. *Clogging, measured through head loss across filters, and the filtration quality of different filters using different effluents were studied. The filters used were: 115, 130, and 200 μm disc filters; 98, 115, 130, and 178 μm screen filters; and a sand filter filled with a single layer of sand with an effective diameter of 0.65 mm. The filters were used with a meat industry effluent and secondary and tertiary effluents of two wastewater treatment plants. It was observed that clogging depended on the type of effluent. With the meat industry effluent, the poorest quality effluent, disc filters clogged more than the other filter types. When the wastewater treatment plant effluents were used, the disc filters showed less frequent clogging. Several physical and chemical parameters, such as total suspended solids, chemical oxygen demand, turbidity, electrical conductivity, pH, and number of particles, were analyzed in the effluents at the entry and exit points of the filters. In general, filters did not reduce the values of the main clogging parameters to a great degree. It was found that the parameter that explained the clogging, expressed as Boucher's filterability index, was different depending on the type of effluent and filter. The best quality of filtration was achieved with a sand filter when the meat industry effluent was used. No significant differences were observed between the quality of filtration of disc and screen filters when operating with the secondary and tertiary effluents.*

Keywords. *Clogging, Drip irrigation, Filters, Wastewater.*

Clogging is one of the most important problems when using effluents in microirrigation because a small percentage of clogged emitters can seriously affect water distribution and cause crop yield reductions (Oron et al., 1979; Tajrishy et al., 1994). Filtration is a basic operation that improves the water quality and diminishes physical clogging (Oron et al., 1979; McDonald et al., 1984).

Although the real process of separation and accumulation of solids in filters is not completely known, there are two models of the filtration process (Adin and Alon, 1986; Perry et al., 1997). The first one is superficial filtration, in which the particles with a size greater than the pores of the filtering media are retained on the media surface and accumulate layer by layer, forming a cake with increasing thickness. This kind of surface filtration takes place in screen and disc filters. The second model is deep filtration, which occurs when suspended matter is retained in the pores of the filtering media. Particles that are retained with this second type of filtration can be smaller than the filter pores since particle capture is controlled by both physical and chemical mechanisms. This second model of filtration occurs in granular media filters, such as sand filters, and to a lesser degree in disc filters.

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In the literature, there are few equations adapted to the filters commonly used in microirrigation. Boucher's relationship can be applied to surface filtration (Adin and Alon, 1986). Boucher's relationship supposes that there are two simultaneous processes: (1) the deposition of particles within the filter pores and the filter cake that accumulates on the filter and obstructs the passage of the solids, and (2) a constant deposition rate of particles on the surface of the filter (Adin and Alon, 1986).

Boucher's relationship shows that the increase of head loss in a filter with fixed water quality is exponential and can be expressed by the following equation:

$$\Delta H = \Delta H_o e^{IV} \quad (1)$$

where

ΔH = final pressure losses across the filter (kPa)
ΔH_o = initial pressure losses across the filter (kPa)
V = volume filtered (m^3)
I = Boucher's filterability index (m^{-3}).

The filterability index depends on the filter's characteristics, such as its geometry, media type, and support, and on water properties, especially the concentration of suspended solids. However, in Boucher's relationship, neither the filter characteristics nor how the cake compressibility affects the filtering is considered.

The higher the filterability index, the more difficult the filtration becomes. So, the filterability index represents the resistance of the filter and the cake. The filterability index is higher, and thus the clogging of the filter is increased, when total suspended solids and the filtration flow rate are higher and the filter pore apertures are smaller (Adin and Alon, 1986).

The objectives of this study were to determine the quality of filtration and the time required between cleanings of various filters used in microirrigation with different effluents

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and to determine the physical and chemical parameters that have the greatest influence on clogging.

Materials and Methods

Several filtration experiments with different filters and effluents were carried out to sample a broad range of operating conditions for the main types of filters used in microirrigation. The experimental setups of the different trials are described below.

Effluents Used

Five effluent types were used in the trials. The first type was a meat industry wastewater, which received preliminary treatment by a rotary drum screen, was transported to a 129 m^3 tank, and was then conveyed from this tank to a 4,000 m^3 reservoir, from which the effluent was taken. The second type was the effluent after secondary treatment through a sludge process at the wastewater treatment plant in Girona, Spain (WWTP Girona). The third type was the previous effluent filtered through a sand filter for microirrigation systems. The fourth type was the effluent after secondary treatment by a sludge process at the wastewater treatment plant in Castell-Platja d'Aro, Spain (WWTP Castell-Platja d'Aro). Finally, the fifth type of type was the effluent after tertiary treatment at WWTP Castell-Platja d'Aro, obtained by filtering the secondary effluent of this plant through sand and disinfecting it by exposure to ultraviolet light and chlorination with 5 mg NaClO L^{-1}.

Filtration Bank

A filtration bank was constructed to carry out the trials with the meat industry and WWTP Girona effluents. In this bank, several filters were fed from a main pipe. At each filter position was a 38.1 mm diameter pressure regulator, a 31.75 mm diameter volumetric counter, valves to take samples of water at the entry and exit points of the filter, and a manometer before the filter and another at its exit point. The filtration bank was easily dismantled, so it could be moved to carry out the different trials at the effluent locations. In addition, it could be modified to vary the operating conditions, as will be explained later.

Filters were chosen in order to test the most common filter types used in microirrigation systems. Specifically, three screen filters, three disc filters, and one sand filter were used. The screen filters were of 50.8 mm diameter with a nylon screen filtration surface of 946 cm^2 and openings of 98 μm (S98), 115 μm (S115), and 178 μm (S178). The disc filters were of 50.8 mm diameter with a filtration surface of 953 cm^2 and openings of 115 μm (D115), 130 μm (D130), and 200 μm (D200). The sand filter was of 508 mm diameter with a filtration surface of 1,963 cm^2 and was filled with 175 kg of sand as a single filtration layer. The effective diameter of the sand (screen opening that retains 90% of the sand) was 0.65 mm.

The filters operated individually or simultaneously in the trials with the meat industry effluent and the WWTP Girona secondary effluent. A diagram of the filtration bank is shown in figure 1a. When the WWTP Girona effluent was filtered with sand, the exit pipe from the sand filter was connected to the inlet of the other filters (fig. 1b). Thus, the sand-filtered flow was distributed uniformly through the screen and disc filters. With this configuration of the filtration bank, it also was possible to backwash the sand by circulating effluent in the opposite direction. In the trials with the meat industry effluent, water was driven by the pumps of the irrigation system. The pumps of the treatment plant were used in the WWTP Girona trials.

When the trials were carried out with the WWTP Castell-Platja d'Aro effluents, fewer filters were used, changing the arrangement of the filtration bank. In this case, each filter had a manometer at the entry and exit point, a volumetric counter of 12.7 mm diameter, and a pressure regulator of 6.35 mm diameter. Valves were placed before the volumetric counter and at the filter exit to take samples of the effluents.

The filters used with the WWTP Castell-Platja d'Aro secondary effluent were an inclined 130 μm nylon screen filter (S130) of 50.8 mm diameter and with a filtration surface of 640 cm^2, and a 130 μm disc filter (D130) of 50.8 mm diameter and with a filtration surface of 953 cm^2. Only one

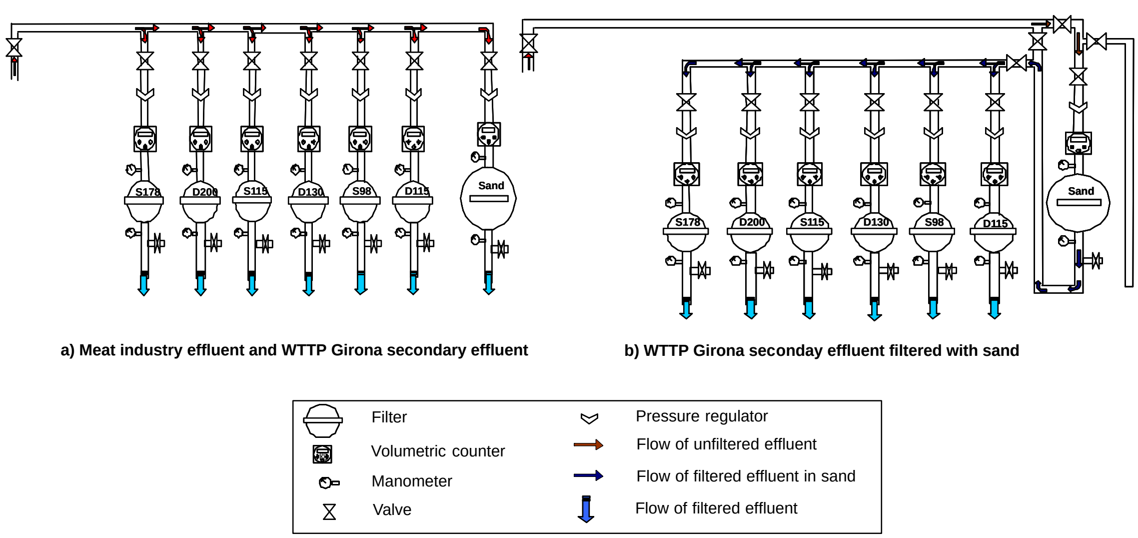

Figure 1. Diagrams of the filtration banks used for the meat industry and WWTP Girona effluents.

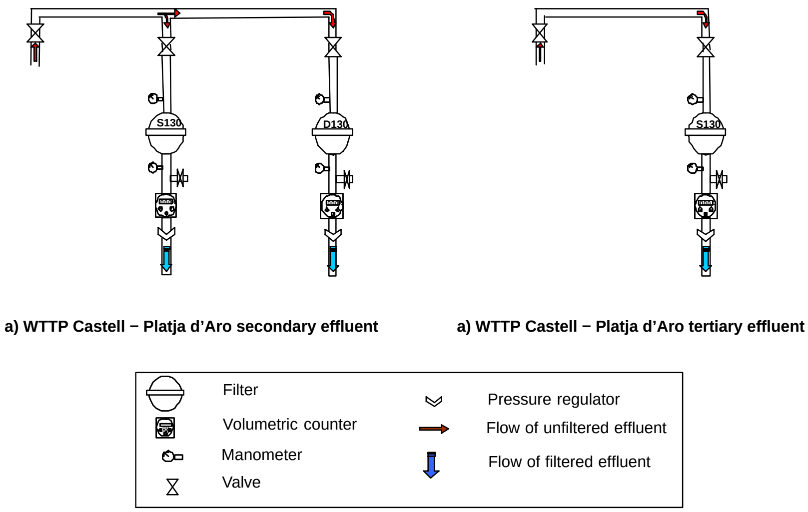

Figure 2. Diagrams of the filtration banks used for the WWTP Castell-Platja d'Aro secondary and tertiary effluents.

filter was used with the WWTP Castell-Platja d'Aro tertiary effluent, a screen filter of the same characteristics as the filter used with the secondary effluent from the same treatment plant. Diagrams of the filtration banks used during these trials are shown in figure 2.

The WWTP Castell-Platja d'Aro secondary effluent was pumped by a 2.2 kW centrifugal three-phase pump, while the tertiary effluent was pumped by a 0.6 kW centrifugal single-phase pump. In both cases, the pumps were controlled by an individual control device with a timetable programmer. In the experiments with the WWTP Castell-Platja d'Aro secondary and tertiary effluents, the filters operated simultaneously because the operation schedule was the same for all the filters.

Experimental Procedure

The experiments consisted of determining the clogging caused by the effluents in the filters tested. Seven tests were carried out using disc filters and the 98 μm and 115 μm screen filters with the meat industry effluent, six tests were done with the 178 μm screen filter, and three were carried out with the sand filter. Each screen and disc filter was tested six times using the WWTP Girona secondary effluent, while the sand filter was tested fourteen times. The number of tests using the WWTP Girona secondary effluent filtered with sand was five (115 μm screen filter), six (115 μm disc and 178 μm screen filters), seven (130 μm disc filter), and nine (200 μm disc and 98 μm screen filters). The 130 μm disc filter was tested four times with the WWTP Castell-Platja d'Aro secondary effluent, while both 130 μm screen filters were tested five times using the secondary and tertiary effluents of this treatment plant.

The parameter used to determine the clogging was the head loss across the filter in relation to the volume of water filtered. Therefore, readings of the manometers at the entry and exit points of each filter and of the volumetric counters were taken at regular time intervals. From the head loss measured, the initial head loss, and the volume of water passing through the filter, the filterability index of Boucher's relationship was calculated by means of equation 1.

In the trials, the filters were considered to be completely clogged when the head loss across the filter was higher than 49 kPa. When the head loss reached this value, the filters were cleaned. The screen and disc filters were cleaned manually using water under pressure, while a system of backwashing with effluent was used with the sand filter until the sand was observed to be clean. The time and volume of water required were controlled during the backwashing of the sand filter. The mean time of backwashing was 32 min, and the mean water consumption was 1.09 m^3.

As has been mentioned, the pumping systems varied in each trial, causing the surface filtration velocities to be different. The surface filtration velocity was calculated as (McCabe et al., 2001):

$$v = \frac{dV/dt}{A} \qquad (2)$$

Table 1. Mean surface filtration velocities (L m^{-2} s^{-1}) and standard deviations for the different filters and effluents.

Filter	Meat Industry Effluent	WWTP Girona		WWTP Castell-Platja d'Aro	
		Secondary Effluent	Secondary Effluent Filtered with Sand	Secondary Effluent	Tertiary Effluent
D115	11.5 ±6.08	4.73 ±2.43	1.40 ±0.03	--	--
D130	7.75 ±5.57	5.11 ±3.02	1.34 ±0.10	3.01 ±0.14	--
D200	7.23 ±5.55	6.42 ±0.22	1.29 ±0.07	--	--
S98	16.2 ±5.09	2.67 ±0.96	0.96 ±0.02	--	--
S115	11.2 ±8.54	3.13 ±3.00	0.91 ±0.08	--	--
S130	--	--	--	4.46 ±0.34	5.09 ±0.08
S178	6.76 ±4.04	5.41 ±2.38	0.92 ±0.01	--	--
Sand	3.88 ±2.47	2.88 ±0.25	--	--	--

where

v = surface filtration velocity (L m^{-2} s^{-1})

V = effluent volume filtered from the beginning of the filtration until a time of filtration (L)

t = time of filtration (s)

A = filtration surface (m^2).

The mean values of the surface filtration velocities are shown in table 1.

Characterization of the Effluents and Filter Efficiencies

Samples of effluents at the entry and exit points of the filters were taken in each experiment. Samples were obtained at different times in each test, first at the entry point and then, by order of starting, at the exit point of each filter.

The physical and chemical parameters analyzed for the meat industry and WWTP Girona effluents (filtered and not filtered with sand) were total suspended solids (TSS), electrical conductivity (EC) at 20°C, pH, turbidity, and chemical oxygen demand (COD). Total suspended solids (TSS), turbidity, and chemical oxygen demand (COD) were determined for the WWTP Castell-Platja d'Aro secondary and tertiary effluents. In all trials, the number of particles of the analyzed samples was determined by means of a Galai Cis1 particle laser analyzer.

Samples taken at the entry and exit points for each disc and screen filter numbered 7 for the meat industry effluent, 8 for the WWTP Girona secondary effluent, 10 for the WWTP Girona secondary effluent filtered with sand, and 8 for the WWTP Castell-Platja d'Aro secondary and tertiary effluents. For the sand filter, 3 and 20 samples, respectively, of the meat industry and WWTP Girona effluents were taken at the inlet and outlet.

With the data obtained from the effluent characterization at the entry and exit points of the filters, the retaining efficiency (E) achieved in the filters was calculated with the following formula:

$$E = \frac{N_o - N}{N_o} \cdot 100 \quad (3)$$

where

N_o = value of a physical and chemical parameter of the unfiltered effluent

N = value of the same physical and chemical parameter of the filtered effluent.

Statistical Treatment of Data

The calculation of the filterability index was made by means of the REG program of SAS (SAS, 1999), taking into consideration an existing intersection with the origin of the coordinates because, if Boucher's relationship is applied, when no water passes through the filter, then no head loss is produced. Duncan's test was used, at the 0.05 level, to study the differences between means.

An analysis of covariance was carried out with the GLM procedure of SAS. The filter was used as a fixed effect, and the different physical and chemical parameters of effluents (TSS, turbidity, pH, EC, COD, and number of particles) as well as the time between the filters becoming clogged were used as covariates. The interactions between the filter and the different effluent parameters were included. Some of the interactions were significant (filter with TSS, EC, turbidity, COD, and clogging time), which means that the relationship between the variables is different depending on the filter. For that reason, the multiple-regression Stepwise method of the same REG program was used to analyze which variables had more influence on the filterability index independently for each filter.

Results and Discussion

Characterization of the Effluents

The effluents had different physical and chemical characteristics (table 2). The meat industry effluent showed a severe physical risk of clogging, according to the classification of Bucks et al. (1979), because the TSS value was higher than 100 mg L^{-1}. On the other hand, all the effluents from the wastewater treatment plants had a low physical risk of clogging due to TSS concentrations lower than 50 mg L^{-1}. The WWTP Castell-Platja d'Aro tertiary effluent had the lowest TSS values. The differences in the particle numbers were not as clear among the effluents, but the lowest values were also those from the WWTP Castell-Platja d'Aro tertiary effluent. The meat industry effluent showed electrical conductivity, turbidity, and COD values considerably higher than those of the other effluents.

The WWTP Castell-Platja d'Aro secondary effluent had lower values of TSS, turbidity, and COD than the WWTP Girona secondary effluent; nevertheless, the number of particles, pH, and electrical conductivity were higher in the former than in the latter. The treatment processes of both wastewater treatment plants were activated sludges. Thus, there is reason to characterize the effluents well, because effluents coming from the same treatment process could have different characteristics.

The WWTP Girona secondary effluent when filtered with sand had low values of TSS, turbidity, and COD, but the pH and the number of particles were higher. The increase in the number of particles is attributed to the fact that sand grains smaller than 750 μm were carried away from the sand filter. The WWTP Castell-Platja d'Aro tertiary effluent was obtained from filtration in sand filtration cells, so it can be

Table 2. Mean and standard deviation of physical and chemical parameters of the effluents used at the point of entry of the filters.

Parameter	Meat Industry Effluent	WWTP Girona		WWTP Castell-Platja d'Aro	
		Secondary Effluent	Secondary Effluent Filtered with Sand	Secondary Effluent	Tertiary Effluent
TSS (mg L^{-1})	176 ±24.8	24.4 ±14.7	8.61 ±3.94	10.6 ±3.42	4.93 ±1.24
EC (μS cm^{-1})	2,594 ±151	1,145 ±186	1,121 ±185	1,630 ±163	--
pH	6.99 ±0.05	7.25 ±0.14	7.40 ±0.13	7.63 ±0.20	--
Turbidity (FNU)	200 ±29.0	11.3 ±3.21	8.78 ±6.05	4.51 ±1.92	2.66 ±1.30
COD (mg O_2 L^{-1})	439 ±39.1	63.3 ±19.7	27.9 ±7.86	42.5 ±9.90	47.1 ±13.8
Particles mL^{-1}	64,048 ±41,479	50,470 ±26,320	52,900 ±21,300	61,909 ±32,516	37,372 ±24,899

considered as an alternative treatment to the sand filter for microirrigation systems, but at higher levels. The tertiary effluent showed an important reduction of TSS as well as the number of particles and turbidity with regard to the secondary effluent of the same treatment plant. However, the tertiary effluent had higher levels of COD than the secondary effluent due to the presence of grass remains at the reservoir where the effluent was stored before pumping.

There was low agreement between TSS and the number of particles. The differences could be because all the particles are counted to determine their number, but to determine TSS, a 2 μm filter is used to retain the suspended solids. Thus, the small particles, which are the most numerous, are not taken into consideration in the TSS analysis.

Filter Efficiency

The mean values of efficiency achieved by the filters in reducing the different physical and chemical parameters related to physical clogging, such as TSS, turbidity, COD, and number of particles, are shown in table 3. Negative efficiencies indicate that an increase in the parameter has been produced at the filter exit. The results had a high variability in each test, probably due to the variability in effluent composition.

Using the meat industry effluent, which was the poorest quality effluent, the sand filter was the only filter that achieved significant reductions with respect to the disc and screen filters in all the analyzed parameters, in accordance with the results obtained by Tajrishy et al. (1994). The effluent characteristics at the sand filter exit posed a moderate risk of physical clogging. This risk of clogging for the meat industry effluent was still severe using the disc and screen filters.

The results for the sand filter with the WWTP Girona secondary effluent were not different from those for the disc and screen filters, except for the number of particles, which was significantly higher in the 115 μm disc filter and 98 μm screen filter than in the sand filter. The physical clogging risk of the WWTP Girona secondary effluent was minor, but all the filters achieved additional risk reduction.

The disc and screen filters did not show significant differences in reducing TSS, turbidity, COD, and number of particles when the WWTP Girona secondary effluent filtered with sand was used. However, the 115 μm disc filter achieved higher reductions in the number of particles than the 130 and 200 μm disc filters. Only the 130 μm screen filter decreased the turbidity more than the 130 μm disc filter using the WWTP Castell-Platja d'Aro secondary effluent.

In most of the cases, the reductions of TSS of the different effluents were not high with screen and disc filters, which agrees with several previous studies (Nakayama et al., 1978; Adin, 1987; Adin and Sacks, 1991; Adin and Elimelech, 1989; Taylor et al., 1995; Ravina et al., 1997). Nevertheless, it is surprising that the efficiency of screen filters with respect to disc filters was slightly higher in reducing TSS in the meat industry and WWTP Castell-Platja d'Aro secondary effluents. Theoretically, and considering the design of disc filters, this type of filter should retain more solids than screen filters. Despite no significant differences being found (table 4), the time between filter cleanings was higher with screen filters using the meat industry and WWTP Girona effluents than with disc filters. Nevertheless, the screen filters tended to clog earlier than the disc filters when using the WWTP Castell-Platja d'Aro secondary effluent. In this case, the higher reductions in solids achieved by the screen filters can be explained by the quicker formation of a thick filtration cake on the filter surface, which allowed additional retention of suspended matter, and thus an increase in the filter efficiency. However, the disc filters became clogged earlier than the screen filters when using the meat industry and

Table 3. Means and standard deviations of filtration efficiency for the physical and chemical parameters most related to clogging, organized by filter and effluent. Within each type of effluent, different letters show significant differences for each parameter ($P < 0.05$).

Effluent	Filter	TSS	Turbidity	COD	Particles mL^{-1}
Meat industry effluent	D115	17.7 ±10.9 b	2.90 ±22.8 b	−1.89 ±11.1 b	17.6 ±46.2 b
	D130	18.5 ±18.5 b	0.49 ±15.9 b	−0.56 ±13.5 b	13.3 ±57.7 b
	D200	13.7 ±6.02 b	2.51 ±5.30 b	3.80 ±14.4 b	16.7 ±34.3 b
	S98	31.6 ±15.5 b	7.49 ±15.9 b	9.03 ±9.82 b	20.6 ±30.8 b
	S115	20.7 ±23.0 b	16.3 ±14.2 b	4.20 ±9.02 b	7.56 ±11.1 b
	S178	23.1 ±22.2 b	14.6 ±14.3 b	10.6 ±2.58 b	20.2 ±7.59 b
	Sand	61.9 ±11.3 a	43.6 ±23.5 a	32.7 ±2.94 a	68.9 ±8.52 a
WWTP Girona secondary effluent	D115	53.7 ±15.3	73.1 ±12.2	41.6 ±4.63	38.7 ±31.6 ab
	D130	50.9 ±15.5	67.3±10.9	45.3 ±16.1	35.4 ±29.6 abc
	D200	45.5 ±14.6	68.3 ±16.7	47.5 ±14.7	8.59 ±9.83 bcd
	S98	49.6 ±20.0	69.6 ±25.5	47.1 ±18.6	48.4 ±32.9 a
	S115	31.8 ±19.2	69.9 ±9.19	42.8 ±17.6	19.4 ±7.70 abcd
	S178	31.9 ±17.0	72.8 ±14.9	44.5 ±15.7	−6.20 ±21.8 d
	Sand	49.6 ±30.0	72.9 ±23.6	54.1 ±20.5	2.70 ±42.8 cd
WWTP Girona secondary effluent filtered with sand	D115	−7.93 ±31.7	−10.7 ±52.3	1.10 ±1.86	34.5 ±26.2 a
	D130	−4.72 ±31.7	−21.2 ±17.6	6.62 ±13.5	7.73 ±22.8 b
	D200	0.01 ±2.06	−2.43 ±11.6	2.67 ±21.7	1.49 ±14.7 b
	S98	−4.69 ±10.7	−11.2 ±10.9	−0.35 ±10.9	25.5 ±34.2 ab
	S115	−1.78 ±10.2	−11.4 ±10.2	4.31 ±6.69	26.5 ±27.3 ab
	S178	−7.48 ±5.54	−8.87 ±16.0	1.80 ±4.27	25.5 ±22.5 ab
WWTP Castell-Platja d'Aro secondary effluent	D130	24.4 ±15.5	−19.6 ±10.9 b	−8.18 ±8.31	19.8 ±28.9
	S130	27.9 ±15.6	22.3 ±13.1 a	−5.28 ±3.97	15.4 ±29.7
WWTP Castell-Platja d'Aro tertiary effluent	S130	−12.4 ±10.1	−37.6 ±17.3	59.3 ±5.65	12.1 ±10.4

Table 4. Mean and standard deviation of the time (min) between filter cleanings. Within each type of effluent, different letters show significant differences (P < 0.05).

Filter	Meat Industry Effluent	WWTP Girona		WWTP Castell-Platja d'Aro	
		Secondary Effluent	Secondary Effluent Filtered with Sand	Secondary Effluent	Tertiary Effluent
D115	8.57 ±9.40 c	212 ±31.9 b	723 ±86.5	--	--
D130	12.9 ±13.2 c	836 ±657 b	732 ±77.0	11,243 ±3,830	--
D200	55.1 ±28.1 ab	2,139 ±1,183 a	746 ±58.1	--	--
S98	17.4 ±11.7 c	167 ±68.0 b	707 ±57.8	--	--
S115	29.2 ±21.1 bc	533 ±492 b	732 ±70.1	--	--
S130	--	--	--	8,992 ±3,324	8,797 ±3,872
S178	60.0 ±48.2 a	1,727 ±1,271 a	746 ±64.2	--	--
Sand	4.00 ±1.00 c	104 ±36.0 b	--	--	--

WWTP Girona effluents, but their efficiency was not higher. So, it seems that the rapid formation of a filtration cake is only useful in screen filters.

Oron et al. (1980) tested different kinds of effluents using sand, screen, and disc filters and found the highest reduction of COD with disc filters. However, the results obtained in these experiments did not show this tendency.

There was an increase in suspended solids but not in the number of particles at the outlet of most of the disc and screen filters using the WWTP Girona secondary effluent filtered with sand. These higher levels of solids at the filter exits, showed by a negative efficiency, are probably due to detachment of solids from the filter cake, as observed by Adin and Alon (1986). When biological particles are retained in the filter media and pressure increases, these particles can be deformed and can pass through the filter.

Filterability Index

The filterability index, calculated according to equation 1, allows a comparison of the tendencies of the different filters to become clogged. Although this index was developed for screen filters, it is possible to apply it to sand filters if the filtration velocity is lower, since in these cases it has been observed that head loss increases exponentially as a function of the filtered water volume, especially at the surface layers (Adin, 2002). The mean values of the filterability indexes and their adjusted regression coefficients are shown in table 5. The obtained adjustments for the filterability index were relatively good, all the regressions being statically significant, even those with a lower regression coefficient. Notwithstanding, Arnó (1990) found low regression coefficients in screen filters because Boucher's relationship, which had a good adaptation in the first phases of filtration, had a greater deviation in the final phases of the process.

Even though Boucher's relationship only takes into consideration the volume filtered and the head loss across the filter, the filtration velocity influences the filterability index. The higher the filtration velocity, the higher the filterability index (Adin and Alon, 1986). In our experiment, the filtration velocity was not set, but no good agreement was found when analyzing the influence of velocity on the filterability index, as shown in figure 3. The experiment was carried out until a set head loss was reached, but as the clogging of the filter was faster in some cases due to a higher clogging potential of the effluent, the filtration time and the filtered volume varied during each trial. Because the filtration velocity showed a reduction over time, the filtered volume was lower over time. In fact, a single value for the filterability index was used, which made the comparison between the clogging capacities of different filters easier. But it does not seem that Boucher's relationship and the filterability index could be used to describe and study the entire filtration process.

Table 5. Means and standard deviations of the filterability index (I) and interval of the adjusted regression coefficient (R^2 adj.) for the different filters and effluents with head losses lower than 49 kPa. Within each type of effluent, different letters show significant differences (P < 0.05).

Filter	Meat Industry Effluent		WWTP Girona				WWTP Castell-Platja d'Aro			
			Secondary Effluent		Secondary Effluent Filtered with Sand		Secondary Effluent		Tertiary Effluent	
	I (m^{-3})	R^2 adj.	I (m^{-3})	R^2 adj.	I (m^{-3})	R^2 adj.	I (m^{-3})	R^2 adj.	I (m^{-3})	R^2 adj.
D115	9.28 ±7.26 ab	0.948 to 0.995	1.31 ±1.20 ab	0.751 to 0.931	0.18 ±0.22	0.669 to 0.998	--	--	--	--
D130	13.4 ±11.4 a	0.583 to 0.992	0.28 ±0.14 c	0.784 to 0.987	0.15 ±0.12	0.502 to 0.973	0.01 ±0.00	0.842 to 0.970	--	--
D200	5.47 ±7.87 ab	0.829 to 0.989	0.03 ±0.01 c	0.840 to 0.995	0.09 ±0.07	0.476 to 0.952	--	--	--	--
S98	2.79 ±1.29 b	0.894 to 0.979	1.85 ±0.83 a	0.814 to 0.959	0.71 ±0.44	0.584 to 0.922	--	--	--	--
S115	2.08 ±0.59 b	0.648 to 0.999	1.61 ±0.80 a	0.820 to 0.931	0.29 ±0.21	0.508 to 0.960	--	--	--	--
S130	--	--	--	--	--	--	0.01 ±0.01	0.921 to 0.971	0.01 ±0.00	0.792 to 0.988
S178	2.10 ±1.87 b	0.809 to 0.988	0.06 ±0.03 c	0.921 to 0.993	0.22 ±0.25	0.595 to 0.996	--	--	--	--
Sand	4.74 ±0.16 ab	0.778 to 0.825	0.52 ±0.17 bc	0.956 to 0.997	--	--	--	--	--	--

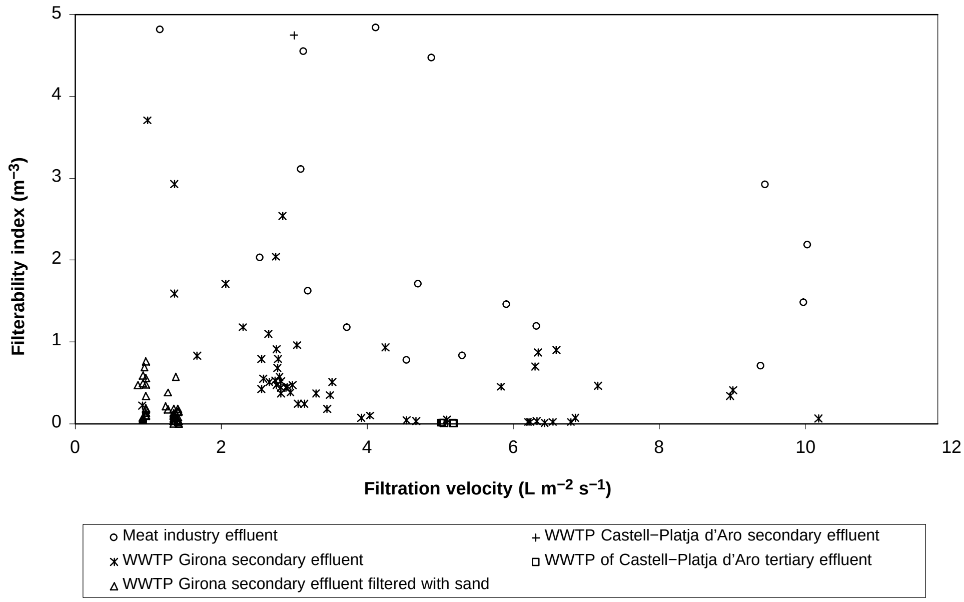

Figure 3. Filtration velocity of each trial related with the filterability index.

The 130 μm disc filter was more sensitive to clogging when using the meat industry effluent because it had a higher filterability index, according to the data in table 5. But this filter was not significantly different from the other disc filters and the sand filter. It is not logical that the filterability index of the 130 μm disc filter was higher than the index of the disc filter with smaller pore apertures, the 115 μm disc filter. Thus, the 115 and 130 μm disc filters, the 98 μm screen filter, and the sand filter had the lowest times before backwashing (table 4), with no differences among them. In general, a higher tendency to clog and lower filtration times were observed in the disc and sand filters with meat industry effluent than in the screen filters. This contrasts with the results of the experiments of Adin and Elimelech (1989), which show that screen filters had a higher clogging rate.

The filterability indexes were considerably lower with the WWTP Girona secondary effluent than with the meat industry effluent. The filters that had a statistically significant higher clogging rate with this secondary effluent were the 98 and 115 μm screen filters. However, the time between cleanings of these two filters was not different from the time needed in the sand filter and the 115 and 130 μm disc filters. The 200 μm disc filter and the 178 μm screen filters had the lowest filterability indexes and the highest filtration times, each with no significant difference. This result shows that the screen and disc filters with smaller pore openings clogged more easily than the screen and disc filters with larger pore openings, in accordance with Adin and Alon (1986). Screen filters became more clogged than disc filters with the WWTP Girona secondary effluent, which can be explained by the fact that disc filters had lower obstruction when the effluent had a lower clogging risk.

When the WWTP Girona secondary effluent was filtered through a sand filter with an effective grain size of 0.65 mm, there were no significant differences either between the filterability indexes or between the filtration times of the different screen and disc filters. However, the mean values of the filterability index were slightly higher in the screen filters than in the disc filters. The filterability indexes of the 200 μm disc filter and the 178 μm screen filter were higher than the indexes obtained with these two filters using the WWTP Girona secondary effluent not filtered through sand.

The filterability indexes of the 130 μm screen and 130 μm disc filters were not significantly different when the WWTP Castell-Platja d'Aro secondary effluent was used, but the lowest indexes were obtained with the disc filter. Only a 130 μm screen filter was used with the tertiary effluent of this treatment plant, and its filterability index was lower than the filterability index of the same filter working with the secondary effluent. Nevertheless, no significant differences existed between the indexes of the 130 μm screen filter operating with the WWTP Castell-Platja d'Aro secondary and tertiary effluents. However, the clogging of the disc filter with the WWTP Castell-Platja d'Aro secondary effluent was slightly smaller than the clogging of the screen filter with the same effluent and even with the tertiary effluent. This lower obstruction of the disc filter with respect to the screen filter was commented on previously with reference to the WWTP Girona secondary effluent, filtered and not filtered with sand. So, disc filters do not clog as easily as screen filters when the effluent has a lower risk of clogging. The filtration cake probably forms more quickly on screen filters than on disc filters, and thus head loss and filter clogging are higher in these filters.

Also analyzed was whether or not differences existed among the filterability indexes for each filter using the different effluents. The filterability indexes for each filter were significantly much higher using the meat industry effluent than using the other effluents, except for the 98 and 115 μm screen filters. With these two filters, there were no differences in the filterability indexes between the meat industry effluent and the WWTP Girona secondary effluent. The higher filterability indexes of the filters with the meat industry effluent show that clogging will be the highest with this effluent. These results agree with those of Juanico et al. (1995), who observed that the poorer the quality of the effluent, the higher the rate of filter clogging.

To determine if there were significant differences among the filterability indexes when only treatment plant effluents were used, a mean separation was made without considering

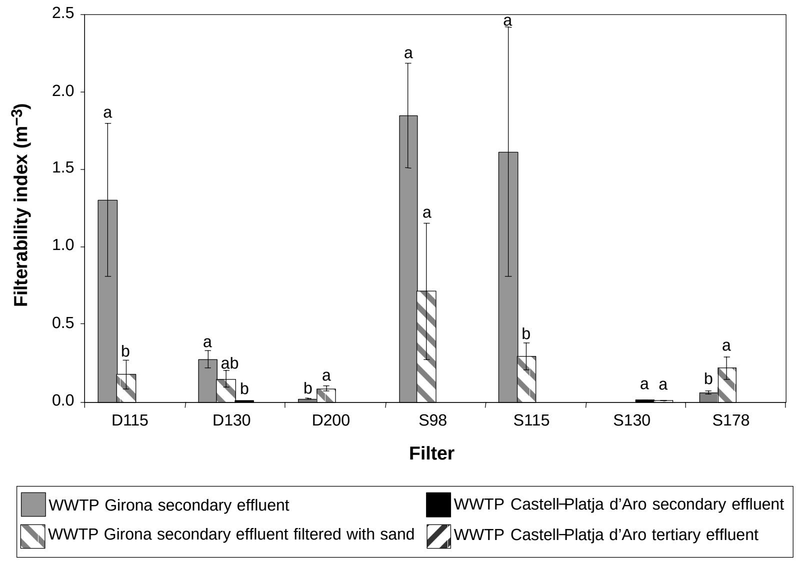

Figure 4. Comparison among mean filterability indexes of all the filters operating until a head loss of 49 kPa related with the effluent, considering only treatment plant effluents. Columns of the same filter with different letters are significantly different (P < 0.05).

the results of the trials with the meat industry effluent. The results show statistically significant differences among the treatment plant effluents (fig. 4). There was significantly higher clogging of the 115 μm screen and disc filters with the WWTP Girona secondary effluent than with this effluent filtered with sand. No significant differences in the filterability indexes were observed between the 98 μm screen filter and the 130 μm disc filters using this effluent, whether filtered with sand or not. On the other hand, the 178 μm screen filter and the 200 μm disc filter had higher filterability indexes with the WWTP Girona secondary effluent filtered with sand than with the same effluent without sand filtration, even though filtering this effluent reduced the amount of suspended solids. The filterability index of the 130 μm disc filter with the WWTP Castell-Platja d'Aro secondary effluent was significantly lower than with the WWTP Girona secondary effluent, but without any differences between either of the two and the WWTP Girona secondary effluent filtered with sand. No statistical differences were observed in the filterability index for the 130 μm screen filter using the WWTP Castell-Platja d'Aro secondary and tertiary effluents. The high influence of water quality in the filterability index for each filter is obvious.

Justification of the Filterability Index

The multiple-regression Stepwise method of SAS was used to determine the effect of the different analyzed parameters on the filterability index. As the analysis of the covariance showed a significant interaction between filters and some effluent parameters, a model to determine the filterability index was obtained for each filter (table 6).

Results in table 6 show high variability in the parameters, justifying the results of the filterability index. Despite all the equations being significant, some of the regression coefficients were low. Therefore, the physical and chemical parameters and the time before filter clogging explained the results of the filterability index, but did not contribute clear

Table 6. Equations to calculate the filterability index (I, m^{-3}) for each filter independent of the effluent through the selected parameters obtained by the multiple-regression Stepwise method of SAS.

Filter	Effluents Used	*N*[a]	Equation	R^2 adj.	Significance Level
D115	Meat industry, WWTP Girona secondary, and WWTP Girona secondary filtered with sand.	19	I = 0.08233·turbidity −0.00274·EC + 0.00358·time	0.920	P < 0.001
D130	Meat industry, WWTP Girona secondary, WWTP Girona secondary filtered with sand, and WWTP Castell-Platja d'Aro secondary.	24	I = 0.06807·turbidity	0.685	P < 0.001
D200	Meat industry, WWTP Girona secondary, and WWTP Girona secondary filtered with sand.	22	I = 0.23482·TSS − 0.11002·EC − 0.03197·COD	0.636	P < 0.001
S98	Meat industry, WWTP Girona secondary, and WWTP Girona secondary filtered with sand.	22	I = 0.00117·EC	0.538	P < 0.001
S115	Meat industry, WWTP Girona secondary, and WWTP Girona secondary filtered with sand.	18	I = 0.02043·TSS + 0.5645·pH − 0.00204·EC − 0.00208·time	0.758	P < 0.001
S130	WWTP Castell-Platja d'Aro secondary and tertiary.	10	I = 0.00081·TSS + 0.00008·DQO	0.960	P < 0.001
S178	Meat industry, WWTP Girona secondary, and WWTP Girona secondary filtered with sand.	18	I = 0.00002·particles mL^{-1}	0.920	P < 0.001
Sand	Meat industry and WWTP Girona secondary.	17	I = 0.00670·TSS + 0.08861·pH + 0.00007·particles mL^{-1} − 0.00674·time	0.991	P < 0.001

[a] *N* = number of data points for each model.

information about the clogging of the filters, as indicated by Ravina et al. (1995). The parameters that appeared most were the TSS and EC, followed by the time before filter clogging.

Conclusions

The main conclusions are:

- The type of effluent influenced the selection of the filter needed to achieve a better quality filtration.
- Boucher's relationship provided some information about the head loss caused by the passing of the effluents through screen, disc, and sand filters.
- No physical and chemical parameters were found to satisfactorily justify the filterability index for all the effluents. The relative importance of each parameter varied with effluent, but those with the highest incidence were total suspended solids and electrical conductivity.

Related to the quality of the filtration, measured through filter efficiencies:

- The best filtration quality using the meat industry effluent was achieved by the sand filter.
- There were no important differences among screen, disc, and sand filters using the WWTP Girona secondary effluent. However, there was a slightly greater efficiency in removing particles when using the screen and disc filters with smaller openings.
- No significant differences were observed using disc or screen filters with the WWTP Girona secondary effluent filtered in a sand filter with an effective size of 0.65 mm.
- Despite no significant differences being observed between the 130 μm disc and screen filters with the WWTP Castell-Platja d'Aro secondary effluent, the filtration quality was slightly higher using the screen filter.

Related to the clogging of filters, measured through the filterability index, and the filtration time:

- The disc and sand filter required earlier backwashing than the screen filters when using the meat effluent, which was the poorest quality effluent.
- The sand filter had a tendency to need more cleanings than the disc and screen filter with the WWTP Girona secondary effluent.
- The disc filters tended to need less time between cleanings than the screen filters with the WWTP Girona secondary effluent, whether filtered with sand or not, but more time when using the WWTP Castell-Platja d'Aro secondary and tertiary effluents.

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APPENDIX

Results of the filterability indexes (I) and time before clogging for each test with head losses lower than 49 kPa.

	Meat Industry Effluent		WWTP Girona				WWTP Castell-Platja d'Aro			
			Secondary Effluent		Secondary Effluent Filtered with Sand		Secondary Effluent		Tertiary Effluent	
Filter	I (m^{-3})	Time (min)	I (m^{-3})	Time (min)	I (m^{-3})	Time (min)	I (m^{-3})	Time (min)	I (m^{-3})	Time (min)
D115	2.50	10	0.45	210	$3.8 \cdot 10^{-17}$	740	--	--	--	--
	5.13	29	0.70	220	0.01	850	--	--	--	--
	6.02	7	0.87	200	0.03	795	--	--	--	--
	7.34	4	0.90	190	0.15	640	--	--	--	-
	8.03	5	1.18	270	0.31	645	--	--	--	--
	11.4	2	3.71	180	0.57	670	--	--	--	--
	24.5	3	--	--	--	--	--	--	--	--
D130	2.03	40	0.07	1,405	0.02	805	$3.1 \cdot 10^{-3}$	12,660	--	--
	3.31	18	0.18	1,435	0.05	825	$6.2 \cdot 10^{-3}$	12,381	--	--
	9.52	13	0.22	180	0.08	785	8.210^{-3}	14,295	--	--
	10.3	8	0.34	260	0.14	735	0.01	5,639	--	--
	11.1	6	0.37	270	0.17	690	--	--	--	--
	24.5	4	0.46	1,465	0.18	665	--	--	--	--
	33.1	1	--	--	0.38	620	--	--	--	--
D200	0.52	56	0.01	180	$2.1 \cdot 10^{-16}$	680	--	--	--	--
	0.71	75	0.02	2,950	0.03	725	--	--	--	--
	0.79	53	0.02	3,095	0.03	725	--	--	--	--
	1.18	102	0.02	2,810	0.06	670	--	--	--	--
	1.19	55	0.02	2,615	0.09	760	--	--	--	--
	15.6	21	0.03	1,185	0.11	840	--	--	--	--
	18.3	24	--	--	0.13	810	--	--	--	--
	--	--	--	--	0.18	790	--	--	--	--
	--	--	--	--	0.21	715	--	--	--	--
S98	0.75	40	0.93	210	0.09	640	--	--	--	--
	1.48	24	2.93	180	0.13	735	--	--	--	--
	2.92	20	0.91	270	0.17	800	--	--	--	--
	2.97	11	2.04	120	0.18	680	--	--	--	--
	3.01	10	1.71	140	0.34	720	--	--	--	--
	3.99	9	2.54	80	0.48	740	--	--	--	--
	4.38	8	--	--	0.69	715	--	--	--	--
	--	--	--	--	0.76	605	--	--	--	--
	--	--	--	--	8.50	725	--	--	--	--
S115	0.13	60	0.24	1,405	0.10	760	--	--	--	--
	1.46	42	0.41	240	0.13	750	--	--	--	--
	1.62	40	0.83	845	0.19	820	--	--	--	--
	2.19	12	1.10	260	0.89	695	--	--	--	--
	2.58	9	1.59	270	0.90	635	--	--	--	--
	2.58	9	5.51	180	--	--	--	--	--	--
	4.47	12	--	--	--	--	--	--	--	--
S130	--	--	--	--	--	--	$6.5 \cdot 10^{-3}$	12,380	$4.5 \cdot 10^{-3}$	15,464
	--	--	--	--	--	--	$8.4 \cdot 10^{-3}$	12,660	$8.4 \cdot 10^{-3}$	5,637
	--	--	--	--	--	--	0.01	7,904	$8.4 \cdot 10^{-3}$	9,071
	--	--	--	--	--	--	0.01	5,639	0.01	7,755
	--	--	--	--	--	--	0.02	6,375	0.01	6,057
S178	0.76	70	0.03	3,095	0.05	825	--	--	--	--
	0.78	135	0.04	2,810	0.06	715	--	--	--	--
	0.83	93	0.05	180	0.07	810	--	--	--	--
	1.71	28	0.06	80	0.08	770	--	--	--	--
	3.11	24	0.07	2,615	0.56	675	--	--	--	--
	5.43	10	0.10	1,185	0.59	685	--	--	--	--
Sand	4.55	4	0.35	150	--	--	--	--	--	--
	4.82	3	0.42	125	--	--	--	--	--	--
	4.84	5	0.44	115	--	--	--	--	--	--
	--	--	0.45	100	--	--	--	--	--	--
	--	--	0.47	110	--	--	--	--	--	--
	--	--	0.51	80	--	--	--	--	--	--
	--	--	0.51	95	--	--	--	--	--	--
	--	--	0.52	90	--	--	--	--	--	--
	--	--	0.55	95	--	--	--	--	--	--
	--	--	0.57	70	--	--	--	--	--	--
	--	--	0.68	75	--	--	--	--	--	--
	--	--	0.79	60	--	--	--	--	--	--
	--	--	0.79	65	--	--	--	--	--	--
	--	--	0.96	45	--	--	--	--	--	--