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Performance and backwashing efficiency of disc and screen filters in microirrigation systems

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The performance of three filtration systems (screen, disc and a combination of screen and disc filters) used in microirrigation systems and their automatic backwashing efficiency were studied at inlet pressures of 300 and 500 kPa. The filters were used for more than 900 h with a biological effluent. The physical parameters of the effluent such as turbidity, total suspended solids (TSS) and number of particles were not affected significantly by the different filtration systems at both pressures. Automatic backwashings were classified as being inefficient depending on the value of the initial head loss across the filter after a backwashing took place. The number of filter backwashings required for the screen filter was reduced at 500 kPa, especially due to an increase in efficient backwashings at this inlet pressure. Filtered volume was significantly larger at the beginning of the experiment than after 800 operation hours. The disc filter at both 300 and 500 kPa consumed more water for backwashing than the other filtration systems.

1. Introduction

Effluents are used in agriculture as a viable alternative to freshwater in areas where water is scarce or there is strong competition for its use. Although microirrigation is the most advantageous irrigation system for applying effluents, especially from public health and environmental points of view, the use of effluents can increase emitter clogging (Bucks *et al.*, 1979), which affects water distribution and, consequently, crop yields (Tajrishy *et al.*, 1994).

As a result, filtration is an essential operation that can prevent emitters from becoming clogged (Oron *et al.*, 1979), although it does not avoid it completely (Tajrishy *et al.*, 1994). The three common filter types used in microirrigation systems are screen, disc and sand media filters. In screen filters, particles are trapped on the surface of a perforated cylinder. Disc filters have many grooved discs pressed together, and the particles are retained in the grooves of the discs. In media filters, solids are caught by the particles of gravel or sand. In screen and disc filters, the particles larger than the pores of the filtering media are retained on the surface of the media and accumulate layer by layer, forming a cake of increasing thickness that reduces the diameter of pores and allows smaller particles to be retained. In sand filters, the particles to be removed can be smaller than the filter pores since particle capture is controlled by both physical and chemical mechanisms (Adin and Alon, 1986).

Screen and disc filters are simple, economical, and easy to manage but sand filters are more complex and expensive, and are only appropriate for farms with high technical and professional standards. Sand filters are also more suitable for waters with high suspended solids content, but disc filters, if

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Nomenclature

A	filtration surface, m^2
C_b	percentage of water used for filter backwashing, dimensionless
E	removal efficiency, dimensionless
FTU	formazine turbidity unit, dimensionless
N_o	value of a physical or chemical parameter of the unfiltered effluent
N	value of the same physical or chemical parameter of the filtered effluent
t	time of filtration, s
TSS	total suspended solids, $g\,m^{-3}$
υ	surface filtration velocity, $l\,m^{-2}\,s^{-1}$
V	effluent volume filtered, m^3
V_b	volume used for every filter backwashing, m^3
V_f	filtered volume in every filtration cycle, m^3

properly designed, can give performance levels similar to those of sand media filters (Capra and Scicolone, 2007).

As suspended particles are trapped by the filters, the filtration rate decreases because the filter becomes clogged and must be cleaned to recover operational conditions. Most filters are cleaned with automatic backwashing based on a fixed head loss across the filter and/or an operation time. Both options allow for easy system automation. Automatic backwashing of filters may require a minimum flushing pressure that pumping system must supply (Nakayama et al., 2007).

The filter performance in microirrigation systems using effluents has been studied by several authors (Adin and Elimelech, 1989; Tajrishy et al., 1994; Ravina et al., 1997; Capra and Scicolone, 2004, 2007; Puig-Bargués et al., 2005a; Ribeiro et al., 2008). In these studies, inlet filter pressure was maintained between 250 and 400 kPa. To save energy in the pumping system, it is preferred to work with the minimum inlet pressure at which filtration and backwashings are effective.

Recently, new equations for describing head loss in filters commonly used in microirrigation have been developed using dimensional analysis (Puig-Bargués et al., 2005b; Yurdem et al., 2008). However, there appears to be no analysis in the literature that deals with filtration cycles and the performance of automatic backwashing in microirrigation systems.

The objective of this study was to analyse the performance of three filtration systems (disc, screen, and screen followed by disc filters) and their automatic backwashing arrangements when using effluents at two different pressures, 300 and 500 kPa.

2. Materials and methods

2.1. *Experimental set-up*

A filtration bank (Fig. 1) with three filtration systems was used to carry out the filtration experiments with the effluents at the wastewater treatment plant (WWTP) of Celrà (Girona, Spain),

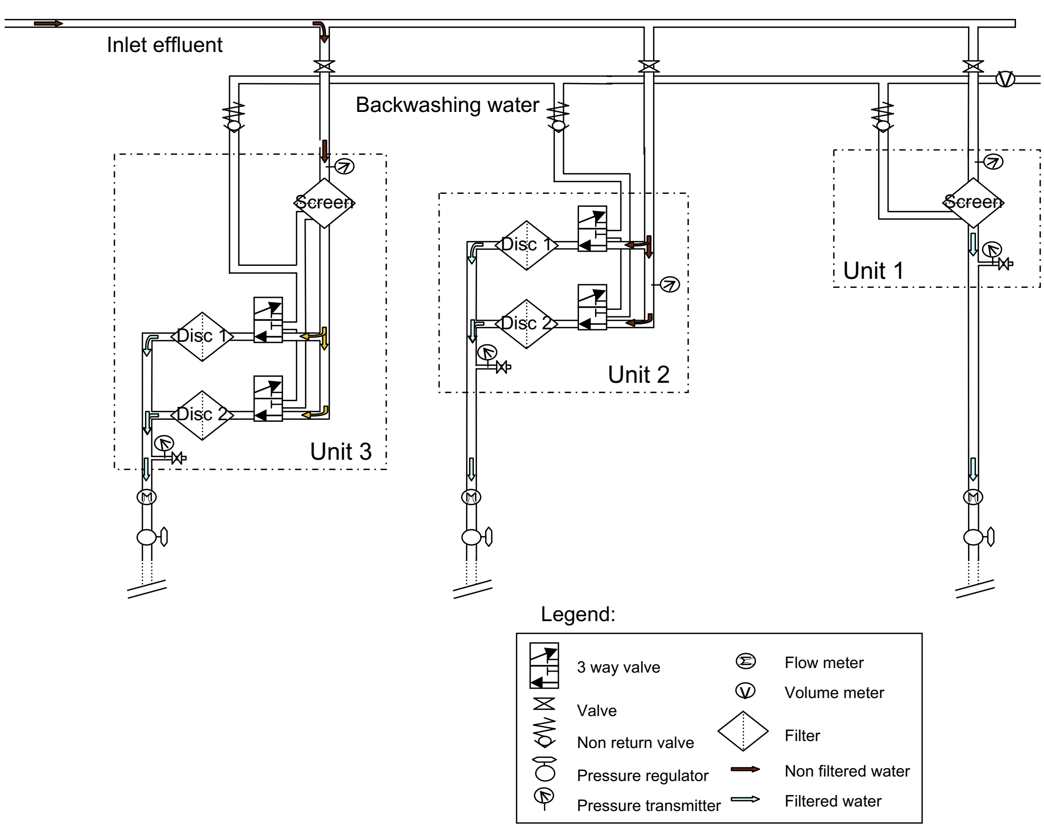

Fig. 1 – Hydraulic scheme of the filtration bank and location of monitoring and control equipment.

which treats urban and industrial wastewater using a sludge process. The first filtration system consisted of one screen filter (Arkal Filtration Systems, Jordan Valley, Israel) with a 50.8 mm diameter, 110 000 mm^2 filtration surface and 120 μm filtration level. The second system was formed by two disc filters (Arkal Filtration Systems, Jordan Valley, Israel) in parallel, both with 50.8 mm diameter, a filtration surface of 94 000 mm^2 and a filtration level of 130 μm. The third filtration system had one screen filter followed by two disc filters in parallel, with the same characteristics as the filters used in the first and second filtration systems. In this third system, the effluent was first filtered with a 120 μm screen filter and then by a 130 μm disc filter. The filtration level of both filters was to the standard in the area. The slight difference in the filtration level should not have a significant effect, according to previous studies (Puig-Bargués *et al.*, 2005a).

The screen and disc filters had an automatic backwashing system triggered by a preset pressure difference. When the screen filter had to be backwashed, a cylindrical device located in the inner part of the screen, created a depression and, as a consequence, water suction from outside freed the trapped particles without stopping filtration over the rest of the screen surface. As there were two disc filters in parallel, effluent previously filtered in the first filter was carried to the second filter for through the discs. Using this process, the captured particles were removed.

Filters were controlled by two different filter backwashing programmers. A Filtron 246 2 DC (Talgil, Kiryat Motzkin, Israel) was used for screen filters, while a Reg 8 Plus (Regaber, Parets del Vallès, Spain) with a Cas 155 (Danfoss, Nordborg, Denmark) differential pressure switch was used for the disc filters.

An MBS 4010 (Danfoss, Nordborg, Denmark) pressure transmitter with flush diaphragm (±0.3% accuracy) measured the pressure at the inlet and outlet of each filtration system. The flow at the filter outlets was measured by an MP-400-CB (Comaquinsa, Llinars del Vallès, Spain) electromagnetic flow meter (±1% accuracy). A WP-Dynamic DN 50 (Sensus, Raleigh, NC, USA) turbine volume meter with impulse emitter (±2% accuracy) was used to determine backwashing water volume. The location of these sensors is shown in Fig. 1. These devices were connected to a supervisory control and data acquisition (SCADA) system, which allowed the control of each filter performance and also to collect filter data performance continuously. As only one volume meter was used to measure the backwashing water volume, the SCADA system was programmed not to allow more than one filter to be cleaned at the same time. Therefore, flush volumes could be measured for each individual filtration system and assigned to every backwashing event.

2.2. *Operational procedure*

Two experiments were carried out. In the first experiment, the inlet filter pressure was 300 kPa, and in the second it was 500 kPa. According to the filter manufacturers, the minimum backwashing pressures were 200 and 250 kPa for screen and disc filters, respectively. The tested pressures allowed irrigation to continue during backwashing, as is desirable in the management of microirrigation systems.

During the first experiment, each filtration system operated two 6-h periods per day up to a total of 930 h. After this time, the screen filter had filtered 7215 m^3, the disc filter 7663 m^3, and the screen filter followed by disc filters 7187 m^3.

Before the start of the second experiment, all the screens and discs were cleaned with pressurised freshwater and submerged for 8 h in a solution of 5% NaClO.

In the second experiment, the operation schedule needed to be changed so that there was sufficient treated effluent for use in the WWTP. Thus, each filtration system operated for 7 h day^{-1} on working days and for two 6-h periods during weekends and holidays. Filtered volume after 1000 h was 9083, 8801 and 8900 m^3 for screen, disc and screen followed by disc filters, respectively.

In both experiments the working time was rotated so that each filtration system operated at different times of the day. Thus, any hourly variation in effluent parameters did not affect always the same filtration unit.

The surface filtration velocity was calculated as:

$$v = \frac{dV/dt}{A} \quad (1)$$

where v is the surface filtration velocity in $l\,m^{-2}\,s^{-1}$; V is the effluent volume filtered in l; t is the time of filtration in s; and A is the filtration surface in m^2.

The mean values of surface filtration velocities (Table 1) were significantly different ($P < 0.05$) in the two experiments, being greater at 500 kPa.

Filters were cleaned automatically by backwashing when the head loss across the filter exceeded 50 kPa (Ravina *et al.*, 1997) for more than 2 min. Backwashing times were 30 and 20 s for disc and screen filters, respectively.

To analyse the physical parameters related with filter clogging, samples were taken 12 times in the first experiment and 10 times in the second at each filter inlet and outlet. Samples were taken in the 15 min after a filter backwashing took place. Turbidity was measured *in situ* using an HI 93703 handheld turbidity meter (Hanna Instruments, Woonsocket, RI, USA). Total suspended solids (TSS) were determined in the laboratory by weighing the solids retained in a glass fibre filter following the Spanish Standard UNE-EN 872 (AENOR, 1996). The number of particles was analysed using a Galai Cis 1 (Galai, Migdal Haemek, Israel) particle laser analyser. In the experiment at 300 kPa, six additional effluent samples from the screen filters, alone and from the combined system, were taken when these filters were clogged.

Table 1 – Mean surface filtration velocities and standard deviations for the different filters and inlet pressures. For each filtration system, different letters mean significant differences ($P < 0.05$)

Inlet pressure (kPa)	Surface filtration velocity ($l\,m^{-2}\,s^{-1}$)			
	Screen	Disc	Combined	
			Screen	Disc
300	20.91 ± 0.91 b	12.47 ± 0.52 b	20.68 ± 0.78 b	12.10 ± 0.46 b
500	22.68 ± 0.18 a	13.14 ± 0.13 a	21.89 ± 0.25 a	12.81 ± 0.15 a

The results of effluent characterisation are shown in Table 2. Values of TSS were in both experiments below the average value of 17.8 g m^{-3} (with a minimum of 2.4 and a maximum of 99.0 g m^{-3}) achieved in the 79 WWTP with biological treatment of the province of Girona in 2006 (ACA, 2007). Although the filtration systems operated at different times of the day, most of the physical and chemical parameters of the inlet effluent for any of the filtration systems showed no differences despite the variability in the effluents. Significant differences ($P < 0.05$) were only observed in the number of particles in the inlet during the second experiment, being higher with the combination of screen and disc filters than with screen and disc filters alone. Although the average values of turbidity and TSS were greater, and the number of particles was smaller, in the effluent used in the first experiment, no significant differences were found between these parameters for the two experiments carried out.

2.3. Assessment of filter removal efficiency

The removal efficiency (E) achieved in the filters was calculated as:

$$E = \frac{N_o - N}{N_o} \times 100 \quad (2)$$

being N_o and N the value of a physical or chemical parameter of the unfiltered effluent and the filtered effluent, respectively.

2.4. Assessment of filter backwashing efficiency

2.4.1. Backwashing classification

Backwashing was carried out automatically when the pressure loss across the filter reached the 50 kPa threshold for more than 2 min. Backwashing was classified according to the value of the head loss across the filter after the backwashing was carried out. Two categories of automatic backwashing were defined:

- *Efficient automatic backwashing*. After this type of backwashing, the initial head loss was acceptable for a clean filter and allowed a normal filtration cycle. At 300 kPa, and according to the manufacturer, acceptable head loss after a backwashing was between 10 and 18 kPa for screen filter and between 18 and 28 kPa for disc filters. In the second experiment, as filters operated with greater pressure, the initial head loss across the filters increased. Therefore, acceptable head loss after a backwashings was considered to be between 15 and 24 kPa for screen filters and between 28 and 36 kPa for disc filters.
- *Inefficient automatic backwashing*. After this backwashing the initial head loss across a clean filter was greater than the head loss thresholds defined for efficient automatic backwashings. Inefficient backwashing, carried out during operational problems, such as insufficient pressure, lack of effluent or breakdown of differential pressure switches, was not considered in the analysis.

An example of this classification is shown in Fig. 2. Two additional categories were used to classify other filter cleanings that needed to be carried out:

- *Provoked backwashing*. Automatic backwashing carried out by a manual order. This backwashing occurred in order to recover the filters that were being continuously backwashed because they were in a clogged cycle.
- *Manual cleaning*. Filter cleaning carried out manually after detecting that a filter remained in a clogged cycle and thus was being continuously backwashed, even though a backwashing was provoked.

2.4.2. Water consumption in filter backwashing

Filter backwashing consumes additional water, which is a characteristic of every filter type. It is thus an interesting variable for microirrigation system design and management.

Data registered during the experiments allowed the filtered volume in every filtration cycle (V_f) and the volume used for every filter backwashing (V_b) to be computed. The percentage of water used for filter backwashing (C_b) was calculated as:

$$C_b = \frac{V_b}{V_f + V_b} \times 100 \quad (3)$$

Table 2 – Mean and standard deviation of the physical and chemical parameters of the effluent at filter inlet. Different letters mean that, for each inlet pressure and parameter, there were significant differences ($P < 0.05$) in the values of the parameter at the filter inlet

Inlet pressure (kPa)	Filtration system	Turbidity (FTU)	TSS (g m^{-3})	Number of particles ml^{-1}
300	Screen	6.15 ± 2.61	10.02 ± 3.25	$2.7 \cdot 10^4 \pm 1.8 \cdot 10^4$
	Disc	6.32 ± 2.47	10.46 ± 4.07	$2.7 \cdot 10^4 \pm 1.4 \cdot 10^4$
	Screen and disc	6.03 ± 2.50	10.59 ± 4.30	$2.8 \cdot 10^4 \pm 1.7 \cdot 10^4$
500	Screen	4.02 ± 2.79	6.26 ± 3.01	$3.3 \cdot 10^4 \pm 1.8 \cdot 10^4$ b
	Disc	4.02 ± 2.79	6.26 ± 3.01	$3.3 \cdot 10^4 \pm 1.8 \cdot 10^4$ b
	Screen and disc	4.29 ± 2.86	6.96 ± 3.00	$4.1 \cdot 10^4 \pm 2.4 \cdot 10^4$a

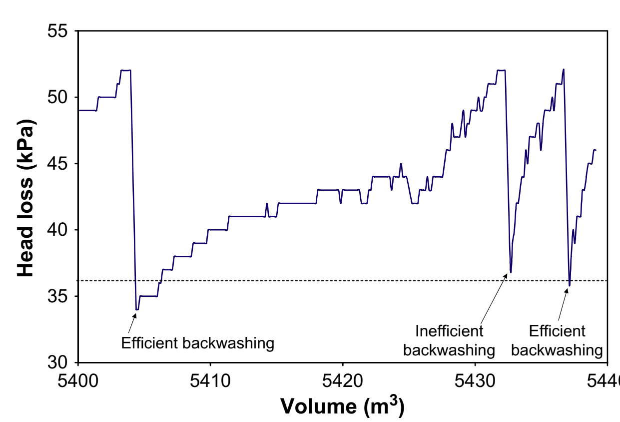

Fig. 2 – Example of backwashing classification for a disc filter at 500 kPa.

Table 3 – Mean and standard deviation of the removal efficiencies of the effluent parameters achieved by the different filtration systems. Negative values show an increase in the parameter. No significant differences ($P < 0.05$) were found for each parameter and inlet pressure

Inlet pressure (kPa)	Filtration system	Removal efficiency (%)		
		Turbidity	TSS	Number of particles ml^{-1}
300	Screen	−1.64 ± 15.72	−0.19 ± 22.51	−39.17 ± 65.76
	Disc	−10.46 ± 13.95	−0.40 ± 17.38	−81.68 ± 204.35
	Screen and disc	1.69 ± 11.16	−0.46 ± 27.89	−68.98 ± 158.45
500	Screen	7.14 ± 26.01	−2.73 ± 23.43	−17.79 ± 95.37
	Disc	3.86 ± 24.58	3.32 ± 31.29	−38.81 ± 72.59
	Screen and disc	12.42 ± 23.53	8.47 ± 18.36	−23.98 ± 100.91

The water volume of manual backwashings could not be registered.

2.5. *Statistical analyses*

Statistical analyses were carried out using the GLM procedure of the SAS statistical package (SAS Institute, Cary, NC, USA). The significance level in the probability analysis was 0.05. Tukey's test was used at the 0.05 level to study the differences between means.

3. Results and discussion

3.1. *Filter removal efficiency*

Removal efficiencies achieved by the different filters in the two experiments are shown in Table 3. Removal efficiency results were highly variable in each experiment, probably due to the variability in effluent composition as the previous work by Puig-Bargués *et al.* (2005a) pointed out. Poor agreement was observed between the TSS and particle removal efficiencies. The explanation might be that all the particles were counted to determine their number, but to determine the TSS a 2 μm filter was used to retain the suspended solids. Thus, the smaller particles, which are the most numerous, may not have been taken into account in the TSS analysis.

No significant differences were observed in removal of turbidity, TSS and number of particles among the three filtration systems for both pressures. However, removals of all of these parameters tended to increase at 500 kPa. The small removals achieved by screen and disc filters are in agreement with other published works (Adin and Elimelech, 1989; Ravina *et al.*, 1997; Puig-Bargués *et al.*, 2005a; Ribeiro *et al.*, 2008).

In Table 4 screen filter removals are compared at an inlet pressure of 300 kPa when the filter was clogged and unclogged. Despite the high variation in results, only the TSS and the number of particle removals achieved by the screen filter alone and by the screen filter placed in the combined filtration system, respectively, depended significantly ($P < 0.05$) on clogging status.

Removal efficiencies of the different filters in the 15 min after a backwashing was carried out (Table 3) and of the screen filter in the clogged and unclogged status (Table 4) were in some cases negative, which means increases in turbidity, TSS and the number of particles at the filter outlet. This is probably due to filtration cake detachment (Adin and Alon, 1986) which has been observed previously in some experiments (Adin and Alon, 1986; Puig-Bargués *et al.*, 2005a). Neis and Tiehm (1997) indicate that some effluents have particles less resistant to deformation than others, so aggregate breakage may often occur.

The increase in turbidity and TSS at the filter outlet was larger when the screen filter was clogged. The filtration cake formed in the screen and disc filters was mainly of biological origin, with most of the particles being compressible. When the screen and disc filters become clogged, pressure increases and these particles can deform and pass through the filter. However, small particles were the most numerous in the effluent because the particle size analysis revealed that 97% of the effluent particles had a diameter of ≤10 μm, as other authors have observed with other effluents (Adin and Elimelech, 1989). Although particles this small should not be retained in the filters used in this experiment, when the screen and disc filter became clogged and a thick filtration cake was formed, the size of the opening for water to pass through was reduced, which led to some particle retention. This could explain why the removal of the number of particles increased when the screen filter was clogged. Thus, there is a process of releasing and retaining different particles that can act in an opposite way to that intended.

Table 4 – Mean and standard deviation of the removal efficiencies of the effluent parameters achieved by the screen filter, alone and in the combined system, working at 300 kPa. Negative values show an increase in the parameter. For each parameter and filter, different letters mean significant differences ($P < 0.05$)

Filtration system	Filter status	Removal efficiency (%)		
		Turbidity	TSS	Number of particles ml^{-1}
Screen	Not clogged	−1.64 ± 15.72	−0.19 ± 22.51 b	−39.17 ± 65.76
	Clogged	−7.31 ± 16.61	−13.83 ± 9.22 a	−4.54 ± 65.03
Screen in combined system	Not clogged	1.69 ± 11.16	−0.46 ± 27.89	−68.98 ± 158.45 a
	Clogged	−11.90 ± 22.22	−4.97 ± 8.33	−15.48 ± 81.83 b

Table 5 – Number of efficient, inefficient, provoked backwashings and manual cleanings at the filter inlet pressures of 300 and 500 kPa during the filtration experiments

Type of filter backwashing and cleaning	Automatic backwashings						Manual cleanings		Total	
	Efficient		Inefficient		Provoked					
Inlet pressure (kPa)	300	500	300	500	300	500	300	500	300	500
Screen filter	85	111	766	52	4	8	58	2	913	173
Disc filter	153	128	1	37	2	7	28	1	184	173
Screen in combined	66	123	586	0	16	10	57	2	725	135
Disc in combined	10	31	0	0	11	11	15	1	36	43

3.2. *Filter backwashing efficiency*

The number of filter backwashings and cleanings, which coincides with the number of filtration cycles, is shown in Table 5. The differences between the number of backwashings when the screen filter worked alone and when it was in front of the disc filters were due to some inefficient automatic backwashing carried out when there were some operational problems. Problems included insufficient pressure and a breakdown of a differential pressure switch, which affected the screen filter of the combined filtration system. The backwashings performed under these conditions were not included in the analysis, as explained in Section 2.4.1.

When the inlet filtration system pressure was increased from 300 kPa to 500 kPa, the number of filtration cycles of the screen filter, working alone or in front of disc filters, was considerably reduced, with reductions of 740 and 590 filtration cycles, respectively. The percentage of automatic efficient backwashings increased when a greater pressure was applied from 9.31% to 64.16% for the screen filter working alone, from 9.10% to 91.11% for the screen filter in the combined system, and from 27.78% to 72.09% for the disc filter placed after a screen filter. The disc filter working alone decreased the efficient backwashings from 83.15% to 73.99%.

Manual cleaning of the screen filter was significantly reduced at 500 kPa in relation to 300 kPa because the backwashing efficiency increased and there were less clogged cycles. Ravina *et al.* (1997), working with irrigation water that contained high amounts of suspended matter, especially filamentous and mucous matter, found that backwashings failed to completely clean the filtering element and manual cleaning was needed, especially in screen and disc filters. In our case, the levels of TSS were lower, but the presence of algae also tend to plug the screen in a way that automatic backwashings were not enough efficient.

Although the disc filter had more inefficient automatic backwashings at 500 kPa, the number of manual cleanings required was clearly lower. The 28 manual cleanings of the disc filter at 300 kPa allowed initial filter conditions to be maintained, which could have resulted in less inefficient backwashing. In this sense, Capra and Scicolone (2004) found that the filter operation time was longer after manual cleaning than after automatic backwashing.

The filtered volumes (Table 6) were larger with the disc filter in the combined filtration system at both pressures. No differences were found in the filtered volume for the other filtration systems. When backwashing was inefficient, the filtered volume was reduced considerably. Filtered volume has been found dependent on both the water quality and the type of filter (Capra and Scicolone, 2007; Ribeiro *et al.*, 2008). The number of cleanings and the filtered volume of the disc filter have also been found to vary with small increases in suspended solids and the turbidity of irrigation water (Ribeiro *et al.*, 2008). As effluent composition is highly variable, the filtered volumes were very different. The work of Puig-Bargués *et al.* (2005a) and also some of the cases reported by Capra and Scicolone (2007) showed longer filtration cycles occurred with disc filters than with screen filters. However, in the present work, this tendency was not observed. The larger filtration surface of the screen filter (110 000 mm^2 instead of 94 000 mm^2 of the disc filter) and the use of an effluent with low suspended solids load (smaller than 10 $g\,m^{-3}$) could explain these results.

The filtered volume after efficient automatic backwashings was significantly larger at 500 kPa than that at 300 kPa with the disc filter and the screen filter alone and in the combined system. When inefficient backwashing took place there was only enough data from screen filters to compare. In this case,

Table 6 – Mean and standard deviation of the filtered volume (V_f), in m^3, for efficient and inefficient backwashing. For each filtration system and backwashing type, different lower case letters mean significant differences ($P < 0.05$) between inlet pressures. For each backwashing type and inlet pressure, different capital letters mean significant differences among filtration systems

Filtration system	Efficient backwashings		Inefficient backwashings	
	300 kPa	500 kPa	300 kPa	500 kPa
Screen	35.14 ± 30.82 b B	56.36 ± 48.61 a B	0.89 ± 3.53 b	11.60 ± 15.20 a
Disc	30.06 ± 20.24 b B	52.40 ± 44.79 a B	9.22	9.45 ± 7.63
Screen in combined	29.19 ± 29.58 b B	48.89 ± 63.92 a B	0.54 ± 0.82	–
Disc in combined	92.95 ± 83.58 A	145.79 ± 171.42 A	–	–

Table 7 – Mean filtered volume (V_f) and standard deviation, in m^3, for the filtration cycles carried out after an efficient backwashing. For every time interval and inlet pressure, different lower case letters mean significant differences ($P < 0.05$) among filtration systems. For every filtration system and inlet pressure, different capital letters mean significant differences during the operation interval

Inlet pressure (kPa)	Filtration system	Operation interval (h)				
		0–200	200–400	400–600	600–800	800–end
300	Screen	59.20 ± 48.58 A	23.80 ± 13.22 BC	19.72 ± 9.36 BC	28.18 ± 14.82 BC	43.22 ± 28.62 a AB
	Disc	65.76 ± 33.80 A	29.12 ± 16.38 B	27.17 ± 13.10 B	28.53 ± 15.79 B	20.42 ± 11.79 b B
	Screen in combined	39.98 ± 45.08	23.22 ± 19.28	23.19 ± 8.52	29.06 ± 14.81	34.94 ± 25.14 ab
500	Screen	187.20 ± 255.87 A	53.24 ± 45.83 ab BC	80.53 ± 35.62 B	43.06 ± 20.68 C	46.34 ± 40.00 BC
	Disc	145.14 ± 86.89 A	80.71 ± 45.13 a B	83.07 ± 49.39 B	34.83 ± 21.39 C	33.65 ± 23.12 C
	Screen in combined	153.46 ± 277.01 A	40.77 ± 54.44 b B	116.23 ± 137.61 A	45.42 ± 31.14 B	37.19 ± 33.14 B

filtered volume was also significantly larger at 500 kPa (11.60 m^3) than that at 300 kPa (0.89 m^3).

Filtered volumes after efficient backwashing at different time intervals are shown in Table 7. Results of disc filter in the combined filtration system do not appear in Table 7 because no backwashings were needed in some intervals. Filtered volumes after efficient backwashing were affected significantly by operation time, being significantly smaller at the end of the experiment (up to 800 h) than in the first 200 operation hours at both pressures, except for the screen filters working at an inlet pressure of 300 kPa. When the inlet pressure was increased to 500 kPa, between 200 and 400 h the volume filtered by screen filter in the combined system decreased, but it recovered later between 400 and 600 h. The reduction in filtered volume was more pronounced in disc filter, probably because of the difficulties in properly washing all the rings of this type of filter. At the beginning of the experiment, filters were completely clean and longer filtration cycles could be carried out, but after some operating time, even though they were manually cleaned, the filters could not reach the initial cleaning levels. One possible solution could be the chlorination of effluent to avoid the development of biological films in the filters, but Ribeiro *et al.* (2008) found this had no significant effect on increasing the filtered volume in disc filters.

No differences in filtered volume were observed among the three filtration systems tested through the experiments at 500 kPa. At an inlet pressure of 300 kPa, only during the last 130 h of the experiment, was the filtered volume significantly smaller in disc filter than in screen filter. Water consumption for backwashing (Table 8) was clearly affected by the type of backwashing and filter. At 300 kPa, the disc filter alone consumed more water in efficient backwashings (1.47%) than screen filters, alone or before disc filter (0.30–0.39%). However, when disc filter was protected by a screen filter, backwashing water consumption felt to an average of 0.10% at 300 kPa. At 500 kPa, the filter that significantly consumed the most backwashing water was also disc filter (0.76%). Backwashing water consumption of disc filter tended to be smaller at 500 kPa than that at 300 kPa. The disc filter in the combined system increased water consumption up to 0.34% at 500 kPa. This filter operated with the effluent that had been previously filtered in a screen filter, which did not affect the physical and chemical effluent parameters significantly (Table 3).

Backwashing water consumption clearly increased with inefficient backwashings, especially at lower pressure. Therefore, screen filters consume between 10.41 and 11.92%, alone or in the combined system. There was only a datum for the inefficient automatic backwashing of disc filter at 300 kPa and it was not possible to compare it with other data. However, at 500 kPa, water consumption in not efficient backwashing for the screen filter was clearly lower (3.25%) than that at 300 kPa and was slightly lower than those needed by disc filters (3.82%).

Ravina *et al.* (1997) found that the backwash water volume of screen and disc filters working with effluents was generally smaller than 0.5% of the total water volume passing the filter. The results for backwashing water consumption in the present study agreed with the results of Ravina *et al.* (1997) for screen filters, but not for the disc filter when working alone. The latter was similar to the consumption of media filters, reported to be between 0.5 and 1.5% (Ravina *et al.*, 1997) or even 3% (Tajrishy *et al.*, 1994).

Table 8 – Mean and standard deviation of the percentage of water used for filter backwashing (C_b) in efficient and inefficient backwashing. For every filtration system and type of backwashing, different lower case letters mean significant differences ($P < 0.05$) between inlet pressures. For every backwashing type and inlet pressure, different capital letters mean significant differences among filtration systems

Filtration system	Efficient backwashings		Inefficient backwashings	
	300 kPa	500 kPa	300 kPa	500 kPa
Screen	0.30 ± 0.48 B	0.24 ± 0.34 B	10.41 ± 6.40 a B	3.25 ± 3.62 b
Disc	1.47 ± 4.03 A	0.76 ± 1.59 A	0.85	3.82 ± 3.40
Screen in combined	0.39 ± 0.38 B	0.40 ± 0.76 B	11.92 ± 7.89 A	–
Disc in combined	0.10 ± 0.18 B	0.34 ± 0.45 AB	–	–

4. Conclusions

Screen, disc and a combination of screen and disc filters showed very small reductions in turbidity and TSS when working with effluents with average values of turbidity and TSS lower than 6.32 FTU and 10.59 g m^{-3}, respectively. However, the average values of number of particles increased at filter outlet, probably due to detachment of particles of biological origin. In general, values of turbidity, TSS and number of particles were smaller at filter outlet when inlet filter pressure increased from 300 to 500 kPa.

No differences in turbidity, TSS and number of particles removal efficiencies were observed among screen, disc and a combination of screen and disc filter at both pressures of 300 and 500 kPa.

Classification of automatic backwashing into efficient and inefficient, depending on the value of the head loss across the filter at the beginning of a filtration cycle was a useful approach to analyse backwashing performance.

The screen filter reduced considerably the amount of filter backwashings required at 500 kPa, especially because of an increase in efficient backwashings observed at this inlet pressure. The increase in inlet pressure to 500 kPa did not reduce backwashings for the disc filters but the number of manual cleanings for clogged disc filters was clearly smaller.

The disc and screen filters in the combined filtration system, the disc filter and the screen filter, reached a head loss of 50 kPa when working efficiently, after filtering an average of 92.95, 29.19, 30.06 and 35.14 m^3 at 300 kPa, respectively, and 145.79, 48.89, 52.40 and 56.36 m^3 at 500 kPa, respectively. The filtered volume in the disc filter was significantly smaller compared to the initial volume after 800 h of operation with the two inlet pressures tested.

The disc filter consumed significantly more water for efficient automatic backwashings at 300 kPa (1.47%) and 500 kPa (0.76%). The screen filter consumed water for backwashing between 0.30 and 0.39% at 300 kPa and between 0.24 and 0.40% at 500 kPa. With inefficient backwashings, water consumption generally increased in all filters.

According to the results, screen and disc automatic backwashing is more effective at an inlet pressure of 500 kPa. Under field conditions, an additional pump, activated only when an automatic backwashing needs to be carried out, or a variable speed pump commanded by a variable frequency drive, could be installed to supply this pressure without excessively increasing energy consumption.

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