# Filter and emitter performance of micro-irrigation systems using secondary and tertiary effluents

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## Abstract

The performance of four filtration systems (sand, screen, disc and a combination of screen and disc) and six emitter types (four pressure compensated and two non-pressure compensated), using secondary and tertiary effluents from a wastewater treatment plant, was studied for 1000 h. Only sand filtration significantly reduced turbidity and suspended solids. The best emission uniformity was obtained by the emitters placed after the sand filter and the screen filter with the secondary and tertiary effluent, respectively. On the other hand, emitters that operated with disc filters showed the worst emission uniformity for both effluents. Emitter type P2 was the only one achieving values of emission uniformity higher than 90% with all filtration systems and effluents except the screen filter and the tertiary effluent.
*Keywords: wastewater, drip irrigation, filtration, clogging.*

## 1 Introduction

The use of effluents in agriculture is a viable alternative in areas where water is scarce or there is strong competition for its use. The best way to apply effluents, from public health and environmental points of view, is micro-irrigation [1]. The main problem when using effluents in drip irrigation systems is emitter clogging [2] because the reduction of emitted flow affects water distribution and,


www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SI080351

consequently, yields [3]. Besides, clogging of filters and emitters makes micro-irrigation system management difficult. For this reason, several researchers have studied micro-irrigation system performance using different effluents [2, 4, 5]. However, the high variability observed in the results has made it necessary to increase the number of experiments with different effluents and irrigation equipment.

The objectives of this study were to analyse the performance of four filtration systems and six emitters when using two effluent qualities.

## 2 Material and methods

Secondary and tertiary effluents from the wastewater treatment plant (WWTP) of Celrà (Girona), which treated wastewater from the urban and industrial areas of this village, were used in the experiments. Secondary effluent was collected at a settling tank placed after a biological reactor-type oxidation ditch and operated by a sludge process. Tertiary effluent was obtained by filtration of the secondary effluent through a disc filter with a 130 μm filtration level and disinfection by ultraviolet radiation.

The performance of four filtration systems was studied. The first system was formed by two sand filters in parallel, both 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 0.40 and 0.27 mm for the experiments with secondary and tertiary effluents, respectively. The uniformity coefficient (relationship between screen openings that retain 40% and 90% of the sand) was of 2.41 in the experiments with secondary effluent and 2.89 in those with tertiary effluent. The second filtration system had two disc filters in parallel, both with a filtration level of 130 μm. The third filtration system consisted of one 120 μm screen filter. The fourth filtration system consisted of one screen filter followed by two disc filters in parallel, with the same characteristics as the filters used in systems 2 and 3. The performance of six different emitters, whose main characteristics are shown in table 1, was also assessed.

Each filtration system supplied water to 24 drip-lines with a length of 87 m. Six types of drip-lines were used, each one with a different emitter and with four replications of every drip-line. Two experiments were carried out, both lasting 1000 h. The first experiment took place in the summer of 2005 with secondary effluent, while the second, during the summer of 2006, used tertiary effluent. In order to control and monitor the micro-irrigation system, a supervisory control and data acquisition (SCADA) system was used, which allowed both continuous collection of filter performance data and irrigation scheduling [6].

Water samples at filter inlets and outlets were taken periodically to characterize the effluents and to determine the effect of filtration on pH, electrical conductivity (EC), turbidity, total suspended solids (TSS), dissolved oxygen (DO) and particle number. With the values of every parameter at the filter inlet ($N_o$) and outlet ($N$), the removal efficiency ($E$) achieved in the filters was calculated with eqn. (1):

$$E = \frac{N_o - N}{N} \cdot 100 \tag{1}$$

Table 1: Main tested emitter and drip line characteristics, according to manufacturer specifications.

| Characteristic | Emitter | | | | | |
|---|---|---|---|---|---|---|
| | UN | RM | P2 | P8 | TO | TI |
| Nominal flow (l/h) | 2.30 | 2.30 | 2.00 | 8.50 | 1.75 | 2.00 |
| Nominal pressure (kPa) | 50-400 | 50-400 | 50-400 | 50-400 | 100 | 100 |
| External diameter (mm) | 17.0 | 17.0 | 16.0 | 16.0 | 16.6 | 16.1 |
| Distance between emitters (m) | 0.40 | 0.75 | 1.00 | 1.00 | 1.50 | 0.75 |
| Drip line flow (l/h) | 499 | 267 | 174 | 740 | 102 | 232 |
| Number of emitters | 217 | 116 | 87 | 87 | 58 | 116 |
| Flow exponent x | 0 | 0 | 0 | 0 | 0.48 | 0.46 |
| Discharge coefficient K | 2.30 | 2.30 | 2.00 | 8.50 | 0.58 | 0.69 |
| Pressure compensation | Yes | Yes | Yes | Yes | No | No |
| Manufacturer variation coefficient | < 3% | < 3% | < 3% | < 3% | < 3% | < 3% |

Emission flow uniformity (*UE*) was evaluated seven times in every experiment using the Merriam and Keller [7] method, modified by Vermeiren and Jobling [8]. Using this method, two contiguous drippers were selected in four drip lines (with the same emitter type and filtration system) at four locations in each emitter line (at the beginning, at 1/3 of the length, at 2/3 of the length and at the end of the emitter line). The working pressure at each location was measured by means of a digital manometer (± 0.07% accuracy). The water delivered for each selected emitter was collected for five minutes to measure the flow of the emitters. The data obtained from field measurements were used to calculate the percentage of totally clogged emitters of the sample and also the emission uniformity by means of eqn. (2):

$$UE = \frac{q_{25}}{\overline{q}} \cdot 100 \qquad (2)$$

$q_{25}$ being the average emitted flow of 25% of the emitters with the lowest flow rate (l/h) and $\overline{q}$ the average emitted flow of all the measured emitters (l/h). On the other hand, pressure uniformity ($U_p$) was computed as:

$$U_p = \left(\frac{p_{25}}{\overline{p}}\right)^x \cdot 100 \qquad (3)$$

where $p_{25}$ is the average pressure of 25% of the emitters with the lowest pressure (kPa), $\overline{p}$ the average pressure of all the tested emitters (kPa) and $x$ the emitter flow exponent.

# 3 Results and discussion

## 3.1 Filtration system performance

Table 2 shows the values of the physical and chemical parameters at the filter inlet during the experiments. Both effluents had, according to the Bucks *et al.*

Table 2: Mean and standard deviation of physical and chemical parameters of secondary and tertiary effluents. For every parameter, different letters mean significant differences (P<0.05).

| Effluent | Parameter | | | | | |
|---|---|---|---|---|---|---|
| | pH | CE (dS/m) | DO (mg/l) | Turbidity (FTU) | TSS (mg/l) | Particles/ml |
| Secondary | 7.50±0.08[a] | 5.43±0.80 | 2.79±0.57[a] | 6.23±2.25 | 10.19±3.07 | 27559±12533 |
| Tertiary | 7.34±0.08[b] | 5.11±1.10 | 1.78±0.17[b] | 4.12±2.79 | 6.53±2.87 | 37111±21385 |

classification [1], a minor physical clogging hazard by total suspended solids and a moderate chemical clogging hazard with regard to pH. Only pH and dissolved oxygen were significantly greater (P<0.05) in the secondary effluent than in the tertiary one. The fact that dissolved oxygen was 1 mg/l smaller with tertiary effluent revealed that this effluent had more organic contamination than the secondary effluent. The explanation could be in the variability of effluents, because the experiments were not simultaneous. EC, turbidity and TSS were greater with secondary effluent, but showed no statistical differences with tertiary effluent. The tertiary effluent had a particle count 36% higher than the secondary one.

No statistical differences (P>0.05) were found between the effluent used by the different filtration units. However, statistical differences (P<0.05) were found between sampling days, which indicates the variability that the same effluent could have throughout the experiment.

Removal efficiencies achieved with both effluents by the different filtration systems are shown in table 3. It should be pointed out that sand filter reduced turbidity from secondary and tertiary effluents 57% and 66%, respectively, and total suspended solids, 47% and 66%, respectively. The performance of sand filters in turbidity and TSS removal was significantly different (P<0.05) from the other filtration systems, which only had slight, or even negative removal efficiencies, probably due to detachment of solids from the filter cake [9]. The low reductions in TSS achieved by screen and disc filters agree with those observed by other authors [2, 10, 11]. On the other hand, sand filter was the only one that reduced the number of particles, but without significant differences with the increments produced in other filters, as Adin and Alon [9] observed in screen filters.

The 5% removal efficiency of dissolved oxygen using a combination of screen and disc filters with tertiary effluent was significantly higher than that achieved with the other filtration systems.

## 3.2 Emitter performance

As the pressure uniformity ($U_p$) was above 90% in the different irrigation units for both studied effluents, the pressure distribution along drip lines was correct. Taking into account that the manufacturer's coefficients of variation were smaller than 3% (table 1), emission flow uniformity variations can only be produced by emitter clogging. Fig. 1 shows *UE* at 1000 h of irrigation in function of effluent, filtration system and emitter.

Table 3: Mean and standard deviation of removal efficiency (%) of the different effluent parameters by filtration system. Negative values show a parameter increment. For each parameter and effluent, a different letter means significant differences (P<0.05) among filtration systems.

| Parameter | Effluent | Filtration system | | | |
|---|---|---|---|---|---|
| | | Sand | Screen and disc | Disc | Screen |
| pH | Secondary | 0.25 ± 0.57 | 0.32 ± 0.53 | 0.18 ± 0.31 | 0.57 ± 1.95 |
| | Tertiary | -0.08 ± 0.94 | 0.43 ± 0.78 | -0.26 ± 0.59 | -0.22 ± 0.72 |
| CE (dS/m) | Secondary | -0.29 ± 0.30 | -0.28 ± 0.23 | -0.37 ± 0.47 | -0.16 ± 1.03 |
| | Tertiary | 0.17 ± 1.13 | -0.07 ± 0.96 | -0.33 ± 0.52 | -0.41 ±0.74 |
| DO (mg/l) | Secondary | 0.49 ± 4.59 | -0.12 ± 4.45 | -1.17 ± 7.24 | -2.69 ± 8.61 |
| | Tertiary | -2.24 ± 13.59 [b] | 5.07 ± 10.00 [a] | -2.32 ± 8.65 [b] | 0.23 ± 7.83 [b] |
| Turbidity (FTU) | Secondary | 57.57 ± 21.97 [a] | 1.69 ± 11.16 [b] | -10.46 ± 13.95 [b] | -1.64 ± 15.72 [b] |
| | Tertiary | 66.38 ± 20.23 [a] | 12.42 ± 23.53 [b] | 3.87 ± 24.58 [b] | 7.14 ± 26.01 [b] |
| TSS (mg/l) | Secondary | 47.30 ± 39.59 [a] | -0.46 ± 27.89 [b] | -0.40 ± 17.38 [b] | -0.19 ±22.51 [b] |
| | Tertiary | 66.63 ± 14.22 [a] | 8.48 ± 18.36 [b] | 3.32 ± 31.29 [b] | -2.73 ±23.43 [b] |
| Particles/ml | Secondary | 17.13 ± 52.58 | -68.98 ± 158.45 | -81.68 ± 204.4 | -39.17 ± 65.76 |
| | Tertiary | 6.12 ± 51.63 | -23.98 ± 100.91 | -38.81 ± 72.59 | -17.79 ± 95.37 |

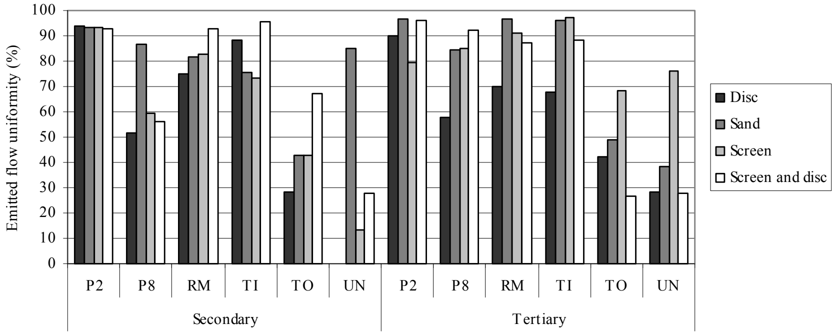


Figure 1: Emission flow uniformity regarding effluent, emitter and filtration system after 1000 h of operation.

The variation of *UE* due to the emitter type was greater than the variation caused by the filtration system by both secondary and tertiary effluents. While the best average *UE* with all six types of emitter was achieved by the sand filter with secondary effluent (77.5% ± 18.1) and by the screen filter with tertiary effluent (82.9% ± 10.5), the worst was found by the disc filter with secondary effluent (56.3% ± 36.8) and tertiary effluent (59.4% ± 21.9). Greater clogging of emitters using effluents filtered through disc filters has been observed previously in other secondary effluents [5].

Table 4 presents the *UE* after 1000 h of operation for every emitter and effluent, considering the average value with the four filtration systems.

Table 4: Mean and standard deviation of *UE* of every emitter after 1000 h of irrigation with secondary and tertiary effluents.

| Effluent | Emitter | | | | | |
|---|---|---|---|---|---|---|
| | P2 | P8 | RM | TI | TO | UN |
| Secondary | 93.30±0.44 | 63.51±15.84 | 83.10±7.30 | 83.22±10.69 | 45.25±15.94 | 31.57±37.52 |
| Tertiary | 90.47±8.01 | 79.96±15.11 | 86.23±11.54 | 87.45±13.54 | 46.50±17.27 | 42.69±22.94 |

Emitters P2, RM and TI achieved the best *UE* with both effluents. Emitter P2 stood out with an *UE* greater than 90%. In contrast, emitters TO and UN had the smallest *UE*, being lower than 45% with emitter UN. Nevertheless, emitter UN showed an acceptable performance with the sand filter and the secondary effluent (*UE* of 85%) and with the screen filter and the tertiary effluent (*UE* of 76%), which reveals the importance of the combination of filter, emitter and effluent. The low *UE* observed with emitter UN could be explained by the fact that this emitter had a higher number of emitters per drip line, as shown in table 1. Thus, the drip lines with emitter UN had higher amounts of water and higher particle quantities, increasing the emitter clogging probability. Besides, the formation of a thick film at the end of the drip lines, which was observed with all filters and effluents, penalized the *UE* values of emitter UN, because the Merriam and Keller [7] method, modified by Vermeiren and Jobling [8], requires the determination of the flow of two emitters placed at the end of the lateral. Due to a distance of 0.4 m between UN emitters, it was not possible to determine *UE* in drip line distal locations that were not affected by the sediment accumulation, which had an obvious influence on results. To be precise, this emitter presented one of the highest percentages of completely clogged emitters at the end of the drip line, as will be commented on later. If the last sample position is not considered, the *UE* of emitter UN is similar to emitters RM and TI. Drip lines with emitter P8 had an effluent volume greater than UN, but did not show such a low *UE*, especially with tertiary effluent. Emitter P8 stands out for the highest resistance to clogging among emitters with a higher nominal flow [12].

The distribution of completely clogged emitters throughout the experiments at the different test locations with secondary and tertiary effluents is shown in figs. 2 and 3, respectively. It was observed that the percentage of totally clogged emitters increased with operation time, but at a different rhythm. Thus, up to 825 h, progressive increases between 0.15 and 1.18% were produced, but at 1000 h the increases were of 3%. Emitter location along the drip line was also a significant factor ($P<0.05$) for the presence of completely clogged emitters at the end of the experiments, because, if at the end of the drip line around 22% of the emitters were totally clogged, in the other positions this percentage was lower than 3%. The highest incidence of clogging at the end of drip lines [2] is attributed to lower flow velocities at these points, which facilitate particle

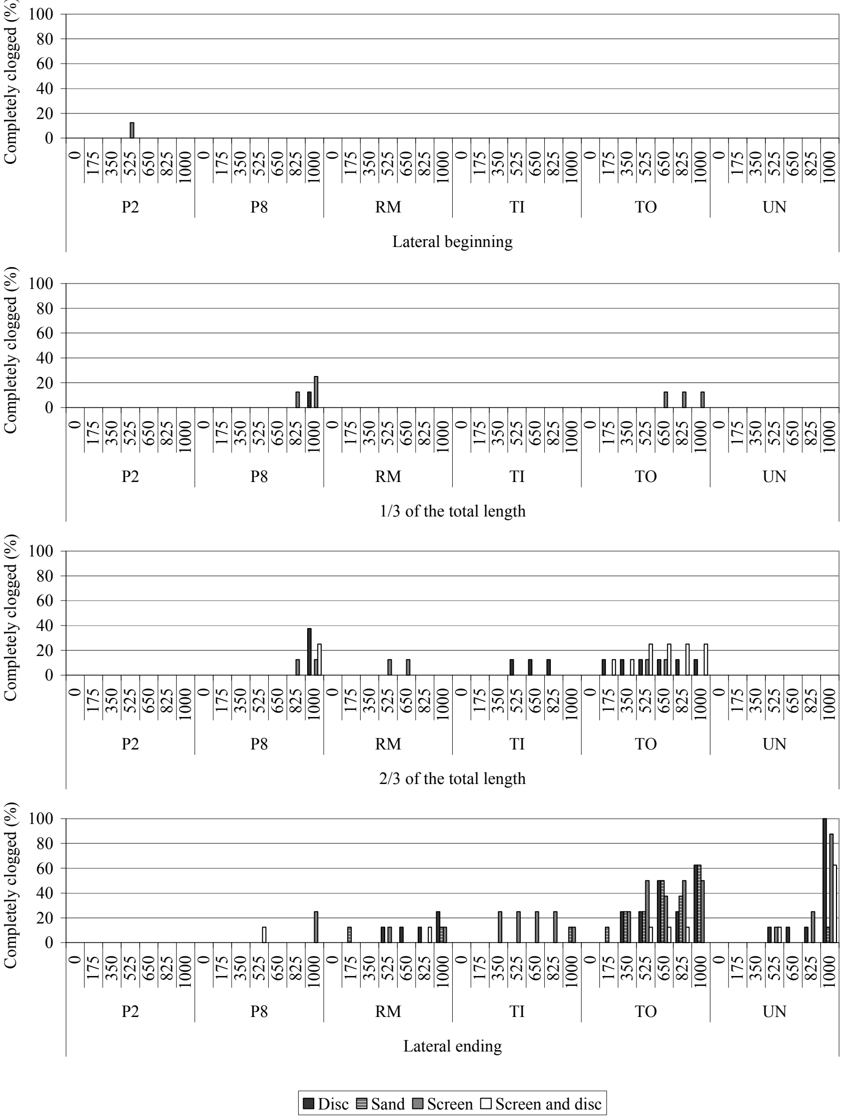


Figure 2: Percentage of emitters completely clogged with secondary effluent in sample locations for measuring *UE* throughout the experiment in function of location, emitter and filtration system.

settling [13]. Whether or not the different locations are taken into consideration, emitters TO and UN showed the highest average amounts of clogged emitters at the end of the experiment: 14% with emitter TO for both effluents and 16% and 12% with emitter UN and secondary and tertiary effluents, respectively. With secondary effluent, 9% of P8 emitters were completely clogged, but with tertiary effluent no totally clogged emitters were found. Emitters RM, P2 and TI, with less than 4% of completely clogged emitters, had the lowest incidence of totally clogged emitters with both the effluents used.

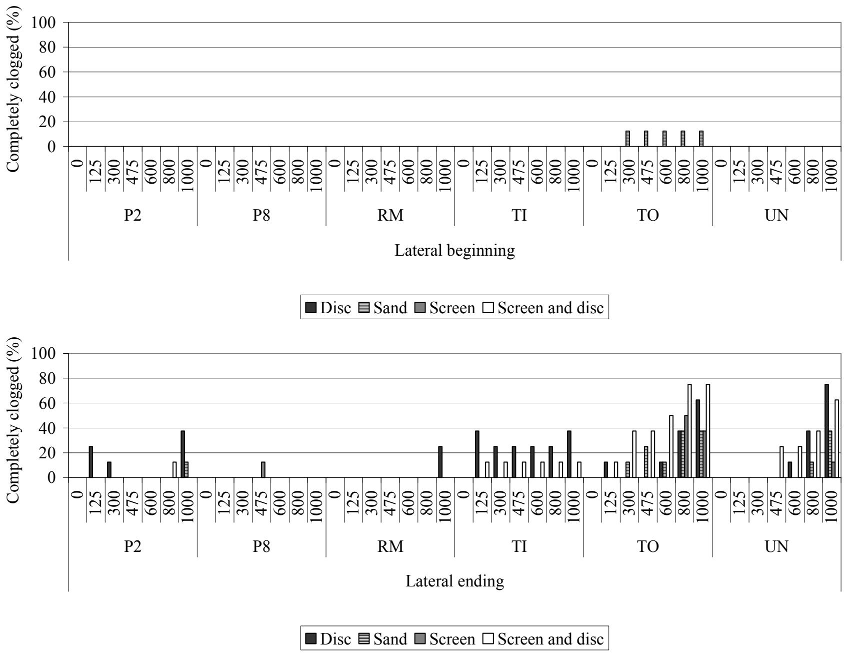


Figure 3: Percentage of emitters completely clogged with secondary effluent in sample locations for measuring *UE* throughout the experiment in function of location, emitter and filtration system. At locations 1/3 and 2/3 of lateral length, no clogged emitters were found.

It is important to point out that, during the experiment, some emitters experienced a reversion in their clogging status. In this sense, Ravina *et al.* [2] pointed out that emitter clogging does not necessarily have to be permanent, because emitters could be self-cleaning.

## 4 Conclusions

Only sand filtration significantly reduced turbidity and suspended solids from both secondary and tertiary effluents. With emitter P2 the best emission uniformities were obtained at the end of experiments, being higher than 90% for all combinations of effluent and filtration systems, except with screen filters and tertiary effluent. On the other hand, emission uniformity was lower than 68% with emitter TO for all filtration systems and effluents, and 40% with emitter UN, but with this last emitter, better values were observed with some other combinations of effluent and filter.

The best emission uniformity was obtained by the emitters placed after the sand filter (76%) and the screen filter (83%) with the secondary and tertiary effluents, respectively. Emitters that operated with disc filters showed the worst emission uniformity for both effluents. Clogged emitters were located mainly at the end of drip lines, where around 22% of the emitters were completely clogged after 1000 h of irrigation.

## Acknowledgements

The authors would like to express their gratitude to the Spanish Ministry of Science and Technology for their financial support for this experiment through grant REN2002-00690/HID. The authors would also like to thank Regaber and the Municipality of Celrà for their help in carrying out this experiment.

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