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Flow rate dynamics of pressure-compensating drippers under clogging effect

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emitters
trickle irrigation
clogging

ABSTRACT

The clogging dynamics of pressure-compensating drippers is still poorly addressed, and its understanding is quite important to control clogging. The aim of this study was to evaluate the flow performance of pressure-compensating drippers under clogging effect. Eight pressure-compensating emitters, model J-SC Jain PC-PLUS with nominal flow rate of 2.2 L h^{-1} were evaluated. The tests were run for 8 h d^{-1} for 4 weeks, a total of 160 h. Every 40 h, the concentration and granulometry of suspended particles were increased, by adding 125 mg L^{-1} of solids, composed of sand. The flow rate of the emitters was determined using a weight measurement system. Flow rate variations of the emitters did not follow a defined pattern. Clogging seems to occur randomly and abruptly. Sometimes the flow rate exceeded the nominal value (maximum relative flow rate of 182%) and other times it was lower than the nominal value (minimum relative flow rate of 0%).

Palavras-chave:
emissores
irrigação localizada
entupimento

Dinâmica da vazão de gotejadores autocompensantes sob o efeito da obstrução

RESUMO

A dinâmica da obstrução de emissores autocompensantes ainda é pouco conhecida, apesar de seu entendimento ser de fundamental importância para o controle da obstrução. O objetivo deste trabalho foi avaliar, em laboratório, o comportamento da vazão de gotejadores autocompensantes sob o efeito da obstrução. Avaliaram-se 8 emissores autocompensantes, modelo Jain J-SC PC-PLUS com vazão nominal de 2,2 L h^{-1} em ensaios com duração de 8 h d^{-1}, durante 4 semanas totalizando 160 h. A cada 40 h eram incrementadas a concentração e a granulometria de partículas, sendo adicionados 125 mg L^{-1} de sólidos, compostos por areia. A vazão dos emissores foi determinada por sistema de medição de massa. Verificou-se que as variações de vazão dos emissores não apresentaram padrão definido, ocorrendo de forma aleatória e em sua maioria de forma brusca, às vezes apresentando vazões superiores à vazão nominal (vazão máxima relativa de 182%); outras vezes, vazões inferiores (vazão mínima relativa de 0%).

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Introduction

Emitter clogging is one of the most serious and complex problems in drip-irrigation systems, and water quality and the emitters' labyrinth geometry are determinant factors in this process. Preventive measures such as filtration, injection of chemicals and washing of the lines (Puig-Bargués et al., 2010; Pinto et al., 2011) can be adopted to avoid this problem.

By monitoring the flow rate, it is expected to detect emitter clogging, allowing to estimate clogging degree and identify the moment in which the maintenance routines must be performed (Camargo et al., 2013).

The literature has some proposals for monitoring the clogging degree of emitters based on indirect measurements of hydraulic variables, such as flow rate and head loss along a lateral line or secondary line (Camargo et al., 2013). Some analyses are made through simulations of the pressure profile along the lateral line, testing different situations, such as uniform clogging, localized clogging in specific sections and variable clogging degree (Nakayama & Bucks, 1981; Bralts et al., 1982; Povoa & Hills, 1994; Talozi & Hills, 2001; Camargo et al., 2013). Although these models have led to advances regarding the monitoring, they are not applicable to pressure-compensating drippers.

The assumptions made in the previously mentioned studies are based on the principle that emitter clogging can be partial or total. However, the clogging of pressure-compensating emitters can both increase or decrease the flow rate of the emitter (Carvalho et al., 2014), evidencing the importance of characterizing the flow rate behavior of this category of emitters due to the accumulation of particles inside them.

In this context, this study aimed to experimentally evaluate the flow rate dynamics of pressure-compensating emitters under the effect of clogging by solid particles.

Material and Methods

The study was carried out at the Laboratoire d'Essais et de Recherche des Matériels d'Irrigation (LERMI/IRSTEA, Aix-en-Provence and Montpellier, France).

Emitter clogging effects were evaluated on a test bench, composed of a motor pump, a mechanical stirrer, pressure regulators and a manometer. The flow rate dynamics of the emitters was evaluated through the methodology used by Alves et al. (2015). The emitters were tested for 8 h a day and 5 days a week. In the first week, solids with diameter from 0 to 80 μm were added, promoting a concentration of 125 mg L^{-1}. In the beginning of the second week, more 125 mg L^{-1} of particles with diameter between 80 and 100 μm were added, totaling the concentration of 250 mg L^{-1} of suspended solids. In the following week, more 125 mg L^{-1} of particles with diameter between 100 and 200 μm were added. Lastly, in the fourth week, the condition of highest risk of clogging was achieved with the addition of more 125 mg L^{-1} of particles with diameter from 200 to 500 μm, leading to a total concentration of suspended solids of 500 mg L^{-1} and a total time of operation of 160 h of test. A helix stirrer was used to maintain the particles in suspension. The fractions of solid particles were separated using sieves with mesh diameters of 50, 80, 100, 130, 200, 260 and 500 μm, at the proportions of 12.5, 12.5, 25, 12.5, 12.5, 12.5, 12.5% of the total weight at the end of the test, respectively.

Before the tests, the flow rate characteristic curve and the flow rate variation coefficient due to the effects of manufacturing (CVM) were determined, evaluating 30 emitters for test pressures from 24.5 to 400 kPa following ISO-9261 standard. The CVM was used to determine the test pressure to evaluate the flow rate dynamics of the emitters subjected to water with solids in suspension. The selected test pressure was 98.1 kPa and the corresponding flow rate was taken as reference or standard. For the analysis of flow rate variation due to emitter clogging, the variable called emitter relative flow rate was defined (Eq. 1).

$$q(\%) = 100\frac{q}{q_{or}} \tag{1}$$

where:

q(%) - emitter relative flow rate, %;

q - emitter flow rate at any instant during the clogging test, L h^{-1}; and,

q_{or} - emitter flow rate before the clogging test, L h^{-1}.

The flow rate of the emitters was directly determined, by collecting water volumes in known time intervals. The determinations of volume were obtained through the measurements of weight, time and water temperature, performing the correction of the water specific weight (Eq. 2). Water specific weight was determined through Eq. 3, suggested by Kell (1975). Water temperature was measured using an ALMEMO 2290-3 digital thermometer (0.01 °C resolution).

$$q = 60\frac{m_{total} - m_{collector}}{\rho t} \tag{2}$$

$$\begin{aligned}\rho \;=\;& \left(0.9998676 + 17.801161\times10^{-3}\,T - 7.942501\times10^{-6}\,T^2 - \right.\\ -\;& 52.56328\times10^{-9}\,T^3 + 137.6891\times10^{-12}\,T^4 - \\ -\;& \left.364.4647\times10^{-15}\,T^5\right)\Big/\left(1 + 17.735441\times10^{-3}\,T\right)\end{aligned} \tag{3}$$

where:

m_{total} - mass of the collector + collected mass of water, kg;

$m_{collector}$ - mass of the collector, kg;

ρ - water specific weight for a given temperature (T, °C), kg L^{-3}; and,

t - time of test, min.

To avoid the influence of water temperature on the emitter clogging process, the temperature was maintained at 23 °C whithin an interval of plus or minus 3 °C during the test, using a water cooling system to avoid heating. Without the cooling system, the water would heat, due to the effects of the pumping system, stirring system and the variation of air temperature along the day. During the tests, water temperature was controlled and maintained at 24.0 °C on average.

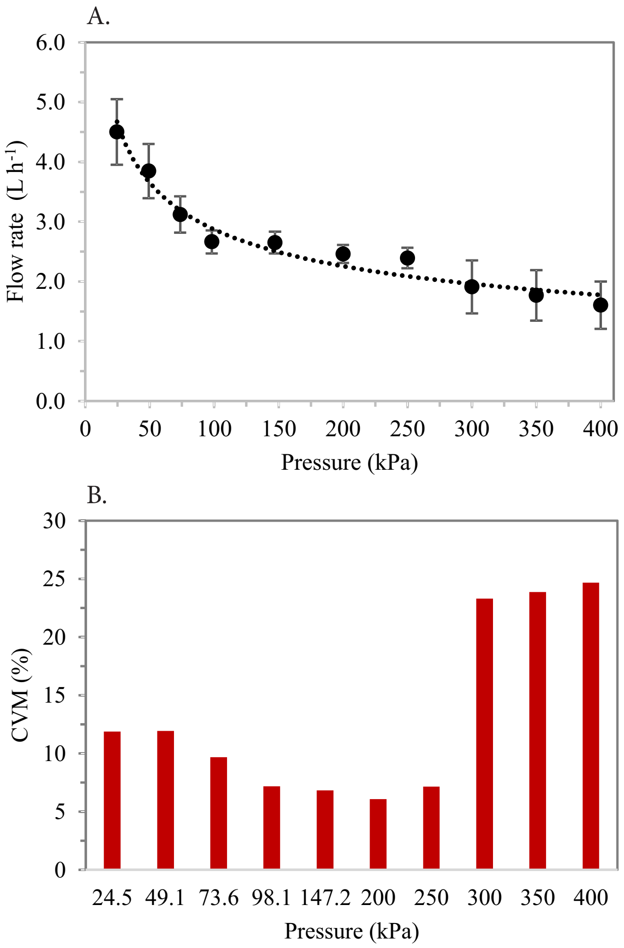
Eight Jain J-SC PC-PLUS emitters with flow rate of 2.2 L h^{-1} were evaluated. The flow rates of half of the emitters were monitored through scales connected to an automatic data acquisition system. The flow rates of the other four emitters were manually determined, by weighing, using an electronic scale (Figure 1). The number of load cells with automatic data acquisition system available in the laboratory was lower than the number of evaluated drippers, thus requiring also the manual method of flow rate measurement. The continuous monitoring of the flow rate part of emitters was important to characterize the flow rate dynamics of the emitters under clogging effect.

Manual weight measurements used a digital scale with resolution of 0.01 g, while automatic measurements used collectors maintained on weighing platforms equipped with HBM SP4C3 load cells. The signals from the load cells were acquired using modules for amplification and conditioning of signals and an NI-DAQ USB 6009 module connected to a computer. The collection and storage of data sent via USB were performed through an application developed in LABVIEW2011®. After being converted into flow rate, the data were saved in a .txt file, with date, hour, weight of each load cell and water specific weight. The interval of data acquisition was 1 min; the values of temperature were informed by the user through the application's interface and were used to calculate the water specific weight, which in turn was used to calculate the flow rate, according to Eq. 3.

The load cells were properly calibrated and the automatic weight measurement system showed expanded uncertainty of 0.2 g. The uncertainty was calculated based on the norm ISO GUM 2008 (INMETRO, 2012), determining the type A uncertainty. The scale used for the manual measurements showed a claimed standard uncertainty of 0.1 g.

Results and Discussion

Figure 2 shows the characteristic curve and standard deviations of the flow rate of the emitters for each test pressure. Although their is no norm associated with clogging tests, the technical norm NBR ISO 9261 (ABNT, 2006) establishes requirements to evaluate the operational characteristics of new drippers under conditions of no risk of clogging. Under such test conditions, a lot of emitters have adequate performance regarding flow rate uniformity when the flow rate variation coefficient is lower than 7%.



Bars indicate the standard deviation between the emitters

Figure 2. Flow rate as a function of pressure of the emitters (A); Flow rate variation coefficient due to manufacturing effects-CVM (B)

According to Figure 2A, for pressures from 98.1 to 250 kPa, the flow rate of the emitters remains almost constant (2.6 to 2.4 L h^{-1}) and with low standard deviation (mean of the range of ±0.17 L h^{-1}). Figure 2B shows the flow rate variation coefficients due to manufacturing effects. It can be observed that the emitters showed adequate variation coefficient, lower than the 7% established by the norm NBR ISO 9261 (ABNT, 2006). Based on this analysis, the test pressure of emitter clogging was established as 98.1 kPa.

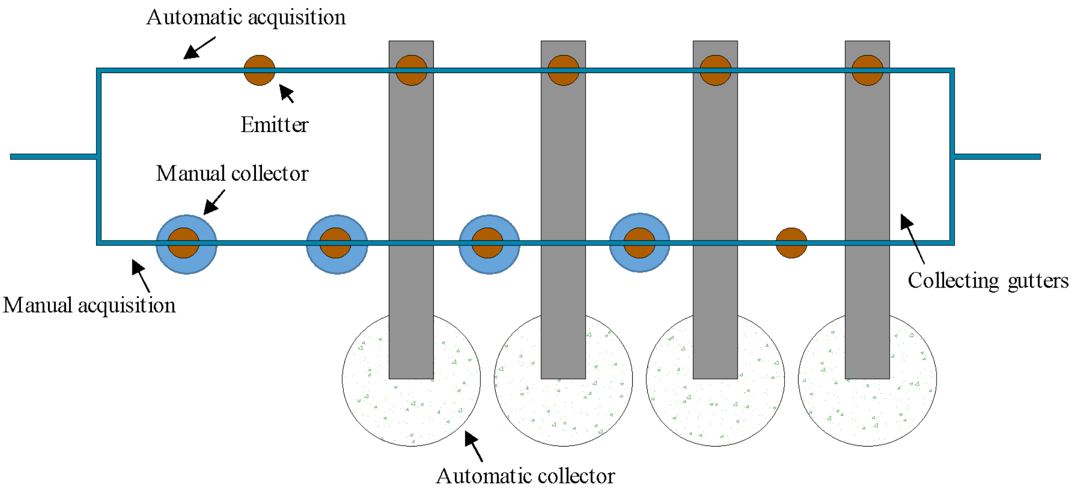


Figure 1. Scheme of the test bench for the characterization of the sensitivity of the emitters to clogging

The flow rate variation between the emitters is basically due to manufacturing factors and, in general, suffers little influence of the operating pressure. However, in the case of pressure-compensating emitters, when the test pressure is outside the adequate range, the functioning of the membrane can be affected, compromising the flow rate uniformity.

Figure 3 shows the relative flow rate profiles over time, for different conditions of solids in suspension. The flow rate profiles of Figures 3A to 3E are result of the emitters monitored using automatic acquisition and those of Figure 3F are a result of the emitters with manual data collection, i.e., they are independent measurements, taken only to confirm the automatically measured values, not allowing the observation of instantaneous flow rate variations.

The flow rate variations did not have a defined pattern between the emitters, occurring randomly and mostly abruptly. These variations occurred mainly when the pumping system started, leading to increase or reduction of flow rate. However, until 64 h of test, when the concentration of suspended solids was 250 mg L^{-1} and particle diameter was lower than 100 μm, a similar behavior was observed for all emitters: the flow rate remained close to the value of the beginning of the test, while the highest variations were observed when the pumping system started. Nevertheless,

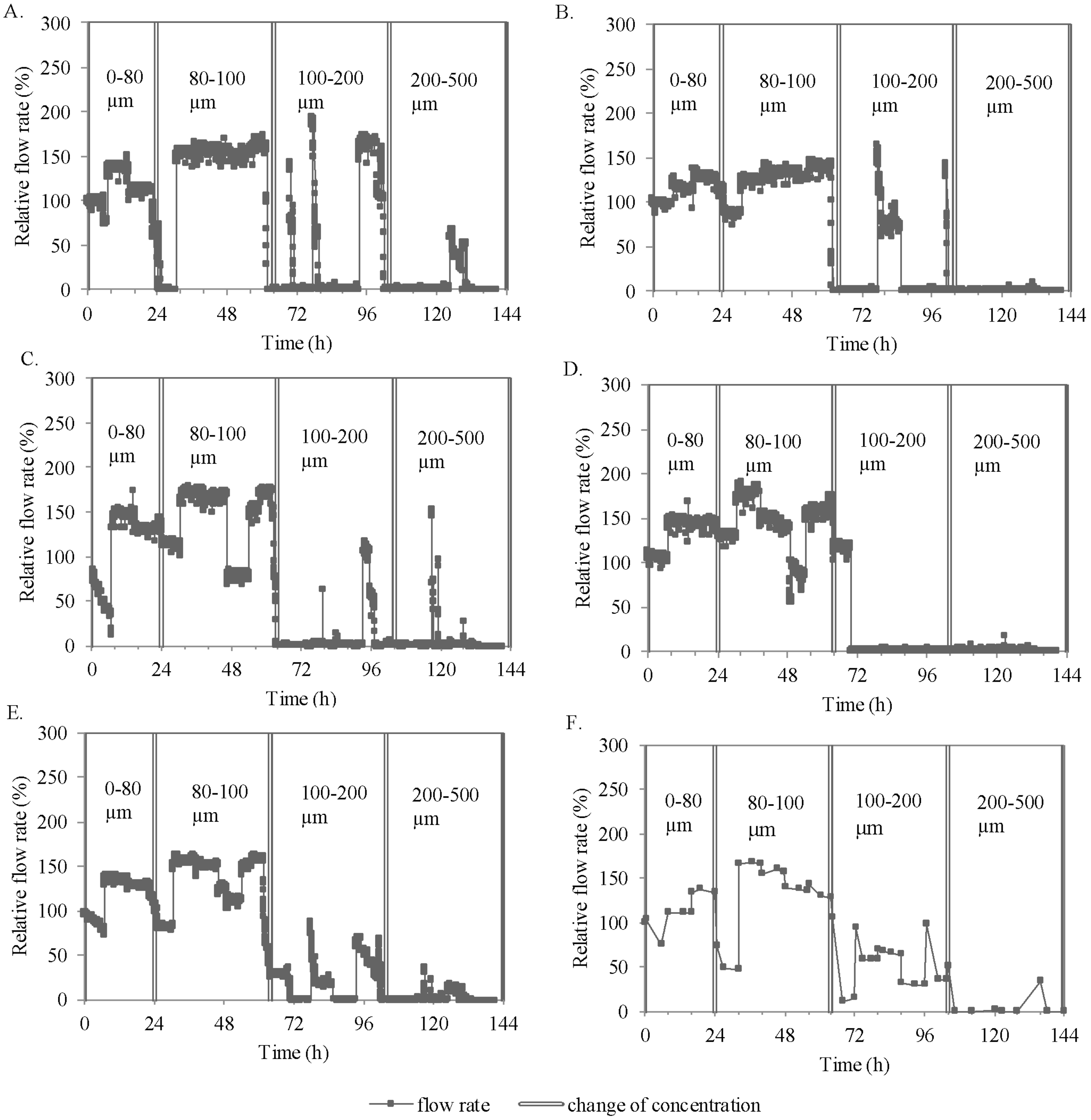


Figure 3. Flow rate profile of the emitters over time and concentration of suspended solids (automatic and manual data acquisition) (A) emitter q1; (B) emitter q2; (C) emitter q3; (D) emitter q4; (E) mean of the emitters with automatic data acquisition; (F) mean of the emitters with manual data acquisition

until this point in most of the time the flow rate was superior to the initial flow rate.

After 64 h of operation, when the concentration of suspended solids was 250 mg L^{-1} and with particles larger than 100 μm, the flow rate variations were more accentuated and in most cases resulted in values lower than the initial flow rate of the emitters (Figure 3).

Clogging does not always lead to reduction of flow rate, as reported by Carvalho et al. (2014), who evaluated different models of pressure-compensating drippers and observed reduction of flow rate for some models and increase for others, especially in the beginning of the clogging process. Liu & Huang (2009) evaluated pressure-compensating and non-pressure-compensating emitters using wastewater and observed reduction of flow rate for both. These differences in the behavior of the flow rate between the different models of emitters were possibly due to the differences in their internal architecture.

In most of the time, the emitters remained totally clogged, but some unclogged when the motor pump started and rapidly clogged again. Probably, the momentary unclogging occurred because of the accommodation of the dripper's membrane, which releases some particles that are trapped. However, over time, the particles accommodated inside the emitter rearranged and, combined with the fact that new particles enter the emitter, the clogging rapidly occurred again.

Besides the quantity of particles inside the emitter, it can be inferred that their size influenced the emitter operation dynamics. For all emitters, in most of the operation time, when the particles were smaller than 100 μm, the relative flow rate was higher than 100% (maximum relative flow rate of 182%) and, when eventually there was total clogging, as in the case of the emitter (q1) in Figure 3A (time from 24 to 32 h), after clogging the relative flow rate returned to values higher than 100%, indicating that many of the solid particles were released. On the other hand, from 64 h on, it no longer occurred, i.e., the particles were released from one part of the emitter, but remained retained in another.

Table 1 shows the relative times in which each emitter had the flow rate higher than the initial flow rate, i.e., the relative flow rate above 100%, in each stage of the emitter clogging test. On average, in the stages in which the diameter of the particles ranged from 0 to 80 μm and from 80 to 100 μm, the relative flow rate remained higher than 100% in approximately 81% of the time. On the other hand, for particle diameters from 100 to 200 μm, the relative flow rate remained above 100% in only 11.8% of the time and, for the last stage, the emitters were clogged in almost 100% of the time.

The increase in emitter flow rate due to the accumulation of solid particles indicates that they interfere with the movement of the membrane to regulate the flow rate of the emitter, since they accumulate mostly in the region between the membrane and the outlet of the emitter, as observed in Figure 4. Similar

Table 1. Relative time in which the emitters remained with flow rate higher than the initial flow rate

Particle diameter (μm)	Emitters				Mean
	q1	q2	q3	q4	
	Time (%)				
0-80	79.2	77.5	71.2	95.9	81.0
80-100	78.3	80.7	76.2	87.1	80.6
100-200	24.0	4.4	4.5	14.2	11.8
200-500	0.0	0.0	0.3	0.0	0.1

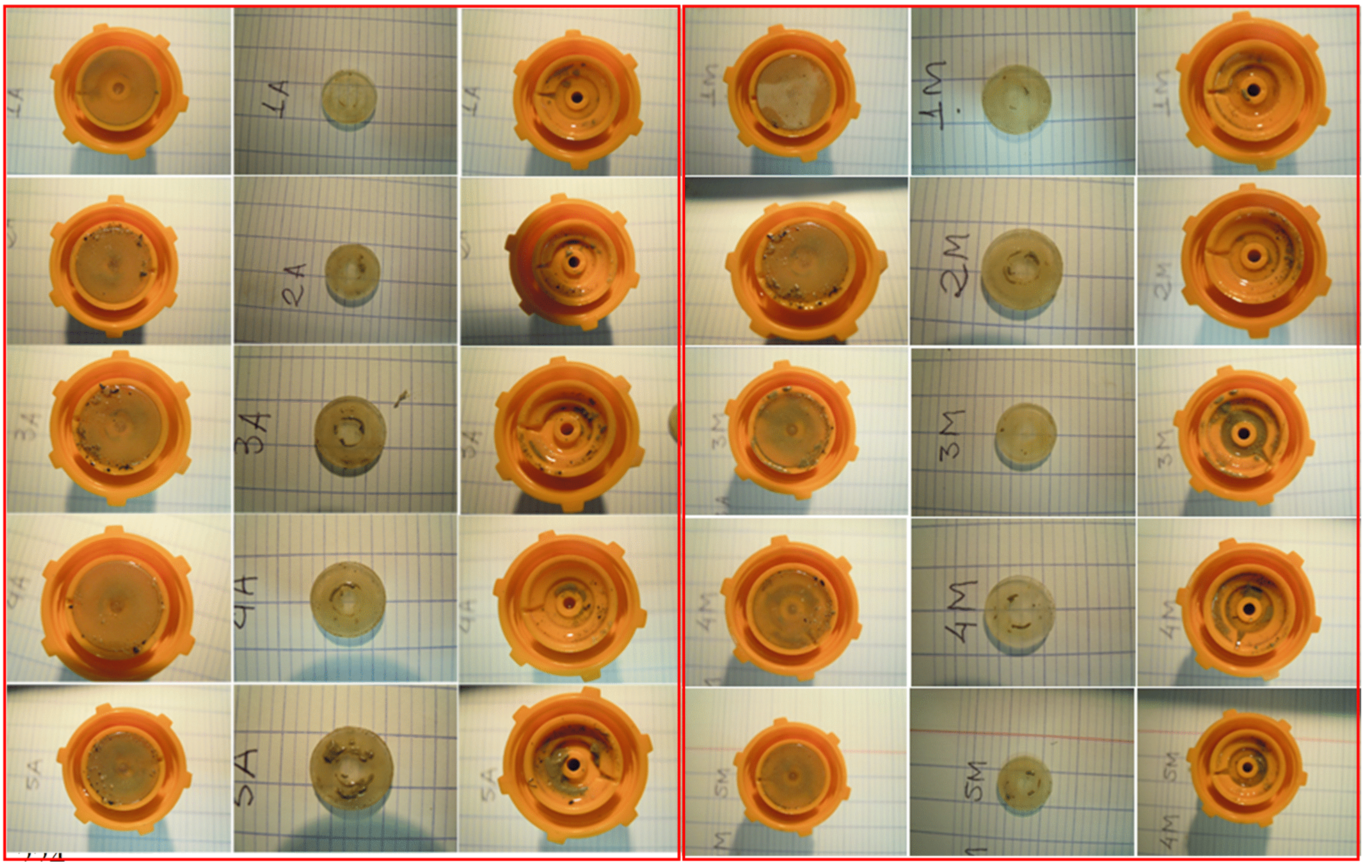


Figure 4. Location and distribution of solid particles inside the emitters (regulating chamber) after the clogging tests

results have been found by Gomes et al. (2013) and Carvalho et al. (2014) for some models of pressure-compensating drippers, a behavior attributed to the imbalance of their membrane.

Particles tend to accumulate in areas where lower flowing speeds occur; thus, it is necessary to characterize these areas to accurately predict emitter clogging (Qingsong et al., 2008; Gamri et al., 2014). However, when this region is completely filled with solid particles, the emitter becomes totally clogged. On the other hand, there is a small hole from the external to the internal part of the regulating chamber, which can be eventually clogged, preventing the passing of water (Figure 4). This same emitter was evaluated by Gamri et al. (2014) regarding the sensitivity to clogging by biological agents. The authors observed that the relative flow rate of the emitters decreased over the time of the tests, evidencing biofilm formation on the membrane.

Regarding the flow rate profile over time, the distribution of particles occurred randomly between the emitters and it was not possible to observe any trend, even when all emitters were totally clogged at the end of the test. Some emitters had particles located on the opposite side of the regulating chamber's entry, while in others the chamber was totally filled and some showed few particles inside the chamber, but, despite that, were totally clogged. This reinforces the idea that total clogging is caused by particles larger than the hole of the flow rate regulating chamber, and these particles are retained in this point, clogging the emitter.

Conclusions

1. The clogging effect on the flow rate of pressure-compensating emitters depends on the size of the solid particles and their concentration.

2. Clogging in pressure-compensating emitters can cause increase in flow rate for smaller particles and decrease in flow rate for larger particles, leading to total clogging.

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