# Predicting emitter sensitivity to clogging: a focus on the biological component

**Oliver, MD Moinul Hosain**
Centre for Water Management and Reuse (CWMR)
School of Natural and Built Environments
P2-50, University of South Australia, Mawson Lakes, SA 5095, Australia
Email: md_moinul.oliver@mymail.unisa.edu.au
M: +61416172020 | T: +61(08)83023093

**Hewa, Guna Aalnkarage**
Centre for Water Management and Reuse (CWMR)
School of Natural and Built Environments
P 2-36, University of South Australia, Mawson Lakes, SA 5095, Australia
Email: guna.hewa@unisa.edu.au | t: +61 (08) 8302 3094

**Pezzaniti, David**
Centre for Water Management and Reuse (CWMR)
School of Natural and Built Environments
University of South Australia Mawson Lakes, SA 5095, Australia |
Email: david.pezzaniti@unisa.edu.au | t: +61 (08) 8302 3652

**Abstract.** *A standard test for prediction of emitter sensitivity to clogging has not been developed yet. One conventional test procedure developed by the IRSTEA, France exists but it predicts emitter sensitivity to physical clogging only. This study was carried out to contribute towards developing a modified clogging test that would consider both physical and biological processes in emitters clogging. In this regard, a microirrigation test rig was constructed containing three types of pressure compensated emitters arranged in four replications inside an environmental chamber. Two tests were conducted, one according to the IRSTEA schedule; and the other according to a modified procedure developed to introduce biological load. The modified test included recycled water and was formed on the principle that biofilms should be allowed to develop and attain maturity during the test span. The results suggest that clogging due to biofilm growth is always a quicker process than clogging by physical particles alone. Emitters were quick to show signs of clogging in the modified test, while all the emitters managed to pass the IRSTEA test. In case of biofouling, particles were found to be trapped into the slimy bacterial biofilms at the emitter's section of entry. In physical clogging, however, particles were found to be passing through the emitter's section of entry, travelling along the labyrinths and settling at the end basin. In almost all the cases, the IRSTEA recommended filtration requirements were found to be overestimating the appropriate filter sizes.*

**Keywords.** Emitter clogging, sensitivity test, biological clogging, biofouling, clogging test, drippers, recycled water, wastewater irrigation.

## Backdrop

Performance of an unclogged emitter in a drip irrigation system is largely dependent on the design characteristics. Modern design tools have made it possible to design emitters with greater precision than ever. Once an emitter is made it needs to go through several processes of testing (Zhang et al., 2010) so as to ensure that its performance is up to the expected standard. The results from these tests and evaluations are usually posted with the product catalogue by the manufacturers, and irrigators completely rely on them. For

sustainable drip practice, it is crucial that this information is obtained by following an appropriate and, where possible, a standard procedure. In the emitter manufacturing industry, there are set standards and procedures to evaluate certain features of a product. One of such tests includes assessment of an emitter's anti-clogging performance. The test methods to assess this property of newly manufactured emitters are but few. A test method is known to be in the process of development (Mecham, 2012) by the ISO through its technical working groups (SC18\TC23\WG5) since 2003 (Nájera, 2013). This work is anticipated to be divided into two parts, one concerning a short duration test method, the second on a longer term basis. This work is contributed by a French organisation, IRSTEA (formerly Cemargref) which developed the first clogging test procedure in 1972 at the Center for Irrigation Equipment in Le Tholonet (Decroix, 1990). It was mainly developed to obtain practical recommendations for the selection of suitable filter sizes. The test method being developed by the ISO is also expected to concentrate on the physical clogging only. Both the IRSTEA and the ISO propose to use an increasing load of solid particles to be mixed with water so as to test the emitter sensitivity in their tests (Zhang et al., 2010). The performance of emitters is then to be compared with the reference characteristics established under clean water condition through four or eight stages of experimentation. Every stage is categorised by a specific amount of operating and non-operating hours. The time for non-operation is provided for the particles to settle in their flow path. The IRSTEA procedure has established five levels of sensitivities (Di Maiolo, 2012) based on the emitter's ability to withstand certain level of physical load in water (four stages of increasing dirtiness). Such categorisation of anti-clogging behaviour based on physical clogging alone is a serious miscalculation of the actual fouling process, especially under reclaimed water irrigation (RWI) where biofilms play a crucial role in clogging. Results and opinions from many long standing studies (Adin and Sacks, 1991; Camp, 1998; Nakayama and Bucks, 1991) including the more recent ones (Li et al., 2013; Puig-Bargués et al., 2010; Sánchez et al., 2014; Yan et al., 2009) also justify the importance of biological growth in the clogging process. Therefore, the fact that biofouling in RWI is far complex than physical blockage must be acknowledged and incorporated in any clogging test.

Biofouling is a popular term to describe emitter clogging when biological agents of are involved in the plugging process. The biomass that blocks the flow has been studied in recent years from multidisciplinary perspectives. Endeavours are known to have been carried out to expose the very fabric of the fouling biomass under irrigation schemes with recycled water ((Capra and Scicolone, 2005; Liu and Huang, 2009)), raw wastewater (Capra and Scicolone, 2007), storm water (Kunhikrishnan et al., 2012), groundwater (Jimenez, 2006; Pavelic et al., 2007) and even with human excreted urine (Zandee, 2012). From the available literature on this topic, it is possible to have a good understanding of the process of biofouling under specific conditions. A consensus (Oliver et al., 2012) seems to have been formed in the scientific community regarding the processes that govern formation of any clogging biomass. It has been well defined that physical (suspended solids), chemical (dissolved solids) and biological (microbes) quality of recycled water are the actual determinant of clogging (Lamm and Camp, 2007). The general agreement, however, is that neither of these parameters work in isolation to form the fouling material (Li et al., 2011). In fact, a sizable biomass emerges only when all three of them, at least two, work simultaneously (Lamm and Camp, 2007). It is also agreed that the biological component of recycled water is responsible for initiating the clogging phenomenon (Ravina et al., 1997). This means that physical parameters (suspended particles & chemical precipitates) may amplify the biomass once it is formed, but its initiation is definitely of microbial origin. This process of biomass development is often described by an adhesion-detachment-regrowth (ADR) model (Nicolella et al., 1997). To be able to fit into this model, suspended particles must need a place inside emitters where they can adhere to. In RWI schemes, biological growth provides this opportunity of assembly by secreting slimy gelatinous matter (Yan et al., 2009) known as biofilms. These microbial secretions are of slimy nature and attract many flowing particles on its periphery. Once a particle is attached to the exterior of biofilms,

further microbial development takes place around the newly captured particle. Once in the exterior, a particle quickly finds itself inside a three dimensional matrix of biofilms (Hermanowicz, 1999). Such propagation of biofilms causes the whole biomass to grow in volume. As the size increases, the hydraulic shear force of water also escalates until a part of the biomass is detached from the main body to travel further downstream in the system. After losing some of its parts, the biofilm biomass regrows again until a substantial biomass blocks the emitter flow. Therefore, generation of biofilm-biomass is a different process than plugging by particles alone. None of the existing anti-clogging performance evaluation procedure considers this factor in their tests. This paper reports the results of two experimental studies carried out to contribute towards developing an appropriate emitter clogging test focusing on the biological components.

## Test Principle

Incorporation of biological components in the clogging test is complex. The sources of complexity originate from the variable water quality and thermal condition although they can be managed if the test is contained in a controlled environmental. The main sources of complexity, however, come from the lack of information about the stages of growth and development of biofilms. For a specific water quality, the biofilm constituents were still not quantified until in a recent study, Oliver et al. (2014a) examined the reclaimed water biofilms at different stages of irrigation using biochemical techniques. The water used was treated with dissolved air flotation and filtration method followed by a onetime chlorination targeted for 1 ppm free chlorine. In an irrigation experiment for 760 hours with pressure compensating (PC) emitters, Oliver et al. (2014a) showed how cohesive bond of a clogging biomass changes with time. In their seven-stage experiment, the biofilms were obtained by destructive sampling from a large lot of emitters and examined for exo-polymeric substances (EPS) that form the biofilm matrix. The major EPS constituents i.e., exo-polymeric protein and polysaccharides were quantified at different stages of irrigation.

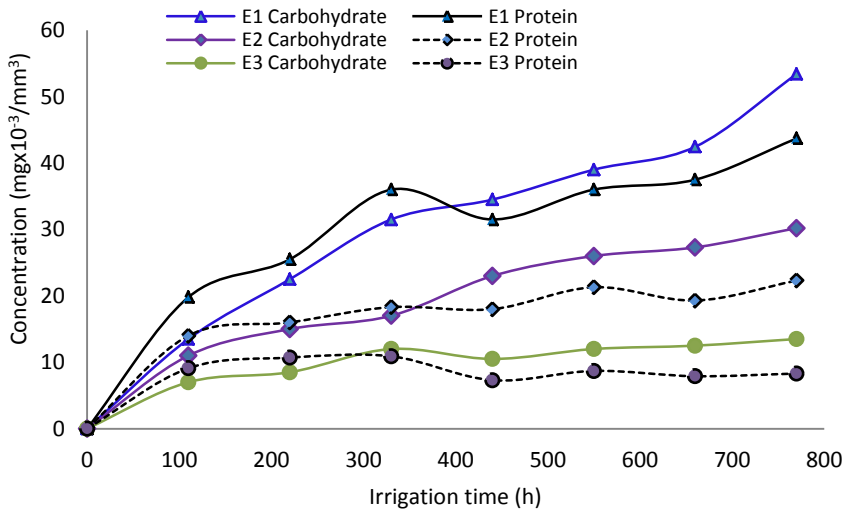



Figure 1. Changes in the exo-polymeric content of recycled water biofilms with irrigation time; after Oliver et al. (2014a)

According to Oliver et al. (2014a), the onset of the recession of protein content (Fig. 1) in the EPS is an indication that the biofilms have attained maturity. It was also shown that biofilms take at least 220 hours of irrigation time to establish themselves to maturity when a specific irrigation pattern (2 days on @8 h/day, the next 24 h off) is followed. The formulation of a new clogging test described in this paper is based on these research outcomes from Oliver et al. (2014a, and b).

### The Test Rig

If the biological components are to be incorporated in the clogging test, the biofilms must be allowed to grow during the test and reach at least the early stage of maturity. Based on this principle (Oliver et al., 2014a), the new test procedure was decided to run for a period of 44 days which is fairly a long term procedure. A DI system was built for this purpose inside a closed environmental chamber where desired temperature could be achieved. All the components were compatible with the ISO standard 9261 (ISO, 2004). The feeding sub-main of the DI was connected to a pump which delivered water into the system from an attached 400 L tank. Three types of commercially available PC emitters; each with different discharge, (emitter E1 with 1.6 l/h, E2 with 2 l/h and E3 with 2.3 l/h) were used in the test. A total of 12 laterals were attached to the sub-main containing a mixture of all three emitter types in four replications (Fig. 2). There were nine emitters (30 cm spacing) in each lateral to be assessed for clogging which would yield a statistically sound data of 36 samples for each emitter type. The emitters would discharge water into the base of the chamber which ultimately drains into the water tank through a return passage (Fig. 2)

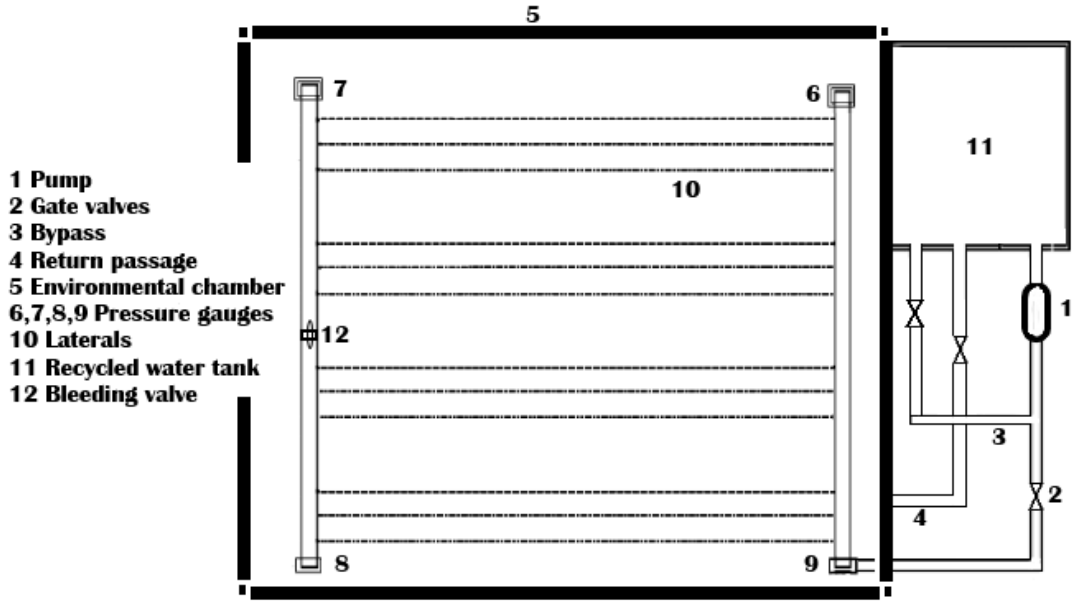



Figure 2. Experimental clogging test rig for the clogging test

## Formulation of the Test

The modified test was divided into four active stages of irrigation. Each stage (11 days) was designed to provide a total of 56 hours of irrigation by following a schedule of 8 hours on and 16 hours off per day for two consecutive days; and the next day (24 hours) off. During the entire test period, this schedule would provide a total active irrigation of 224 hours (Table 1) allowing the biofilms to reach their early stage of maturity. Class A reclaimed water (heterotrophic bacterial count 0.003 to 1.22 × $10^6$ CFU/100 mL) from the Bolivar wastewater treatment plant in South Australia was used for irrigation. The other water quality data can be obtained from Oliver et al. (2014a). This water comes with less than 1 ppm of suspended solid which is ideal for this kind of test. At the beginning of the first stage, 75 mg/l of suspended solids (0-25 µm size range) was added into the water and irrigation was given according to the schedule. This threshold of 75 mg/l is only valid when the above mentioned scheduled is followed together with Class A recycled water. The second stage was designed to reflect an increasing level of dirtiness in the water. Therefore, another 75 mg/l of suspended solid containing larger particles (25-50 µm) was added into the water. During

each of the next two stages, the same amount of suspended loads was added containing different particle sizes.

Table 1. Modified clogging test encouraging biological growth (experiment 1)

| **Stages** | **Stage 1** | **Stage 2** | **Stage 3** | **Stage 4** |
|---|---|---|---|---|
| Particle load, mg/l | 75 | 75 | 75 | 75 |
| Particle sizes, µm | 0-25 | 25-50 | 50-150 | 150-250 |
| Day 1 | Operation* | Operation | Operation | Operation |
| Day 2 | Operation | Operation | Operation | Operation |
| *Day 3* | *Non-OP* ^ | *Non-OP* | *Non-OP* | *Non-OP* |
| Day 4 | Operation | Operation | Operation | Operation |
| Day 5 | Operation | Operation | Operation | Operation |
| *Day 6* | *Non-OP* | *Non-OP* | *Non-OP* | *Non-OP* |
| Day 7 | Operation | Operation | Operation | Operation |
| Day 8 | Operation | Operation | Operation | Operation |
| *Day 9* | *Non-OP* | *Non-OP* | *Non-OP* | *Non-OP* |
| Day 10 | Operation | Operation | Operation | Operation |
| *Day 11* | *Non-OP* | *Non-OP* | *Non-OP* | *Non-OP* |
| | TEST | TEST | TEST | TEST |
| Irrigation time | 56 hours | 56 hours | 56 hours | 56 hours |
| Time of Non-OP | 208 hours | 208 hours | 208 hours | 208 hours |
| Total irrigation time | 224 hours | | | |
| Total time of Non-OP | 832 hours | | | |
| Total experimental time | 1056 hours † | | | |

Table 2. IRSTEA clogging test schedule (experiment 2)

| **Stages** | **Stage 1** | **Stage 2** | **Stage 3** | **Stage 4** |
|---|---|---|---|---|
| Particle load, mg/l | 125 | 125 | 125 | 125 |
| Particle sizes, µm | 0-80 | 80-100 | 100 - 200 | 200 – 500 |
| Day 1 | Operation* | Operation | Operation | Operation |
| Day 2 | Operation | Operation | Operation | Operation |
| Day 3 | Operation | Operation | Operation | Operation |
| Day 4 | Operation | Operation | Operation | Operation |
| Day 5 | Operation | Operation | Operation | Operation |
| *Day 6* | *Non-OP* ^ | *Non-OP* | *Non-OP* | *Non-OP* |
| *Day 7* | *Non-OP* | *Non-OP* | *Non-OP* | *Non-OP* |
| Irrigation time | 40 hours | 40 hours | 40 hours | 40 hours |
| Time of Non-OP | 128 hours | 128 hours | 128 hours | 128 hours |
| | TEST | TEST | TEST | TEST |
| Total irrigation time | 160 hours | | | |
| Total time of Non-OP | 512 hours | | | |
| Total experimental time | 672 hours †† | | | |

* Operation means 8 hours continuous irrigation and 16 hours OFF
^ Non-OP means complete shutoff of the system for 24 hours
† Total experimental time under 28±3 $^{O}$C temperature
†† Total experimental time under 23±3 $^{O}$C temperature

The particle size range in the last stage was selected to be 150-250 µm according to the results of Oliver et al. (2014b) who showed that the interior of the initial biofilm biomass is exclusively built by particles less than 30 µm in size with a standard deviation of 15 µm.

Some larger particles (>150 µm) were discovered at the periphery of biofilms but was not significant in amount. Similar results were also reported by Niu et al. (2013) who found that smaller particles (31-38 µm) actually forms the interior of the clogging biomass. Therefore, the test procedure was designed to provide an opportunity for circumferential establishment of the larger particles (up to 250 µm) while encouraging the central existence of the smaller particles (0-50 µm) in the biomass. All the particles were soil mineral aggregates dried in the oven at 105 $^{O}$C for 24 hours and screen to their sizes before being added into the test water.

**Experiment 1 – Modified Test**

The schedule for the modified test is described in Table 1. At the beginning of each stage the suspended solid was thoroughly mixed with the reclaimed water and the mixing continued while the system was under operation. Inside the test chamber, a temperature of 28±3 $^{O}$C was set and maintained throughout the experiment. Selection of this thermal regime was done according to the results of a series of experiments conducted by the authors (Oliver et al. 2014a and b) under varying soil thermal conditions. The PC emitters were found to be showing their worst performances at the range of 24-31 $^{O}$C. In the clogging test, the hypothetical target was to expose the test samples to the worst possible condition that an emitter faces in the field. This test was, therefore, run at a temperature of 28±3 $^{O}$C to achieve the worst clogging scenario. The authors can be contacted for additional unpublished data on this topic. A throttle was added at the end-of-line sub-main to achieve a minimum velocity (ranges from 30-50 cm/s) in the laterals so as to prevent settlement of particles near the dead end.

**Experiment 2 – IRSTEA Test**

In order to compare the results of the modified test, the IRSTEA clogging test (Di Maiolo, 2012) was also conducted under the same arrangement shown in Fig. 2 and with the similar set of emitters. However, for the IRSTEA clogging test (Table 2), the thermal regime was maintained at 23±3 $^{O}$C. It involved standard clean water as specified by the ISO 9261 with less than 2 mg/l of total suspended matters. The minimum velocity maintained in the laterals was 50 cm/s because of the higher suspended load.

Both the tests were conducted under a pressure of 100 kPa and the pressure variation was contained within 1% of the design pressure. The base of the environmental chamber was regularly cleaned so that particles do not settle on it and thoroughly mixes with the running water in the tank. At the end of each experiment, the throttle was used for gravitational drainage of the laterals. Emitter flow rates were measured every day during the first stage and once at the end of each subsequent stage for a period of 5 minutes using graduated plastic cylinders according to ISO (2004). The degree of clogging due to physical/biophysical substances was then assessed by comparing the emitter flow at any stage with the reference discharge of that particular emitter type. The reference characteristics were established according to the ISO 9261 procedural clause of 9.1, 9.2 and 9.8 (ISO, 2004).

## Evaluation of the Result

Reduction of emitter flow ($q_{fr}$) at any stage was used as the prime measure to assess the effect of clogging. It was calculated as

$$q_{fr} = 100 \times (1 - q_r) \quad (1)$$

Here, $q_r$ is the relative discharge of an emitter. It is defined as the ratio of average emitter flow at any time ($q_a$) to the emitter's reference flow rate ($q_d$):

$$q_r = \frac{q_a}{qd} \quad (2)$$

The average flow rate ($q_a$) for a particular emitter type was obtained by averaging the individual flow rates ($q_i$) of emitters from each lateral.

$$q_a = \frac{1}{n} \sum_{i=1}^{i=n} q_i \quad (3)$$

Equation 3 was also used to calculate the average of the lower quarter flow rates ($q_{1/4}$) from each lateral. Interpretation of the results from IRSTEA test was carried out following the existing recommendations (Decroix, 1990) presented in Table 3.

Table 3. Interpretation of results from the clogging test of IRSTEA

| Test Results | Sensitivity Level | Recommended Filtration Size |
|---|---|---|
| sample did not pass the 1st stage | Ultra-Sensitive | Below 80 µm |
| sample did not pass the 2nd stage | Very Sensitive | 80 µm |
| sample did not pass the 3rd stage | Sensitive | 100 µm |
| sample did not pass the 4th stage | Little Sensitive | 125 µm |
| sample passed all the stages | Very Little Sensitive | 150 µm |

## Results and Discussion

The results of both the modified and the IRSTEA test procedure came into having considerable contrast among them. Emitters (E1) with low flow rate (1.6 l/h) were the quickest to accumulate considerable clogging biomass which resulted in significant reduction of flow. IRSTEA suggests that any reduction of 30% or more at any stage is a sign of sensitivity to clogging. As can be seen from Fig. 3a, emitter E1 experienced a 22% reduction of flow and therefore passing the fourth stage of the IRSTEA test. The last concentration of suspended load that emitter E1 withstood was 500 mg/l containing 0-500 µm particle sizes. According to Table 3, this emitter would be marked as “very little sensitive to clogging” and 150 µm filter size would be recommended. However, the results from experiment 1 show that 150 µm filter size could be insufficient for E1 if reclaimed water is used. In the modified test, emitter E1 did not pass (Fig. 3a) the third stage (0-150 µm) although the concentration of suspended solid was much lower (225 mg/l) compared to the same stage of the IRSTEA test. This means biomass accumulation was much quicker in the modified test although the dose of suspended solid was only 75 mg/l/stage compared to 125 mg/l/stage of the IRSTEA test. According to Table 1, our interpretation is that a 100 µm filter size would be more appropriate for this type of emitter and this size will be able to address the effect of biological intervention in the fouling process.

On the other hand, emitter E2 (2 l/h) passed all the stages of IRSTEA test (20% reduction of flow) but failed to pass the last stage of the modified test. It’s flow rate diminished by almost 32% by the end of 224 hours of irrigation. According to Table 1, a filtration size of 125 µm seems more appropriate for this type of emitter compared to 150 µm as recommended (Table 3) by the IRSTEA. Fig. 3 also shows that initial cogging was almost similar in both the tests for all emitter types (≈10% reduction of flow). Nonetheless, as irrigation time progressed, the difference between the two tests became evident, especially after stage two. In general, emitters in the modified test involving reclaimed water experienced more flow reduction than those in the conventional IRSTEA test with clean water. This means that clogging is more acute if biological intervention occurs. A possible reason is that

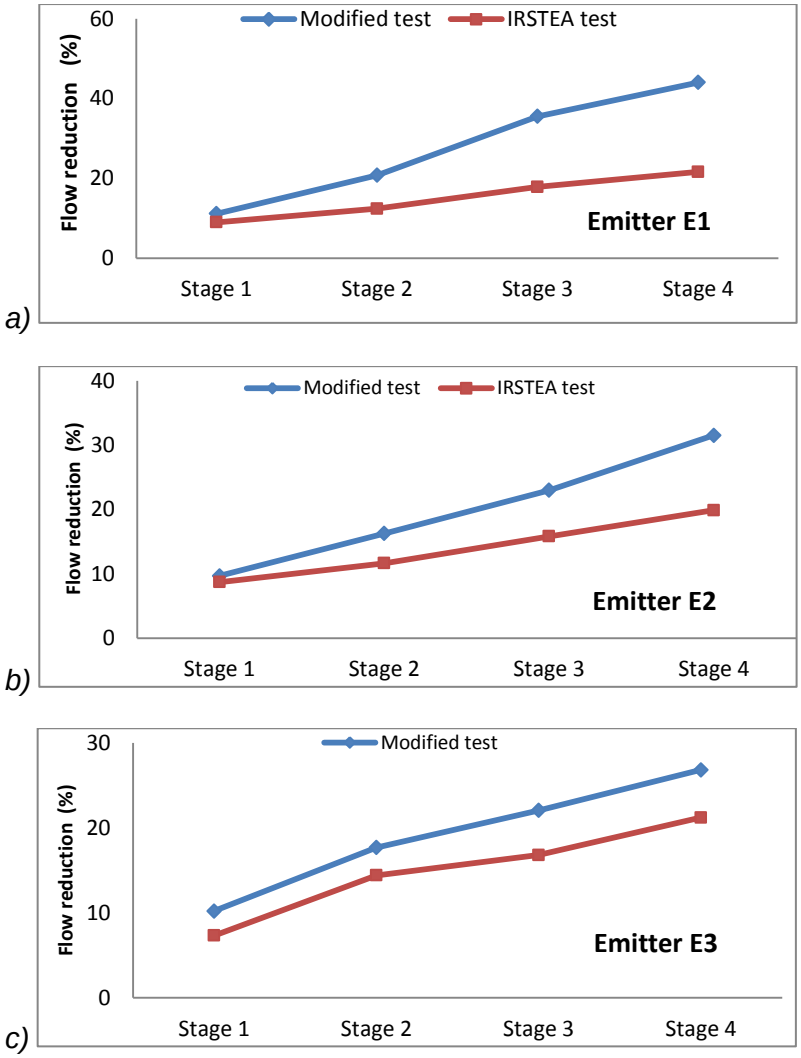



Figure 3. Reduction of emitter flow rates with the progression of irrigation stages in two different clogging tests for *a)* emitter E1; *b)* emitter E2, and c) emitter E3

Emitter E1 (1.6 l/h) and E2 (2 l/h) were comparatively smaller emitter sizes and both of them failed to pass the modified test although they were successful in the IRSTEA test (Table 4). The other specimen tested in this study was emitter E3 which had slightly larger flow rate (2.3 l/h) than E1 and E2. Interestingly, E3 managed to pass both the tests and the reduction of flow was limited to 30% in all cases.

Table 4. Flow rate of emitters at different stages of the clogging tests

| Procedure followed | | Stage 1 | | Stage 2 | | Stage 3 | | Stage 4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | $q_a$ $(l/h)$ | $q_r$ | $q_a$ $(l/h)$ | $q_r$ | $q_a$ $(l/h)$ | $q_r$ | $q_a$ $(l/h)$ | $q_r$ |
| **Modified Test** | Emitter E1 | 1.42 | 0.89 | 1.27 | 0.79 | ***1.03*** | ***0.64*** | 0.90 | 0.56 |
| | Emitter E2 | 1.81 | 0.90 | 1.67 | 0.84 | 1.54 | 0.77 | ***1.37*** | ***0.68*** |
| | Emitter E3 | 2.07 | 0.90 | 1.89 | 0.82 | 1.79 | 0.78 | 1.68 | 0.73 |
| **IRSTEA Test** | Emitter E1 | 1.46 | 0.91 | 1.40 | 0.88 | 1.31 | 0.82 | 1.25 | 0.78 |
| | Emitter E2 | 1.83 | 0.91 | 1.77 | 0.88 | 1.68 | 0.84 | 1.60 | 0.80 |
| | Emitter E3 | 2.13 | 0.93 | 1.97 | 0.86 | 1.91 | 0.83 | 1.81 | 0.79 |

*Note: values in bold and italics are the points of failure i.e., $q_r$< 0.7*

The relative discharge for E3 in the final stage stood out to be 73% in the modified test and 79% for IRSTEA test (Table 4). Although the performance was similar, the test without reclaimed water (IRSTEA) showed low biomass accumulation than the one with it (modified test). In all the cases where emitters could not pass the modified test, the IRSTEA recommended filtration size was found to be greater than what was obtained through the modified test. This means an emitter branded as 'not sensitive' by the existing test procedure may actually be sensitive to clogging if used in conjunction with poor quality water. It is understood from the available documents that the ISO is going to recommend a new flow reduction threshold to assess an emitter's sensitivity to clogging. The new standard will take 25% flow reduction as a sign of sensitivity to clogging. If this value is applied to Table 4, emitter E2 and E3 along with emitter E1 will fail to pass the modified test. Emitter E1 will nonetheless fail at stage three and the remaining emitters will fail at stage four. However, all of them will be passing the IRSTEA test indicating that the sensitivity of emitters is being underestimated in the existing procedure. In almost all the cases, the IRSTEA clogging test seems to be overestimating (Table 4) the appropriate filter size.

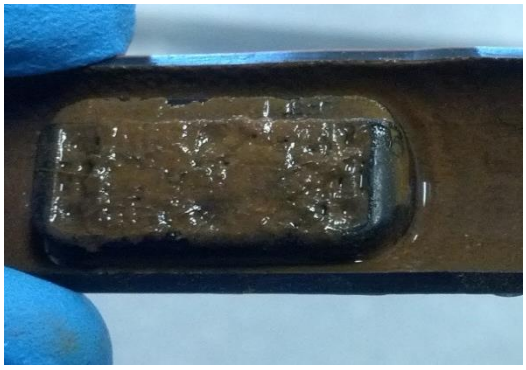
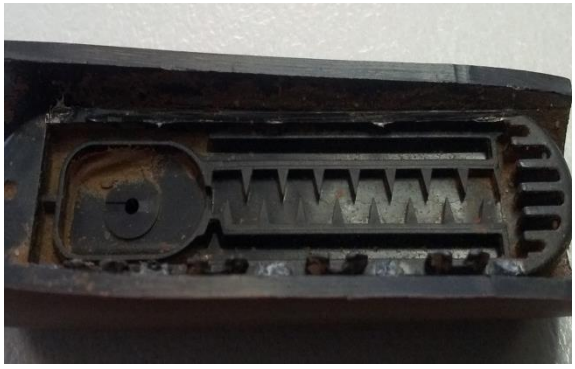
*a)*  *b)* 

Figure 4. *a)* biomass development and average particle size trapped in E1 during the modified test b) accumulation of physical clogging material in emitter E2 during IRSTEA test

In the modified test samples, the slimy fouling biomass was found to be sprawling over the section of entry (Fig. 4a) and obstructing the flow. However, in the IRSTEA test, the physical clogging materials were found to have passed through the section of entry; travelling along the labyrinths and settling at the edge of the detention basin (Fig. 4b). No slimy material was observed in the IRSTEA test samples. This fundamental difference between the biofouling process and the physical clogging must be acknowledged in any clogging test. The overall experience from this study suggests that incorporation of biological component in the clogging test can help obtain more accurate information about the filtration requirement in drip irrigation. This study was, therefore, carried out to contribute towards developing a universal clogging test in the near future.

## Conclusion

Testing emitters for their sensitivity to clogging is very important because users rely on these test results to decide which emitter is best for their condition. This paper presents the results obtained from two experimental clogging tests. One test was carried out according to the existing procedure of IRSTEA which predicts emitter sensitivity to physical clogging only. The other clogging test was carried out according to the procedure proposed by the authors

from their previous studies where recycled water is used to encourage biological growth. It was found that the filtration size obtained through the clogging test of IRSTEA may not be appropriate if recycled water is used. The dose of suspended solid added into the water during the four-stage experiments was much lower (75 mg/l) in the modified test but quite high (125 mg/l) in the IRSTEA test procedure. Nevertheless, emitters in the modified test showed signs of clogging much earlier than those in the IRSTEA module. Three types of PC emitters having different discharges (1.6 l/h, 2 l/h, 2.3 l/h) were tested. Interestingly, all the emitters managed to pass the existing IRSTEA test but at least two of them failed to pass the modified test. This suggests that if biological growth is not encouraged in the clogging test, emitter sensitivity cannot be predicted property. The modified test is based on the idea that biofilms are able to establish and attain early maturity during 220 hours of irrigation time if a particular schedule is followed. Since biofilm growth largely depends on the water quality, this study recommends that some benchmark experiments must be carried out to establish the quantitative relationship between water quality and biofilm growth. Only then, a comprehensive clogging test can be developed for prediction of emitter sensitivity to all sorts of clogging agents.

**Acknowledgement**

The authors would like to thank Mr Tim Golding, Laboratory Coordinator at the Centre for Water Management and Re-use (CWMR) in the University of South Australia and his team for providing necessary space, equipments and technical support in building the experimental test rig.

## References

Adin, A., and M. Sacks. 1991. Dripper-clogging factors in wastewater irrigation. J. Irrig. Drain. Eng. 117:813-826.

Camp, C. R. 1998. Subsurface drip irrigation: A review. Trans ASAE 41:1353-1367.

Capra, A., and B. Scicolone. 2005. Assessing dripper clogging and filtering performance using municipal wastewater. Irrig. Drain. 54:S71-S79.

Capra, A., and B. Scicolone. 2007. Recycling of poor quality urban wastewater by drip irrigation systems. J. Cleaner Prod. 15:1529-1534

Decroix, M. 1990. Testing micro-irrigation emitters in France. Plasticulture. 4:13-22.

Di Maiolo, P. 2012. Tests conducted on irrigation dealers and distributors to determine the manufacturer uniformity, flow pressure relationship and sensitivity to physical obstruction, Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, France. Also at http://www.irstea.fr/sites/default/files/ckfinder /userfiles/files/procedure essais micro irrigation.pdf. pp. 3 -6.

Hermanowicz, S.W. 1999. Two-dimensional simulations of biofilm development: effects of external environmental conditions. Water Sc. Tech. 39:107-114.

ISO. 2004. Agricultural irrigation equipment-emitters and emitting pipe-specifications and test methods, ISO 9261:2004 (E), Geneva.

Jimenez, B. 2006. Special feature on groundwater management and policy: irrigation in developing countries using wastewater. Int. Rev. Env. Str. 6:229-250.

Kunhikrishnan, A., N.S. Bolan, K. Müller, S. Laurenson, R. Naidu, and W. Kim. 2012. The influence of wastewater irrigation on the transformation and bioavailability of heavy metal(loid)s in soil. Adv Agron. 115:215-297.

Lamm, F.R., and R.C. Camp. 2007. Subsurface drip irrigation. Chapter 13 in Microirrigation for Crop Production: Design, Operation and Management, pp. 473-551. Amsterdam.

Li, Y., Y. Liu, G. Li, T. Xu, H. Liu, S. Ren, D. Yan, and P. Yang. 2011. Surface topographic characteristics of suspended particulates in reclaimed wastewater and effects on clogging in labyrinth drip irrigation emitters. Irrig. Sc. 30:43-56.

Li, Y., B. Zhou, Y. Liu, Y. Jiang, Y. Pei, and Z. Shi. 2013. Preliminary surface topographical characteristics of biofilms attached on drip irrigation emitters using reclaimed water. Irrig. Sc. 31:557-574

Liu, H., and G. Huang. 2009. Laboratory experiment on drip emitter clogging with fresh water and treated sewage effluent. Agric. Water Manage. 96:745-756.

Mecham, B. 2012. Agricultural Irrigation Standards Update. A report presented at the 31st meeting of the secretariat of ISO/TC23/SC18. IA Irrigation Show 2012, Orlando, FL.

Nájera, Y. 2013. Proceedings of the 32nd meeting of the secretariat of ISO/TC23/SC18. June 13-14, 2013, Naucalpan, Mexico.

Nakayama, F.S., and D.A. Bucks. 1991. Water-quality in drip/trickle irrigation-a review. Irrig. Sc. 12:187-192.

Nicolella, C., S. Chiarle, R. Di Felice, and M. Rovatti. 1997. Mechanisms of biofilm detachment in fluidized bed reactors. Water Sc. Tech. 36:229-235.

Niu, W., L. Liu, and X. Chen. 2013. Influence of fine particle size and concentration on the clogging of labyrinth emitters. Irrig. Sc. 31:545-555.

Oliver, M.M.H., G.A. Hewa, and D. Pezzaniti. 2014a. Bio-fouling of subsurface type drip emitters applying reclaimed water under medium soil thermal variation. Agric. Water Manage. 133:12-23.

Oliver, M. M. H., D. Pezzaniti and G. A. Hewa 2014b. Subsurface emitter clogging in a reclaimed water irrigation scheme with controlled suspended solid. Int. J. Sust. Dev. Plan. Manuscript accepted for publication, Manuscript No. SDP#442.

Oliver, M.M.H., G. A. Hewa and D. Pezzaniti 2012. Subsurface drip irrigation with reclaimed water: issues we must think now. WIT Trans. Ecol. Env. 168:203-212.

Pavelic, P., P.J. Dillon, K.E. Barry, J.L. Vanderzalm, R.L. Correll, and S.M. Rinck-Pfeiffer. 2007. Water quality effects on clogging rates during reclaimed water ASR in a carbonate aquifer. J. Hydrol. 334:1-16.

Puig-Bargués, J., G. Arbat, M. Elbana, M. Duran-Ros, J. Barragán, F.R.de Cartagena, and F.R. Lamm. 2010. Effect of flushing frequency on emitter clogging in microirrigation with effluents. Agric. Water Manage. 97:883-891.

Ravina, I., E. Paz, Z. Sofer, A. Marm, A. Schischa, G. Sagi, Z. Yechialy, and Y. Lev. 1997. Control of clogging in drip irrigation with stored treated municipal sewage effluent. Agric. Water Manage. 33:127-137.

Sánchez, O., I. Ferrera, L. Garrido, M.M. Gómez-Ramos, A.R. Fernández-Alba, and J. Mas. 2014. Prevalence of potentially thermophilic microorganisms in biofilms from greenhouse-enclosed drip irrigation systems. Arch. Microbiol. 196:219-226.

Yan, D., Z. Bai, M. Rowan, L. Gu, R. Shumei, and P. Yang. 2009. Biofilm structure and its influence on clogging in drip irrigation emitters distributing reclaimed wastewater. J. Env. Sc. 21:834-841.

Zandee, M. 2012. Risk of clogging of drip-line emitters during urine fertilization through drip irrigation equipment. Report from Swiss Federal Institute of Aquatic Science and Technology. Dübendorf, Switzerland. 6 pp.

Zhang, J., W. Zhao, Y. Tang, and B. Lu. 2010. Anti-clogging performance evaluation and parameterized design of emitters with labyrinth channels. Comp. Electron. Agric. 74:59-65.