Agricultural Water Management 133 (2014) 12–23

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Bio-fouling of subsurface type drip emitters applying reclaimed water under medium soil thermal variation

M.M.H. Oliver[a,b,*], G.A. Hewa[a,b,1], D. Pezzaniti[a,b,2]

[a] SA Water Centre for Water Management and Reuse (CWMR), University of South Australia, Mawson Lakes, SA 5095, Australia[3]
[b] School of Natural and Built Environments, University of South Australia, Mawson Lakes, SA 5095, Australia[4]

ARTICLE INFO

Article history:
Received 13 August 2013
Accepted 21 October 2013
Available online 13 November 2013

Keywords:
Emitter clogging
Bio-fouling
Drip irrigation
Reclaimed water
Suspended solids
Exo-polymeric substance (EPS)

ABSTRACT

Emitter clogging is very common in reclaimed water drip irrigation schemes. The clogging biomass appears due to bio-fouling of the emitters' flow paths. The fouling biomass is a composite of microbial secretions and suspended particles both of which originate from the reclaimed water. This study investigates the process of bio-fouling in three types of pressure compensated (PC) emitters applying reclaimed water in South Australia. An experimental drip irrigation (DI) system containing subsurface type emitters was built and operated under a specific thermal range (16–24 °C). A constant load of suspended solid in the reclaimed water was maintained throughout the experiment. Four ranges of organic particles (up to 300 μm) were applied as the suspended load. The study identified series of definable web structures in the matrix of premature biofilms. The majority of the particles that contributed in building the interior of the biofilm were smaller than 30 μm. The protein–carbohydrate ratio (>1) in the exo-polymeric substance (EPS) was recommended as a tool to predict the best period for flushing. Weaker hydrodynamic forces were observed in the low flow emitters (<2 L/h) which were also very sensitive to clogging. On the contrary, emitters with higher flow rate experienced much stronger shear forces in the system and showed better anti-clogging performances throughout the experiment.

1. Introduction

Pressurised microirrigation is one of the most efficient irrigation techniques. Subsurface drip irrigation (SDI) is particularly well known for its ability to irrigate specific areas of a root zone. It reduces surface evaporation by targeting delivery of water directly into the subsurface soil. In reclaimed water irrigation (RWI) schemes, this technology is frequently being advised (Ayers and Westcot, 1994; ANZECC, 2000; FAO, 2003). Although SDI limits human exposure to the effluents (DHS and EPA, 1999) and offers precision watering (Lamm and Camp, 2007; Puig-Bargués et al., 2010), it does exhibit problems such as bio-fouling of emitters. By definition, fouling refers to a gradual process of microbial development inside the drip laterals; mainly in the emitter labyrinth. Coupled with physiochemical elements of reclaimed water the biomass grows in volume (Nakayama and Bucks, 1991) and blocks the flow of water through the labyrinths. Eventually, the emitter flow rate diminishes over time and the service life of SDI system shortens.

The biomass matrix in the emitter flow path has been studied in recent years using reclaimed water (Adin and Sacks, 1991; Capra and Scicolone, 2005; Liu and Huang, 2009; Yan et al., 2009; Li et al., 2011a,b) and even raw wastewater (Capra and Scicolone, 2007). These studies suggest that preventive measures against clogging have been relatively ineffective due to the complexities involved in the fouling process. Unlike biological growth in water distribution lines, emitter clogging is a factorial of water quality (Ravina et al., 1997; Trooien et al., 2000; Taylor et al., 2006), microflow regimes (Qingsong et al., 2008), labyrinth designs (Zhang et al., 2010), and irrigation practices. The prominence of these factors in relation to clogging has been widely debated in the scientific community (Capra and Scicolone, 2005; Yan et al., 2009). Multidisciplinary approaches (Qingsong et al., 2008; Zhang et al., 2010; Li et al., 2011a,b) have suggested that designing emitters with turbulent flow regime offer some degree of protection against

* Corresponding author at: SA Water Centre for Water Management and Reuse (CWMR), P2-50, School of Natural and Built Environments, University of South Australia, Mawson Lakes, SA 5095, Australia. Tel.: +61 08 8302 3093; fax: +61 08 8302 3386; mobile: +61 4 16 17 20 20.
E-mail addresses: md_moinul.oliver@mymail.unisa.edu.au, oliver@bsmrau.edu.bd (M.M.H. Oliver), guna.hewa@unisa.edu.au (G.A. Hewa), david.pezzaniti@unisa.edu.au (D. Pezzaniti).
1 Address: SA Water Centre for Water Management and Reuse (CWMR), School of Natural and Built Environments, P2-36, University of South Australia, Mawson Lakes, SA 5095, Australia. Tel: +61 08 8302 3094.
2 Address: SA Water Centre for Water Management and Reuse (CWMR), School of Natural and Built Environments, University of South Australia, Mawson Lakes, SA 5095, Australia. Tel.: +61 08 8302 3652.
3 http://www.unisa.edu.au/Research/CWMR/.
4 www.unisa.edu.au/nbe.

0378-3774/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2013.10.014

clogging. A more recent study by Li et al. (2013) has also claimed that turbulent models of emitters have effective anti-clogging mechanism. Computational fluid dynamics (CFD) modelling has been applied to optimise the design criteria of turbulent emitters in recent years (Zhang et al., 2010; Li et al., 2013). As a result, most of the commercially available emitters are now turbulent (Zhang et al., 2010). Nevertheless, other factors such as water quality and varying thermal conditions of soil are still aiding the process of bio-fouling in subsurface emitters.

Several studies have shown that the benefits of reclaimed water in SDI may be compromised due to emitter clogging (Bucks et al., 1979; Camp, 1998; Puig-Bargués et al., 2005) though it may fulfil the requirements for other purposes. Among the water quality requirements in RWI schemes, the most important of all is the microbial quality which is responsible for biofilm development in emitters (Capra and Scicolone, 2004; Duran-Ros et al., 2008). In most cases, bacteria are found in biofilms (Lemon et al., 2008) though the presence of other microbes has also been identified. Biofilm is attributed to the growth of exo-polymeric substances (EPS) secreted from microbes, predominantly bacteria. This polymer is often resistant to disinfectants because of their very adaptive nature (Kim et al., 2008). Being slimy and gelatinous, it is able to accrue suspended particles of different sizes resulting in growth of biomass which ultimately blocks the emitter flow. Additionally, reclaimed water often comes with high organic content along with elevated salinity level. At suitable temperature range, the salts in water can potentially interact with each other in the colloidal interface (Brown et al., 1997). The resulting chemical reaction causes flocs to appear in the irrigation water which also contributes to emitter clogging.

The clogging phenomenon has been observed both in the pressure compensated (PC) and the non-compensated emitters (Capra and Scicolone, 2007). However, the problem is more complex in PC emitters where the flow path is protected by a diaphragm that resists any change in the flow regime. As a result, clogged PC emitters do not show any significant recovery of flow unlike non-PC emitters when corrective measures are applied to the system. Nevertheless, PC emitters are popular for their ability to maintain consistent discharge over a range of pressure variation, thus giving better uniformity of application. Moreover, they are often the only choice for irrigators in the hilly regions of the world. Therefore, clogging of PC emitters is the immediate threat for sustainable drip irrigation practice, especially in RWI schemes. In subsurface drip irrigation practice, it is even more important because of the cost involved in replacing the fully clogged laterals in the field. Since SDI emitters are laid down below the soil surface, they are exposed to a different thermal patterns (Oliver et al., 2012) than the surface drip irrigation (DI). In fact, subsurface thermal regimes determine the temperature of water inside the laterals of SDI. Several studies have outlined the effect of water temperature on the lateral properties (Amin and Svehlik, 1994) and the emitter flow (Dogan and Kirnak, 2010). Growing evidences (Capra and Scicolone, 2005; Yan et al., 2009) suggest that the thermal changes in soil also affect the development of biomass inside the laterals. For implementing effective strategies against clogging, it is crucial that the biomass response to the changes in soil thermal regimes is well understood in RWI schemes.

An experimental DI model has been developed in this regard at the Australian irrigation and hydraulics technology facility (AIHTF). It is investigating the bio-fouling process under varying thermal conditions. This paper presents experimental studies carried out to understand clogging in PC emitters and identify the structural pattern of biofilms under medium soil thermal variation. It involved construction of an experimental test rig with a drip assembly where thermal changes were simulated. The study is comprised of repeated biophysical, microscopic and microbial analysis of the recycled water and biofilms. It also includes interpretation of the biophysical techniques in the process. The results are being presented in light of the correlations observed amongst the parameters.

2. Materials and methods

2.1. Experimental set up and emitters

The experimental rig was constructed inside a large environmental chamber (4.5 m × 3.5 m) made of 50 mm thick insulated walls; steel sided on both sides. It contained four replications of DI system with 12 laterals each 4.5 m long (Fig. 1a). Each replication consisted of three different types of pressure compensated (PC) emitters with different labyrinth designs (Fig. 1b) manufactured in Australia, Israel and the United States. Basic physical and hydraulic characteristics of the emitters are given in Table 1. We followed ISO: 9261 standards when testing for the hydraulic parameters of these emitters. The scanning electron micrograph (SEM) images of the emitters were taken and analysed using image segmentation software (SPIP-6 and Image-J). All the drip lines were of 13 mm nominal diameter fixed with inline pressure compensating (PC) emitters spaced 30 cm apart.

The test rig was coupled with a water tank (700 L) below the chamber from which water was supplied into the drip lines (Fig. 1a). Water droplets from the emitter discharge would fall on the base of the chamber which drains the water back into the tank for recirculation through the system. A 120 mesh (130 μm) screen filter (*Netafim*) was used to filter the water before its delivery to the system.

The SDI rig was continuously fed with reclaimed water (class A) collected from Bolivar wastewater treatment plant (WWTP), Adelaide. This plant uses dissolved air flotation and filtration (DAFF) method followed by chlorination to disinfect sewage water. A bigger onsite reserve (50 ML) was built near the experimental site (not shown in figure) for temporary storage and quick transfer of water into the 700 L tank of the rig. The level of suspended solids in the tank water was analysed at every 25 h of irrigation. Other quality parameters described in Section 2.2 were analysed after every 110 h of intermittent irrigation. Values presented in Table 3 are the average of these 110 hourly measurements along with their corresponding standard deviations over the experimental period.

2.2. Water quality

Since water quality characteristics can be influenced by various factors, it was important that we consider a range of parameters in this study. Bucks et al. (1979) and Boswell (1990) proposed two water quality guidelines and defined emitter sensitivity to clogging for low flow emitters (2–4 L/h). Later, Capra and Scicolone (1998) defined the water quality guideline for large size emitters (8–16 L/h). No such guideline exists for commonly used lower flow emitters (<2 L/h). Moreover, the existing guidelines cover only a few parameters, such as total suspended solids (TSS), pH, total dissolved solids (TDS), Manganese (Mn), Iron (Fe^{2+}), Hydrogen sulphide (H_2S), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and total bacterial number. In our study, the analyses were extended to some more parameters including Bicarbonate (HCO^{3-}), Sodium (Na^+), Chloride (Cl^-), Potassium (K), total Nitrogen (TN), total Phosphorus (TP), total organic Carbon (TOC) and free residual chlorine (OCl^-). The metals were analysed using an inductively coupled plasma mass spectrometry, ICP-MS (Agilent, model 7500c). For total carbon and nitrogen, a CNS-analyser (vario-MAX, Elementar III) was used. A portable combined pH and conductivity metre (Jenway, model