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Thermal variation and pressure compensated emitters

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ABSTRACT

A number of factors may contribute to the non-uniformity of an unclogged drip irrigation (DI) system. It is understood that DI emitters respond to the thermal changes in the environment resulting in variable flow-rates. This study investigates the effect of thermal variation (air and water) on the performance of inline pressure compensated (PC) emitters. In order for this, three different types of emitters were subjected to a wide range of continuous heating (eight stages) and cooling (eight stages) cycles inside an enclosed environmental chamber. Both the air and the irrigation water temperature was carefully maintained throughout the experiment. The results showed a general tendency of declining emitter flows during the heating cycles followed by a partial recovery during the cooling cycles. As a result, the variation in flow-rates formed a one-cycle hysteresis loop for all emitter types. Changes in the viscosity of water was shown to have little or no effect on the overall performance of PC emitters. The looped return of emitter flows due to the continuous heating and cooling treatments was explained by the elastic changes in pressure membrane. The results of this study also revealed a transitional temperature range (15–18 °C) during which the flow-rate of PC emitters was found to be stable. Hence, this range was taken as a reference temperature in establishing the characteristics of emitter samples. Conducting hydraulic testing of emitters at this range showed promising results compared to the existing recommendation of 23 ± 3 °C by the ISO. The overall experience of the study suggests that the potential hydraulic performance of PC emitters can only be achieved at lower temperature levels.

1. Introduction

Poor water application uniformity is very common in the drip irrigation (DI) practice. The major source of non-uniformity comes from the failing system pressure Demir et al. (2007) that may cause variation (Oliver et al., 2014b; Puig-Bargués et al., 2005) in the individual emitter flows. Theoretically, pressure compensating (PC) emitters are thought to be immune (Zhengying et al., 2012) to any change in lateral pressure (Barragan et al., 2006; Kirnak et al., 2004), although some variation has been reported (Gil et al., 2008; Rodriguez-Sinobas et al., 1999). Ideally, in PC emitters, the pressure regulation is achieved by means of a resilient membrane that covers the flow path. This elastic membrane contracts or stretches (Zhao et al., 2009) when the system pressure increases or decreases to maintain the flow-rate of PC emitters to a near-constant value. However, growing evidences (Clark et al., 2004; Dogan and Kirnak, 2010; Goyal, 2012; Rodriguez-Sinobas et al., 1999) suggest that thermal variation can also change the membrane properties (Al-Amoud et al., 2014) and contribute to the variation of flow rates in PC emitters. Despite several of these scholarly efforts, very few information have emerged to shed light on the performance of PC emitters under varying thermal conditions. It is therefore important to understand how the PC emitters behave when temperature changes occur at various stages of irrigation.

For point source emitters, the flow rate, $q = kh^x$ is usually defined (Ahmed et al., 2007) in terms of the pressure head of water (h), and a discharge coefficient (k) which is a function of the viscosity of water. Theoretically, the exponent (x) is equal to 1 for laminar flow emitters, and 0.5 for fully turbulent flow emitters (Rodriguez-Sinobas et al., 1999). The intermediate values stand for partially turbulent flows (Burt, 2004; Smajstrla et al., 1997). For

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the tortuous path emitters, x ranges from 0.5 to 0.7 while for long path emitters, x varies between 0.7 and 0.8. If an emitter is pressure compensated, theoretically, the exponent's value would be zero. Ideally, this means that the flow of PC emitters at a certain range of pressure is constant which can be experimentally determined (ASABE, 2006; ISO, 2004). However, Kirnak et al. (2004) found that PC emitters have exponent values which, for their specimen, ranged from 0.02 to 0.05. Similar studies with the subsurface drip irrigation (SDI) emitters by Gil et al. (2008) showed that the exponent x was 0.035 for all PC emitters irrespective of their sizes. These contradictory results are thought to be contributed by the thermal conditions of the experiments. Although 23 °C has been recommended as a reference water temperature for these tests (ISO, 2004), there have been reports of use of other temperature levels i.e., 20 °C (Dogan and Kirnak, 2010) and 15 °C (Al-Amoud et al., 2014). Selection of these temperatures were made merely on assumptions (Rodriguez-Sinobas et al., 1999) as there is no general agreement on what should be a reference temperature for evaluation of emitters. Moreover, the test conditions of all these previous research efforts was such that only water temperature was controlled during the experiments ignoring the effect of ambient thermal changes. It is, therefore, crucial that emitter specific investigations are made at different thermal conditions. This must involve temperature-control mechanism for both the air and the irrigation water. Only then, a reference temperature for hydraulic testing of PC emitters can be experimentally established.

Since the viscosity of water is a function of temperature, it is apprehended that the thermal properties of irrigation water may also affect the flow rate of PC emitters. Keller and Karmeli (1974) opined that the change in viscosity of water can be neglected in case of fully turbulent emitters ($x \approx 0.5$). Some studies (Parchomchuk, 1976; Zur and Tal, 1981) have found that the emitter-flow rises with temperature in case of labyrinths emitters ($x > 0.5$) but falls for $x < 0.5$. Similar results were reported by Decroix and Malaval (1985). Later, Rodriguez-Sinobas et al. (1999) argued that a linear relationship between emitter flow and ambient temperature might exists. It was also opined that PC emitters were mostly insensitive to thermal changes in the environment. These results stand clearly in contrast with those who reported significant increase (up to 97%) in emitter flows when temperature was risen from 21 to 50 °C in a laboratory experiment. Such large variation in water temperature has been observed in the field. In practice, water temperature also varies along the laterals because of the flux lost during the transport from the submain to end of the laterals. Parchomchuk (1976) reported 16.7 °C difference in water temperature along the laterals when placed on the surface. It was also shown that water in the surface laterals was significantly hotter (42 °C) than those in the subsurface laterals (32 °C) at 15 cm depth on a sunny day in British Columbia. Without a vegetative cover, the subsurface temperature can be even higher. For example, at 20 cm below the surface, temperature as high as 38 °C has been reported (Gamliel and Stapleton, 1993) in California. Similar results has also been reported for the semi-arid Australian Plains where the daily, and the seasonal variation in subsurface soil (20 cm) reach up to 6 and 25.8 °C, respectively (Oliver et al., 2012).

Despite several efforts (Di Maiolo, 2012; Li et al., 2011; Zandee, 2012) to quantify the sources of flow-variation, the effect of long-term thermal changes on the performance of PC emitters has not been quantified yet. Previous studies (Clark et al., 2004; Rodriguez-Sinobas et al., 1999) have indicated that the non-PC emitters are usually responsive (±1.4% of the design flow) to thermal variation. Early experiments by Parchomchuk (1976) also showed that the flow of turbulent type non-PC emitters increases by up to 3.2% while that of the vortex emitters decreases (up to 26.7%) if water temperature is increased. However, the PC emitters received little attention from the researchers and its response to long term thermal exposure has not been quantified yet, especially, under oscillating thermal regimes. Only the effect of short term thermal exposures i.e., 15 min (Dogan and Kirnak, 2010) and 30 min (Clark et al., 2004) have been reported in the rare body of literature on this topic.

Therefore, it is important that the relationship between thermal variability and emitter performance is well quantified. In this regards, an experimental DI model enclosed by an environmental chamber has been developed at the Australian irrigation and hydraulics technology facility (AIHTF). This paper presents the results of a series of experiments carried out to understand how thermal variation affects the performance of PC emitters. It would also contribute to the establishment of a reference temperature for the hydraulic testing of emitters. The study involved construction of an environmental test rig inside which specific thermal regimes were simulated around the laterals of PC emitters. The results of these experiments are being presented in this paper in light of the correlations observed amongst the parameters.

2. Materials and methods

2.1. Experimental test rig

A large enclosed environmental chamber (4.5 m × 3.5 m) was constructed using 50 mm thick insulated walls; steel guarded on both sides. The chamber was set one meter above the ground, and a drip irrigation system was placed inside. The DI assembly contained laterals of three different types of pressure compensated emitters; Emitter E1 (1.6 L/h), Emitter E2 (2 L/h), and Emitter E3 (2.3 L/h) arranged in four replications. Each replication contained one lateral (5 m long) per emitter type totalling an assembly of 12 laterals (Fig. 1) in the chamber. The emitters were of inline type, and had different labyrinth designs (Fig. 2). Dimensional characteristics of the emitters can be obtained from Oliver et al. (2014a). All the drip lines were of 13 mm nominal diameter with inline emitters spaced 30 cm apart. The test rig was coupled with a thermal control unit which is able to achieve specific temperature regimes inside the chamber. A water tank (700 L) from which water was supplied to the laterals was placed just below the chamber (Fig. 1). During an active irrigation period, emitter flows would fall on the bottom wall of the chamber which drains the water back into the tank. As a result, a continuous recirculation of irrigation water through the system is possible. The standard irrigation water used in the experiment meets the requirements suggested by the FAO (2003). The total suspended solid (TSS) level of this water was <1 ppm, and therefore, it had no apprehension of clogging. Most importantly, this unique system would allow the water temperature to equalise with the air temperature of the chamber during the experiment simulating the field DI experience.

2.2. Temperature test

Emitters inside the chamber were exposed to different temperature ranges (Table 1) in order to understand the effect of ambient thermal variation on their flow-rates. There were two subsequent runs in this test. In the first run, the effect of heating on the flow-rate was tested. This was immediately followed by the second run to test the effect of subsequent cooling on the emitter flows. The temperature range for this entire test was taken to be 9–34 °C. It range encompasses the thermal experience of subsurface type emitters in most agricultural soils of the world (Dutcher, 2014; IEM, 2014; Lemmela et al., 1981; MDA, 2014; USDA-NRCS, 2003). The whole range (9–34 °C) was then broken into the following eight sub-ranges (Table 1); each simulating an average variation of 3 °C at each stage of the experiment.