Water Resources and Irrigation Management
Universidade Federal do Recôncavo da Bahia, Cruz das Almas, BA
Instituto Nacional do Semiárido, Campina Grande, PB
v.1, n.1, p.25-29, Sept-Dec, 2012

ISSN 2316-6886
WRIM
www.wrim.com.br

Efficiency of chemical treatment on drip irrigation systems with sanitary sewage

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Protocol 10.2012 - Received: September 22, 2012 - Accepted: October 30, 2012

Abstract: The efficiency of chemical treatment to prevent the clogging of emitters applying treated sanitary sewerage is discussed. The experiment was carried out at the Sewerage Treatment Pilot Plant of the Universidade Federal de Viçosa, Viçosa MG Brazil. A test platform was built for this experiment to supply four units of drip irrigation with treated sanitary sewerage, filtered in a 120-mesh disc filter. Three different models of drippers were tested (Naan Drip-Paz 25, Plastro Hydro PC and Naan-Tif) for 560 hours. Concentrations of free residual chlorine of 0.4; 1.0 and 1.9 mg L^{-1} were tested for chemical treatment. Phosphoric acid was used in the treated sanitary sewerage to reduce pH to a mean value of 6.6. The results showed that the joint application of chlorine and phosphoric acid in the treated sanitary sewerage minimized the development of the biofilm inside the drippers and the lateral lines. The concentration of free residual chlorine of 0.4 mg L^{-1} proved to be the most appropriate to prevent clogging of emitters. The treated sanitary sewerage applied by drip irrigation system produced a biofilm caused by the interaction between bacteria colonies and algae in the drippers. Consequently, CUC mean values decreased, varying between 3.63 and 16.96%, depending on dripper model, after 560 working hours by irrigation units.

Key words: chlorination, acidification, biofilm, drippers

Eficiência do tratamento químico em sistemas de irrigação por gotejamento operando com esgoto sanitário

Resumo: O presente trabalho objetivou analisar a eficiência do tratamento químico na prevenção do entupimento de gotejadores operando com esgoto sanitário tratado. O experimento foi realizado na Estação Piloto de Tratamento de Esgoto da Universidade Federal de Viçosa, em Viçosa-MG, Brasil. A bancada experimental foi montada com quatro unidades de irrigação por gotejamento, abastecidas com esgoto sanitário filtrado em filtro de discos de 120 mesh. Três diferentes modelos de gotejadores (Naan Drip-Paz 25, Plastro Hydro PC e Naan-Tif) foram ensaiados por um período de 560 horas. No tratamento químico testaram-se as concentrações de cloro residual livre de 0,4; 1,0; e 1,9 mg L^{-1}. Aplicou-se ácido fosfórico no esgoto sanitário tratado para reduzir o pH, mantendo-se um valor médio de 6,6. Os resultados obtidos indicaram que a aplicação conjunta de cloro e ácido fosfórico no esgoto sanitário tratado minimizou o desenvolvimento de biofilme dentro dos gotejadores e das linhas laterais. A concentração de cloro residual livre de 0,4 mg L^{-1} foi a mais adequada na prevenção do entupimento dos gotejadores. O esgoto doméstico tratado aplicado via sistema de irrigação por gotejamento propiciou a formação de biofilme, resultante da interação entre colônias de bactérias e algas nos gotejadores. No período experimental ocorreram reduções nos valores médios do CUC variando de 3,63 a 16,96%, dependendo dos modelos de gotejadores, após 560 horas de funcionamento das unidades de irrigação.

Palavras-chave: cloração, acidificação, biofilme, gotejadores

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Introduction

Dripper obstruction is a major problem in the drip irrigation systems using wastewater (Ravina et al., 1997; Batista et al., 2010). The formation of sticky material, caused by the interaction between bacterial mucilage, algae and zooplankton, has been the main cause of the obstruction process of the drippers that use sanitary sewerage (Dazhuang et al., 2009). Studies carried out by Taylor et al. (1995) demonstrated that the interactions among physical, chemical and biological factors caused 90% of the obstructions in the drippers.

Batista et al. (2010) reported that algae in the treated sanitary sewerage obstructed the drippers only when mineral deposits or sticky material occurred. The reduction of uniformity in water application due to changes in the flow rate caused by total or partial obstruction of the drippers is a crucial disadvantage linked to the use of treated sanitary sewerage in localized irrigation systems. Cunha et al. (2006) reported significant decrease of distribution uniformity of drippers which received coffee wastewater, 144 hours after the start of the experiment. Liu & Huang (2009) reported that the reduction percentage of emitter discharge, the coefficient of variation of emitter discharge and percentage of complete emitter clogging were greater for treated sewage effluent treatment than for freshwater treatment. However, emission uniformity, Christiansen's uniformity coefficient and operation times during which mean discharge decreased to 90% and 50% of the initial values were smaller.

The methods for preventing obstructions must involve not only aspects related to system management (filtration, field inspection and washing of distribution nets), but also measures for the chemical treatment of fertigation water (Nakayama et al., 2006). The filtration process by itself does not prevent dripper obstruction, even when sand filters are used (Tajrishy et al., 1994). Although chlorination is the most common process in chemical treatment, other substances, such as hydrochloric and phosphoric acids, copper salts, ammonia and others may be also used too.

Working with drippers of different models and commercial brands, Ravina et al. (1992) reported that the level of obstruction by wastewater was similar in systems with 80- and 120-mesh screen filters. Greatest obstruction, however, occurs with 40-mesh screen filters. The authors concluded that most types of drippers were more reliable for the operation when associated to an 80-mesh screen filter, daily chlorination (10 mg L^{-1}) and washing of the lateral lines every other week.

According to Tajrishy et al. (1994), chlorination is necessary to prevent the growth of bacterial slime and algae inside the drip irrigation systems that apply secondary sanitary sewerage. Using non-pressure compensated drippers, sand filter (with real size particles of 0.45 mm) and with an addition of 2 mg L^{-1} of free residual chlorine during the last hour of an irrigation cycle, the above-mentioned authors achieved a 92% statistical uniformity coefficient of water application (Us). However, for the tortuous labyrinth drippers of turbulent outflow, the filtration of over 80 μm particles, with continuous application of 0.6 mg L^{-1} of free residual chlorine, made it possible for the system to achieve a 97% statistical uniformity coefficient (Us).

Hills & Brenes (2001) evaluated the performance of four kinds of drip tape applying with wastewater from systems of activated mud treatment. The effluent treatment included the passage through two sand filters (silica # 20), a screen filter (105 μm) and continuous application of chlorine (0.4 mg L^{-1} of free residual chlorine). In spite of the above, many drippers were partially or completely obstructed, mainly at the end of the lateral lines. The authors recommended the washing of the lateral lines (with minimal flow velocity of 0.5 m s^{-1}) every other week to avoid particles that would possibly pass through the sand filters. Trooien et al. (2000) recommended that pH should be 6.3 in the fertigation wastewater, achieved by acid addition, to increase chlorination efficiency.

The present study verified the efficiency of the chemical treatment (chlorination and acidification) to prevent the obstruction of drippers applying treated sanitary sewerage.

Materials and Methods

The experiment was carried out at the Sewerage Treatment Pilot Plant of the Universidade Federal de Viçosa, Department of Agricultural Engineering, Viçosa MG Brazil. The pilot plant was supplied with crude sanitary sewerage from a residential area, where it received a three-phase treatment. First, the crude sewerage received initial treatment by which a tank of sedimentation removed solids with high specific mass. Decrease of organic charge (DBO_5) was obtained by depositing the sanitary sewerage on bands 1.0 m wide, 25 m long with an inclination of 2%, cultivated with Tifton 85 grass of the genus *Cynodon*. The secondary treatment comprised sanitary sewerage cast in a maturing pond with a storage capacity of 300 m^3, for the removal of pathogenic organisms.

For the experimental assay, a test platform was built, next to the maturation pond, between October 26 and December 13, 2003. In the final corner of the maturation pond, a control unit was set up, with a 3 cv pump and a common 120-mesh disc filter, to supply water to four drip irrigation units, built under the test platform. Table 1 shows the technical characteristics of the commercially available drippers. The model drippers were manufactured for the application of good quality water, but due to the scarcity of information about the operating performance of drippers with wastewater, they were tested under harsh conditions on the manufacturers' recommendations.

The irrigation units received the following treatments: T1, applying sanitary sewerage from the maturing pond and ordinary filtration in disc filter; T2, applying sanitary sewerage from the maturing pond and ordinary filtration in disc filter, acidification (pH 6.6) and chlorination (0.4 mg L^{-1} of free residual de chlorine); T3, applying sanitary sewerage from the maturing pond and ordinary filtration in disc filter, acidification (pH 6.6) and chlorination (1.0 mg L^{-1} of free residual de chlorine); T4, applying sanitary sewerage from the maturing pond and ordinary filtration in disc filter, acidification (pH 6.6) and chlorination (1.9 mg L^{-1} of free residual chlorine).

In the manifold line of each irrigation unit, nine connectors in PVC with nominal diameter of 32 mm, were inserted. For each model, three lateral lines 25 m long were installed. In each lateral line of models Naan Drip-Paz 25 and Plastro Hydro PC, there were 32 drippers, whereas 41 drippers were extant in the lines of the Naan-Tif model. Thirty-two drippers were identified by a lateral line for the evaluation of uniformity of water application. During the test period, the levels of water application uniformity were tested eight times, every eight hours, in the four irrigation units. The flow rate of 32 drippers selected in each lateral line was determined and each emitter had a predetermined collection time of three minutes. The data were then used to determine the uniformity coefficient of water application (Eq. 1).

$$CUC = 100\left[1 - \frac{\sum_{i=1}^{n}\left|q_i - \bar{q}\right|}{n_e \bar{q}}\right] \quad (1)$$

Christiansen's uniformity coefficient (CUC), shown in Eq. 1, was adopted from sprinkler irrigation.

Table 2 presents a classification of localized irrigation systems, according to Christiansen's uniformity coefficient (CUC).

Table 2. Classification of localized irrigation systems according to Christiansen's Uniformity Coefficient (CUC)

Classification	CUC (%)
Excellent	90 – 100
Good	80 – 90
Reasonable	70 – 80
Poor	60 – 70
Unacceptable	< 60

Source: Mantovani (2002)

A 120-mesh disc filter was installed downstream the 3 cv pump, with a filtration capacity of 8 m^3 h^{-1}. Filter cleaning was done every time there was a 20 kPa decrease in the pressure measured after the filtration, according to criteria recommended Pizarro Cabello (1990).

Chemical treatment was carried out for one hour, at every 35 hours of irrigation units performance, corresponding to treatments T2, T3 and T4. The chemical products sodium dichloroisocyanurate (65%) and phosphoric acid (85%) were employed. Each product was separately diluted, in plastic containers, with 10 L of water, and injected in the pipeline, after the filtration system, by two fertilizer injectors, such as Venturi, with 70 L h^{-1} capacity each. The injectors were installed in series downstream the disc filter. The first one injected phosphoric acid and the second sodium dichloroisocyanurate; both were regulated by sphere records for an injection rate of 10 L h^{-1}. The amount of chlorine applied was monitored by a kit of free residual chlorine analysis so that its contents would be 0.4; 1.0 and 1.9 mg L^{-1} at the end of the lateral lines of T2, T3 and T4 treatments, respectively. During

Table 1. Technical characteristics of commercially available dripper models Naan Drip-Paz 25 (M1), Plastro Hydro PC (M2) and Naan-Tif (M3), used in the experiment under the test platform

Model	Type*	Nominal flow rate (L h^{-1})	Working pressure (kPa)	Distance between drippers (m)	Labyrinth length (mm)	Labyrinth aperture (mm)	Number of secondary filters per dripper
M1	Non- P.C.	1.7	40-250	0.75	177	1.7	1
M2	P.C.	2.1	50-400	0.75	260	2.1	2
M3	Non-P.C.	2.0	100-400	0.60	396	2.7	2

* P.C. - pressure compensating

the chemical treatment, pH of the treated sanitary sewerage collected at the end of the lateral lines of each treatment was monitored and maintained at mean value of 6.6 by the addition of phosphoric acid to warrant hypochlorous acid (bactericide agent). After the application, the lines that received the chemical treatment were left resting for 12 hours; the next day, the irrigation units performed normally until the next application was carried out. Pressure was maintained at 101 kPa by a controlling valve installed at the start of the manifold line. The irrigation units worked, on average, 12 hours a day, seven days a week, until the 560-hour operation time was fulfilled. After 560 hours of sewerage application through the system were completed, samples from the obstructed drippers were collected so that the obstructing material could be identified. The samples were taken at the start, middle and end of the lateral lines. They were eventually kept in a container with ice and immediately sent to specific laboratories.

The experiment was assembled in a split plot scheme, in a completely randomized design, with three replications. After variance analysis, means were compared by Tukey's test at 0.05 probability.

Results and Discussion

The results of the Christiansen's uniformity coefficient (CUC) obtained during operation time for emitter models Naan Drip-Paz 25 (Model M1), Plastro Hydro PC (Model M2) and Naan-Tif (Model M3) with wastewater under different treatments T1, T2, T3 and T4, are shown in Figures 1A, 1B, 1C and 1D, respectively.

Figure 1A shows in T1 a decrease in CUC mean values for the irrigation units with the three models of drippers due to the application of the treated sanitary sewerage. However, decrease in water application uniformity was more significant in the irrigation units containing the models Plastro Hydro PC and Naan-Tif. Such susceptibility to obstruction was attributed to the longer labyrinths and to a greater amount of secondary filters in the two models when compared to the Naan Drip-Paz 25 dripper model. CUC of the irrigation units with the Naan Drippaz 25 model was ranked as excellent in all eight evaluations in spite of a small decrease, approximately 3.63%, when CUC mean values between the first and the last evaluation were compared. In the Naan Drip-Paz 25 dripper model, the shortest length of the labyrinth warranted the permanence of the turbulent outflow

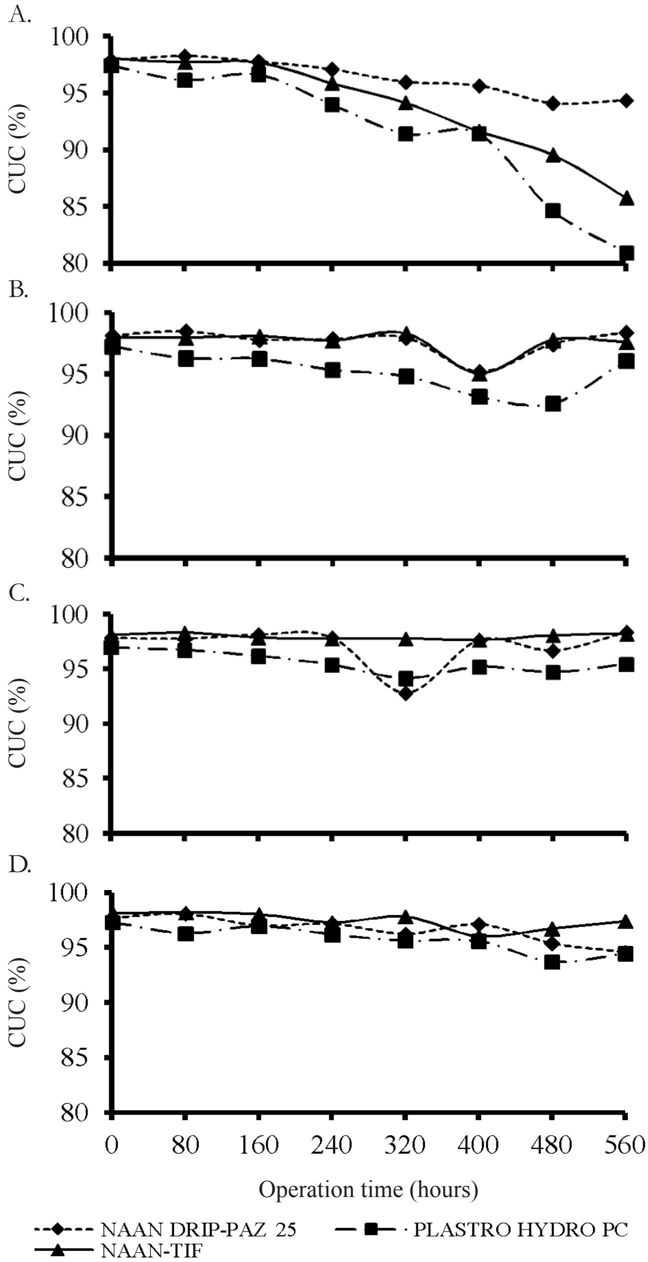

Figure 1. CUC average rates, obtained during the operation period, with Naan Drip-Paz 25 (Model M1), Plastro Hydro PC (Model M2) and Naan-Tif (Model M3) models of drippers in treatments T1, T2, T3 and T4

regime, which, in its turn, reduced the deposit of organic material in the protuberances in the outflow routes of the treated sanitary sewerage inside the emitter. CUC mean values in models Plastro Hydro PC and Naan-Tif presented reductions up to 16.96 and 12.53%, respectively. This resulted in a change from excellent to good in the classification of water application uniformity (Table 3).

The obstruction material was produced by the interaction between bacterial mucilage and algae in the wastewater. Genera of the bacteria *Clostridium*, *Bacillus*, *Pseudomonas* and *Enterobacter*, coupled to the iron bacteria of *Cremothix* sp. species, produced a microbial mucus to which the particles ad hered, mainly those from organic

Table 3. Christiansen's Uniformity Coefficient (CUC) obtained in each treatment and dripper model

Dependent variable	Model	Treatment			
		T1	T2	T3	T4
CUC (%)	M1	96.42 a	97.68 a	96.96 a	96.67 a
	M2	91.59 b	95.25 a	95.64 a	95.77 a
	M3	93.85 b	97.59 a	98.02 a	97.45 a

* Mean followed by the same letter in columns, do not represent significant differences by the Tukey test at 0.05 level of probability
M1 - Naan Drip-Paz 25; M2 - Plastro Hydro PC; M3 - Naan-Tif

origin, represented by live or rotten seaweed cells. The prevailing seaweeds belonged to the groups Cyanophyta (*Chlorococcus* genus), Euglenophyta (*Euglena* and *Phacus* genera) and Chlorophyta (*Selenastrum*, *Scenedesmus* and *Sphaerocystis* genera).

The simultaneous application of sodium dichloroisocyanurate and phosphoric acid kept mean CUC values of the irrigation unit always above 90%, classified as excellent (Table 2), for the three models of drippers, presented in Figures 1B, 1C and 1D. In treatments T2, T3 and T4, there were variations in CUC mean rates, attributed to the random opening of some drippers.

Table 3 shows CUC mean values and comparison. In the Naan Drip-Paz 25 model, the treatments T1, T2, T3 and T4 did not differ. This fact confirmed that its resistance to obstruction was more than the resistance of the other tested dripper models.

With regard to Plastro Hydro PC and Naan-Tif models, the treatments T2, T3 and T4 were similar to the CUC dependent variable, but differed from T1 treatment. Thus, T2 treatment may be the most appropriate because it presents the least concentration of residual free chlorine, implying lower costs and environmental impacts.

Drippers Naan Drip-Paz 25, Plastro Hydro PC and Naan-Tif were designed to operate with good quality water. The above emitters were tested in the present research owing to growing demands for water resources and especially the use of wastewater associated with the availability of only few types of drippers for wastewater.

Conclusions

1. The joint application of the chlorine and phosphoric acid in treated sanitary sewerage minimized the development of the biofilm inside the drippers and in the lateral lines. Treatment T2 proved to be the most appropriate in preventing clogging of emitters.

2. The application of treated sewerage after 560 hours of performance caused reduction in CUC mean rates by 3.63, 16.96 and 12.35% in drip irrigation systems operating with models Naan Drip-Paz 25, Plastro Hydro PC and Naan-Tif, respectively.

3.Drippers with longer labyrinths and greater number of secondary filters (Plastro Hydro PC and Naan-Tif) are more susceptible to obstructions when supplied with treated sanitary sewerage.

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