SENSITIVITY OF MICRO IRRIGATION EMITTERS TO PLUGGING USING TREATED MUNICIPAL WASTEWATERS

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ABSTRACT

Treated municipal wastewater can be used in trickle irrigation methods, but if we want to have a high application efficiency a good management is required. Clogging of emitters is one of the most important problems directly associated with the quality of irrigation water. This problem is increased when poor quality waters like wastewaters are used.

The sensitivity of different commercial emitters was studied when they were working continously during 620 hours. The objective was to find a relationship between emitter type and partial or complete plugging. A lateral with six different emitters was placed in a controlled experiment in laboratory. Municipal wastewater with a primary treatment was used. Later, this water was also filtered.

Results showed that pressure compensating emitters have a high sensitivity to clogging. Small pressure increments can help to clean plugged emitters. Plugging can also be decreased if wastewater with primary treatment is filtered. Non compensating pressure emitters showed a best behavior versus poor quality water.

INTRODUCTION

Drip irrigation systems have a large number of emitters that are easily clogged due to small flow paths they have. The quality of water is one of the main causes of plugging. The problem is furthermore increased if wastewater is used to irrigate. Clogging produces a poor irrigation uniformity.

Although previous works have been mainly devoted to study procedures to fight against clogging, several authors have also analysed the influence of emitter geometry. In this way, Lesavre and Zairi (1988) selected emitters resistant to clogging using wastewaters. Gamble (1986) and Nakayama and Bucks (1991) considered self-cleaning emitters to decrease clogging problems. Massoud et al. (1994) gave a classification of emitters sensitivity to plugging as a function of the minimum flow path.

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The quality of irrigation water has been more widely considered. Nakayama and Bucks (1991) provided a table given the risk of emitter clogging depending on plugging factors: suspended solids; biological growths or chemical reactions. Gilbert et al. (1982) studied the clogging of eight different emitters using Colorado river water with several treatments. As a conclusion, the water treatment affects the normal operation of emitters. In this way, several authors (Bucks et al., 1979; Gilbert and Ford, 1986; and Nakayama and Bucks, 1986) give practical recommendations about treatments depending on specific water quality.

Although filtration and water treatments reduce the potential of clogging, Massoud et al. (1994) conclude that the problem can't be avoided in some conditions. Lau et al. (1981) also conclude that any chemical product can totally control clogging.

The main goal of this work is to study the sensitivity of different models of trickle irrigation emitters to plugging. Two types of treatments applied to wastewaters were considered. Finally, we present some recommendations about the most adequate emitter to decrease the risk of clogging.

MATERIAL AND METHODS

Experimental Procedure

Figure 1 shows an experimental bench used for emitter tests. Six different emitters were analysed. They are placed in each of the four laterals (16 mm of diameter) we have in a random way. Then, four repetitions of each emitter were considered. Separation between emitters is 0.2 m. Lateral length is short enough to accept that pressure distribution along lateral is uniform. Besides this, each lateral is supplied with water by both ends.

Filtration equipment consist on a disc filter (equivalent to 120 mesh) and sand filter (particle size of 1.2 mm of diameter). Due to the fact that water is recirculated through the experimental bench, the total suspended solids are disminished with time.

Emitters

Six commercial types were selected. The parameters (*k* and *x*) of the emitter discharge equation are shown in table 1 (Chica, 1999):

$$Q = kp^x \qquad (1)$$

Where Q represents flow rate ($L\ h^{-1}$) and p is the operating pressure (kPa). That table also includes the characteristic of emitters.

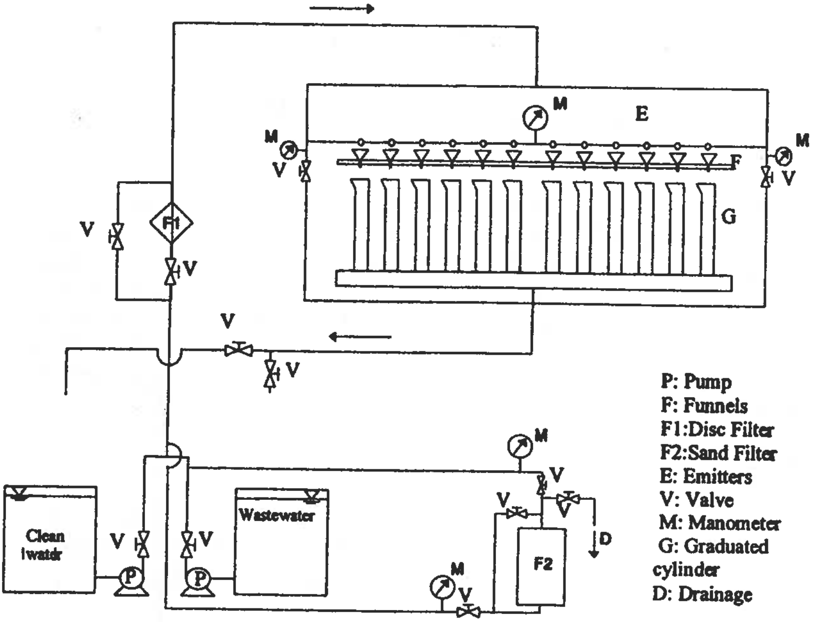

Fig. 1. Experimental Bench for Emitter Test

Table 1. Characteristics of Emitters and Parameters of Emitter Discharge Equation

Emitter	Parameters of discharge equation		Q_n (L/h)	Type
	k	x		
A	2.79	0.08	4	Pressure compensating on line
B	0.38	0.49	4	Labyrinth inserted (non compensating)
C	0.41	0.48	3.8	Labyrinth on line (non compensating)
D	4.61	-0.02	4	Pressure compensating on line non draining
E	0.44	0.48	4	Labyrinth in line detachable (non compensating)
F	0.54	0.44	4	Labyrinth in line non detachable (non compensating)

Wastewaters

Wastewater we have used in this work comes from the wastewater regenerated municipal station of the city of Córdoba (Spain). Two different types of wastewater have been used:

1. Wastewater with primary treatment (WPT).
2. The same water that once before has passed through the disc and sand filters (WPTF).

Some of the average physics and chemistry characteristics of the wastewater are shown in table 2. Those values were analysed each time we took water from the wastewater station. The first column shows the values of wastewater with primary treatment. The second column has the values of the same type of water once the wastewater has passed through the filters the first time. The third column shows the values after four hours of recirculation through the experimental bench. In the last case, only the suspended solids were analysed because it is the characteristic most affected by the filters.

Table 2. Characteristics of Wastewaters Used in Laboratory Tests

	Primary treatment	**Primary treatment + Initial filtering**	**Primary treatment + total filtering**
Suspended (mg/L) solids	109	45	6
BOD[3] (mg/L)	264	235	-
COD[4] (mg/L)	567	500	-
PH	7,64	7.88	-
Conductivity (dSm^{-1})	0.96	1.10	-
Fe (µg/L)	2000	-	-
P (mg/L)	9	-	-
Nitrates (mg/L)	<5	-	-

[3] Biological Oxygen Demand
[4] Chemical Oxygen Demand

A problem we found in this type of test was that the wastewater station was very far from the experimental laboratory. Then, wastewater was carried out in small tanks with a capacity of 25 liters. Although the water was changed very frequently (each four hours), we need to recirculate it during that time and characteristics of wastewater were modified mainly in the case that filters were installed (see table 2). However, it appears that only suspended solids decreased their values in a significant way. In another experiment, we studied the deposits in the emitters and pipes after four hours of recirculating water. The analysis demostrated that they were mainly constituted by organic matter (Chica, 1999). Therefore, the influence of filters does not affect other parameters in table 2.

Methodology and Experimental Procedure

The experimental test was conducted for 620 hours, that is, the current duration of the irrigation season. First, we worked with a type of wastewater and, once the experiment concluded, we started with the other type of water. In order to simulate, as exact as possible, the field irrigation practices, the system operated four hours each day up to reach the 620 hours.

Each four hours, flow discharge at the nominal operation pressure (100 kPa) was measured. Each 100 hours, the flow discharge was also measured at 60, 100, 140 and 180 kPa, to determine the flow discharge equation. Temperature was measured with a mercury termometer with precision ±1°C.

The sensitivity to plugging was studied computing two parameters:

1. The decrease of flow discharge (D_q), after 620 hours, in relation to the nominal discharge expressed as a percentage:

$$D_q = \frac{\overline{Q}_f - Q_n}{Q_n} \times 100 \qquad (2)$$

where Q_n (L h^{-1}) is the nominal discharge, and $\overline{Q}_f$ (L h^{-1}) is the average emitter discharge after 620 hours.

2. The level of clogging (LC) after 620 hours expressed as a percentage:

$$LC = \left(1 - \frac{\overline{Q}_f}{\overline{Q}_i}\right) \times 100 \qquad (3)$$

where $\overline{Q}_i$ (L h^{-1}) is the mean discharge of each emitter when the test starts.

Results were statiscally studied by means of a variance analysis (VA). Means were separated using a least significant difference (LSD) test at a significance level of 95% (González and Ollero, 1997).

Values of emitter discharges with time were fitted through a regression analysis to several types of curves: lineal; potential; polinomial; exponential and logarithmic.

Emitter discharge equation was determined from the discharge values obtained at the pressures of 60, 100, 140 and 180 kPa, by a regression analysis as well.

The variation of emitter discharge in drip irrigation is the result of several factors: hydraulic variation; manufacturing variability; emitter plugging and water temperature changes. At a given operating pressure, as in our case (100 kPa), there is no hydraulic variation. The importance of each of the remaining three factors can be evaluated through a factorial variance analysis (Cooper, 1969). The contribution of each factor is expressed by the coefficient of variation. The variance analysis permits us to write:

$$CV^2 = \frac{\sigma^2}{\overline{Q}^2} = CV_m^{\,2} + CV_t^{\,2} + CV_c^{\,2} \tag{4}$$

where σ is the standard deviation of emitter discharge, CV is the total coefficient of variation for emitter discharges, CV_m is the variation coefficient of the manufacturer, CV_t is the variation coefficient due to temperature and CV_c is the variation coefficient due to clogging.

CV_c can be obtained from equation 4 once the other CV have been experimentally measured. CV_t can be neglected because temperature variation in laboratory is very low (22-29 °C) and hydraulic regime of emitter is turbulent (Rodríguez-Sinobas et al., 1999).

RESULTS AND DISCUSSION

Deviation of emitter discharge from nominal discharge (D_q) and level of clogging (LC)

Values of D_q and LC obtained after 620 hours of system operation with the two types of wastewater (WPT and WPTF) at nominal pressure (100 kPa) are shown in table 3.

Table 3. Flow Discharge Deviation and Level of Clogging of Emitters after 620 Hours at 100 kPa

Emitters	Q_n (L h^{-1})	WPT				WPTF			
		Q_i (L h^{-1})	Q_f (L h^{-1})	D_q (%)	LC (%)	Q_i (L h^{-1})	Q_f (L h^{-1})	D_q (%)	LC (%)
A	4	3.04	0.02	-99.5	99.3	4.54	3.90	-2.5	14.1
B	4	3.73	3.18	-20.5	14.8	3.74	3.25	-18.7	12.9
C	3.8	3.79	2.98	-21.6	21,4	3.74	3.25	-14.5	13.1
D	4	4.11	4.21	-52.5	53,0	4.03	4.18	-5	8.6
E	4	4.31	4.32	-31.5	37.4	4.37	4.23	-1	10.8
F	4	4.13	3.70	-7.5	10.4	4.12	3.75	-6.3	9.0

A negative value of D_q in table 3 means that flow discharge has decreased and, therefore, clogging has increased. Order of emitter according to its level of clogging is:

- For the WPT: A-D-E-C-B-F
- For the WPTF: A-C-B-E-F-D

The pressure compensating emitter A was the worse in both cases. However, the other pressure compensating emitter D had the best performance when the water was filtered.

A variance analysis taking into account the two different types of used wastewaters and several emitters was done and the means separated (LSD). From the results (see table 4) it can be deduced that there is a significant difference between the two types of wastewaters. When the emitters are compared, a significant difference in the level of clogging was found between emitter A and emitters C, B, and F.

TABLE 4. Test of Means Comparison for the Level of Clogging of Emitters

Emitters	**Homogeneous groups**		**Type of wastewater**	**Homogeneous groups**	
A	I				
D	I	II	**WPT**	I	
E	I	II	**WPTF**		II
C		II			
B		II			
F		II			

<u>Emitter Discharge Variation with Time at Nominal Pressure</u>

Figures 2 and 3 show emitter flow discharge with time using WPT and WPTF respectively. In the first case, emitter A was quickly clogged. For emitter D the flow discharge recovered as the pressure was increased. Then, this raise of pressure is recommended as a method to prevent clogging once the irrigation is finished. In the second case all emitters have the same behavior.

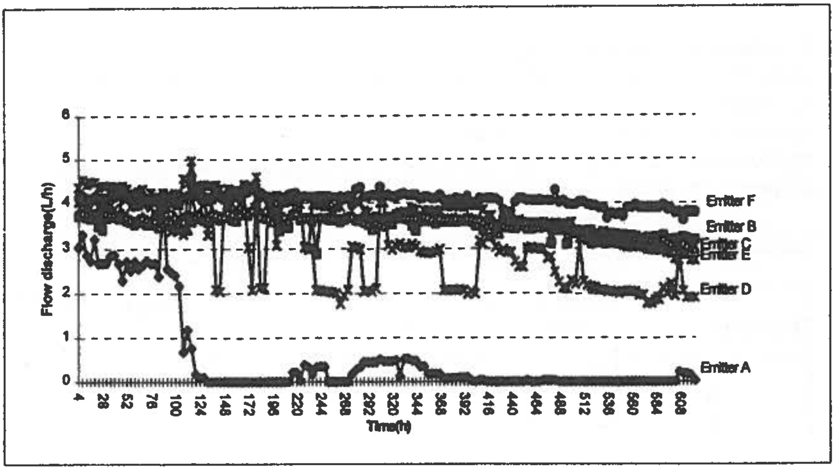

Fig. 2. Flow Discharge Variation with Time at Nominal Pressure Using WPT

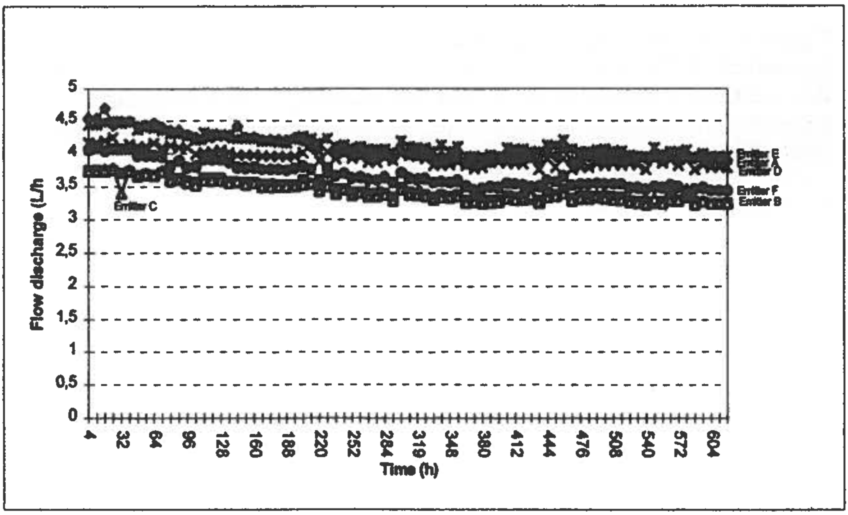

Fig. 3. Flow Discharge Variation with Time at Nominal Pressure Using WPTF

A regression analysis has shown that the general trend of flow discharge along time is best described by a polynomial curve for all emitters. Fitting equations (where y is discharge in L h^{-1} and x is time in hours) and correlation coefficients are in table 5.

Table 5. Equations Q-t for Each Emitter at Nominal Pressure Using two Different Wastewaters

Emitter	**WPT**		**WPTF**	
	Equation	**R^2**	**Equation**	**R^2**
A	$y=0.003x^2-0.0609x+2.93$	0.72	$y=0.0002x^2-0.0232x+4.58$	0.88
B	$y=-4E-05x^2+0.0033x+3.58$	0.69	$y=8E-05x^2-0.0123x+3.77$	0.92
C	$y=-5E-05x^2+0.0033x+3.68$	0.81	$y=9E-05x^2-0.0133x+3.76$	0.85
D	$y=-4E-05x^2-0.0205x+4.19$	0.56	$y=7E-05x^2-0.0099x+4.18$	0.81
E	$y=-5E-05x^2-0.0022x+4.38$	0.85	$y=0{,}001x^2-0.0141x+4.48$	0.87
F	$y=-4E-05x^2+0.0038x+4.07$	0.53	$y=2E-05x^2-0.0041x+4.0365$	0.78

Variation of Emitter Discharge Equation (Q-p) with Time

Parameters of emitter discharge (k, x) were calculated for all emitters and for the two types of wastewaters at the beginning of the test and at the end after 620 hours. Results are shown in table 6.

Table 6. Comparison Between Parameters of Emitter Discharge Equation at the Beginning of the Test and after 620 Hours Using two Different Wastewaters

Emitters	**Phases**	**WPT**			**WPTF**		
		k	**x**	**R^2**	**k**	**X**	**R^2**
A	Q_i	0.76	0.32	0.85	1.47	0.24	0.97
	Q_f	-	-	-	1.53	0.20	0.95
B	Q_i	0.53	0.42	0.99	0.60	0.40	0.99
	Q_f	0.47	0.42	0.99	0.41	0.45	0.99
C	Q_i	0.57	0.41	0.99	0.49	0.44	0.99
	Q_f	0.33	0.48	0.98	0.40	0.46	0.99
D	Q_i	0.58	0.003	0.02	0.70	0.006	0.02
	Q_f	0.33	0.33	0.60	0.47	-0.02	0.32
E	Q_i	0.58	0.44	0.99	0.70	0.40	0.99
	Q_f	0.33	0.47	0.99	0.47	0.46	0.99
F	Q_i	0.57	0.43	0.99	0.77	0.37	0.98
	Q_f	0.75	0.35	0.98	0.39	0.48	0.99

Except for emitters A and D, the correlation coefficient (R^2) tends towards 1. Then, the potential form of the discharge equation is adequate. For emitter D, and in some cases for emitter A, R^2 tends to zero and, therefore, their discharge equation is best represented by a constant function because they are pressure compensating emitters.

A variance analysis of the characteristics parameters of the discharge equation was done. The comparison between means of those coefficients for each emitter showed no significant differences between parameter *k* and significant differences for coefficients *x* between compensating pressure emitters (A and D) and non compensating pressure emitters (C, E, F, and B) (see table 7).

Table 7. Test of Means Comparison for Coefficients of Discharge Equation k and x

k coefficient		**x coefficient**	
Emitters	**Homogeneous group**	**Emitters**	**Homogeneous group**
D	I	**C**	I
A	I	**E**	I
F	I	**F**	I
E	I	**B**	I
C	I	**A**	II
B	I	**D**	II
Treatment	**Homogeneous group**	**Treatment**	**Homogeneous group**
T1	I	**T3**	I
T4	I II	**T2**	I
T2	I II	**T1**	I
T3	II	**T4**	I
T5	II	**T5**	I

The comparison between means of those coefficients for each treatment is also shown in table 7. In this table we have called:

T1: coefficients (*k*, *x*) of the nominal emitter discharge equation
T2: coefficients of the discharge equation at the beginning using WPT
T3: coefficients of the discharge equation after 620 hours using WPT
T4: coefficients of the discharge equation at the beginning using WPTF
T5: coefficients of the discharge equation after 620 hours using WPTF

In this case, we can distinguish two homogenous groups for coefficient *k*, and there are significant differences between the values of *k* in the nominal discharge equation and in the expression obtained after 620 hours using WPT. However, there were no significant differences for coefficient *x*.

As an example, figure 4 shows the discharge equation *Q-p* for all the above conditions in the case of two emitters: one non compensating pressure (B) and other compensating pressure (D).The trend for all curves is the same except for the discharge equation obtained after the system has been operating for 620 hours with WPT.

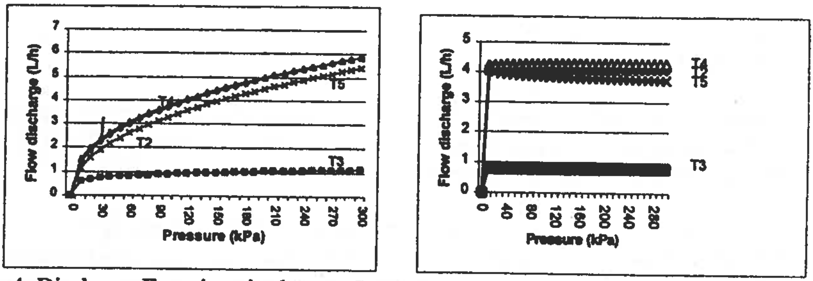

Fig. 4. Discharge Equations in the two Stages of the Test and for the two Types of Wastewaters

Calculation of the Coefficient of Variation Due to Clogging (CV_c)

As we have mentioned before, the CV_c was obtained from expression 4 neglecting previously the coefficient of variation due to temperature (CV_t). The values of the different coefficients of variation (total CV; manufacturing CV_m and CV_c) are shown in table 8. In most cases, CV_c is greater than CV_m when WPT is used. On the contrary, CV_c is lesser than CV_m when the wastewater is filtered (WPTF). Then, the quality of water influences the coefficient of variation.

Table 8. Coefficients of Variation of Emitters after 620 Hours Using the two Types of Wastewaters

Waste water	Coefficient of variation	Emitter					
		A	B	C	D	E	F
WP T	CV^2	4	0.010	0.00480	1.3628	0.01431	0.00034
	CV_m^2	0.00116	0.0012	0.00015	0.0036	0.00094	0.0009
	CV_c^2	3.998	0.0087	0.00358	1.3616	0.01399	0.00055
WP TF	CV^2	0.00054	0.00394	0.00047	0.0019	0.00014	5.8E-05
	CV_m^2	0.00116	0.0012	0.00015	0.0036	0.00094	0.0009
	CV_c^2	0.00061	0.00272	0.00031	0.0016	0.0008	0.00086

CONCLUSIONS

The type of emitter affects significantly the level of clogging. With all types of wastewaters we have used, a compensating pressure emitter (A) has the worse performance. However, we cannot conclude against this type of emitter because emitter D has the best performance when the wastewater is filtered.

The variation of emitter discharge with time is best fitted with a second order polynomial equation.

A pressure increment is recommended after the irrigation has finished in order to prevent clogging. A complementary study is necessary to look for the limits of that increment to avoid the system results very expensive.

The coefficients (k, x) of the emitter discharge equation show significant differences depending on both the type of emitter and wastewater comparing their values at the beginning of the test and after 620 hours. Those differences appear for coefficient x when emitters are considered and for coefficient k when we works with different types of wastewaters.

The coefficient of variation due to the manufacturer is the main factor of variability when the wastewater with primary treatment is filtered. If that water is not filtered, the coefficient of variation due to clogging is the main cause of poor behavior of emitters.

The quality of wastewater influences significantly the level of clogging of the emitters. Plugging can be decreased if wastewater with primary treatment is filtered because the amount of suspended soils is lowered until values quite similar to those obtained with a secondary treatment.

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