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Full Length Research Paper

Emitter clogging and effects on drip irrigation systems performances

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Emitter clogging is one of the most important factors that affect the performances on drip irrigation systems. Emitter clogging, which is formed in a short time due to irrigation systems' running under an inadequate pressure or owing to water quality, not only negatively influences uniformity of water distribution but also causes inadequate irrigation. In this survey, the clogging level determination of the emitters used in drip irrigation systems of some agricultural farms situated in Canakkale and their effects on irrigation performances were observed. The emitters were obtained from different farms in the investigated area, and were tested under the pressures of 50, 100, 150, 200, 250, 300 kPa in hydraulic laboratories. The clogging extend of emitters, flushing of clogging increased pressure and also performance values as coefficient of variation (Cv) under 100 kPa pressure, statistical uniformity (Us), emission uniformity (Eu) and Christiansen's uniformity coefficient (Cu) were established through the tests. Acquired performance values must be matched with emitter performances that have not been used in irrigation. As a result of the study it was determined that some emitters are plugged on laterals used for 2 or 3 years in consequence of the tests. It as also determined that emitter coefficient of variation varied in the ranges of 0.43 and 0.63, 0.43 and 0.69, 0.48 and 0.58, 0.56 and 0.73 for unused emitters, for one year, for two years and for three years used emitters. Coefficient of variation between emitter flows remained within the limit of 5% in all laterals, except for one of the laterals used for one year. Coefficient of variation of emitters along two of the laterals used two years and all of those used three years remained out of 5% limitation. Similar results to CVm (manufacturing variation coefficient) were determined for performance parameters in respect of statistical uniformity (Us), emission uniformity (Eu) and Christiansen's uniformity coefficient (Cu).

Key words: Drip irrigation, emitter clogging, drip irrigation performance.

INTRODUCTION

Nowadays water distribution uniformity on land surface is accepted as one of the key criteria for evaluating irrigation system performances. The uniformity of the total infiltration originated through furrow and border in furrow irrigation systems, the uniformity of water collected in catch cans in sprinkle irrigation systems and the uniformity of emitter flows in micro-irrigation systems are overall measurements which are taken into consideration through performance evaluation (Wu and Barragan, 2000).

Along with high water distribution uniformity in drip irrigation method, increased application efficiency due to minimized water losses by runoff and deep infiltration can be accepted potential advantage of the irrigation method. Because of these superiorities the method has become popular among the other irrigation methods. In order to apply for wide agricultural lands, a portion of project cost has started to be supported by the state in Turkey like in other countries lately (Anonymous, 2007). Besides the advantages mentioned above, drip irrigation method has some disadvantages as decreased water distribution

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Abbreviations: CVm, manufacturing variation coefficient; **Us,** statistical uniformity; **Eu,** emission uniformity; **Cu,** Christiansen's uniformity coefficient; **TDS,** total dissolved solids; **X,** emitter discharge exponent; **K,** emitter discharge coefficient; **R,** correlation coefficient; **Q,** flow.

Table 1. Long term monthly values of some climatic events in Canakkale district (DMGM, 2009).

Meteorologic elements	Months						
	IV	V	VI	VII	VIII	IX	X
Temperature (℃)	12.5	17.4	22.3	25.0	24.7	20.8	16.0
Wind velocity (m s^{-1})	3.7	3.5	3.3	3.7	3.8	3.6	3.8
Total precipitation (mm)	50.6	34.4	20.8	13.3	4.2	17.1	45.8
Evaporation (mm)	105.2	162.4	214.1	258.7	238.7	166.6	102.6
Vapor Pressure (hPa)	11.6	15.4	19.4	21.5	21.4	17.9	14.4
Relative Humidity (%)	79	76	71	68	70	72	78

uniformity due to the emitters. The factors that cause a failure of uniform distribution of water in drip irrigation systems have been presented by different researchers (Bralts et al., 1981; Giay and Zelenka, 1986; Pitts et al., 1986).

The problem of plugging may occur even when all of the factors relating to emitter are suitable for a uniform water distribution. In micro-irrigation systems that are characterized by a number of emitters with narrow nozzles, irrigation uniformity can be spoilt by the clogging of the nozzles with particles of chemical character (Oron et al., 1979; Merriam and Keller, 1978; English, 1985; Capra and Scicolone, 1998). Emitter clogging is directly related to irrigation water quality, which appears a function of the amount of suspended solids, chemical constituents of water and micro-organism activities in water (Gilbert and Ford, 1986). Therefore the mentioned factors have a strong influence on the precautions that will be taken for preventing the plugging of the emitters. During irrigation some cloggings due to micro-organism activities take place in cases when wastewater is used (Ravina et al., 1997; Capra and Scicolone, 1998; Capra and Scicolone, 2006; Ould Ahmet et al., 2007). In locations where the amount of the ingrediens as dissolved calcium, bicarbonate, iron, manganese and magnesium are excessive in irrigation water, the emitters are clogged by the precipitation of these solutes (Gilbert and Ford, 1986; Hills et al., 1989). Thin materials like silt, clay and organic matter suspending in quite narrowing emitter outlet due to the precipitation, accelerate clogging by means of piling up easily. This kind of plugging can widely appear in drip irrigation systems in which ground water or surface water rich in minerals is used for irrigation purposes. Hereunder the emitter clogging is directly related irrigation water quality, in other words the amount of suspending clay, chemical constituents and biological activities.

The province of Canakkale is situated on Biga peninsula which is located in the north-west part of Turkey. Approximately 330.4 thousand ha from the total of 993.3 thousand ha province area, are cultivable land, 34% of which is irrigated land. Among the agriculture enterprises located in provincial borders 66.3% have 0 - 5 ha and 31.7% have 5 -10 ha areas agricultural lands. The small sizes of the cultivated area in the farms make compulsory the usage of the production equipment as drip irrigation systems for longer term. This study was carried out with aim to determine the causes for emitter plugging and to investigate the performance of perennially used emitters on drip irrigation systems across Canakkale district.

MATERIAL AND METHOD

The research was conducted in the agricultural enterprises situated around the province of Canakkale. The investigation area has a climate within a transition characteristic between Mediterranean and Black Sea belts. Since minor part (6.38%) of the of total annual precipitation takes place during the summer months and high average temperature (23.6℃), irrigation appears a fundamental agricultural input (Table 1).

In order to establish the water distribution performances of drip irrigation systems in the district, sample lateral fragments were collected from randomly selected 14 different agriculture enterprises. The samples with 15 emitters along have been taken from 3 different parts of the laterals. Four of the samples were collected from laterals had been used during 3 irrigation seasons, 5 of them for 2 and 5 of them for 1 season. In the course of sample taking, the measurements of flow and pressure were made for evaluating the execution conditions of irrigation systems.

The measurements were taken from initial part of the laterals, from in the 1/3 and 2/3 lateral lengths and from the end of the lateral. It was seen in the performed measurements that the systems execute between 40 and 70 kPa. As there were no different emitter types the samples comprise of inline and point source emitters. The performance tests were carried out in the hydraulic laboratory of Agricultural Structures and Irrigation Department, Canakkale Onsekiz Mart University. Six different pressures of 50, 100, 150, 200, 250 and 300 kPa were tested. The flow pressure relationship and flow regime of emitters were calculated using Equation 1 (Keller and Karmeli, 1975).

$$q = k H^{x} \quad (1)$$

In the equation "q" is the emitter flow that was measured in the laboratory, "k" is emitter discharge coefficient, "x" is the emitter discharge exponent, which characterizes the flow regime and "H" is the entry water pressure (Keller and Karmeli, 1975; Bralts, 1986; Yasar and Anac, 1989).

Although the samples gathered for the purpose of testing are emitters already used for irrigation in order to evaluate their attitude under existing conditions, manufacturing variation coefficient (Cvm) has been measured by Equation 2 (ASAE, 2002).

Table 2. Clogged emitter rate in laterals in reference to the year of usage.

Period of use	The amount of completely clogged emitters (%)					
	50 kPa	100 kPa	150 kPa	200 kPa	250 kPa	300 kPa
1 year	-	-	--	-	-	-
2 years	5.6	5.3	3.7	2.2	1.5	0.94
3 years	18.8	15.6	10.0	6.8	4.8	2.4

$$Cv = \frac{S}{\overline{X}} \quad (2)$$

In Equation 2 "$\overline{X}$" is described as the average flow of emitters "*S*" is as standard deviation. In point source emitters, if Cvm value is less than 0.05 it is assessed as perfect, between 0.05-0.07 is as good, 0.07-0.11 is at limit, 0.11-0.15 is very bad and if it is more than 0.15 that is unacceptable (ASAE, 2002). The S value given in Equation 2 has been calculated by Equation 3.

$$S = \left[\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n-1}\right]^{1/2} \quad (3)$$

Where "x_i" is the emitter flow (1/h) and "n" is the number of emitters. The statistical uniformity between the emitters has been determined by Equation 4 (Bralts and Kesner; 1983).

$$U_s = 100\,(1 - V_q) = 100\,(1 - \frac{Sq}{\overline{q}}) \quad (4)$$

In the equation "Us" defines statistical uniformity (%), "V_q" describes the overall change in emitter flows, "S_q" is the standard deviation of emitter flows and "$\overline{q}$" mean emitter flow rate. Statistical uniformity is evaluated as perfect for 95-100%, good for 85-90%, tolerable for 75 - 80%, very bad for 65-70%, unacceptable for 60% and less (ASAE, 1994).

Application uniformity (Eu) expresses the uniformity of emitters under constant pressure (ASAE, 1994). As given by Keller and Karmeli, (1974) and calculated by Equation 5, Eu is described according to ASAE (1994) standards as perfect for 94-100%, good for 81-87%, tolerable for 68-75%, very bad for 56-62% and unacceptable for 50% and less than it.

$$Eu = 100\,(1 - \frac{1.27Cv}{\sqrt{n}})\frac{q_n}{q_a} \quad (5)$$

In the equation "Eu" is system application uniformity (%), "Cvm" is manufacturing variation coefficient, "n" is the number of emitters per plant, "q_n" is the lowest flow under the lowest pressure and "q_a" is the average emitter flow. Christiansen's uniformity coefficient (Cu) is calculated by Equation 6. The obtained results have been assessed by considering the circumstance of Cu ≥ %97.5 when the distinction between the highest and the lowest emitter flows is 10% (Korukcu, 1980; Yildirim and Apaydin, 1999).

$$Cu = 100\,(1 - \frac{\Delta q_o}{q_o}) \quad (6)$$

"Cu" is defined as Christiansen's uniformity coefficient (%), "Δq_o" is as average absolute deviation of the average of each emitter or lateral inlet flow, "q_o" is the average emitter or lateral inlet flow.

RESULTS AND DISCUSSION

Firstly, clogging of emitters has been controlled among the samples from the agriculture enterprises. Controls performed using different pressure applications showed that the flow is obtained from one year used emitters while no flow appear from the used two or three years (Table 2). Though the pressure was increased in the test code, the emitters could not be flushed completely blocked, especially in the samples with 3 years of usage. Since waste waters are not used as irrigation water source in Canakkale province the plugging of the emitters obviously appears due to inadequate filtration of the chemical ingredients and sediments in water, Some chemical analysis results of the samples taken from the water sources used for agricultural purposes are given in Table 3.

According to chemical analysis results the hardness identifying the formation of $CaCO_3$ has been calculated as 94.76 ppm at least and 286.564 ppm at most. PH values of irrigation water were determined in the ranges of 7.2 and 8.1. Total dissolved solids (TDS) were determined to fluctuate between 190 - 656 ppm and Ca^{+2} have been measured between 26.62 ppm and 89.63 ppm.

The emitters that were used in irrigation were placed on lateral pipes having the ability of at least 5 years of usage. So, through the lateral's economic life its flow and performance values can be used without a change. But, after three years some emitters with no water flow were determined. If hardness is between 150 and 300, it causes medium sized emitter clogging (James, 1988; Hills et al., 1989; Kuslu et al., 2005). On the other hand the amounts of TDS less than 550 ppm, it causes a small sized clogging, while higher values causes medium sized

Table 3. Chemical characteristics of some agricultural water sources in the province of Canakkale.

Water source	Hardness[a]	pH	TDS*	SO_4	Cl	Al	B	Ca	Cu	Fe	Mg	Mn	Na	Pb	Zn
1	168.69	7.9	438	30.15	21.46	0.01	0.07	41.88	0.01	0.02	15.57	0.00	31.45	0.01	0.01
2	151.68	7.9	386	19.39	16.59	0.01	0.05	43.82	0.01	0.00	12.69	0.00	23.99	0.01	0.00
3	108.92	7.3	219	5.18	4.27	0.01	0.04	31.96	0.01	0.01	7.07	0.00	7.94	0.02	0.02
4	286.564	7.6	656	183.78	20.49	0.01	0.06	89.63	0.01	0.00	15.24	0.00	36.80	0.01	0.01
5	94.76	8.1	190	7.32	5.31	0.02	0.04	26.62	0.01	0.01	6.87	0.00	6.24	0.03	0.00
6	208.25	7.8	483	105.08	9.24	0.01	0.01	58.86	0.01	0.00	14.88	0.00	24.76	0.00	0.00
7	115.79	7.2	366	40.95	16.77	0.00	0.05	31.91	0.02	0.03	8.77	5.98	37.95	0.02	0.02

Measured by [a] $mgCaCO_3/L$, (2.497 [Ca^{+2}, mg/L] + 4.118 [Mg^{+2}, mg/L])
*TDS: Total dissolved solids

Table 4. Average flow values obtained under different pressures.

Emitter		Average flow values (ml/h)					
Period of use	Sample	50 kPa	100 kPa	150 kPa	200 kPa	250 kPa	300 kPa
Unused	1	2801	3630	4523	5283	5966	7104
	2	3224	4334	5488	6141	7088	7887
	3	3670	4830	5743	6764	7194	7986
	4	2876	3843	4902	5664	6390	6991
	5	3019	4368	5847	6999	8111	9204
1 Year	1	2108	3392	5015	5839	6311	7142
	2	3642	4264	5612	6411	6955	7617
	3	3630	4223	5636	6965	7622	8358
	4	3449	4183	5067	5990	6482	7154
	5	2821	3518	4539	5391	5721	6485
2 Years	1	2807	3693	4464	5283	5975	6677
	2	2813	3919	4930	5786	6455	6898
	3	3028	4097	4787	5779	6547	7137
	4	3266	4095	5403	6764	7526	8446
	5	2065	3034	3752	4665	5283	5809
3 Years	1	2378	3012	4310	5700	6309	7284
	2	2644	3925	5073	5972	6962	7558
	3	1741	2910	3870	4896	5618	6372
	4	2530	3230	4037	5096	5783	6954

All analysis results are in given as ppm"

sized plugging (Pitts et al., 1990). As could be concluded from analysis results included in Table 3, the precipitation of the existing Ca^{+2} and Mg^{+2} ions in irrigation waters due to the influence of the temperature and pH, plays a major role in the rise of the flow change and clogging problems among emitters.

Results of the tests carried out in order to determine the performance values show that emitter flow increase with increasing application pressure (Table 4). All the emitters used in tests are self pressure compensating emitters expected discharge flow of 4 l/h under operating pressure of 100 kPa. Only manufacturer coefficient (Cv) is supposed to be effective on emitter flows in the laboratory conditions (Ozekici and Bozkurt, 1999; Camoglu, 2004; Camoglu and Yavuz, 2006).

Though, the possible cloggings of the water outlets have also been effective on the flow of sampled emitters. The rise of flows on applied pressure increases through the tests materialized to the extent that the plugging allowed. The values of the type of flow, emitter discharge

Table 5. The characteristics of emitters used in tests.

The symbol of emitter		The emitter characteristics acquired in the consequence of the tests*			
		x	k	r	Q (l/h)
Unused	1	0.5079	1.2048	0.9908	3.63
	2	0.4985	1.4446	0.9977	4.33
	3	0.4341	1.8356	0.9983	4.83
	4	0.5045	1.2753	0.9982	3.84
	5	0.6276	1.0993	0.9985	4.37
1 Year	1	0.6905	0.7196	0.9938	3.39
	2	0.4308	1.7485	0.9862	4.26
	3	0.4960	1.5324	0.9796	4.22
	4	0.4162	1.7080	0.9915	4.18
	5	0.4741	1.2767	0.9920	3.52
2 Years	1	0.4844	1.2585	0.9958	3.69
	2	0.5129	1.2383	0.9991	3.92
	3	0.4818	1.3767	0.9964	4.10
	4	0.5509	1.2769	0.9884	4.10
	5	0.5844	0.8057	0.9988	3.03
3 Years	1	0.6549	0.7716	0.9844	3.01
	2	0.5943	1.0230	0.9996	3.93
	3	0.7274	0.5507	0.9997	2.91
	4	0.5613	0.9631	0.9841	3.23

*: In calculations 100 kPa=9.8 m is accepted.

Table 6. The control of x coefficient of the flow regime by T test.

Year	Average Flow (l/h)	$\overline{X} \pm S\overline{x}$ (1)	P (2)
Unused	4.2	0.515± 0.0313	-
Used 1 year	3.9	0.502± 0.0494	0.8297
Used 2 years	3.8	0.523± 0.0198	0.8273
Used 3 years	3.3	0.634± 0.0365	0.0407

1: Average and standard error; 2: depends on the comparison of used and unused emitters with T test.

exponent (x), emitter discharge coefficient (k), correlation coefficient (r) and flow (Q) obtained from the emitters under the pressure of 100 kPa, are presented in Table 5. Despite some emitters had partial or complete clogging, the flow was estimated to increase with increasing pressure. Hence the correlation coefficients of the relationship between pressure and flow in each of the four emitter groups were determined to be almost 1.00 (Puskulcu and Ikiz, 1986). As given in Table 3, water outlet's existence of being partly or completely clogged, induced a higher result of x coefficient among the emitters with 2 or 3 years of usage. After T tests performed by using x values (Table 6) it has been concluded that the difference between x values of the ones with one or two years of usage is of no statistical importance ($P>0.05$) whereas x value of the emitters with 3 years of usage statistically differentiates from the unused ones in a significant way ($P = 0.0407$).

The tests on performance of the emitters were performed under predicted pressure of 100 kPa (Goldberg et al., 1976; ASAE, 2002). The results of the tests have been presented in Table 7. When the performance values were evaluated according to years, all of them went bad as the year of usage increased. Assessment of the performance criteria of pointed out that while the performance values of the unused emitters and those used one year could be evaluated as similar and perfect, three of the emitters with 2 years of usage could be identified as perfect, but only one sample of those used 3 years could be described as good and the rest as tolerable or

Table 7. Obtained performance values from the emitters under the pressure of 100 kPa.

	Unused [1]			**Uniformity parameter values**				
	Number of Emitters	**Number of Iteration**	$\bar{q}$ **(L/h)**	q_{var}	**CV (%)**	**EU (%)**	**Us (%)**	**CU (%)**
1	24	3	3630	0.066	2.64	96.58	97.36	97.90
2	24	3	4830	0.087	3.78	95.77	96.22	96.47
3	24	3	3843	0.105	3.09	96.27	96.91	97.53
4	24	3	4368	0.074	1.67	97.91	98.33	98.75
5	24	3	3183	0.069	1.62	98.12	98.38	98.84
	Used one year			**Uniformity parameter values**				
	Number of Emitters	**Number of Iteration**	$\bar{q}$ **(L/h)**	q_{var}	**CV (%)**	**Us (%)**	**EU (%)**	**CU (%)**
1	10	3	3392	0.073	2.66	97.34	96.97	97.73
2	23	3	4097	0.078	2.10	97.90	97.46	98.31
3	23	3	4095	0.072	1.59	98.41	97.79	98.80
4	24	3	3518	0.038	1.23	97.77	98.41	98.94
5	19	3	4264	0.091	2.24	97.76	97.47	98.33

	Used two year				**Uniformity parameter values**			
	Number of Emitters	**Number of Iteration**	$\bar{q}$ **(L/h)**	q_{var}	**CV (%)**	**Us (%)**	**EU (%)**	**CU (%)**
1	22	3	3266	0.077	2.70	97.30	96.21	97.65
2	23	3	3693	0.389	17.17	82.83	74.14	84.72
3	19	3	3919	0.053	1.63	98.37	97.91	98.64
4	23	3	3028	0.095	2.58	97.42	96.63	97.96
5	19	3	3034	0.668	25.72	74.28	70.52	76.71

	Used three year				**Uniformity parameter values**			
	Number of Emitters	**Number of Iteration**	$\bar{q}$ **(L/h)**	q_{var}	**CV (%)**	**Us (%)**	**EU (%)**	**CU (%)**
1	23	3	3012	0.691	31.55	68.45	60.72	72.44
2	19	3	3925	0.332	8.11	91.89	90.23	94.66
3	22	3	2910	0.691	23.51	76.49	72.94	79.34
4	24	3	3230	0.658	29.32	70.68	66.59	74.07

Unused [1] : Taken from the research results used for a post graduate thesis called "The Analysis of Uniform Water Distribution on the Emitters with Different Manufacturer and Manufacturing Characteristics".

or very bad.

Conclusion

Laboratory tests results pointed out that 15.6% of 3-year used emitters collected form drip irrigated lands do not have any flow under operating pressure of 100 kPa. Evaluations done on the performance of the emitters showed that performance values of unused emitters and those used one year are at acceptable limits, while the performance of some of the emitters used 2 or 3 years is inadequate in terms of manufacturing variation coefficient (Cv), statistical uniformity (Us), emission uniformity (Eu) and Christiansen's uniformity coefficient (Cu). In the process of negative changing in emitter performances by years, the chemical constituents of water resources and siltation, as well as the operating the irrigation systems under low pressures like 40 and 70 kPa are influential.

Among the other methods drip irrigation came to the forefront by some basic advantages. But this method's success is particularly based on the effective use of the emitters. For this purpose:

- Producers must be familiar with use of the drip irrigation systems.
- Drip irrigation systems must be executed under the prescribed pressure (100 kPa).

- The performance values of emitters that will be selected must be well known at project, design and application stages of drip irrigation system.
- Emitters must be flushed by reducing pH of the irrigation water before or after each irrigation season. In order to prevent any precipitation due to acid used for flushing, the Ca and Na contents of irrigation water must be taken into consideration.
- Emitters flow must be controlled constantly during the process of irrigation and in case of the determination of the clogging flushing process must be repeated.

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