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Effect of Different Pipe Wall Thicknesses on Flow Rate of Cylindrical Type Integrated Emitters Used in Drip Irrigation Pipes

Silindirik Tip Damlatıcılı Damla Sulama Borularında Farklı Boru Et Kalınlıklarının Damlatıcı Debileri Üzerine Etkisi

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Keywords:

Drip irrigation, in-line drip emitter, pressure-discharge relationship

ABSTRACT

Objective: The objective of this study was to investigate the effect of different pipe wall thickness on the flow rate of cylindrical type integrated emitters used in drip irrigation pipes.

Material and Methods: Cylindrical in-line integrated type, non-pressure compensated two drip emitters were considered within the scope of this work. The drip emitters (E1 and E2) manufactured by two different companies were integrated in 1.1, 0.9 and 0.6 mm wall thickness pipes. The emitter flow rate measurements were carried out at five different pressure levels for all drip irrigation pipes.

Results: The operating pressure and flow rate relationships for the emitters and drip irrigation pipes at each pipe wall thickness were also determined. In general, it was also observed that when the wall thickness decreased sequentially from 1.1 mm and 0.9 to 0.6 mm, average emitter flow rate increased about 30% based on the brand of the emitter as well as on pressure. The variation of emitters flow rate based on the wall thickness at the nominal pressure of 100 kPa was analyzed statistically. Based on the results, these variations were found statistically significant ($P<0.05$) for all drip irrigation pipes equipped with E1 and E2 type emitters.

Conclusion: The results of the study clearly showed that these wall thickness changes caused significant changes in emitter flow rates.

Anahtar Sözcükler:

Damla sulama, içine gecik damlatıcı, basınç-debi ilişkisi

ÖZ

Amaç: Bu çalışma, aynı tip damlatıcının farklı et kalınlığına sahip damla sulama borularına entegre edilmesi durumunda, damlatıcı debisi üzerine etkilerini ortaya koymak amacıyla yapılmıştır.

Materyal ve Metot: Çalışmada iki farklı firma tarafından imal edilen türbülanslı akış rejimine sahip, boru içine entegre, silindirik tip, basınç dengeleyici özelliği olmayan damlatıcılar ele alınmıştır. İki farklı firma tarafından imal edilen damlatıcılar (E1 ve E2) 1.1, 0.9 ve 0.6 mm et kalınlığına sahip borulara yerleştirilmiştir. Damlatıcı debi ölçümleri beş farklı basınçta gerçekleştirilmiştir. Denemeler sonucunda, her bir boru et kalınlığındaki damlatıcı ve damla sulama borusu için basınç-debi ilişkileri ortaya konulmuştur.

Bulgular: Genel olarak boru et kalınlığının 1.1 mm'den, 0.9 mm'ye ve en düşük değer olan 0.6 mm'ye düşmesi durumunda, üretim yapan firmanın damlatıcısına ve deneme basıncına göre %30'lara varan oranlarda artış meydana geldiği gözlenmiştir. Çalışma kapsamında, 100 kPa nominal çalışma basıncında damlatıcı debilerinde, et kalınlığına bağlı olarak meydana gelen bu değişim değerleri istatiksel yönden araştırılmış ve Duncan istatistik analiz sonuçlarına göre damlatıcı debilerinde meydana gelen değişimin E1 ve E2 marka damlatıcılı damla sulama borularının tümünde istatistiksel olarak önemli ($P<0.05$) olduğu bulunmuştur.

Sonuç: Çalışma sonuçları açıklıkla göstermiştir ki boru et kalınlığındaki değişimler, damlatıcı debileri üzerinde önemli değişikliklere neden olmaktadır.

INTRODUCTION

The optimization of irrigation water requires both the correct design of the water distribution system and the choice of management options that limit crop water requirements, without affecting crop yields and quality (Autovino et al. 2016). Fundamentally, the success of a drip irrigation system is affected by imprecise design or inaccurate management. Therefore, it is necessary to select the appropriate system components to have a success of a drip irrigation system. One of the most important ones is selecting of the appropriate drip emitter flow rate. Based on the selected drip emitter flow rate, the system is designed to provide a uniform water distribution. Water can be supplied to the soil and plant with a uniform distribution with a well-designed system so that drip irrigation systems provide better advantages as compared to other irrigation methods.

Factors affecting water distribution uniformity can be divided into two groups: the first is directly related to the structure and manufacture of the drip emitter, such as having pressure or non-pressure compensating, and manufacturing variations of the emitters. The second factor is related to the flowing characteristics in the lateral line, such as the changes in assembling of the emitter, pressure loss along the pipe, clogging of the emitters in partial or completely (Bralts et al. 1981; Pitts et al.1986). The flow rate variations due to the above causes play an important role on the uniform water distribution.

Drip emitters are usually classified according to flow rates at operating pressure 100 kPa, and the flow rate of the non-compensated emitters depends on the operating pressure of the emitter. The relationship between these two variables has been defined by the following equation in numerous past studies (Howell and Hiler, 1974; Keller and Karmeli, 1974).

$$q = kH^{x} \tag{1}$$

where; q is the emitter flow rate in L h^{-1}; H is the emitter operating pressure in kPa, and k is the emitter flow coefficient in L h^{-1} kPa^{-x} and x is the emitter flow exponent in dimensionless. The value of the coefficient of k in the equation (1) depends on the physical dimensions of the water passage paths in the emitter. The value of x characterizes the emitter's flow regime and represents the most important factor in designing the irrigation system because it affects the uniform water distribution.

The emitter flow exponent (x) is equal to 0.5 for fully turbulent flow, while is equal to 1.0 for when the flow inside the emitters is laminar and when x equals to 0, emitter would be fully pressured compensating type (Bralts, 1986).

The uniform water distribution in the drip irrigation systems is quite important. Therefore, variations in the emitter flow rate or operating pressure should not exceed acceptable limits on the lateral lengths. For this reason, several variations and uniformity equations were developed such as the emitter flow variation (q_{var}) and the Christiansen uniformity coefficient (C_u) (Bralts, 1986; Christiansen, 1942). A reasonably high value of distribution uniformity coefficients can be obtained by limiting the variations of emitter discharge and of pressure head, respectively of 5% and 10% of the corresponding nominal values (Baiamonte et al. 2015).

Numerous important studies in order to determine the optimal lateral lengths have been carried out to calculate the friction losses in the past and the researchers employed analytical solution methods (Warrick and Yitayew, 1988; Wu, 1992; Hathoot et al. 1993; Valiantzas, 1998; Baiamonte et al. 2015), statistical solution methods (Anyoji and Wu, 1987), analysis with finite element method (Kang and Nishiyama, 1996), with computational fluid dynamics (CFD) (Provenzano et al. 2007), and by considering dimensionless terms (Demir et al. 2007; Marti et al. 2010; Provenzano et al. 2014) in previous works.

The actual emitter flow rate is an extremely important variable not only to define irrigation timing according to the soil-plant-water relationship but also to determine the friction losses in the lateral line. There are two important stages in the manufacturing of drip irrigation pipes. The first stage is the manufacturing of the drip emitter, while the second stage is the integrating of the emitter into the pipe during the pipe manufacturing. The emitter flow rate could be different than the planned value due to some problems in the described manufacturing stages. These differences could arise from the mold and injection machine used in the manufacturing of the drip emitter, as well as from the extrusion machine used during the integration of the emitter into the pipe in the manufacturing of the pipe.

Doğan (2011) investigated the effects on lateral diameter and on emitter flow rate consequent to the increase operating pressure. The study was conducted at five different operating pressures in between 100 and 200 kPa using drip irrigation pipes manufactured by six different manufacturers. Based on the findings of this study, it was determined that statistically significant expansions took placed in the lateral diameters by the variation of pressure. In another recent study conducted by Provenzano et al. (2016) an experimental investigation carried out to model the pipe effective diameter as a function of water pressure, as well as to analyze the values of friction losses per unit of pipe length in deformable polyethylene pipes characterized by different wall thicknesses. In the study, the aim was identifying and assessing a general procedure for their evaluation.

In general, the increase of flow rate at rising operating pressure is associated to the turbulent flow regime inside the emitter flow path. Furthermore, the flow rate of the emitter is directly related to the flow cross-section area of the designed emitter. Any changes in the flow cross-section area during the manufacturing process may affect the emitter flow rate. This situation could cause deviations according to the nominal flow rates of the emitters and application problems in the projects designed by considering the nominal flow rates. Hence, a study was conducted and the objective of this study was to investigate the effect of wall thickness on the emitter flow rates in drip irrigation pipes manufactured with different wall thicknesses using the same type of drip emitters.

MATERIAL and METHOD

Material

Drip irrigation pipes with 16 mm nominal external diameter manufactured by two different local companies (E1 and E2) were used in this study. Integrated in-line drip emitters were co-extruded into pipes with three different wall thicknesses. All emitters had similar properties in terms of their turbulent flow regime and long flow path, and they were also cylindrical and non-pressure compensating. The general dimensions of emitters and laterals are given in Table 1. General specifications of the drip irrigation pipes and integrated in-line emitters are presented in Figure 1.

Method

The drip irrigation laterals with the same type drip emitters were placed horizontally on the 6 m long test stand (Korukçu, 1980; Mizyed and Kruse, 1989). The schematic view of the drip irrigation experimental layout is presented in Figure 2. The emitter spacing was selected as 20 cm to minimize the effects of the flow rate variation that may occur due to the friction losses along the pipe. Water was supplied to the test stand passing through the disc filter by using a centrifugal pump, and the operating pressures of 50, 100, 150, 200 and 250 kPa were adjusted by the control valves at the pump outlet. The pressure values were controlled by a digital manometer (Keller LEO1, Switzerland) having a precision of <0.1% of the full scale and it was placed after filter into the lateral inlet. The flow rates of a total 30 emitters in each drip irrigation pipes were measured by using 1000 ml graduated cylinders (Bralts and Wu, 1979; Mizyed and Kruse, 1989). Emitter flow rate measurements were repeated on three different sample of the same pipe. Water temperature was measured approximately between 18 and 22°C during the experiments.

Wall thickness of the pipes was measured from four points at 5 different sections with an accuracy of 0.01 mm by employing a digital caliper. The operating pressure-flow rate relationships of the emitters were obtained using the measured flow rates at each pressure value.

The difference between the variations in the drip emitters' flow rates depending on the wall thickness was investigated statistically at 100 kPa, which is accepted as the nominal operating pressure. For this purpose, Duncan statistical analysis test (Duncan's Multiple Range Test) was performed and the results were evaluated statistically (Efe et al. 2000). The computer-based statistical program called IBM SPSS (2011) was used for the statistical analysis.

Table 1. General dimensions of the emitters and laterals considered in the study

Çizelge 1. *Çalışmada ele alınan damla sulama borularının genel boyutları*

Emitter					Lateral				
							Wall thickness, e (mm)		
Drip emitter	Nominal flow rate q (L h^{-1})	External diameter d_o (mm)	Internal diameter d (mm)	Length L_e (mm)	External diameter D_o (mm)	Internal diameter D (mm)	Nominal wall thickness (mm)	Measured wall thickness (mm)	Variation Δe (mm)
E1	2	16.0	11.6	39.3	15.4	14.3	1.1	1.08	+0.02
					15.4	14.5	0.9	0.93	-0.03
					15.4	14.8	0.6	0.63	-0.03
	4	16.0	11.6	39.3	15.4	14.3	1.1	1.06	+0.04
					15.4	14.5	0.9	0.89	+0.01
					15.4	14.8	0.6	0.60	0.00
E2	2	16.0	11.7	37.3	16.0	14.9	1.1	1.07	+0.03
					16.0	15.1	0.9	0.94	-0.04
					16.0	15.4	0.6	0.64	-0.04
	3	16.0	11.7	37.3	16.0	14.9	1.1	1.05	+0.05
					16.0	15.1	0.9	0.85	-0.05
					16.0	15.4	0.6	0.71	-0.11

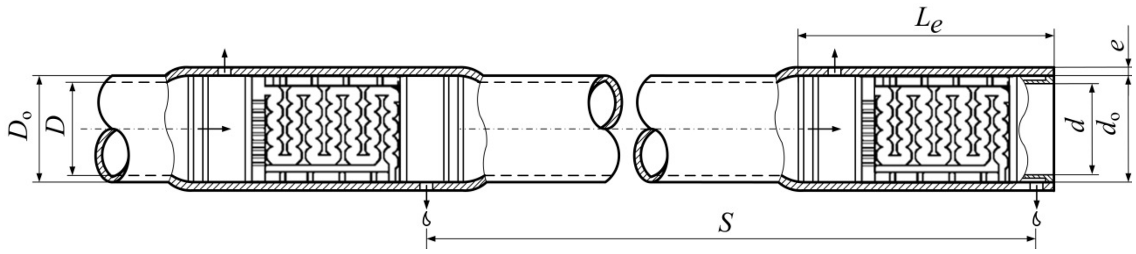

Figure 1. General specifications of the drip irrigation pipes and integrated in-line type emitters
(*D* and *Do*, internal and external pipe diameter; *d* and *do*, internal and external emitter diameter; S, emitter spacing; *Le*, emitter length)
Şekil 1. *Çalışmada ele alınan damlatıcıların genel yapısı*

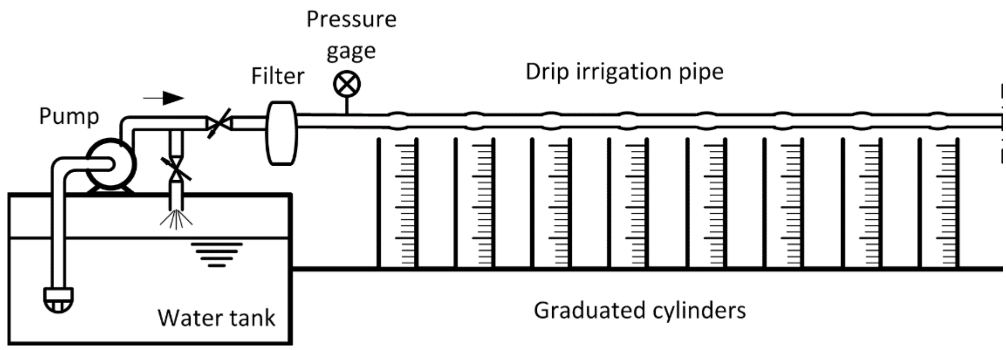

Figure 2. Schematics of experimental layout
Şekil 2. *Deneme düzeninin şematik görünümü*

RESULTS and DISCUSSION

Parameters related to the operating pressure-flow rate relationships of the examined emitters in the study are given in Table 2.

As can be seen from Table 2, the flow regime coefficients were found to be very close to *x*=0.5. This result indicated that all of the examined emitters were in the fully turbulent flow regime, and the emitters flow rates changed depending on the operating pressure (Pitts et al. 1986, Demir, 1991, Demir and Yurdem, 2000).

From Table 2, it could be seen that the coefficient *k* varied considerably depending on the nominal flow rate of the emitter. When the variation of *k* coefficients according to pipe wall thickness at the same nominal flow rate was analyzed, it was found that the emitter flow rates increased due to a decrease of pipe wall thickness, generally. The variation in k value was also very important in that showing the effect on the change of flow cross section of the clearance formed between pipe wall and emitter after integration except for delivering the properties of each drip emitter's manufacture. Average flow rates and the variations of flow rate based on the different pipe wall thicknesses for E1 and E2 emitters are given in Tables 3, and the comparison of the variations is given in Figures 3 and 4.

Table 2. Parameters related to the operating pressure-flow rate relationships of the examined emitters

Çizelge 2. *Çalışmada incelenen damlatıcıların basınç-debi ilişkilerine ait parametreler*

Drip emitter	Nominal flow rate of emitter q (L h^{-1})	Nominal wall thickness of lateral pipe e (mm)	Flow coefficient of emitter k (L h^{-1} kPa^{-x})	Flow exponent of emitter x	Coefficient of determination R^2
E1	2	1.1	0.2005	0.5104	0.964
		0.9	0.2353	0.4854	0.987
		0.6	0.2561	0.4880	0.995
	4	1.1	0.4139	0.4921	0.991
		0.9	0.4064	0.4992	0.986
		0.6	0.4452	0.4848	0.988
E2	2	1.1	0.1459	0.5225	0.937
		0.9	0.1870	0.5120	0.941
		0.6	0.2130	0.5028	0.926
	3	1.1	0.2452	0.5435	0.994
		0.9	0.2949	0.5275	0.992
		0.6	0.2960	0.5347	0.994

Table 3. Average flow rates and the variations of flow rate based on the different pipe wall thicknesses for E1 and E2 type drip emitters

Çizelge 3. *E1 ve E2 damlatıcılarının ortalama damlatıcı debileri ve farklı boru et kalınlıklarına göre debi değerlerindeki değişimler*

Operating pressure of emitter H (kPa)	E1				E2			
	Nominal flow rate of emitter q (L h^{-1})	Variations of flow rate based on the pipe wall thicknesses (%)			Nominal flow rate of emitter q (L h^{-1})	Variations of flow rate based on the pipe wall thicknesses (%)		
		1.1-0.9 (mm)	0.9-0.6 (mm)	1.1-0.6 (mm)		1.1-0.9 (mm)	0.9-0.6 (mm)	1.1-0.6 (mm)
50	2	6.04	9.49	16.11	2	21.24	11.68	35.40
100		4.78	10.50	15.79		23.93	7.43	33.13
150		3.10	10.90	14.34		21.67	6.48	29.56
200		2.65	9.68	12.58		20.60	9.61	32.19
250		2.08	10.17	12.46		20.38	10.22	32.69
50	4	0.70	3.83	4.56	3	14.15	2.14	16.59
100		2.27	2.22	4.55		10.26	5.71	16.56
150		1.43	1.41	2.87		10.40	4.11	14.93
200		1.96	1.57	3.56		11.78	3.51	15.70
250		2.07	1.56	3.66		10.10	4.22	14.75

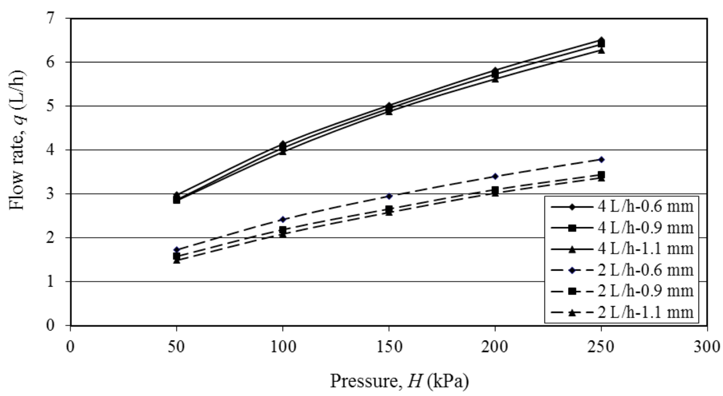

Figure 3. Variations of emitter flow rates based on different pipe wall thicknesses for E1 type emitter
Şekil 3. *E1 damlatıcısının farklı boru et kalınlıklarına göre debi değerlerindeki değişimler*

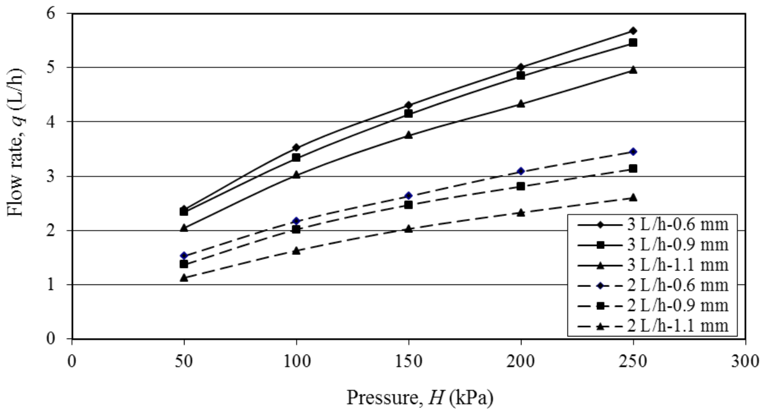

Figure 4. Variations of emitter flow rates based on different pipe wall thicknesses for E2 type emitter

Şekil 4. *E2 damlatıcısının farklı boru et kalınlıklarına göre debi değerlerindeki değişimler*

As seen from Table 3 and Figure 3, it was found that emitter flow rate increased due to the decreasing of the pipe wall thickness for E1 type drip irrigation pipes.

The flow rate of the emitter having 2 L h^{-1} nominal flow rate at different operating pressures increased an average 3.7% when the pipe wall thickness was 0.9 mm instead of 1.1 mm, and increased an average 10.1% when the pipe wall thickness was 0.6 mm instead of 0.9 mm. The total increasing in the emitter flow rate was found an average 14.3% when the pipe wall thickness was 0.6 mm instead of 1.1 mm. Similarly, for the 4 L h^{-1} nominal flow rate, the emitter flow rate increased an average of %1.7 when the pipe wall thickness was 0.9 mm instead of 1.1 mm, and increased an average of %2.1 when the pipe wall thickness was 0.6 mm instead of 0.9 mm at different operating pressures. On the other hand, an increase of totally 3.8% was observed when the pipe wall thickness was 0.6 mm instead of 1.1 mm.

As can be seen from the Table 3 and Figure 4, it was found that the results were similar to those of E1 type drip irrigation pipe, and the emitter flow rate increased due to the decreasing of pipe wall thickness in E2 type drip irrigation pipes. The increase in the flow rate at all operating pressures was found to be an average 32.6% and 15.7% for 2 L h^{-1} and 3 L h^{-1} nominal flow rate, respectively, when using the pipe with minimum wall thickness of 0.6 mm instead of 1.1 mm.

A decrease of emitter flow rates based on the increase in pipe wall thickness could be explained could be explained by the change in emitter flow cross-section area depend on the integration of pipe wall line and emitter. This variation in flow rates may also be explained by the increase in emitter flow cross section due to the reduction of overlap of the emitter with the plastic material during the connection of the pipe and the drip emitter in the extruder line. In addition, it appears that more influence due to the increase in pressure on the material with less pipe wall thickness. In previous studies carried out by Dogan (2011) and Provenzano et al. (2016) have shown that the expansion in the periphery of polyethylene pipes has changed due to the pipe wall thickness under the same pressure. Also, Dogan (2011) stated that the emitter flow rates had changed as a result of these changes. It could be said that the results in the study are compatible with the other study results.

Based on the standard of TS EN ISO 9261 (2007) the variation between the average emitter flow rate of the test sample and the nominal flow rate should not exceed the value of ±7%. In general, the deviation values in the flow rate for the drip irrigation pipes investigated in the study were found considerably higher than the nominal value. The results show that this situation had come out especially in drip irrigation pipes with low nominal flow rate. Considering the study that Baiamonte et al. (2015) pointed out that as a criterion of 5% variation of the nominal emitter flow rate was widely used for the design of drip irrigation laterals. It could be concluded that high flow rate variations depending on pipe wall thickness must be considered when designing drip irrigation systems.

According to TS EN ISO 9261 (2007) nominal operating pressure for non-pressure compensating emitters in drip irrigation systems is accepted as 100 kPa. In the study, Duncan statistical analysis test was employed to determine the difference between the nominal and the measured flow rates variation depending on the pipe wall thickness of the E1 and E2 drip irrigation pipes at the nominal operating pressure of 100 kPa. The statistical analysis results and variations of flow rates based on the nominal flow rate are given in Table 4.

Table 4. Variations in the emitter flow rates based on different pipe wall thicknesses at 100 kPa operating pressure for E1 and E2 type drip emitter

Çizelge 4. *A ve B damlatıcıları için 100 kPa çalışma basıncında boru et kalınlığına bağlı olarak damlatıcı debilerinde meydana gelen değişimler*

Drip emitter	Nominal flow rate of emitter q (L h^{-1})	Nominal wall thickness of lateral pipe e (mm)	Average emitter flow rate q_{avg} (L h^{-1})	Variations of flow rate based on nominal flow rate (%)
E1	2	1.1	2.09^{a}	4.38
		0.9	2.19^{b}	9.30
		0.6	2.42^{c}	20.98
	4	1.1	3.96^{A}	−0.94
		0.9	4.05^{B}	1.31
		0.6	4.14^{C}	3.37
E2	2	1.1	1.63^{aa}	−18.50
		0.9	2.02^{bb}	1.00
		0.6	2.17^{cc}	8.25
	3	1.1	3.02^{AA}	0.50
		0.9	3.33^{BB}	10.83
		0.6	3.52^{CC}	17.17

Means with the same letter are not significantly different from each other (Significant at $P<0.05$).

In Table 4, in both types of drip emitters (E1 and E2), it was found that the flow rate of the emitters increased with the decrease of the pipe wall thickness. The change in flow rate due to pipe wall thickness was found statistically significant at 95% significance level.

For E1 type emitter, the variations of flow rates based on the nominal flow rate for different pipe wall thickness were found between 4.38% and 20.98% and from −0.94% to 3.37% for 2 L h^{-1} and 4 L h^{-1}, respectively. It was determined that the percentage change was found higher for the emitter with low flow rate (2 L h^{-1}). In addition, as the pipe wall thickness decreased, the variation of flow rate from its nominal value had an increasing trend at both nominal flow rates (2 and 4 L h^{-1}).

For E2 type emitter, the variations of flow rates based on the nominal flow rate for different pipe wall thickness were found between −18.5% and 8.25% and from 0.50% to 17.17% for 2 and 3 L h^{-1}, respectively.

The average values of the emitter flow rates obtained at different wall thicknesses of E1 and E2 emitters of 2 L h^{-1} were found different from each other. It could be concluded that this difference may be caused by the fact that the emitter properties or integration characteristics of the emitter with the pipe wall were not the same during manufacturing.

CONCLUSION

The followings were concluded from the conducted study:

- Emitter flow rate increases as the wall thickness of pipes decreases.
- In general, it was observed that when the wall thickness decreased sequentially from 1.1 mm and 0.9 to 0.6 mm, average emitter flow rate increased about 30% based on the brand name of the emitter as well as an increase in pressure.
- The variations of emitter flow rate based on the different pipe wall thicknesses were found to be statistically significant ($P<0.05$) for all drip irrigation pipes equipped with E1 and E2 type emitters.

Drip irrigation pipes manufacturers generally prefer to change pipe diameter or wall thickness of the pipe to reduce the manufacturing costs due to economic reasons and competition in the market. Manufacturers can easily change the wall thickness with basic adjustments in the extruder line during the manufacturing. However, the results of the study clearly showed that these wall thickness changes caused significant changes in the emitter flow rates. As a result, it can be said that the planning and management of the drip irrigation systems which are preferred for water saving can be negatively affected.

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