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Hydraulic Performances of Various Trickle Irrigation Emitters

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Abstract: The objectives of this study were to collect discharge rates at 4 different pressure levels of 50, 100, 150 and 200 kPa to assess the hydraulic performances of various kinds of emitters (including Mono-tandem, Hydrogol, In line-168, Matic, Katif 4 and Katif 8), calculate the Coefficient of manufacturing variation, emitter discharge coefficient and emitter discharge exponent, in order to establish the emitter´s flow rate sensitivity to pressure and comparing the results to the manufactures´ specifications. Results indicated that design should be based on reliable test data, not on manufacturer´s supplied data. Mono-tandem, In-line 168 and Hydrogol, were classified as NPC and Matic, Katif 4 and Katif were classified as PC as expected. Except Matic, discharge of emitters was uniformly distributed at all operating pressures.

Key words: Trickle irrigation, drip tube, manufacturing variation, hydraulic performance

INTRODUCTION

Trickle irrigation is gaining importance in the world, especially in areas with limited and expensive water supplies, since it allows limited resources to be more fully utilized. One of the primary goals in the design of trickle irrigation system is to have a hydraulic balance to ensure uniform discharge and emitters or drippers, as a heart of trickle irrigation system, represent the most important element of a trickle irrigation installation with respect to uniform water application to have high irrigation efficiency. In reality, unit-to-unit emitter discharge is variable, as observed by Bralts *et al.* (1981) and Solomon (1979). With this purpose in mind, it is essential that the emitter flow variation and/or the uniformity of the water distribution be known, particularly since drip irrigation system efficiency depends on application uniformity and a successful uniform drip irrigation system application depends on the physical and hydraulic characteristics of the drip tubing (Al-Amound, 1995).

Accurate emitter manufacturing is necessary in order to achieve a high degree of system uniformity. However, the complexity of emitter and their individual components make it difficult to maintain precision during production. Changes in production temperature, mold damage and nonuniform mixing of raw materials are some of the factors affecting emitter homogeneity. Elastomeric materials are used to achieve flushing action and pressure compensation in the manufacture of pressure compensating emitters. These parts are difficult to manufacture with consistent dimensions. Also, the resilient material may creep over a period of time and gradually change the flow rate even though pressure is constant (Solomon, 1979). Ideally, all emitters in the system should discharge equal amounts of water, but due to manufacturing variations, pressure differences, emitter plugging, aging, friction head losses throughout the pipe network, emitter sensitivity to pressure and irrigation water temperature changes, flow rate differences between two supposedly identical emitters exist (Mizyed and Kruse, 2008). In surface drip irrigation systems, uniformity can be evaluated by direct measurements of emitter flow rates. Capra and Scicolone (1998) indicated that the major sources of emitter flow rate variations are emitter design, the material used to manufacture the drip tubing and precision.

Several evaluation criteria are available to quantify emitter performance. Keller and Karmeli (1974) and Howell and Barinas (1980) calculated the relationship between emitter discharge and operating pressure in the design of drop irrigation systems given by as follows:

$$q = K_e H^x \tag{1}$$

where, q is emitter discharge, (L h^{-1}), K_e is emitter discharge coefficient that characterize the emitter dimensions, H is operating pressure at the emitter, in kPa and x is emitter discharge exponent which is a characteristic of the emitter flow regime and may be used to characterize hydraulic performance of any given emitter

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(Bralts and Wu, 1979) and can be determined from the slop of logarithm of discharge versus logarithm of pressure.

In the manufacturing processes, there will be variations in passage size, shape and final finish. Manufacturing variations exist due to the inability to hold constant pressure and temperature during the processes such as molding and welding and inconsistencies in the materials used. Due to these manufacturing variations, any two emitters of the same type from the same box, tested at the same temperature and pressure can have different flow rates. The flow rate in trickle irrigation emitters is small, therefore any variation in the critical dimensions of the emission devices can cause large variation in relative flow rates, although the absolute magnitude of the variation might be very small. Emitter must be resistant to extreme conditions in the environment and must maintain physical characteristics over their lifetime in order to have consistent flow rates. Coefficient of manufacturing variation (CV), Emission Uniformity (EU) and emitter flow variation (q_{var}) are three indexes to determine irrigation uniformity. The variations resulting from manufacturing processes are generally assumed to be distributed normally about their mean value. It is one of the significant parameters related to uniformity and efficiency of the system. It could be obtained by taking a random sample of emitters and obtaining the discharge rates at the same temperature and pressure. Keller and Krameli (1974) introduced the coefficient of variation as a statistical measure for emitter manufacturing variation. This coefficient of manufacturer´s variation was the included in design equations for emission uniformity.

$$CV = (Sq / q_{ave}) * 100 \tag{2}$$

where, CV is discharge coefficient of variation (%), Sq is standard deviation of discharge rates of the emitters in the sample (L h^{-1}) and qav. Ismean of emitter discharge rate (L h^{-1}). Where, q_{ave} is mean of all the measured discharge rates (L h^{-1}), Sq is standard deviation of the discharge rate of the emitter and CV is coefficient of manufacturing variation (%).

Numerous guidelines have been suggested to classify CV values, but those given in the ISO standards (International Standard, 1991) are used in this study (Table 1). Also Keller and Karmeli (1974) calculated EU as followed:

$$EU = (q_n/q_a) * 100 \tag{3}$$

where, EU is the emission uniformity of emitters (%), q_n is average discharge from emitters in the lowest 25% of the discharge range (L h^{-1}) and q_a is average discharge of all emitters, in L h^{-1}.

They recommended that EU values of 94% or more are desirable and in no case should the designed EU be below 90%. q_{var} can be shown by comparing maximum and minimum emitter flows and was expressed by Wu and Gitlin (1983) as followed:

$$q_{var.} = (q_{max.}-q_{min.})/q_{max.} *100 \tag{4}$$

where, $q_{var.}$ is emitter flow variation (%), qmax. is maximum emitter discharge (L h^{-1}) and qmin is minimum emitter discharge (L h^{-1}).

Manufactures normally supply discharge curves. However, they seldom publish information relating pressure to emitter discharge variability. Also, numerous researchers have investigated sources of variation and their effects on uniformity (Bralts *et al*., 1981; Bucks and Mayer, 1973; Nakayama and Bucks, 1986; Nakayama *et al*., 1979; Solomon, 1979; Wu and Gitlin, 1983; Zur and Tal, 1981). Conversely little research has been done on the evaluation of the hydraulic characteristics of drip irrigation tubing and to find the effects of various emitter designs (compensating vs. non-compensating) on the uniformity of water application. With due attention to many different products from different companies, the objectives were to find more details on hydraulic characteristics and pressure-discharge relationships of drip tubes by collecting discharge rates at 4 different pressure levels of 50, 100, 150 and 200 kPa to assess the hydraulic performances of various kinds of emitters (including Mono-tandem, Hydrogol, In line-168, Matic, Katif 4 and Katif 8), calculate the CV, x and k, in order to establish the emitter´s flow rate sensitivity to pressure and comparing the results to the manufactures´ specifications.

MATERIALS AND METHODS

Six different types of commercial In/On-line drip tubes (three NPC and three PC) obtained from four different manufacturers were used in the laboratory tests to assess the hydraulic performances. Drip tubes were tested in the laboratory at the Federal

Table 1: Classifications of coefficient of variation values according to ISO standards (1991)

Category	CV	Details	Classification
A	0 to±5%	Higher uniformity of emission rate and smaller deviations from the specified nominal emission rate	Good
B	±5 to±10%	Medium uniformity of emission rate and medium deviations from the specified nominal emission rate	Medium
C	>10%	Lower uniformity of emission rate and greater deviations from the specified nominal emission rate	Poor

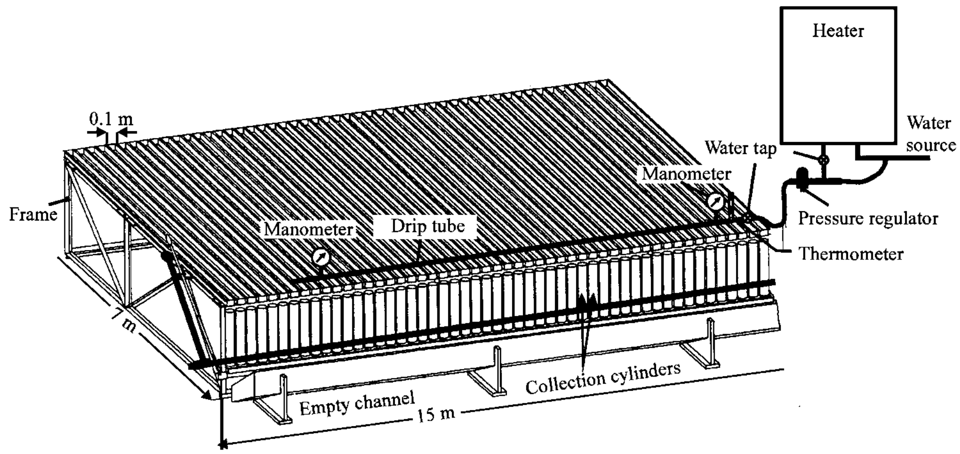

Fig. 1: Measurement of the emitter discharge rate in the laboratory

Agricultural Research Centre (FAL)/Institute of Production Engineering and Building Research/ Braunschweig/ Germany during summer, 2006. These drip tube were available on the market and its manufacturer's characteristics are presented in Table 1.

The distance between emitters was 15 to 20 cm. The drip lines were a polyethylene pipe with an outer diameter of 16 mm. Two drip tubes of every type and every tube including 25 emitters (totally 50 emitters) were tested under different pressure. The ASAE test standards procedure (1996) was followed to determine the effects of different drip emitter design CV and consistency of flow rates. Two-litre measuring cylinders with 20 mL divisions were used to collect the water from the emitters as shown in Fig. 1. A sliding tray containing graduated cylinders was placed directly below the tubes with each cylinder positioned to receive water from one emitter. To compare different types of emitters and with due to influence of water temperature on emitter discharge (Nakayama and Bucks, 1985; Parchomchuk, 1976; Peng *et al*., 1986) the standard water temperature must be 22°C±2 (International Standard, 1991). The water temperature was adjusted at 22°C and measured using a mercury thermometer with an accuracy of 1°C. The water in the line was heated first by using an electrical heater (Fig. 1). One end of each tube was connected to a water source and the other end was sealed. The operation pressure was monitored using gauges at each end of the tubes to check if there was a noticeable pressure drop across the line and was controlled and adjusted by two valves and a pressure regulator. This ensured that the pressure remained constant during each set of measurements. Emitter discharge was measured over a range of four pressures of 50, 100, 150 and 200 kPa to determine the manufacturing variation of each type. The discharge of the emitters was measured volumetrically and three times replicated. A stopwatch was used to measure the flow times. The water volumes were collected in the graduated cylinders and manually read and recorded.

RESULTS AND DISCUSSION

Different performance parameters were calculated in laboratory to illustrate the relationship between the operating pressure and discharge rate, the emitter discharge exponent, the coefficient of variation, flow variation and emission uniformity. Results indicated that measured discharge flow rates of all emitters at 100 pKa (Fig. 2, 3) were very near to the design flow rate as claimed by the manufacturer in Table 2. Average differences between measured and design flow rate of Mono-tandem, Hydrogol, In line-168, Matic, Katif 4 and Katif 8 were -5.5, +10.5, 1.2, 7.5, 0.0 and 0.0%. The pressure-discharge relationships of emitters are expressed by Eq. 1. Except Matic, discharge of emitters was uniformly distributed at all operating pressures as shown in Fig. 2 and 3. At the same time for Mono-tandem, Hydrogol and In line -168, the discharge increased linearly by increasing operating pressure as they were classified as NPC emitters based on the general manufacturers characteristics of all tested emitters (Table 2). By increasing pressure from 50 to 200 kPa, discharge was generally increased from 9 to 22 L h^{-1}, 7 to 16 L h^{-1} and 5.5 to 13 L h^{-1} for Mono-tandem, Hydrogol and In-line emitters, respectively. But in the cases of Matic, Katif 4 and Katif 8), the discharge was not increased as the operating pressure grew (Fig. 2, 3). Discharge was relatively the same at all operating pressures because the type of emitters used was a PC based on Table 2. By increasing pressure from 50 to 200 kPa, discharge was

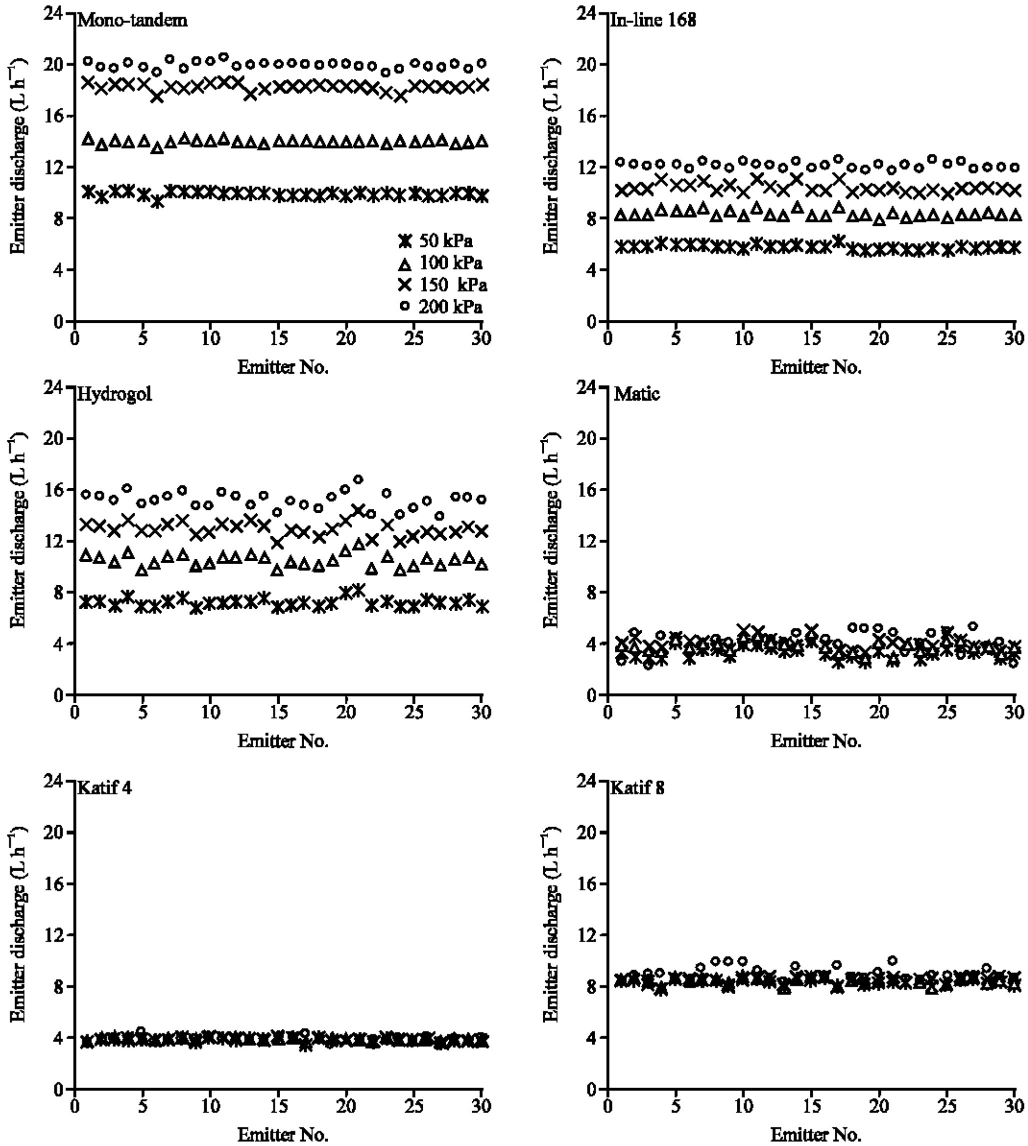

Fig. 2: Emitter discharge rate at different operating pressures

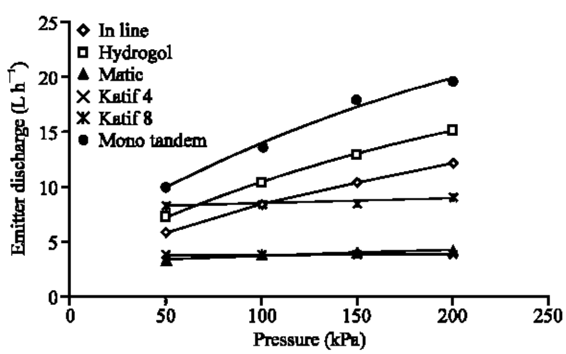

Fig. 3: Means of measured discharge rates for all tested emitters at different pressures under laboratory condition

generally increased from 2.5 to 5 L h^{-1}, 3.5 to 4 L h^{-1} and 7.5 to 10 L h^{-1} for Matic, Katif 4 and Katif 8, respectively.

The emitter discharge rate was increased with operating pressure by using the Mono-tandem, In line 168 and Hydrogol (NPC types). However, it was relatively constant when the Matic, Katif 4 and Katif 8 L h^{-1} types were used (Fig. 3).

The data from the laboratory experiments were analysed with an SAS program. The statistical analysis indicated that the effect of operating pressure on the emitter discharge in the case of Mono tandem, In line 168 and Hydrogol (NPC emitters) was highly significant and

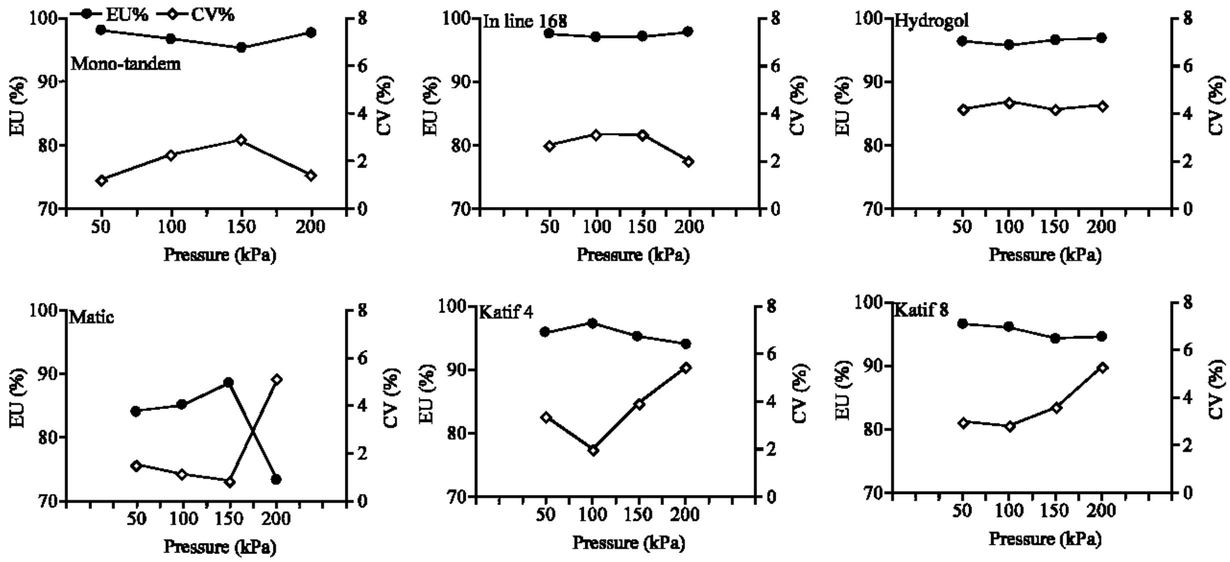

Fig. 4: Relationship between the operating pressure and both the coefficient of variation and emission uniformity

Table 2: The general manufacturers characteristics of all tested emitters

Emitters	Company	-----------Type-----------		Nominal discharge (L h^{-1} at 100 kPa)	Manufacturers CV at 100 kPa (%)
Matic	Aqua-pro	PC	On-line	4.0	13
Katif 4	Plastro	PC	On-line	3.8	5-10
Katif 8	Plastro	PC	On-line	8.4	5-10
In-line168	Netafim	NPC	In-line	8.3	10
Hydrogol	Plastro	NPC	In-line	9.5	5-10
Mono-Tandem	Siplast	NPC	In-line	14.5	3

Table 3: The hydraulic characteristics of tested emitters

Emitter	K_e	X	$H_{var-10\%}$	R^2
Mono-tandem	1.370	0.510	20.6	0.994
In-line	0.675	0.544	19.0	0.999
Hydrogol	0.860	0.542	20.1	0.999
Matic	1.800	0.158	82.8	0.981
Katif 4	6.100	-0.090	-65.3	0.512
Katif 8	10.670	-0.040	-90.8	0.169

the emitter discharge was strongly influenced by the operating pressure. However, it was not significant in the case of Matic, Katif 4 and Katif 8 (PC emitters). Also the hydraulic characteristics of emitters were calculated using Eq. 1 and regression analysis. Values of K_e and x for all emitters are presented in Table 3. Mono-tandem, Hydrogol and In line -168 emitters are classified as NPC (or full turbulent flow regime) because they had an emitter exponent value higher than 0.5, however, Matic, Katif 4 and Katif 8 had x values around zero as predicted and are classified as PC emitters. With due attention to high value of x for Mono-tandem, Hydrogol and In line-168 emitters, it is concluded that discharge sensitivity of these emitters to pressure variation is high. Results showed that only pressure variation of about 20% can result in 10% emitter discharge variation of NPC emitters. But required pressure variation to make 10% emitter discharge variation of Matic, Katif 4 and Katif 8 is 82.8, 65.3 and 90.8%. On the other hand, for PC emitters, pressure variations caused little discharge variation. Although an ideal emitter with a high degree of pressure compensation which has an x level equal to 0 (Braud and Soon, 1980; Solomon and Bezdek, 1980; Boswell, 1985) has not yet been invented, but is technically possible. In Table 2, the statistical coefficient of determination R^2 is also reported for each emitter type. High values of R^2 shows that Eq. 1 is an appropriate model to describe the relationship between the discharge and the pressure of Mono-tandem, Hydrogol, In line -168 and Matic emitters but this equation can not describe this relationship for both of Katif emitters because of date scattering.

The coefficient of discharge variation of emitters in the sample falling within a given deviation from the mean discharge was calculated using Eq. 2. Results indicated measured CV values of all emitters at 100 kPa (Fig. 4) were less than design CV as claimed by the manufacturer in Table 2. The results indicated that the CV values for Mono-tandem, In-line 168, Hydrogol, Katif 4 and Katif 8 were followed by a normal distribution at each operating pressure. However, in the case of Matic type, the coefficient of discharge variation was relatively high. CV

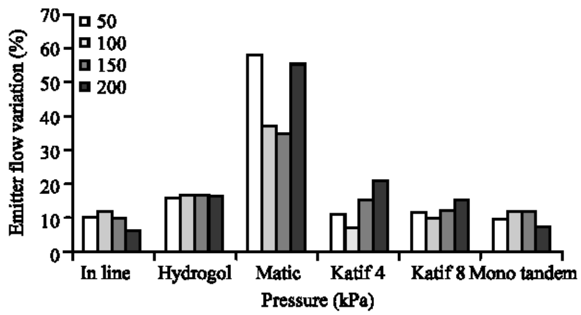

Fig. 5: The relationship between different operating pressures and emitter flow variation for the tested emitters

values of Mono-tandem, In-line 168 and Hydrogol and both katif were classified as good and Matic as poor on the basis of ISO, International Standard (Table 1). Emission uniformity was calculated using Eq. 3. Moreover except Matic all emitters had a low CV (less than 5%) to achieve reasonable uniformity of water application in agreement with Pitchford (1980), Boswell (1985) and Solomon (1977) that mentioned typical range value for CV from 2 to 15%, although higher values are also possible. In the case of Matic, the mean value of EU and CV were undesirable and about 83 and 14%, respectively. The results showed that an increasing value of the CV leads to decreasing emission uniformity EU for all tested emitters. Solomon (1977) contended that the benefits inherent in employing PC over NPC type emitters could be negated if the CV is too high.

With due attention to using the fluctuation of the CV with pressure to define emitter discharge sensitivity to pressure, the relationship between the operating pressure and both the CV and EU of all drip tubes were calculated. Our results indicated higher CV values for non-compensating emitters than those of compensating ones. This implied that our results were in agreement with other researchers conclusions (Bralts *et al.*, 1981; Decroix and Malaval, 1985; Madramootoo *et al.*, 1988), except for those of Ozekici and Sneed (1995). As it is show in Fig. 4 and in agreement with Keller and Karmeli (1974) except Matic all emitters had a desirable EU (higher than 94%).

Calculation of the q_{var} using equation 4 showed that the mean value of the q_{var} at operating pressures ranging from 50 to 200 kPa for the Mono-tandem, In-line 168, Hydrogol, Matic, Katif 4 and Katif 8 were 10.9, 9, 14, 46, 16, 13%, respectively. Also maximum value of the q_{var} for the Mono-tandem, In-line 168, Hydrogol, Matic, Katif 4 and Katif 8 were created by 150, 100, 100, 50, 200 and 200 kPa, respectively. These results are presented in Fig. 5.

CONCLUSION

High uniformity of water distribution is required in trickle irrigation to minimize irrigation losses. After the system is installed, flow variation due to pressure differences, emitter plugging, temperature variation and aging have an adverse effect on uniformity. It is also very important to look at manufacturing variation when choosing an emitter. Design should be based on reliable test data, not on manufacturer´s supplied data. Because of the need for high uniformity in trickle system, every effort should be taken to test the emitters before and after they are installed. Manufacturers should provide specifications that describe their products.

The effect of operating pressure on the emitter discharge in the case of Mono-tandem, In-line 168 and Hydrogol (NPC emitters) was highly significant and the emitter discharge was strongly influenced by the operating pressure. However, it was not significant in the case of Matic, Katif 4 and Katif 8 (PC emitters). CV values of Mono-tandem, In-line 168 and Hydrogol and both katif were classified as good and Matic as poor on the basis of ISO, International Standard (Table 1). Results indicated that measured discharge flow rates of all emitters at 100 kPa were very near to the design flow rate as claimed by the manufacturer. But measured CV values of all emitters at 100 kPa were less than design CV as claimed by the manufacturer. Except Matic, discharge of emitters was uniformly distributed at all operating pressures. Mono-tandem, In line 168 and Hydrogol, were classified as NPC and Matic, Katif 4 and Katif were classified as PC as expected. In-line 168 and Matic had minimum and maximum mean value of the qvar equal to 9 and 46%, respectively.

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