EVALUATING THE PERFORMANCE OF COMMON EMITTERS TYPES IN AL-QASSIM, SAUDI ARABIA

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ABSTRACT

A field study has been carried out to evaluate the performance of common types of emitters in Al-Qassim area, Saudi Arabia. Seven different emitters have been chosen to represent three major types of emitters; turbulent flow; laminar flow and pressure compensating emitters. The emitters have been tested under different operating pressures. A simplified procedure has been developed to perform a comparison between the theoretical and the measured emitter flows, considering the effect of head loss along the lateral. The tested laminar flow emitters have shown a noticeable difference between the measured and the corresponding nominal flows. Moreover, they have shown a non-uniformity of flow and unsatisfactory performance. Turbulent flow and pressure compensating emitters have shown a good uniformity of flow and their variation of flows due to manufacture were low. Meanwhile, low difference between the nominal and measured flows have noticed. Therefore, they are recommended for use in the area under study.

INTRODUCTION

Trickle irrigation has a distinguished place among irrigation systems, especially in arid regions, due to its advantages in water saving where water resources are limited. In a trickle irrigation system, a small controlled amount of water is applied near the plant by the emitters. There are various types of emitters available commercially, but basically they can be classified into three main types based on their modes of operation (Von Brenuth & Solomon, 1986): (a) laminar flow emitters; which are either microtubes or spiral long path emitters, (b) turbulent flow emitters; which are either tortuous long path emitters maintain turbulence with continuously changing flow direction, or the short path type that decreases the flow passage diameter under increasing pressure, and (c) orifice emitters; which include the simple orifice, the vortex orifice and multiple orifices in series. Manufacturers have developed emitters that provide the same flow rate over a wide range of lateral line pressure and they are called pressure compensating emitters.

Ideally, an emitter permits a uniform flow of water to trickle at constant discharge that does not vary significantly throughout the field. From a practical point of view, it is difficult to achieve this ideal performance because along the lateral there is a pressure gradient due to friction losses and, as a result, the discharge of the different emitters will vary. Moreover, the design, manufacture and material quality control of emitters greatly affect their performance to deliver constant discharges (Solomon & Keller, 1987). The hydraulic specifications of emitters include the operating pressures at their inlet and the corresponding nominal flow rates expressed at water temperature of 25°C. Every manufacturer drew especially the relation of pressure to flow with a best suitable scale for his emitter (Gaiy & Zelenka, 1985). However, in many cases, the emitters are not carefully manufactured and no care has been paid to the standard specifications. Accordingly, a difference between the actual and the theoretical pressure-flow relationship is expected, which in turn effects the accuracy of the trickle network design.

Keeping arid region conditions in mind, where atmospheric demand is very high, the uniformity and

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efficiency of water flow from emitters are more important and have to be well known. Kingdom of Saudi Arabia is considered as a good example of the arid regions. Al-Qassim area is the most important agricultural area in the Kingdom, where irrigated land by trickle irrigation is expected to expand in the near future. Therefore, such studies concerning trickle irrigation evaluation should take more attention.

The objective of the present work is to evaluate the performance of the common types of emitters in Al-Qassim Area, Saudi Arabia, and to recognize the reliability of their nominal flow under different operating pressures.

CRITERIA OF EMITTERS EVALUATION

The following are criteria by which the different emitters' types will be evaluated in this study:

(1) *Emitter Discharge Variation*

which is a measure of the variation of the emitter discharge rate. The manufacturer's coefficient of emitter variation (which reflects the normal distribution of emitter discharge variation) will be used to determine emitter discharge variation as follows (Solomon & Keller, 1978):

$$V_{qs} = \frac{S_q}{q'} \qquad (1)$$

$$S_q = \left\{ \frac{1}{n-1} \left[\sum_{i=1}^{n} q_i^2 - \frac{1}{n} \left[\sum_{i=1}^{n} q_i \right] \right]^2 \right\}^{\frac{1}{2}} \qquad (2)$$

$$q' = \frac{1}{n} \sum_{i=1}^{n} q_i \qquad (3)$$

where:

V_{qs} = the manufacturer's coefficient of variation.
q_i = emitter flow rate.
i = subscript identifying individual emitter.
q' = mean flow for a number of n emitters tested at a fixed pressure and temperature.
S_q = standard deviation of emitters flows.

Typical values of V_{qs} may range from 0.02 to 0.1 for non-compensating emitters and even to above 0.1 for some pressure compensating emitters, depending on the type of emitter and the consistency of the pressure by which the emitter is made (Solomon & Keller, 1978). Emitter flow variation can also be evaluated by determining the statistical uniformity as follows (Bralts and Kesner, 1983) and (Bralts et al, 1987):

$$U_s = 100\ (1 - V_{qs})$$

where U_s is the statistical uniformity of the emitte flow rates.

The general criterion for an acceptable statisti uniformity is 90% or more, excellent; 80 to 90%, ve good; 70 to 80%, fair; 60 to 70%, poor; and less th 60%, unacceptable (ASAE EP458, 1988).

(2) *Emission Uniformity:*

Two parameters are applied herein to expre uniformity as suggested by (Karmeli & Keller, 197 They are:

(a) The Emission Uniformity **(EU)**: which can b considered as the most important factor of applicati uniformity and is defined as the relationship betwe the minimum and average of emitter flow (Fry, 198

$$EU = 100\ \left(\frac{q_n}{q'}\right) \qquad (5)$$

where $(q_n)$is the average of the lowest 1/4 of emitte flows. According to (ASAE EP458, 1988) , EU% i considered as excellent; good; fair; poor o unacceptable when its value is 100-94; 87-81; 75-6 62-56 or less than 50%, respectively.

(b) The Absolute Emission Uniformity **(EU_a)**: which i the parameter of application uniformity, including th maximum and minimum flow rates, and can b calculated as follows:

$$EU_a = 100 x \frac{1}{2} \left(\frac{q_n}{q'} + \frac{q'}{q_x} \right) \qquad (6)$$

Where q_x is the average of the highest 1/8 of th emitters flow rates.

(3) Characterizing the Flow Regime of Emitters:

The flow rate of an emitter may be characterized b the following equation (Vermeiren & Jobling, 1978):

$$q = KP^{x} \qquad (7)$$

where:

q = emitter flow rate.
P = operating pressure.

K = a constant of proportionality that characterizes each emitter.

x = the emitter flow exponent that is characterized by the flow regime.

In laminar flow x = 1.0 and in fully turbulent flow x = 0.5. For pressure compensating emitter x varies from 0.50 to 0.0. The lower the value of x, the less the flow is affected by pressure variation. Having known the emitter flow rate at two different operating pressure heads, the exponent (x) can be determined by measuring the slope of a log-log plot of P vs. q, or analytically by:

$$x = \frac{\log(q_1/q_2)}{\log(P_1/P_2)} \quad (8)$$

where q_1 and q_2 are emitter flows at two different operating pressures p_1 and p_2, respectively.

Types of Emitters under Evaluation

A comprehensive survey of common emitters in AL-Qassim area was made. Although there are many emitters in the market but many of them are adjustable ones and, therefore, are excluded. As a result, seven commercial marks of on-line emitters are collected from retail outlets. They are grouped into three categories according to their nominal flows. Illustrated in Table (1) are some characteristics of the seven emitters taken from their catalogues. The flow-pressure relationships of these emitters are collected and drawn in one graph as shown in Figure (1).

Table 1. Some Characteristics of Emitters.

Group	Commercial name	Emitter type	Features	Specifications
A (8 l/h)	E-2*	(I) Laminar flow	• Spiral flow path • Barbed outlet for remote water discharge • Removable key insert	• 4 mm barbed inlet and outlet
	Turbo-Key*	(II) Turbulent Flow	• Removable cap for cleaning	• Stable pollyproplylene and polyethylene material
B (4 l/h)	E-2*	(III) Laminar flow	as in No. 1	as in No. I
	Key Clip*	(IV) Laminar flow	• Proven spiral flow path and removable key insert	• Stable polypropylene material • 4 mm barbed inlet
	K-4*	(V) Turbulent flow	• Labyrinth turbulent water flow path • Barbed outlet for remote water discharge • Removable key insert	• Stable polypropylene construction • 4 mm barbed inlet • 4 mm barbed inlet
	Turbo-key*	(VI) Turbulent Flow	as in No. II	as in No. II
C (0.5 gal/h)	Rain Bug**	(VII) Pressure compensating	• Highly inert silicone elastomer diaphragm • Self-piercing barbed inlet	• Single outlet

* *RIS, "Hardie Irrigation", Roma, Italy, 1989.*

** *Rain Bird, "Turf Irrigation Equipment", Glendora, USA, 1992.*

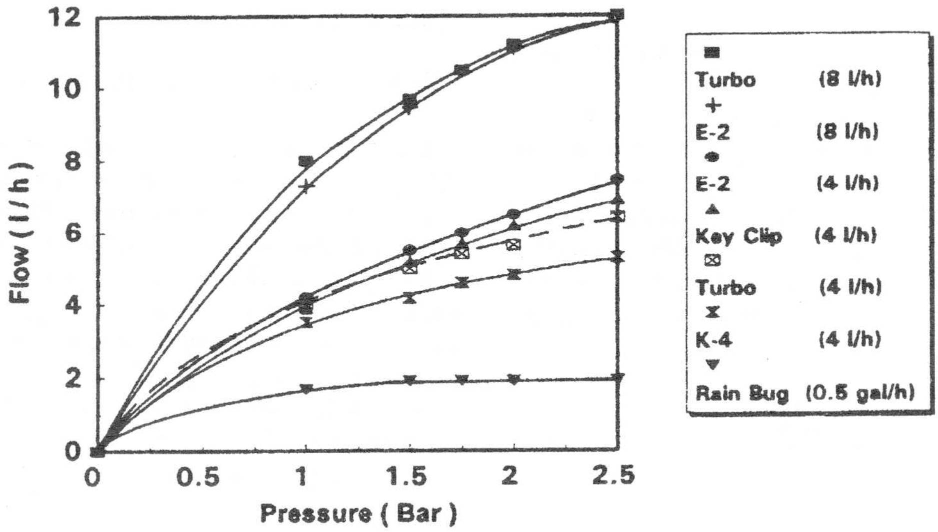

Figure 1. Performance curves of emitters under evaluation.

Field Work Procedures

The field work was conducted at the Agricultural Station Research, Al-Qassim Branch of King Saud University, Buriadah (Latitude 26°N, Altitude 44°E and elevation 625 m). It was carried out in October to December, 1993 when the atmospheric temperature was nearly 22° to 23° C. Irrigation water salinity in the site was about 1200 ppm.

A new trickle irrigation network was installed in a leveled area with no slope. Only one inlet along the manifold was chosen to carry out the study. For each type of emitter, new polyethylene lateral was connected with the manifold. The lateral has an inner diameter of 0.5 inch with a total length of 100 m. A new calibrated pressure gauge was installed at the lateral inlet. The first emitter was fitted two meters distance from the lateral inlet and the emitters were then spaced every four meters, making the total number of emitters 24, A small hole was dug underneath each position of emitter and a catch can with a capacity of one liter was put in to receive the trickled water. The study was carried out under three operating pressures (P = 1.0, 2.0 and 2.5 bar) at the lateral inlet and the pressure was controlled by a valve fitted after the pressure gauge. Before starting the test, water was left to flow for sometime from the lateral outlet to make sure that it flows freely from air bubbles and, then, the lateral outlet was closed. Applying the operating pressure P at the lateral inlet, the flow of each emitter was then measured using a scaled tube and a digital stop watch. This procedure was carried out for the seven emitter types.

RESULTS AND ANALYSIS

1. Emitter Flow-Distance:

The location of emitter is referred by relative position X/L, where X is the distance between the emitter and the lateral inlet and L is the distance between the last emitter and the lateral inlet. Under the three operating pressures P, the relationships between the measured emitters flows q and the corresponding values of X/L are shown in figures (2), (3) and (4) for emitters of groups A, B and C, respectively. For emitters with a nominal flow of 8 l/h (Figure (2)), non-uniformity of flow of emitter type I (laminar flow type) can be seen along the lateral. On the other hand, a much better uniformity of flow is noticed for emitter type II (turbulent flow type), although a sharp drop of flow is noticed at the lateral end for this emitter type. For emitters with a nominal flow of 4 l/h (Figure (3)), one can see the non-uniformity of emitters types III and IV (laminar flow type) along the lateral. In addition, there are many extreme values of q noticed in case of emitter type III. Therefore, these values will be excluded during the evaluation procedure. Referring to Figure (3), one can notice the very good uniformity of emitters types V and VI (turbulent flow type) except one extreme value of q in case of emitter type V that will also be excluded during the evaluation procedure. Figure (4) shows the flow distribution of emitter type VII (pressure compensating type). Although this emitter type has the advantage of giving a nearly constant flow under a wide range of pressure as shown from its performance curve (Figure (1)), the field measurements show a noticeable difference between emitter flows under the applied operating pressures and doubling the operating pressure from 1 to 2 bar caused an increase of emitter flow q by about 36%. However, this type of emitters shows a good uniformity of flow along the lateral.

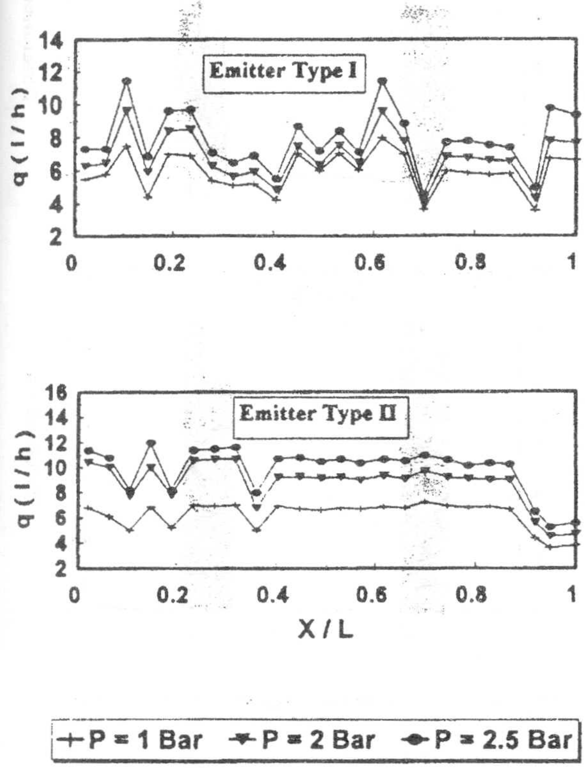

Figure 2. Emitters flow-distance relationship of group A.

2. Measured and Nominal Emitters Flows:

A comparison between the theoretical and the measured emitter flow is valuable to investigate the emitter performance efficiency. However, comparing the average measured emitters flows q' and the emitter nominal flow q_{nom}, at a specific value of P is not logic. This is due to the head loss along the lateral Δh, where the emitter operating pressure decreases the emitter distance from the lateral inlet X increases. Accordingly, the average nominal flow for a group of emitters along the lateral q'_{nom} should be less than the nominal flow of an emitter q_{nom}. Thus, the determination of q'_{nom} is essential to perform such a comparison between the theoretical and the measured average flows for a group of emitters. The following procedure is developed to determine q'_{nom} considering the head loss along the lateral:

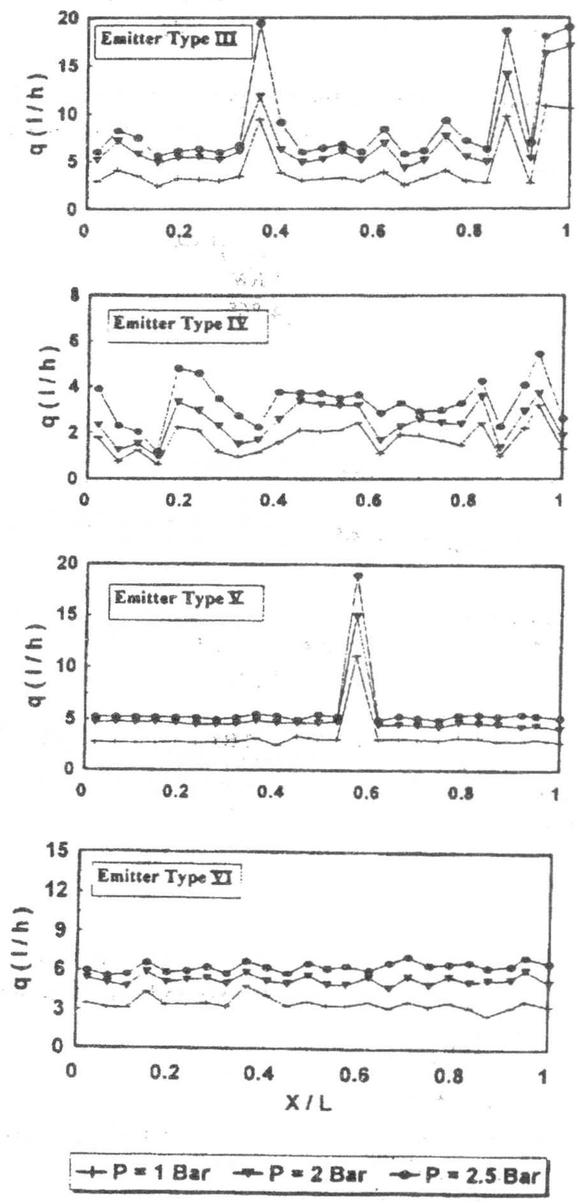

Figure 3. Emitters flow-distance relationship of group B.

1) calculate flow velocity v through the lateral assuming that all water is carried to the end of the lateral:

$$v = \frac{q_{nom} . n}{a} \qquad (9)$$

where:

q_{nom} = nominal flow of emitter at a specified value of P (Figure (1)).

n = number of emitters along the lateral.

a = cross-section area of the lateral.

2) using the Hazen-Williams equation to determine the head loss along the lateral Δh (Vermeiren & Jobling, 1978):

$$\Delta h = \frac{FCL(\frac{Q}{C_{HW}})^{1.852}}{d^{4.865}} \qquad (10)$$

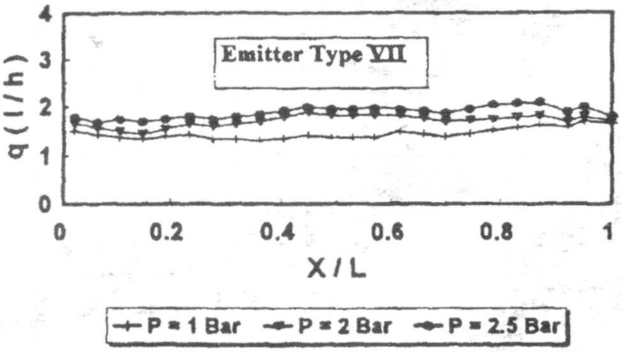

Figure 4. Emitters flow-distance relationship of group C.

where:

F = coefficient to compensate for the discharge along the lateral and depend on number of openings.

C = 10.77 for h, L, d (m), Q (m^3/s).

Q = total flow at lateral inlet.

C_{HW} = coefficient of Hazen-Williams and equal to 150 for plastic or PVC pipes.

d = diameter of lateral.

3) since the average operating pressure along the lateral P_{av} occurs at 0.39 L at which 77% of Δh is resulted (Karmeli & Keller, 1975), then

$$P_{av} = P - 0.77 \; \Delta h$$

in which P is the operating pressure at the lateral i Using figure (1), the average nominal flow for a g of emitters q'_{nom} corresponding to P_{av} can determined.

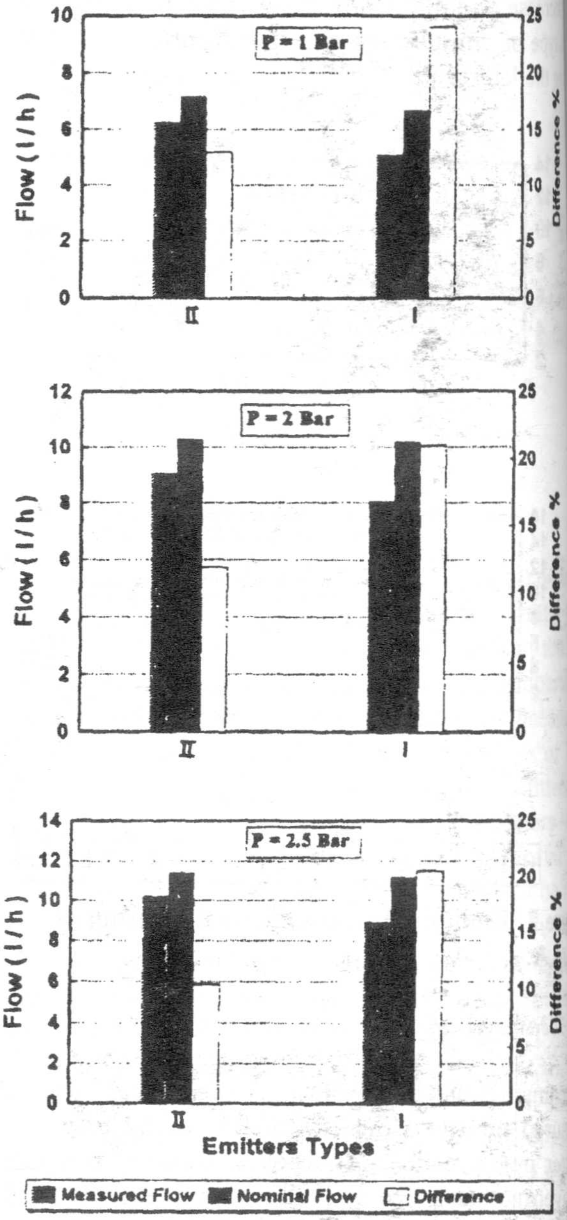

Figure 5. A comparison between measured a nominal flows of group A.

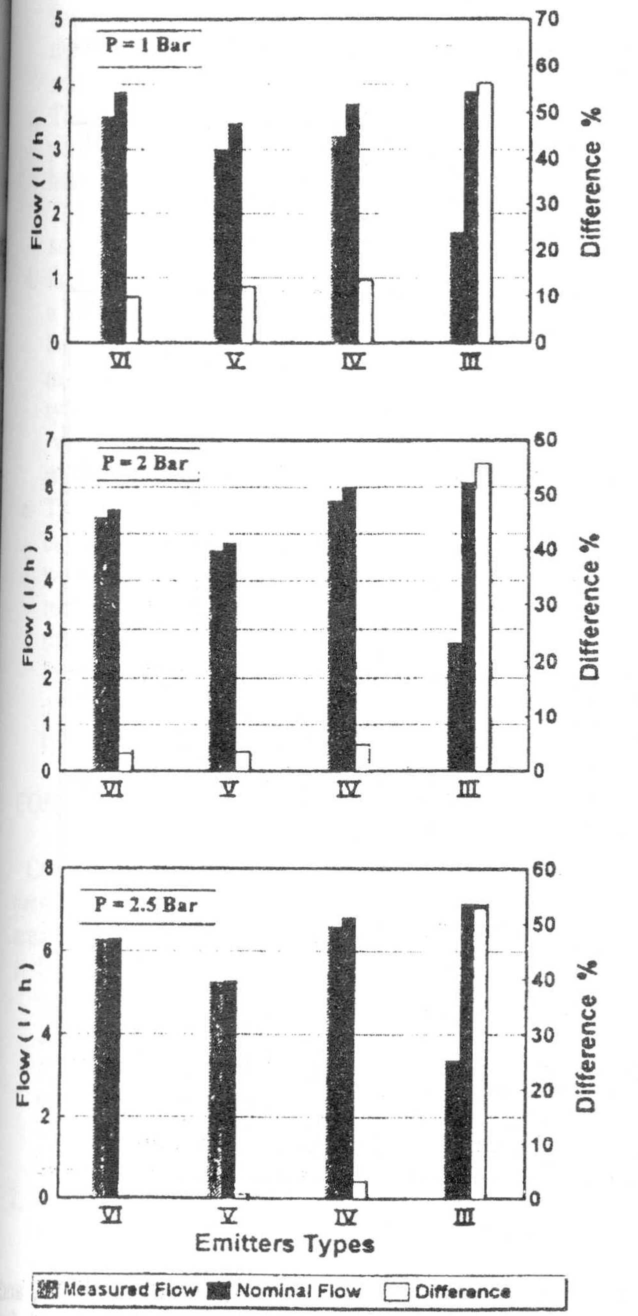

Figure 6. A comparison between measured and nominal flow of group B.

Figures (5), (6) and (7) show the comparison between the average measured emitters flows q' and the corresponding average nominal emitters flows q'_{nom} for emitters of groups A, B and C, respectively, and for different values of P. Generally speaking, it can be noticed that q' is always less than q'_{nom} for all types of emitters. However, this difference varies according to emitter type and the operating pressure. For emitter of group A (Figure (5)), it can be seen that emitter type I (laminar flow type) has a high difference between q' and q'_{nom} and it reaches about 24% at $P = 1$ bar and drops to 20.5% at $P = 2.5$ bar. For emitter type II (turbulent flow type), less difference is noticed and it ranges from 13% to 10.5% at $P = 1$ and 2.5 bar, respectively. For emitter of group B (Figure (6)), emitter type III (laminar flow type) has the highest difference between q' and q'_{nom} and it is about 56% at $P = 1$ bar. Emitter type III (laminar flow type) has also a noticeable difference, but it is relatively less than emitter III and it is about 13.6% at $P = 1$ bar. This is may be attributed to its large water passage way compared to emitter type III and it may also be attributed to the emitter manufacturing.

Emitters type V and VI (turbulent flow type) have the minimum difference between q' and q'_{nom} and this difference nearly vanishes at $P = 2.5$ bar. For emitters of group C (Figure (7)), a small difference between q' and q'_{nom} is noticed. A general look at figures (5), (6), and (7) shows that the difference between q' and q'_{nom} decreases as the increase of the operational pressure P. This is attributed to the capability of high pressure to push out any accumulated salts in the water passage way compared to low pressure. One can conclude from the above analysis that there is always a noticeable difference between the theoretical (nominal) and the measured emitters flow rates in the laminar flow type compared to turbulent flow or pressure compensating types.

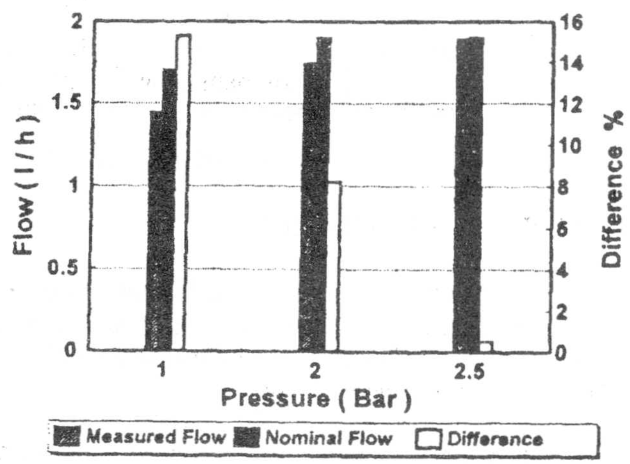

Figure 7. A Comparison between measured and nominal flows of group C.

Table 2. Evaluation of Different Emitters.

Group	Type of Emitter	P (bar)	S_q	V_{qs}	U_s %	EU%	EU_a%	x
	(I) Laminar flow	1.0	1.174	0.2324	76.75 F	73.116 F	75.824	0.67
		2.0	1.614	0.20	79.95 F	78.61 F	76.22	
		2.5	1.757	0.202	79.80 F	75.127 F	87.56	
	(II) Turbulent flow	1.0	1.104	0.17	82.9	81.03 G	85.3	0.502
		2.0	1.645	0.181	V.G.			
		2.5	2.257	0.22	81.18	79.20 G	80.26	
A					V.G			
(8 l/h)					80.9 F	76.37 F	81.9	
	(III) Laminar flow	1.0	0.4828	0.151	84.88	84.35 G	82.11	0.78
					V.G.			
		2.0	0.909	0.159	84.08	84.41 G	80.68	
		2.5	1.103	0.167	V.G.			
					83.29	87.02 G	82.15	
					V.G.			
B	(IV) Laminar flow	1.0	0.647	0.3817	61.83 P	60.59 P	61.64	0.70
(4l/h)		2.0	0.8162	0.302	69.77 P	58.63 P	79.31	
		2.5	0.051	0.312	68.77 P	65.13 P	64.27	
	(V) Turbulent flow	1.0	0.214	0.073	92.69 E	91.59 E	90.8	0.61
		2.0	0.1886	0.0704	95.93 E	94.78 E	97.39	
		2.5	0.189	0.036	96.43 E	80.97 G	88.05	
	(VI) Turbulent Flow	1.0	0.477	0.1365	86.35	89.77 E	83.72	0.55
					V.G.			
		2.0	0.3559	0.0666	93.34 E	92.85 E	90.91	
		2.5	0.465	0.074	92.59 E	90.55 E	90.12	
C (0.5 gal/h)	(VII) Pressure compensating	1.0	0.148	0.1018	89.98 E	89.07 E	87.52	0.13
		2.0	0.207	0.1187	88.13 V.G.	91.10 E	84.70	
		2.0	0.32	0.169	83.07 V.G	86.06 G	80.79	

E. Excellent, V.G. Very Good, G: Good, F: Fair, P: Poor

3. EMITTERS EVALUATION

Applying equations (1) to (8), different criteria for emitters evaluation have been calculated and they are summarized in Table (2). The following remarks can be noticed from these results:

a. Laminar flow emitters have given unsatisfactory performance with a manufacturer's coefficient of variation V_{qs} as high as 0.38 (emitter type IV) or more, while the reasonable value may ranges from 0.02 to 0.10 (Solomon & Keller, 1978).

b. Fair or poor statistical uniformity of flow U_s and emission uniformity EU have been obtained for emitter type IV (laminar type). This is mainly attributed to its tiny water passage and, therefore, they can be easily blocked by any little particle in the water, implying that the problem may be getting worth by the time. However, emitter type III has very good values of U_s and EU. This is attributed to its relative large flow path cross-section and, therefore, an increase of the flow rate is obtained compared to the other laminar flow emitter. This was clearly indicated in the comparison between the average emitter flow and the corresponding nominal flow (Figure (6)).

c. Turbulent flow emitters have given a satisfactory performance of V_{qs} (emitters type V and VI). They have excellent or very good values of U_s and EU. This is expected due to their higher turbulence to any silting in the water passage.

d. Pressure compensating emitter (type VII) has a quite higher value of V_{qs} than 0.10. This is may be attributed to the difficulty to obtain manufacturing precision of materials used in this type of emitter. However, this type of emitter has very good to excellent values of U_s and EU as well.

e. The emitter flow exponent x, for laminar flow emitters, varies between 0.67 and 0.70 although it would be expected to have a value of 1.0. For turbulent flow emitters, x ranges from 0.50 to 0.60 that agrees well with the expected value ($x = 0.50$). For pressure compensating emitters, x has a value of 0.13 that lies within the expected range for this type of emitter ($0.0 < x < 0.50$).

CONCLUSIONS

Concluding remarks from the field evaluation of the performance of common emitters types in Al-Qassim area are as follows:

1. For laminar flow emitters, a noticeable difference between the measured emitter flow and the corresponding nominal flow is generally observed. A non-uniformity of flow along the lateral and an unsatisfactory performance is noticed. These types of emitters are characterized by their high values of the coefficient of manufacturer's variation.
2. Laminar flow emitters are not desirable if the used water has a high salinity because of their sensitivity to clogging by accumulating of small particles in their narrow flow passageways.
3. Turbulent flow and pressure compensating emitters are recommended to be used in the area under study, where very good uniformity of flow along the lateral is noticed and a negligible difference between the measured and nominal flows is obtained. Moreover, they are characterized by their low coefficient of manufacturer's variation.
4. Before selecting emitters for a new trickle system, it is recommended to do a field evaluation of different available types of emitters to select the most appropriate and efficient one.

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Notations

The following symbols are used in this study:

a	=	cross-section area of the lateral.
C	=	constant.
C_{HW}	=	coefficient of Hazen Williams.
d	=	diameter of the lateral.
EU	=	emission uniformity.
EU_a	=	absolute emission uniformity.
F	=	coefficient.
K	=	constant.
L	=	distance between last emitter in the lateral and the lateral inlet.
n	=	number of emitters along the lateral.

P	=	operating pressure.
P_{av}	=	average operating pressure along the lateral.
Q	=	total flow at the lateral inlet
q'	=	average measured mean flow for number of emitters.
q_i	=	emitter flow rate.
q_n	=	average of the lowest 1/4 of emitters flows.
q_{nom}	=	emitter nominal flow.
q'_{nom}	=	average nominal flow for a group of emitters along the lateral.
q_x	=	average of the highest 1/8 of emitters flows.
S_q	=	standard deviation of emitters flows.
U_s	=	statistical uniformity of emitters flow rate.
V_{qs}	=	manufacturer's coefficient of variation.
x	=	emitter flow exponent.
X	=	distance between emitter and the lateral inlet.