Hydraulic Characterization of Locally Manufactured Drip Emitters

Abdul Ghafoor Mangrio*, Zakir Hussain Dahri, M. Z. Ikram and Bashir Ahmed
Water Resources Research Institute, National Agricultural Research Centre, Islamabad, Pakistan

Abstract. Trickle irrigation systems were designed and managed to deliver frequent light water applications to wet only a portion of the soil surface. Initially, selection of an emitter depends on the soil to be wetted, plant water requirement, emitter discharge and the topography of the soil. The pressure-discharge relationships and manufacturers' coefficient of variation of five different locally manufactured drip emitters were determined. The emitters were tested with different placements. They were operated at pressure ranging from 3.50-21.00 meter head (5-30 psi) with increments of 5 psi. All the measurements were replicated thrice for the five types of emitters. The coefficient of variation (C_v) is an average for all types of micro-tube and nursery emitters, marginal for turbo and micro-jet and unacceptable for spiral emitters. On the basis of water application uniformity coefficient (Us %), turbo, micro-jet, nursery and micro-tube emitters fall in the acceptable range. The emitters were developed and evaluated in collaboration with the local industry.

Keywords: trickle irrigation, hydraulic characterization, drip emitter

Introduction

In the regions, where rainfall is insufficient to meet crop water requirements, the artificial irrigation becomes imperative for healthy plant growth and sustained crop yields. There are a number of methods to irrigate crops, each having its own benefits and limitations. However, all of them are similar in their basic objective of providing desired quantity of irrigation water most economically and most efficiently. Nevertheless, the economics and efficiency of each irrigation method varies quite significantly. The selection of any type of irrigation system depends on a number of considerations including the compatibility of the system with other agricultural operations, economic factors, topographic limitations, soil properties and agronomic influences.

Drip irrigation is no panacea, no automatic guarantee of efficiency and it has certain drawbacks as well. Careful thinking in its design, operation and management, however, can minimize the systems drawbacks. Drip irrigation eliminates up to 95% of the field application losses. The system provides water to the crops on a low tension and high frequency basis thereby creating nearly optimum soil moisture environment. Water is directly applied right at the root zone of the individual plants according to their needs, instead of irrigating the entire area as with surface or sprinkler irrigation methods. The drip irrigation system is often operated frequently (daily or several times per week) to satisfy the crop evapotranspiration (ET) needs. Drip irrigation is particularly suitable for extremely water deficit areas, sandy desert areas, or hilly and mountain areas where other methods of irrigation cannot be executed properly. Drip irrigation offers several potential advantages over other irrigation systems, the primary being the precise application of water to the plants. The overall precision of water application, however, depends on many factors but the most critical one is probably the emitter. The emitters must supply enough water to the plant root zone to meet the plant water requirements. Normally, one-third to as much as three-fourth of the plant rooting volume should be supplied with adequate water (Wu *et al.*, 1986).

A drip irrigation system consists of a main line, a sub main, manifolds, lateral lines and emitters. Laterals are designed to distribute irrigation water throughout the field with an acceptable degree of uniformity. Although drip irrigation systems have several advantages over other irrigation systems, it is impossible to obtain ideal water distribution along the lateral line due to variations in emitter discharge caused by operating pressure, water temperature differences, emitter manufacturing variations, emitter clogging and pressure variations caused by slope and friction losses. Hence, for the design of an appropriate drip irrigation system, the properties of the system components, especially the emitter properties and friction losses in laterals for uniformity, must be known (Demir and Yurdem, 2002; Wu *et al.*, 1989; Howell and Barinas, 1980).

The ideal irrigation system is one in which all emitters deliver the same discharge so that each plant would receive equal amount of water during the an irrigation period. From practical point of view, it is impossible to achieve this ideal performance because emitter flow will be affected by variations in water pressure and manufacturing characteristics. Pressure variations, in drip irrigation system are unavoidable due to land

*Author for correspondence; E-mail: mangrio_67@yahoo.com

and distribution system hydraulics. Adequate pressure, however, must be maintained within the distribution system to overcome distribution losses and elevation differences. The difference in pressure, between the distribution lines and atmospheric pressure must be dissipated at the emitter. Adopting optimum hydraulic design of the system can control emitter flow variations caused by pressure variation.

Information pertaining to emitter's flow variations, caused by operating pressure and manufacturing characteristics of the emitter is usually given in the manufacturer's literature. Since local industries in Pakistan, involved in manufacturing of irrigation system components, are still in their infancy, there is hardly any reliable literature available in this regard. Therefore, a series of laboratory experiments were conducted at the hydraulic laboratory of Water Resources Research Institute, National Agricultural Research Centre (NARC), Islamabad to develop pressure-discharge relationships for various types of commonly used locally manufactured drip emitters such as: spiral, turbo, micro-jet, nursery and micro-tube emitters and determine the manufacturer's coefficient of variation for each type.

Materials and Methods

Layout of the experiment. Study was conducted at hydraulic laboratory of Water Resources Research Institute, National Agricultural Research Centre (NARC), Islamabad. It consists of two main parts; (1) pumping unit and (2) hydraulic unit. Pumping unit has been installed in a well. Pressure and water meter were installed at 25 mm delivery line to regulate the pressure and the discharge. Each set of emitters was installed on 13 mm diameter size low-density polyethylene (LDPE) lateral lines.

Data collection. The system was operated for a period of 0.5 h for each reading, replicating thrice for each of the five selected emitters. Emitter discharge was measured by volumetric method at pressure range from 3.50-21.00 m (5-30 psi) with an increment of 3.50 m (5 psi). Operating pressure was regulated through a bypass valve installed at the pump house. The pressure measurements were taken by means of pressure gauges installed at the beginning and end of each lateral line. Finally, the average emitter discharge was calculated for each pressure range. Layout of the study/experiment is shown in Fig. 1.

Measurement of discharge. The Hazen-William equation has been used to describe flow variation in an emission device as under:

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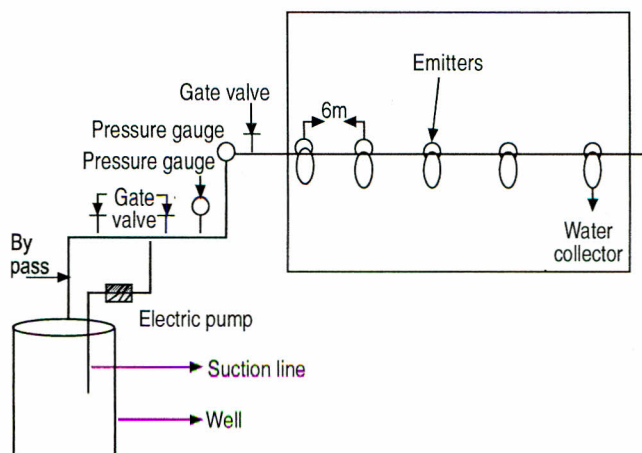
where:

q = emitter discharge (VT^{-1})

Fig. 1. Layout of drip emitter system.

k = emitter constant

H = operating pressure head (L)

x = emission exponent

The values of 'k' and 'x' were determined from the logarithms of flow and operating pressures (von Bernuth and Soloman, 1986).

Coefficient of variation. The parameter, which is generally used as measure of emitter flow variation due to variations in manufacturing, characteristics of the emission devices is called manufacturer's coefficient of variation (C_v). It describes the quality of the material and processes used to manufacture the emission devices. It is determined through flow measurements for several identical emission devices and is computed using the following equation.

$$C_v = s/q_{avg} \tag{2}$$

where:

s = the standard deviation of flow

q_{avg} = the mean flow for a sampled number of emitters of the same type tested at a fixed pressure and temperature (20 °C).

Soloman, (1979) and ASAE (1984) provided the following ranges of C_v values and their appropriate interpretations.

C_v value	Interpretation
0.05 or less	good
0.05 - 0.1	average
0.1 - 0.15	marginal
0.15 or more	unacceptable

Water application uniformity coefficient (Us, %). The water application uniformity co-efficient (Us) was assessed by the following formula developed by Braltas (1986):

$$Us = 100(1-Vq) = 100(1-Sdq/qaf) \qquad (3)$$

where:

Vq = co-efficient of variation of emitter flow
Sdq = standard deviation of emitter flow
qaf = average emitter flow, (Lh^{-1})

Results and Discussion

Pressure vs discharge. The discharge of each emitter type was measured at six different pressures ranging from 5 to 30 psi (3.50-21.00 meter head) with an increment of 5 psi. At 30 psi pressure the discharge values were: 2.39, 4.16, 7.82, 1.16, 12.90, 29.15, 4.16, 24.40 and 26.52 gph for (1) spiral; fully closed, one thread opening and two thread opening (2) turbo (3) micro-jet (4) nursery and (5) micro-tubing of different diameters; 1.00 mm, 1.50 mm and 2.00 mm, respectively; while at 5 psi, the discharge amount was reduced to 1.08 gph, 1.78 gph, 2.56 gph, 0.60 gph, 4.35 gph, 12.91 gph, 1.76 gph, 8.99 gph and 11.73 gph, respectively, (Figs. 2a, 2b and 2c).

Discharge variations. Variations in the emitter discharge mainly depend on pressure differences. Average values of discharge for pressure range of 3.5 to 21 meter head i.e. 1.79, 3.29, 4.96, 0.96, 9.58, 21.94, 3.06, 17.70 and 19.63 gph were recorded for emitters: spiral: fully closed, one thread opening, two thread opening, turbo, micro-jet, nursery and different diameters of micro-tubing i.e. 1.00 mm, 1.50 mm and 2.00 mm, respectively (Fig. 3). The pressure and discharge data of different types of emitters revealed that discharge increased with increase in pressure for all types of emitters (Table 1).

Relationship between pressure and discharge of different types of emitters were established using power function. Discharge was analyzed and regression relationship has been developed as shown by the equation.

$$Q = Kp^x \qquad (4)$$

The relationship between pressure and discharge of different types of locally manufactured emitters has been shown in Fig. 2 (a, b and c). The best fitted curve with highest value of correlation (R^2) for each type of emitter has been drawn. The values of 'K', 'x', 'R^2' for different type of locally manufactured emitters are presented in Table 2.

These relationships hold true for a pressure range of 3.50 to 21.00 meters. Coefficient of variation R^2 ranges from 0.99 to 0.88 for different types of emitters with highest for micro tubing and lowest for one thread opening spiral emitters.

Water application uniformity coefficient (Us, %). The uniformity of water application describes how evenly drip emitters distribute water over a field. Application uniformity
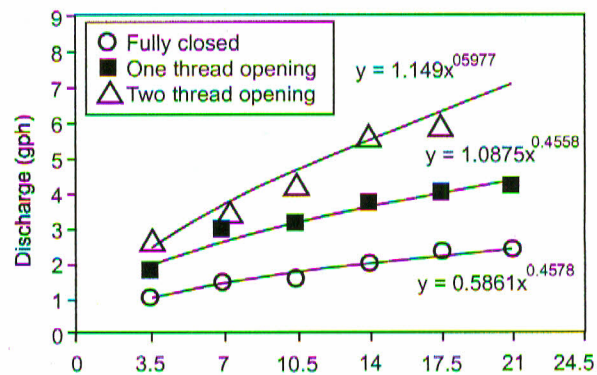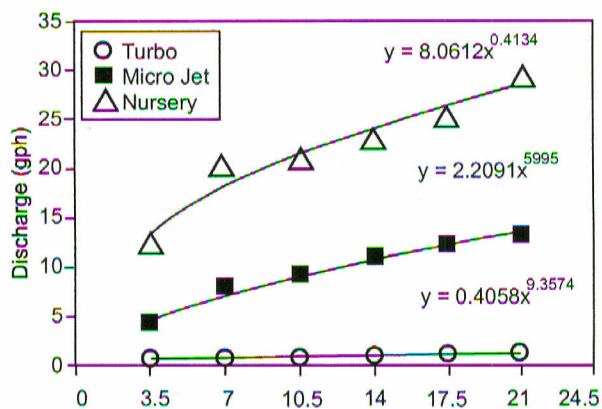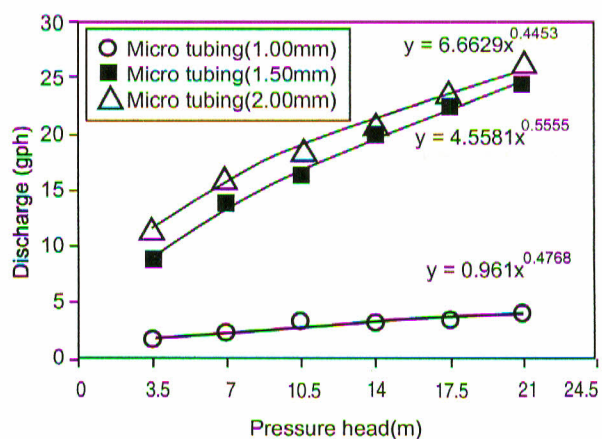

Fig. 2(a-c). Pressure-discharge relationship of locally manufactured drip emitters; (a) Spiral, (b) Turbo, Micro-jet and nursery, (c) Micro-tubing.

coefficient for each type of emitter was calculated under six operating pressures ranging from 3.50 to 21.00 meter head with an increment of 3.50 meter pressure head. At 21.00 meter pressure head the Us values were: 70, 77, 73, 92, 85, 90, 95, 89 and 98 % for (1) spiral; fully closed, one thread opening and

Table 1. Water application uniformity coefficient (Us, %) for different types of emitters at different operating pressure heads

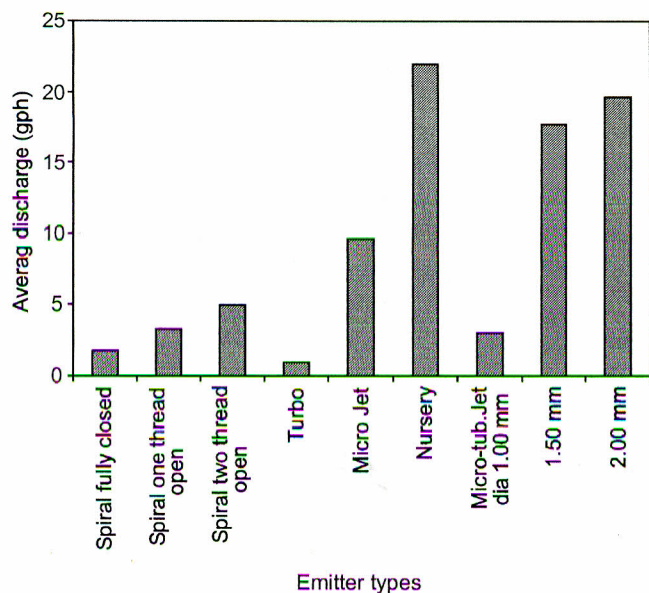| Emitter type		Pressure head (m)						
		3.50	7.00	10.50	14.00	17.50	21.00	Average
Spiral	fully closed	71	70	80	71	71	70	72.00
	one thread opening	84	78	81	85	72	77	79.50
	two thread opening	87	76	85	88	92	73	83.50
Turbo		82	86	75	77	91	92	83.80
Micro-jet		97	85	85	82	87	85	86.83
Nursery		97	95	97	91	92	90	93.66
Micro-tubing	1.00 mm dia	94	95	94	95	95	95	94.66
	1.50 mm dia	98	91	91	92	87	89	91.33
	2.00 mm dia	97	97	98	96	99	98	97.55

Fig. 3. Average discharge (gph) of different emitter types at 3.5 to 21.0 pressure head (meters).

two thread opening (2) Turbo (3) micro-jet (4) nursery (5) micro-tubing of different diameters; 1.00 mm, 1.50 mm and 2.00 mm, respectively, while at 3.50 meter head the Us values were measured to be 71, 84, 87, 82, 97, 97, 94, 98 and 97%, respectively.

The average Us % values of drip emitters for pressure range of 3.50 to 21.00 m pressure head were 72, 79.5, 83.5, 83.80, 86.83, 93.66, 94.66, 91.33 and 97.55 (%), respectively, for (1) spiral; fully closed, one thread opening and two thread opening (2) turbo (3) micro-jet (4) nursery (5) micro-tubing of different diameters; 1.00 mm, 1.50 mm and 2.00 mm, respec-

tively. The results of coefficient of uniformity based on the equation 2 are given in Table 1.

The overall average (Us) of 80% was observed in turbo, micro-jet, nursery and all types of micro-tubings that shows reasonably good performance for drip emitters. Also variation in the Us, (%) depends on manufacturing variation in emitters and pressure variations in a system due to pipe fraction and elevation changes (Pitts, *et al.*, 1986). However, the application uniformity above 80% is an indicator of good performance of the system as recommended by Jensen, *et al.* (1980). Us (%) for spiral fully closed emitters were found to be 71, 70, 80, 71, 71, 70 with 72 as an average value. Us (%) for fully closed spiral emitters were lowest. Coefficient of variation (C_v) for 2.00 mm dia micro-tubes with 98% was highest among all emitter types.

Table 2. Summary of regression analysis for different types of emitters

Emitter type		k	x	R²
Spiral	fully closed	0.586	0.458	0.973
	one thread opening	1.087	0.455	0.887
	two thread opening	1.140	0.598	0.967
Turbo		0.405	0.357	0.958
Micro-jet		2.209	0.599	0.971
Nursery		8.061	0.413	0.959
Micro-tubing	1.00 mm dia	0.961	0.476	0.976
	1.50 mm dia	4.558	0.555	0.996
	2.00 mm dia	6.662	0.445	0.996

Table 3. Manufacturer's coefficient of variation for different emitter types

Pressure head (m)	Spiral at different positions			Turbo	Micro Jet	Nursery	Microtube 35 cm long		
	fully closed	one thread open	two thread open				1.00 mm dia	1.50 mm dia	2.00 mm dia
3. 50	0.29	0.16	0.13	0.17	0.03	0.03	0.06	0.02	0.03
7. 00	0.3	0.22	0.24	0.14	0.15	0.05	0.05	0.09	0.03
10. 50	0.2	0.19	0.15	0.20	0.14	0.03	0.06	0.1	0.02
14. 00	0.29	0.15	0.17	0.20	0.17	0.09	0.05	0.08	0.02
17. 50	0.29	0.28	0.09	0.09	0.15	0.08	0.05	0.13	0.01
21. 00	0.3	0.23	0.25	0.09	0.15	0.09	0.05	0.11	0.02
average	0.28	0.21	0.17	0.15	0.13	0.06	0.05	0.09	0.02

Manufacturer's coefficient of variation. Manufacturer's coefficient of variation (Cv) is given in Table 3. If is the highest for fully closed spiral emitters. Its value ranges from 0.20 to 0.30 with 0.28 as average for pressure ranging from 3.50 to 21.00 m head.

Manufacturer's coefficient of variation is lowest for 2.00 mm dia micro-tubes. It ranges from 0.01 to 0.03 with 0.02 as an average. Average value of manufacturers coefficient of variation for fully closed one thread open, two thread open spiral emitter, turbo, micro-jet nursery and micro tubes of 1.00 mm, 1.50 mm, 2.00 mm dia are 0.28, 0.21, 0.17, 0.15, 0.13, 0.06, 0.05, 0.09 and 0.02, respectively.

Conclusion

The results of the study indicate that (C_v) is an average for all types of micro-tube and nursery emitters; marginal for turbo and micro jet; and unacceptable for spiral emitters. Thus the emitters with marginal and unacceptable C_v ranges need attention for precision and more research for quality emitters, for better water application to orchards and other valuable crops. On the basis of Us (%) tubro, micro-jet, nursery and micro-tube emitters fall in the acceptable range.

References

ASAE, Engineering Practice. 1984. *ASAE EP405-Design, Installation and Performance of Trickle Irrigation Systems,* pp. 502-505, Amer. Soc. Agric. Engr., St. Joseph, Michigan, USA.

Bralts, V.F. 1986. Operational Principles / Field performance and evaluation. In: *Trickle Irrigation for Crop Production*, F.S. Nakayama, D.A. Bucks (eds.), Elsevier Science Publisher, Netherland.

Demir, V., Yerdem, H. 2002. Ayni damlaticiya sahip damla sulama borularinda boru capinin en uygun boru uzunluouna etkisi. *Egi. Univ. of Ziraat Fak. Derg.* **39:** 120-127.

Howell, T.A., Barinas, F.A. 1980. Pressure losses across trickle irrigation fittings and emitters. *Trans. ASAE.* **23:** 928-933.

Jensen, M.E. 1980. *Design and Operation of Farm Irrigation Systems.* ASAE, Monograph No. 3, Amer. Soc. Agric. Engr., St. Joseph, Michigan, USA.

Pitts, D.J., Ferguson, J.A., Wright, R.E. 1986. Trickle irrigation lateral line design by computer analysis. *Trans. ASAE* **29:** 1320-1324.

Solomon, K.H. 1979. Manufacturing variation of trickle emitters. *Trans. ASAE* **22:** 1034-1038, USDA (1984).

Von Bernuth, R., Solomon, K.H. 1986. Design Principles: Emitter construction. In: *Trickle Irrigation for Crop Production,* F. S. Nakayama, D. A. Bucks (eds.), pp. 27-52, Phonex: Elsevier Science Publishers, Netherland.

Wu, I.P., Gitlin, H.M., Solomon, K.H., Saruwatari, C.A. 1986. Design Principles-System Design. In: *Trickle Irrigation for Crop Production,* F.S. Nakayma, D.A. Bucks (eds.), pp.53-92, Elsevier Science Publishers, Netherland.

Wu, I.P., Feng, J., Yabusaki, K. 1989. Emitter spacing and uniformity of irrigation application. *ASAE Paper No. 89-2080,* pp. 16, Amer. Soc. Agric. Engr., St. Joseph, Michigan, USA.