Research Article

Evaluating Hydraulic Performance of Locally Available Drip Emitters Used in Pakistan

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Abstract | In drip irrigation system, emitters are the key system components. The hydraulic performance of these drip emitters may affect the efficiency of irrigation schemes if not conforming to specified standards. The main objective of this study was to investigate the hydraulic characteristics including average flow rate, emitter exponent, distribution uniformity, emitter discharge coefficient of variation, and statistical uniformity of locally available drip emitters. These indices were compared with the manufacturer data and available technical standards. A test bench was developed to measures the flow of emitters at different operating pressures. Data was consequently used for evaluating the hydraulic flow characteristics. Nine types of emitters marked S1-S9 having sample size of 27 were tested on the hydraulic bench. When evaluated for compliance with manufacturer claim for being marked as PC and Non-PC, all the emitters passed the test except for S1. The statistical uniformity of S9 ranked highest (96.62%) compared to other emitter types, while S2 ranked lowest (87.99%). When appraised for discharge variation under variable head, S3 discharge variation was not significant (2%) whereas S8 had the highest discharge variation of 38%. Overall the distribution uniformity of tested emitters ranged from 83.84% to 96.67%. Based on the outcome of this study it is suggested that drip emitters should be tested before adoption to ensure uniformity of water application.

Received | April 25, 2019; **Accepted** | December 08, 2019; **Published** | February 01, 2020
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Citation | Khalil, T.M., M. Ajmal, T.A. Khan, Z.U. Haq, M.S. Khattak and A. Malik. 2020. Evaluating hydraulic performance of locally available drip emitters used in Pakistan. *Sarhad Journal of Agriculture,* 36(1): 185-191.
DOI | http://dx.doi.org/10.17582/journal.sja/2020/36.1.185.191
Keywords | Drip irrigation, Emitter, Flow rate, Operating pressure, Distribution uniformity

Introduction

The Climate change and decrease in per capita water availability associated with increasing global human population have intensified the water conservation practices (Elliot et al., 2014). Like rest of the world, in Himalayan region the snowcaps are shrinking, reducing the freshwater resources across China, India, and Pakistan (Morrison et al., 2009). Pakistan ranked 4th for having the largest irrigated area in the world (ICID, 2003) but sprinting from a water stress to water scares country. The per capita water availability is declining from 5600 m^3 to 1000 m^3 over the past seven decades against the Falkenmark water stress thresholds of 1800 m^3 per capita (Iqbal and Iqbal, 2015). Unlike the developing countries where70 to 80 percent of the fresh water is used for agricultural purposes, Pakistan is using its 93% for agriculture (PARC, 2017). This high percentage is mainly attributed to low water use efficiency. Main factors responsible for lower efficiency are the higher water losses in unlined sections of irrigation network, water allocation strategies, and archaic field application methods (Jacoby and Mansuri, 2018; Chaudhry, 2018). The water scarcity and large water consumption by agriculture encourages the conservation practices through adaptation of high efficiency irrigation systems (Ward and Pulido-Velazquez, 2008). Compared to other means of high efficiency irrigation systems, drip irrigation allows water application with higher efficiency and low energy requirement compared to sprinkler irrigation (Abadia et al., 2008). However, other than the operational parameters such as the irrigation frequency, water application rate, irrigation duration, and drip emitter placement, the success of these drip irrigation schemes requires the proper selection of emitters (Skaggs et al., 2004). In Pakistan, drip irrigation is prevalent on growing cash crops and orchards, though the farmers have seen the benefits as well as difficulties associated with faulty design parameters. Previous studies (Hezarjaribi et al., 2008; Kusre et al., 2016) suggest that design parameters should be based on experimental results rather than relying on the manufacturer data only to ensure uniformity of water application. There is lack of authentic empirical data for the available drip emitters in Pakistan on discharge and distribution uniformity when operated at different pressure regimes. The main objective of this study was to investigate the hydraulic flow characteristics of locally available drip emitters and its comparison with the manufacturer data and standards available in literature.

Material and Methods

Drip emitters

For this study, nine types of custom emitters available in the local market were selected. Eight of them were different type of online point source emitters, while one was inline built-in emitter with 0.3 m emitter to emitter spacing. The details and origin of these drip emitters is provided in Table 1. For evaluating the hydraulic performance, eight online type emitters having barb inlet were installed on 13 mm diameter, class 6 bar pressure rating High Density Polyethylene (HDPE) drip line. The drip lines were cut into the 0.8 m long pieces, three drippers were installed on each line with 0.20 m spacing from each other (Figure 1). For each type of emitters three laterals were assigned, therefore 27 drip lines were prepared with a total of 51 emitters on it. Each lateral line was tested three times thus an individual type of drip emitter was tested 27 times.

Table 1: *Emitters types, average rated flow, and manufacturers classification as pressure and non-pressure compensated.*

Emitter ID	Emitter name	Manufacturer/ Origin	Rated Discharge	Type
S1	Turbo Key PC	Al Wassel KSA*	4 lph	PC
S2	Turbo Key	Al Wassel KSA	4 lph	Non-PC
S3	Turbo Plus	Toro Australia	8 lph	PC
S4	Turbo Key	Al Wassel KSA	8 lph	Non-PC
S5	Turbo Key PC	Al Wassel KSA	8 lph	PC
S6	Turbo-Key	Hardie Australia	4 lph	Non-PC
S7	General Drip	-	16 lph	Non-PC
S8	The Clip	Thermoplast UAE!	8 lph	Non-PC
S9	GR	Euro Drip Greece	2 lph	Non-PC

**Kingdom of Saudi Arabia; !United Arab Emarates.*

Figure 1: *Samples of drip line with emitters.*

Hydraulic bench

A hydraulic bench was fabricated indigenously at the workshop of the Agriculture Engineering Department of University of Engineering and Technology Peshawar (Figure 2). The main components of hydraulic bench included a water storage tank, pump, flow control valves, pressure regulating valve, lateral testing cistern, pressure gauge, and electric control switches. The water storage tank had total capacity of 125 liters and could be refilled during the experiment if required. The main cistern drain of the hydraulic bench was also connected back to the water tank for recirculating the water during the preparatory stage of entrap air removal as per ISO standards (ISO, 2004) for drip equipment testing. A drain plug was provided at the bottom of the tank to facilitate drainage when the equipment is stowed.

Though the maximum hydraulic requirement of our system for drippers under consideration was 75-100 lph at 0.75-1 bar pressure head, an electric mono-block centrifugal pump (0.37 KW) capable of

300-2400 lph discharge and 0.5-4 bar pressure head capacity was installed on the hydraulic bench, enough to meet the system requirement of all ranges of drip emitters available. On the pump delivery side, a spring activated pressure relieve valve was provided to match the system requirements without building excessive pressure in lateral lines, the pressure relief valve was calibrated to the desired set hydraulic parameters in LDPE lateral lines. Pressure relief valve was also helpful in swift reading, enabling the observer without shutting off the pump, even if the main valve is set to complete shut position.

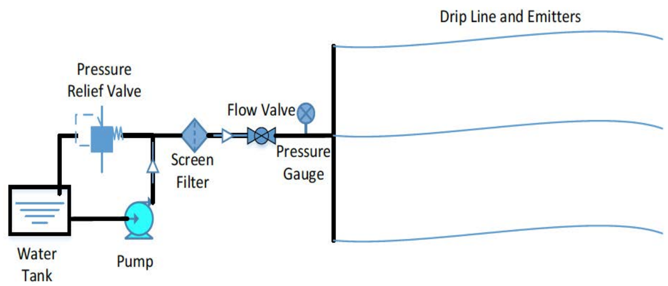

Figure 2: *Drip emitter hydraulic bench schematic layout.*

For this experiment potable water was used. However, to safeguard against accidental drip emitters plugging, a Y-type PN 6 brass metal screen filter was installed after pressure relief valve to trap sand or other foreign material that may clog the emitters on test. Primary flow regulation valve was installed after the pressure release valve; its main function was to set the pressure at certain fixed value selected for emitter discharge within the pressure range already set by the pressure relief valve. Secondary flow regulation valve combined with a pressure gauge was installed at flow measuring deck. The structural detail of the valve assembly was such that even with closed flow condition of the secondary flow regulation valve the pressure gauge showed the reading. This special feature of secondary flow regulation assembly gives us the accuracy in readings and eliminates minor snags when set of samples are tested for discharge measurements. The drip lines with inline built-in emitters were cut in such a manner that the emitters were accommodated in the cistern of the hydraulic bench. The samples were connected at one end to the secondary flow regulation valve with the help of push fit hose nozzle at one end and to the dead-end barb plug at the left corner of hydraulic bench. The drip lines were fastened over the connection points with clamps to make them leak proof. For Electric Control, a direct online (DOL) single phase starter was provided, a current and voltmeter was also installed at hydraulic bench front panel.

Hydraulic performance of drip emitters

Drip emitters were evaluated for their performance using emitter exponent, a statistical index which is used for classifying an emitter as pressure compensating (PC) and non-pressure compensating (Non-PC). We also considered the concept of low-quarter distribution uniformity which is influenced mainly by manufacturing variation and pressure variation within the system. Emitters performance was also evaluated using a new statistical uniformity index. For this purpose, the emitters were tested at two operating pressures of 1 and 0.75 bar, a typical pressure head at emitter under locally installed systems. The summary of drip emitter data used in this study is provided in Table 1. These include commercial brand name, manufacturer name, country of origin, and manufacturer classification as pressure compensating and non-compensating (PC/Non-PC). Among these emitters S1, S3, and S5 is reported by the manufacturer as PC, while rest of the emitters were Non-PC. The flow rates of the emitters were in the range 2-18 lph, emitters S1-S8 were of on-line type while S9 was of built-in inline type.

Determination of emitter exponent

The emitter exponent (x) measures the pressure induced drip emitters' flow variation. It categorizes the emitter type and/or flow regime of emitters. Hillel (2013) reported the drip emitter flow in term of x and H:

$$q = K_d H^x \quad \text{.... (1)}$$

Where;

K_d is the emitter discharge coefficient. The most common method for the determination of x and K_d is to perform the linear regression considering a logarithmic transformation of the above equation:

This is of the typical linear form of:

$$\log q = x\log H + \log K \quad \text{.... (2)}$$

$$y = mx + b \quad \text{.... (3)}$$

By simple log transformation it is possible to extend x from the discharges calculated at two different operating pressure using following relation.

$$x = \frac{\log \frac{Q1}{Q2}}{\log \frac{H1}{H2}} \quad \text{.... (4)}$$

Where;

Q_1 and Q_2 are the emitters flows (lph) at pressures (bar) H_1 and H_2 respectively. The value of x ranges from 0 to 1, an ideal full pressure compensating emitter has an x value of zero having a fully turbulent flow regime while emitter flow regime is considered laminar if the x got a value of unity (Karmeli, 1977).

Distribution uniformity

Other than the issue how well the water is provided at farm gate with minimum conveyance losses, the next important factor is how evenly the water is applied to the crop field. The USDA handbook 82 published in 1956 provided the concept of application uniformity while evaluating the performance of furrow, border, and hand-move sprinkler irrigation systems. The concept was later refined by Burt et al. (1997) using the concept of low quarter distribution uniformity (DU_{lq}) as a numerator in the uniformity ratio.

$$DU_{lq\ flow\_rate} = \left(\frac{q_{min\ lq}}{q_{avg}}\right) \times 100 \quad \dots(5)$$

Where;

$q_{min\ lq}$ is low quarter average flow rate, while q_{ave} is the average flow rate of the drip emitters of whole system.

Statistical uniformity using ASAE EP458 method compared to traditional distribution uniformity index, we also tested the drip emitters performance using American Society of Agricultural and Biological Engineers (ASABE) procedure outlined in ASABE standards EP458. The statistical uniformity (U_s) was determined using following relation.

$$U_s = (1 - V_{qs}) \times 100 \quad \dots(6)$$

The emitters flow coefficient of variation (V_{qs}) was calculated from the ratio of average flow rate ($\bar{q}$) and standard deviation (S_q).

$$V_{qs} = \frac{S_q}{\bar{q}} \quad \dots(7)$$

Average flow and standard variation of the emitters flow is determined using following equations:

Where; *q* is the emitter flow and *n* is the number of emitters.

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \quad \dots(8)$$

$$S_{qs} = \sqrt{\frac{\sum_{i=1}^{n} q_i^2 - \frac{1}{n}[\sum_{i=1}^{n} q_i]^2}{n-1}} \quad \dots(9)$$

Results and Discussion

Average discharge verses pressure of emitter

The overall results reveal that discharge of all emitters increased with increase in operating pressure, generally discharge variation of the non-pressure compensating emitters were found higher than the pressure compensating drip emitters (Figure 3). Among all, the highest variation in average emitter flow was found in S8 (38%), followed by S4 and S7 with 26% and 25% variation in discharge respectively, while S3 had the lowest flow variation of 2% trailed by S5 and S9 with when operated at 0.75 and 1 bar respectively.

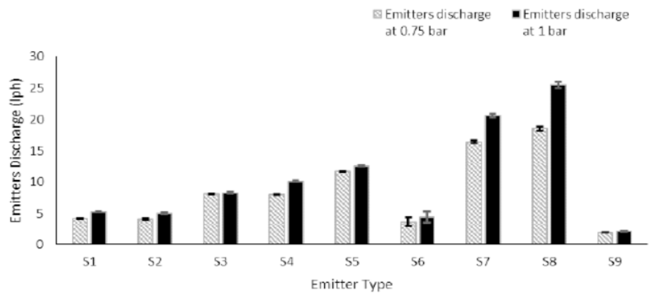

Figure 3: *Emitter flow rate when operated at two pressures (i.e. 1 and 0.75 bar).*

Emitter S9 had the lowest overall standard variation (SD) of 0.52% in discharge, while S6 had the highest SD of 20% (Figure 3) when evaluated for flow variation (n=54). Based on emitter flow rate evaluations emitters were found in compliance to the reported flow rate value at 0.75 bar, except for S5 whose flow rate was 1.45 times higher than the reported values even at 0.75 bar. Emitters S9 and S3 was found in compliance with manufacturer reported values at both 0.75 and 1 bar operating pressure.

Gil et al. (2008) found similar trend of emitter flow response to the operating pressure for pressure compensating and non-pressure compensating emitters during laboratory investigation of subsurface drip irrigation in uniform soils.

Low quarter distribution uniformity

Pressure variation had mixed effects on the emitter's distribution uniformity; for S1, S2, S4, S5, S6, and S7 the distribution uniformity was increased with increase in operating pressure, while for S3, S8, and S9 the pressure increases reduced the distribution uniformity (Figure 4). Overall, S9 had the highest while S8 had the lowest distribution uniformity, and on average S4, S5, and S6 had very close distribution uniformity.

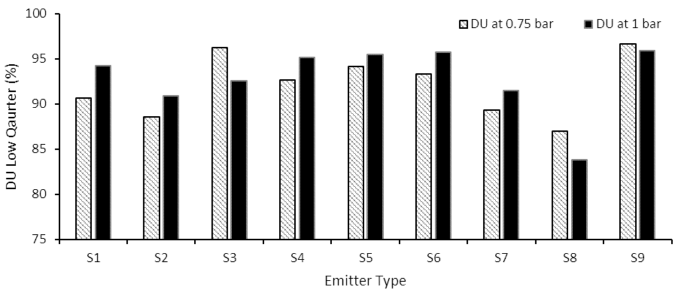

Figure 4: *Distribution uniformity values calculated for various drip irrigation emitters irrigation systems using measured flow at different operating pressures.*

While selecting the drip emitters, proper attention should be given to the component distribution uniformity. This is due to the fact that drip irrigation system distribution uniformity is estimated mathematically combining the component distribution uniformity values and flow variation induced by the field pressure variation, emitters plugging and wear in system (Burt, 20014). The water quality used in drip irrigation could also impact the hydraulic performance of drip emitters (Liu and Huang, 2009). The field distribution uniformity was adversely affected due to the growth of biofilm when reclaimed wastewater was used in drip irrigation (Dazhuang et al., 2008). In sub-surface drip irrigation, root intrusion may also cause the drip plugging thereby reducing the field distribution uniformity (Camp et al., 2000).

Effect of pressure on emitter exponent and classification based on flow regime

According to Bralts et al. (1987), theoretically the compensating drip emitter discharge should not show any variation under different pressure heads. However, in accordance with some other studies (Madramootoo et al., 1988; Ozekici and Bozkurt, 1999), our results did not support that theory. Even a properly designed pressure compensating drip emitter will behave like a non-pressure compensating emitter if the pressure variation limits exceeds certain predefined limits provided by the manufacturers. Usually the pressure variations are in the limits of 0.25 to 0.40 bar pressure for most of the emitters by different manufacturer. For some emitters (water diffuser bugcap 24 lph, Irritec siplast) the increase in pressure had the effect in the reverse order, and the reason for this was the faulty design of diaphragm that swells and restricts the flow even at higher pressure. Data of this type of emitter was discarded and not presented the results of this study.

Flow regime was determined on basis of emitter exponent (x) value. Result showed (Table 2) that S3 and S5 comes out to be pressure compensating emitters categorized as good and poor respectively in same class. S2, S6 and S9 classified as Non-PC in very tolerant category. S1, S4, and S7 as Non-PC, Tolerant, while S8 as Non-PC, Low Tolerance. S1 was found in contrary to the manufacturer claim.

Table 2: *Summary of test results for emitter exponent and their classification as pressure/non-pressure compensated.*

Emitter ID	Emitter exponent	Classified as	Category
S1	0.54	Non-PC!	Tolerant
S2	0.48	Non-PC*	Very Tolerant
S3	0.06	PC*	Good
S4	0.56	Non-PC*	Tolerant
S5	0.17	PC*	Poor
S6	0.48	Non-PC*	Very Tolerant
S7	0.55	Non-PC*	Tolerant
S8	0.78	Non-PC*	low Tolerance
S9	0.23	Non-PC*	Very Tolerant

**Emitter class was found same as specified by the manufacturer; ! Emitter class was not found same as specified by the manufacturer.*

Table 3: *Uniformity parameter values for emitters hydraulic performance.*

Emitter ID	Emitter discharge coefficient of variation	Emitter statistical uniformity
S1	0.32	93.32
S2	0.56	87.99
S3	0.42	94.91
S4	0.42	95.41
S5	0.52	95.69
S6	0.21	94.93
S7	1.63	91.21
S8	2.43	88.95
S9	0.07	96.62

Statistical uniformity

Drip emitters were evaluated using both traditional emitter discharge uniformity parameters and a relatively new method included in ASAE EP458. Among all emitters, S9 had the highest statistical uniformity (96%) and very low discharge coefficient of variation, where as S2 and S8 had the lowest statistical uniformity of 88% and 89% respectively (Table 3). Though the S2 and S8 statistical uniformity were much closer, however, coefficient of discharge variation for S8 (2.43) was much higher than S2

(0.56). when compared with the emitter hydraulic classification, emitters having higher coefficient of discharge variation was corelated with poor hydraulic performance (i.e. low tolerant to pressure variation) and conversely true for emitters having lower coefficient of discharge variation. Based on the results of ASABE EP458 when compared to traditional indices and previous literature finding of Camp et al. (1997) it appears that that both traditional and ASABE EP458 can be used to evaluate the drip emitters hydraulic performance.

Conclusions and Recommendations

Nine types of Emitters installed on 27 drip lateral lines in triplicates were tested on procedure previously outlined. When tested in compliance with manufacturer claim for being marked as PC and/or Non-PC all the emitters passed the test except for S1. When tested for statistical uniformity S9 gives highest performance among all tested emitters type (97%), while S2 had the lowest (88%). When appraised for discharge variation under variable head, the S3 discharge variation was negligible (2%), whereas S8 had the highest discharge variation of 38%. Overall the distribution uniformity was ranged from 84% to 97%. The purpose of this study was to appraise the hydraulic performance of emitters locally available in market. These results must not be quoted for commercial purposes or referred against any brand/company.

Acknowledgements

We would like to thank the Board of Advanced Studies and Research (BOASAR), University of Engineering and Technology Peshawar for financing this project. We appreciate Rainmakers High Efficiency Irrigation System Lahore for the provision of emitters and parts of Hydraulic Bench. We are also thankful to Mr. Obaid Ullah Foreman working in Agricultural Engineering Department, University of Engineering and Technology Peshawar for his help in the fabrication process.

Novelty Statement

In Pakistan, there is lack of authentic hydraulic performance data for drip emitters. This study investigated the hydraulic of locally available drip emitters and was compared with the manufacturer data and standards available in literature.

Authors Contribution

Tariq Mahmood Khalil: Planned, designed, conducted the experiments and wrote the manuscript.
Muhammad Ajmal: Technically reviewed the manuscript to ensure the structure and style.
Taj Ali Khan: Supervised the research work and helped in statistical analysis.
Zia Ul Haq: Compiled the results for assessment.
Muhammad Shahzad Khattak: Helped in editing the manuscript.
Abdul Malik: Helped in collection of drip emitters and preparation of samples.

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