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HYDRAULIC PERFORMANCE EVALUATION OF PRESSURE COMPENSATING (PC) EMITTERS AND MICRO-TUBING FOR DRIP IRRIGATION SYSTEM

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Abstract

Drip irrigation system is necessary for those areas, where the water scarcity issues are present. The present study was conducted at the field station of Climate Change, Alternate Energy and Water Resources Institute (CAEWRI), National Agricultural Research Center (NARC), Islamabad, during 2013, regarding drip irrigation system. Drip irrigation system depends on uniform emitter application flow. All the emitters were tested and replicated thrice at pressure head (34 to 207Kpa) with an increment of 34 Kpa. The minimum and maximum discharges were 1.32 - 3.52, 3.36 - 5.42, and 43.22 - 100.99 Lph, with an average of 2.42, 4.63 and 73.66 Lph, for Bow Smith, RIS and Micro-tubing, respectively. It indicates that more than 90% of emission uniformity (E_U) and uniformity coefficient (C_U) for all Emitters, which shows excellent water application with least standard deviation, ranging 0.12 to 2.37, throughout the operating pressure heads in all emitters. An average coefficient of variation (C_V) of all emitters were behaving less than 0.07, indicating an excellent class at all operating pressure heads between 34 to 207 Kpa. Moreover, the relationship of discharge and pressure of emitters indicates that discharge increased with the increase of pressure head. The Q-H curve plays key role in the selection of emitters.

Keywords: Drip irrigation, Emitters, Pressure, Discharge, Uniformity, and Relationship.

Introduction

Arid and semi-arid regions are predominantly dependent on artificial irrigation. Water in these regions is the most limiting factor requiring its optimal use. Irrigation water is supplied to the plants/crops to replenish root-zone moisture storage when natural rainfall is inadequate or poorly distributed. However, it is nearly impossible and economically unfeasible for traditional flood irrigation methods to apply the same amount of water to all plants within a field, which results in reduced crop yields (Wu, 1987; Bhatnagar and Srivastava, 2003). Moreover, the traditional flood irrigation methods waste huge amount of water as deep percolation. When irrigation supplies are in small quantity, the more efficient use of the available water becomes compulsory. The efficient utilisation of irrigation water is possible by the adoption of high efficient irrigation system, such as, drip irrigation systems.

Drip irrigation, which is known as a trickle irrigation system, is also considered as the most efficient water application system. Drip irrigation can be defined as a precise, slow application of water in the form of discrete drops that are achieved through pressure reducing paths and emitters/drippers. The emitters are emission devices, which provide water to the root zone of soil with proper duration. They are located at prescribed points along the drip tubing, or tape, which correspond to required-crop spacing. The drip systems are suitable where traditional surface irrigation methods do not work properly, such as, deserts and hilly terrains. In such areas, the pressurised systems can work quite satisfactorily (Bhutta and Azhar, 2005). Drip irrigation can deliver water and chemicals more precisely and uniformly at a higher frequency of application than furrow and sprinkler irrigation. It can increase the yield and revenue, reduce water and

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fertiliser cost and decrease cultural cost as compared with other irrigation methods. The drip system includes the water source, shut off valves, control valves, pressure gauges, drip tapes and tubings/emitters, main line, sub main lines and laterals (Schwankl and Prichard, 1999). Most drip irrigation systems work well in the pressure range of 34-69 kpa or higher. However, some pressure compensating emitters operate at greater than 69 kpa to be effective. Pressure, higher than 276 kpa, should be avoided, since it may cause fitting emitters to pop out of the drip tubings (Schwankl, Prichard, 1999). The differences in emitter geometry may be caused by variation in injection pressure and heat instability during their manufacture, as well as, by a heterogeneous mixture of materials used for the production (Kirnak et al., 2004).

The ideal drip irrigation system is one in which all emitters deliver the same amount of water so that each plant can receive equal amount of water during an irrigation period. The pressure and discharge variation in drip irrigation system is unavoidable due to material quality standards, emitter's hydraulics or less uniformity of emissions. The growing water shortages have prompted the irrigation industry and a number of local as well as multinational companies have started to provide irrigation service to farmers in Pakistan. However, there is no check and balance on quality control to avoid the sub-optimal materials, designs and services. The farmers are totally dependent on the claims of the service providers which, in most cases, are based on assumptions. The main objective of the present study was to investigate and evaluate performance of few imported drippers or emitters focusing on their emitter discharge, uniformities, relationship between pressure-discharge and coefficient of variations or material quality standards. The outcome of the study will greatly aid in an overall system evaluation and will assist in achieving quality control in the adoption of drip irrigation system in Pakistan.

Materials and Methods

Experiment Layout

The experiment was conducted at the field station of Climate Change, Alternate Energy and Water Resource Institute (CAEWRI), National Agricultural Research Center (NARC), Islamabad, during 2013. The water is supplied to sub main line (1 inch diameter) through the main line having 2 inches diameter. Lateral line, having diameter of 0.5 inch, was connected to the sub-main line. The each end of the lateral line was closed with the help of end plug. A pressure gauge, control valve and a water meter were installed for measuring of pressure and discharge. The diagram of the system is elaborated in Fig. 1.

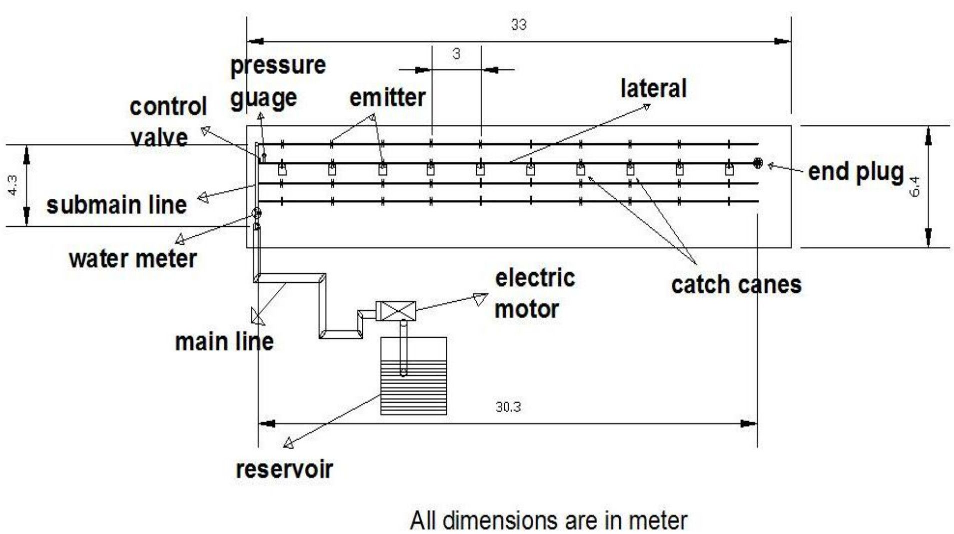

Fig. 1. Sketch of drip irrigation system at CAEWRI field station.

Data Collection

Three types of emission devices, viz., Turbo Bow Smith – US-made, Turbo RIS – AUS-made and locally made Micro-tubings, were selected to test and evaluate hydraulic characterisations. The system was operated for a period of 30min for each data reading, replicating thrice for each of the three selected emissions. The emitter discharge was measured by volumetric method at pressure range from 34-207 Kpa with an increment of 34 kpa. The volume of the water collected in the catch canes was measured with the help of graduated measuring cylinder. The operating pressure head was regulated through a bypass, installed at the pump house. The pressure and discharge measurements were taken by the use of pressure gauges and water meter installed at beginning of lateral line/sub-main line.

Discharge Measurement and Variation

The emitter discharge was measured by volumetric method (volume collected and divided by operating time or time taken during discharge of emission):

$$q = V/t \quad \ldots \quad (1)$$

where,

q = Discharge of emission, Lph
V = Volume collected (ml)
t = Time taken (hours)

The following equation, reported by Camp et al. (1997) and Nakayama and Bucks (1986), was employed to compute and analyse uniformity of the drip system. The method is simple and straight forward and is still widely used.

$$q_{var} = (q_{max} - q_{min})/q_{max} \quad \ldots \quad (2)$$

Coefficient of Variation (C_V)

Coefficient of variation measures the non-uniformity of the discharge in the emitters due to variation in manufacturing. It describes the quality of the material, used in manufacturing of the emission devices. In drip design, any C_V greater than 0 means that plant will receive different amount of water because of the inability of new emitters to discharge the same flows at same pressure. However, this non-uniformity is smoothed out somewhat if multiple emitters supply individual plants. The C_V can be calculated, using the following formula (Burt and Styles, 2007).

In summary, friction coefficient reveals the material quality standard or the loss of pressure head and volume of water due to less standardisation of material. Bralts and Kesener (1983) and Keller and Bliesner (1990) represented localised irrigation sub-units classification according to coefficient of variations as presented in Table 1.

$$C_V = S_q/q_{avg} \quad \ldots \quad (3)$$

Table 1. Classification of coefficient of variation

Coefficient of variation, C_V	Classification
> 0.4	Unacceptable
0.4-0.3	Low
0.3-0.2	Acceptable
0.2-0.1	Very good
< 0.1	Excellent

Uniformities Investigation

Uniformity coefficient, C_U (%): Ability of the emitters in drip irrigation system to distribute the water in whole field equally is known as uniformity. Uniformity cannot be flawless. Therefore, the problem of under- and over-irrigation develops non-uniformities during the irrigation. Thus, uniformity plays a vital role in selection, design and management of the irrigation systems. One of the widely used C_U is Christiansen uniformity coefficient (Mosh, 2006):

$$C_U = 100 - (80 * S_d/V_{avg}) \quad \ldots \quad (4)$$

where,

C_U = Uniformity coefficient (%),

Sd = Standard deviation of observations,

V_{avg} = Average volume collected.

The coefficient of uniformities, standards/ classifications is presented by (ASABE standards EP458, 1999). Micro-irrigation system uniformity classifications based on uniformity coefficient are presented in Table 2.

Table 2. Classification/standards of uniformity coefficient

Uniformity coefficient, C_U (%)	Classification
Above 90%	Excellent
90-80%	Good
80-70%	Fair
70-60%	Poor
Below 60%	Unacceptable

Emission uniformity, E_U (%): Emission uniformity is also known as distribution uniformity. It is expressed as a percentage and is a relative index of the variability between emitters in an irrigation block. It measures the consistency of the water application across the field during irrigation. Emission uniformity is defined as the average discharge of 25% of the sampled emitters with the least discharge, divided by the average discharge of all sampled emitters. It is typically used to evaluate manufacturing quality of the emitters. Emission uniformity was calculated using the equation presented by (Ortega et al., 2002):

$$E_U(\%) = (q_{avg25\%}/q_{avg})*100 \quad \dots \quad (5)$$

where,

$q_{avg25\%}$ = mean of the lowest 0.25 of emitter discharge.

According to Merriam and Keller (1978) and IRYDA (1983), the classifications of emission uniformities are expressed in Table 3.

Table 3. Classification of emission uniformity

E_U %	Classification Merriam and Keller (1978)	Classification IRYDA (1983)
<70%	Poor	Unacceptable
70-80%	Acceptable	Poor
80-86%	Good	Acceptable
86-90%	Good	Good
90-94%	Excellent	Good
>94%	Excellent	Excellent

Results and Discussion

Analysis of Discharge and Discharge Variation

The average values of discharge were 1.32, 1.80, 2.25, 2.64, 3.01 and 3.52lph for pressure compensating emitter made by Bow Smith – US company, 3.36, 4.21, 4.63, 4.97, 5.21 and 5.42 lph for pressure compensating emitter made by RIS – AUS company and 43.22, 56.87, 68.86, 79.58, 92.45 and 100.99 lph, for Pakistani made Micro-tubing (1.5mm diameter) at operating pressure ranges from 34-207Kpa. The detail data presented in Tables 4 and 5.

Table 4. Series wise detail discharge (Lph) of various emitters at different operating pressure heads.

Operating pressure (Kpa)	Emission wise discharge (Lph)								
	Bow Smith Turbo Emitter, US made								
	E1	E2	E3	E4	E5	E6	E7	E8	E9
34	0.95	1.06	1.06	0.95	1.06	1.06	1.10	1.02	1.17
69	1.29	1.29	1.40	1.55	1.40	1.40	1.51	1.44	1.55
103	1.59	1.63	1.81	1.74	1.78	1.85	1.85	1.81	1.97
138	1.93	1.89	2.12	2.00	2.12	2.12	2.19	2.12	2.31
172	2.27	2.19	2.38	2.27	2.38	2.42	2.57	2.38	2.57
207	2.61	2.57	2.84	2.57	2.84	2.87	2.91	2.87	2.95
	RIS Turbo Emitter, AUS made								
34	2.76	2.61	2.38	2.65	2.57	2.65	2.72	2.72	2.84
69	3.40	3.21	2.99	3.36	3.18	3.29	3.40	3.55	3.59
103	3.78	3.86	3.36	3.67	3.55	3.59	3.67	3.70	3.78
138	4.04	4.16	3.67	4.01	3.74	3.82	4.08	4.01	3.82
172	4.23	4.38	3.82	4.20	4.01	4.01	4.23	4.20	4.01
207	4.38	4.42	4.38	4.27	4.08	4.16	4.35	4.35	4.16
	Micro-tubing 1.5mm dia, local made								
34	33.98	35.91	35.61	34.59	34.70	31.41	36.21	34.70	30.50
69	46.31	46.42	46.68	45.59	46.00	39.99	47.10	45.59	41.09
103	55.19	56.21	55.19	53.79	56.28	51.48	55.79	54.58	51.60
138	64.60	65.47	63.69	62.67	63.96	62.63	63.77	61.95	57.61
172	75.18	73.60	75.00	72.80	72.80	70.99	78.21	71.40	68.00
207	81.61	81.38	81.80	77.19	81.19	78.59	83.39	78.59	75.00

Table 5. An average of Discharge of various emissions (Lph) at different operating pressure heads.

Operating pressure (Kpa)	Average Discharge (Lph)		
	Emission type		
	Bow Smith Turbo (US)	RIS Turbo (AUS)	Micro tubing (1.5mm diameter) local
34	1.32	3.36	43.22
69	1.80	4.21	56.87
103	2.25	4.63	68.86
138	2.64	4.97	79.58
172	3.01	5.21	92.45
207	3.52	5.42	100.99

Data revealed that Bow Smith Turbo had lower discharge than the RIS Turbo and Micro-tubing 1.5mm diameter. Moreover, the discharge behaviour (maximum to minimum) ranging were calculated, which are 3.52 - 1.32, 5.42 - 3.36, 100.99 - 43.22, with an average of 2.42, 4.63 and 73.66, for Bow Smith Turbo, RIS Turbo and Micro-tubing (1.5mm diameter), respectively, presented in Fig. 2. It shows that no significant change within both Turbo emitters. The highest discharge difference was observed in Micro-tubing (1.5mm diameter). The results also show that the discharge and pressure of different types of emissions indicate that discharge increased with the increase of pressure head. Moreover, the average increased discharges were 0.44, 0.41 and 11.55 lph between 34 to 207Kpa for Bow Smith, RIS Turbo and Micro-tubing, respectively. It also shows that the significant variation in increased discharge of emitters. However, emitters discharge variation was higher in lower operating pressure head than a higher one. It showed that by increasing the pressure heads, the discharge variations decreased as presented in Table 6.

Evaluation of Uniformities

The uniformity coefficients for each type of emission were calculated for operating pressure head range of 34-207 Kpa. Both uniformities showed average values greater than 95, 97 and 97% for coefficient of uniformity, C_U and 89, 94 and 93% for emission of uniformity, E_U, in Bow Smith, RIS Turbo and Micro-tubing, respectively, as shown in Table 7. The result indicated that C_U (%) of all emitters is in excellent class as described by ASABE and EP458 (1999). Moreover, the result showed that all emitters are among the excellent class except Bow Smith emitter for E_U according to Merriam and Keller (1978), but all of emitters lying in "good class" as presented by IRYDA (1983). However, uniformity parameters are quite significant for evaluation of uniform distribution of water for the plant.

Table 6. Variation of Discharge of various emissions (Lph) at different operating pressure heads

Operating pressure (Kpa)	Discharge Variation (Lph)		
	Emission type		
	Bow Smith Turbo (US)	RIS Turbo (AUS)	Micro-tubing (1.5mm diameter) local
34	-	-	-
69	0.48	0.85	13.65
103	0.45	0.42	11.99
138	0.39	0.34	10.72
172	0.37	0.24	12.87
207	0.51	0.21	8.54
Avg.	0.44	0.41	11.55

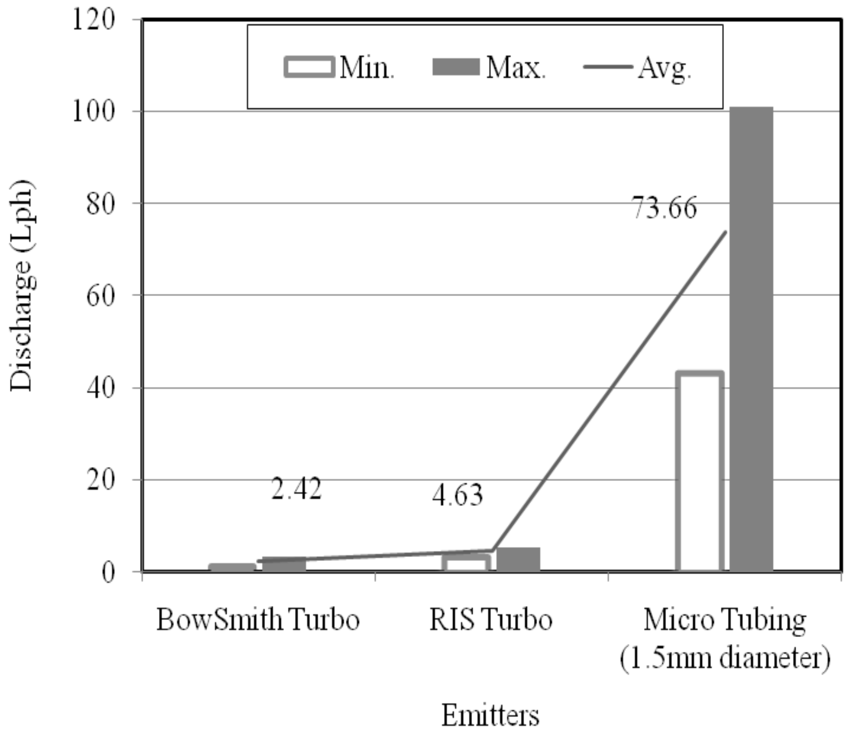

Fig. 2. Detail of minimum, maximum and an average discharge of various emitters

Table 7. Manufacturer's uniformities parameters (calculated) for imported and local emissions.

Operating pressure (Kpa)	Uniformities parameters (calculated)					
	Emission type					
	Bow Smith Turbo (US)		RIS Turbo (AUS)		Micro tubing (1.5mm diameter) local	
	Uniformities (%)					
	CU	EU	CU	EU	CU	EU
34	94.30	90.71	96.15	92.89	95.39	90.58
69	94.31	90.17	95.42	92.30	95.43	90.13
103	94.69	90.61	96.81	94.52	97.32	94.63
138	95.25	91.46	96.48	94.36	97.12	95.00
172	95.72	80.13	96.66	94.81	96.82	95.34
207	95.49	92.42	97.74	96.19	97.32	94.42

Coefficient of Variation Analysis, C_V

The C_V was determined; the lowest values were 0.05, 0.03, and 0.03 at 172, 207 and 207kpa, whereas, the highest readings were 0.07, 0.06 and 0.06 at 34, 69 and 34Kpa for Bow Smith, RIS and Micro-tubing, respectively. It showed that by increasing the pressure heads, the coefficient of variation decreased, as presented in Table 8. Coefficient of variation shows that all the emitters are in excellent class at all operating pressure heads as presented by (Keller and Bliesner, 1990). Moreover, coefficient of variation describes the irregular application of water in the field, due to variation in the manufacturing of the emission devices. It depends on the quality of the material used and temperature differences during manufacturing.

Table 8. Manufacturer's coefficient variations (calculated) for imported and local emissions.

Operating pressure head (Kpa)	Coefficient of variations (calculated)		
	Emission type		
	Bow Smith Turbo (US)	RIS Turbo (AUS)	Micro-tubing (1.5mm diameter) local
34	0.07	0.05	0.06
69	0.07	0.06	0.06
103	0.07	0.04	0.03
138	0.06	0.04	0.04
172	0.05	0.04	0.04
207	0.06	0.03	0.03

Relationship between Pressure and Discharge

The minimum and maximum discharges were determined: 1.32, 3.36, 43.22 and 3.52, 5.42 and 100.99 lph, for Bow Smith, RIS and Micro-tubing at 34 and 207 Kpa operating pressure heads, respectively. The relationship of discharge and pressure of emitters indicate that discharge increased with the increase of pressure head by using of statistical analysis with power function shown in Fig. 3. The development of a Q-H curve for emitter plays an important role in the emitter type selection and system design. In this study, the emitter exponent X and emitter coefficient K were derived using poly nominal regression in Microsoft Excel for the pressure-discharge relationship.

$$Q = KH^X \quad \dots \quad (6)$$

where,

Q = Emitter flow rate (lph)

K = Emitter Coefficient

H = Pressure head in the lateral at the location of emitters (m)

x = Exponent Characteristics of emitters

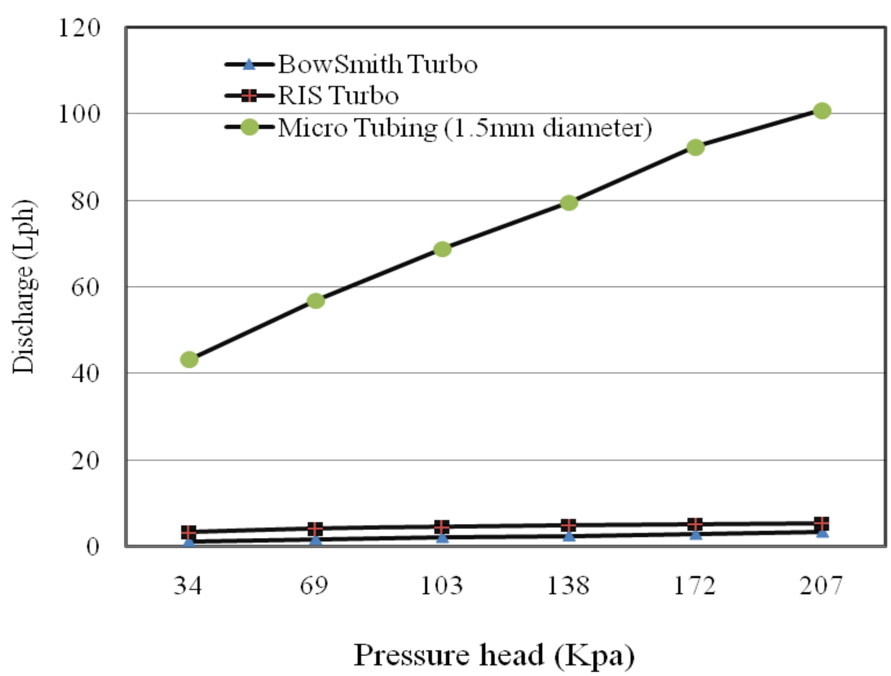

Fig. 3. Pressure-discharge relationship for different emitters

Exponent x is an indication of the flow regime and emitter type. It is an indirect measure of the sensitivity of flow rate to the change in pressure. The value of x typically ranges between 0-1.0, where a lower value indicates a lower sensitivity and a higher value indicates a higher sensitivity. The values of exponent x were 0.5389, 0.2615 and 0.4769 for Bow Smith Turbo emitter (US), RIS Turbo emitter (AUS) and Micro-tubing (local), respectively. It was revealed that RIS Turbo emitter (AUS) was less sensitive and Bow Smith Turbo emitter (US) was more sensitive. The values of K were 0.1358, 0.5287 and 4.8297 for Bow Smith Turbo emitter (US), RIS Turbo emitter (AUS) and micro-tubing (local), respectively. The values of K, x and R^2 for different types of emission discharge were numerically calculated as presented in Table 9.

Table 9. Detail of regression analysis for different type of emissions.

Type of emission	K	X	R^2
Bow Smith Turbo Emitter, US made	**0.1358**	**0.5389**	**0.992**
RIS Turbo Emitter, AUS made	**0.5187**	**0.2615**	**0.9915**
Micro tubing 1.5mm dia, local made	**4.8297**	**0.4769**	**0.9923**

The relationship between pressure and discharge of different emission types, i.e., Bow Smith, RIS and Micro-tubing, has been shown in Fig. 3. The best fitted curve with the highest value of correlation (R^2) for each type of emission has been drawn. Statistical analysis was used with power function for the investigation of regression correlation (R^2) between pressure and discharge for selected emitters. The regression values R^2 were more than 0.991 in all emitters, which shows the strongest and highest relationship between pressure and discharge.

Conclusion

The results of presented emitters indicate that the C_v is less than 0.07, during all ranges of pressure heads and emitters, which classifies them as “excellent” and within permissible limit. On the basis of C_U and E_U (%), all emitters performed more than 90%, also in “excellent class” and shows, that good indicator to reduce the head loss and saving of energy during system operation.

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