ASSESSMENT OF VARIABILITY IN HYDRAULIC PARAMETERS IN LOCALLY MANUFACTURED DRIP IRRIGATION LATERALS

Sami Ullah [1,*], Muhammad Masood [2], Muhammad Mohsin Waqas[3], Kashif Nadeem[4]

[1] Centre of Excellence in Water Resources Engineering, Faculty of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan

[2] Centre of Excellence in Water Resources Engineering, Faculty of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan

[3] Department of Irrigation and Drainage, Faculty of Agricultural Engineering, University of Agriculture, Faisalabad, Pakistan

[4] Urban Sector Planning & Management Services Unit (Pvt.) Ltd., Lahore, Pakistan

*Correspondence Author: engrsami_ullah@yahoo.com

ABSTRACT: *A simplified analytical and experimental method has been followed to determine hydraulic losses in plain lateral pipes caused due to the variability in smoothness during manufacturing and by emitter's insertion. The difference in losses between plain lateral pipes and with sealed emitters were calculated for constant increasing pressure head. Equal lengths locally extruded from four different pipe rolls were selected for diameters i.e. 12.5 mm and 16 mm. Four types of locally available emitters were selected for testing purpose. Characteristic curves were plotted between flow rates (Q) versus pressure head loss (H_L). The analysis was done at recommended design flow velocity of 1.5 m/s. The losses of plain lateral pipes showed variation not only due to the change in diameter but also within the same diameter lateral pipes due to manufacturing variabilities. Up to 26% reduction in head loss was estimated as the pipe diameter increased from 12.5 mm to 16 mm. The head losses within the same diameter pipes also varied from 2.3% to 16.2% in small diameter pipe and 0.7% to 11.1% in large diameter pipe of equal lengths. The percentage of hydraulic loss due to emitters as compared with plain lateral pipes varied from 12.23% to 37.0% with emitter barb face area of 15.63 mm^2 to 44.05 mm^2. The equivalent lengths (Le) for different emitters were found ranged from 17 cm to 53 cm.*

Keywords: Equivalent length, hydraulic characteristics, head losses, manufacturing variability, on-line emitters

INTRODUCTION

Drip irrigation system is playing significant role in efficient water application for the production of food, fruits, vegetables and horticulture practices. The desired amount of water is obtained by only accurate designing which has a key importance and it can be achieved by knowing the detailed hydraulics of system components. The proper design of drip irrigation laterals comprehends emitter discharge variations, change of flow stream lines due to emitter's barb protrusion, change of hydraulic head due to elevation, friction head losses in the laterals to provide uniform water application. The idea of the system design also includes emitter discharge variations due to change in pressure head, which depends upon variability in manufacturing, change in temperature of water and choking in flow. Water loss in field application is more as compared to its effective utilization by the plants. Drip irrigation offers the opportunity to deliver the optimum amount of water with minimal losses. Considerable research has already been carried out to understand the variations in head losses in laterals caused due to manufacturing variations in many countries using analytical, numerical, computational fluid dynamic (CFD) approaches, empirical equations, laboratory experiments and practical evaluation through field data but no one has overseen the changeability in hydraulic parameters in locally manufactured drip irrigation laterals in Pakistan [1-4]. Inclusion of emitters along a drip irrigation line modifies flow streamlines, inducing local turbulence that results in additional head losses rather than frictional losses in the pipe. In order to evaluate accurate losses along the laterals, both frictional losses during manufacturing process and local losses due to the presence of emitters in the pipe must therefore be considered **[5-8]**. Drip irrigation lateral design procedure needs to evaluate accurately both the pipe head losses and local losses which are due to the protrusion of emitter barbs into the flow. These local losses, in fact related to the high number of emitters located along the line, can become significant compared to the overall energy loss [9, 10]. Manufacturing variations, pressure differences, emitter plugging, aging, frictional head losses, irrigation water temperature changes, and emitter sensitivity results in flow rate variations even between two identical emitters [11-13]. The losses due to emitter connections as an equivalent length based on the laboratory measurements were found to count these losses [14-17]. However, all these research studies are carried out to determine the losses due to different types of emitters using various diameter of laterals but conventional hydraulic design procedures of drip irrigation system usually fails to consider the pressure head loss caused by the projection of the emitter barbs into the flow. Local manufacturing companies in Pakistan are making drip irrigation components, pipes of different materials and online emitter of various types through their specific processes. However, information related to hydraulics of these drip irrigation system components are not available. Therefore, it was important to understand the losses caused by internal smoothness of pipes, manufacturing variability and emitter connections. The aim of the study was to accomplish these gaps by determining the variability in hydraulic parameters caused by manufacturing process using different pressure head for multi-diameter locally manufactured low-density polyethylene (LDPE) drip lateral pipes. The losses were also determined due to the projection of locally made online emitter barbs. These calculations of losses were performed on an equivalent length basis. Moreover, these objectives were pursued assuming the emitter flow constant throughout the length and ignoring the variability due to the change in temperature.

MATERIALS AND METHODS

Experiments were conducted at the hydraulic testing lab of high efficiency irrigation system of Climate Change Alternate Energy and Water Resources (CAEWRI) Institute (Lat. 33°40'30.00"N and Long. 73° 8'15.79"E) in National Agricultural Research Centre (NARC), Islamabad. Layout of the laboratory testing apparatus used in this research study is shown in Figure 1. The experiment was performed in the area of about 33 m by 5 m with zero gradient level. Clean water from dug well was used in this study in order to avoid any probable effects of biological growth. A centrifugal pump with discharge capacity of 2.0 *l*/s was installed on a dug well. The water was pumped from this dug well into a pond of volume 180 m^3 and then with a pump to test the lateral pipes and emitters. Lateral pipes were placed horizontally on the ground, connected through 1" diameter buried pipe with multi-stage pump, driven by single phase of 3 HP motor with suction and discharge diameter of 1.5 inches each, having rotational speed of 2850 revolution per minute, was already installed for drip and sprinkler system laboratory. A pressure gauge was plugged after the ball valve of each lateral pipe to monitor inlet pressure in the laterals. Different pressures were developed by the control valves installed between the pump and ball valves. Flow meter was attached at the end of laterals with the ball valve to measure flow rate of water. A pressure gauge at the end of each lateral before the water meter was also plugged to read outlet pressure. For quick and direct pressure measurement, bourdon gauges (in psi units) with graduations that allow pressure reading to the nearest 1 psi (0.693 m) were installed at the both ends of the pipes. Two mostly used local pipes in the field of sizes 12.5 mm and 16 mm internal diameter were experimented in the laboratory. Four equal lengths of lateral pipes (L1, L2, L3 and L4) of each diameter from the same pipe roll were tested. The length of 31 m each was selected according to the availability of space in the lab and to determine for assessable amount of losses. Four different types of emitters **(**Figure 2.) Turbo Key, Spray Jet, Key Clip and Micro-tubes (1.30 mm Ø and 2.0 mm Ø) were tested on each pipe. Their general specification and barb dimensions are given in Table 1.

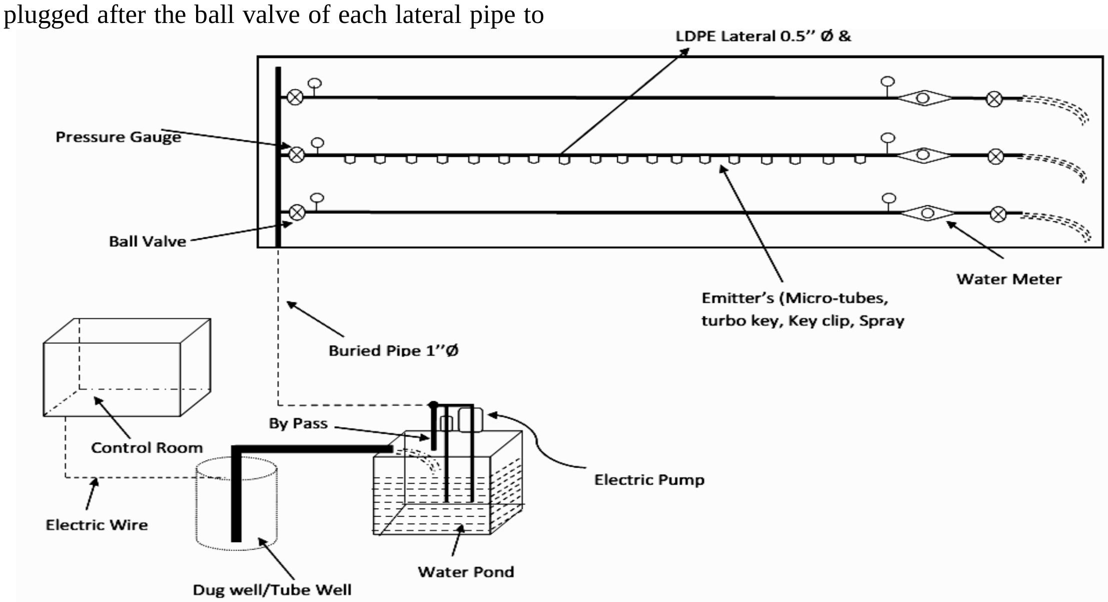

Figure 1. **Layout of laboratory experiment**

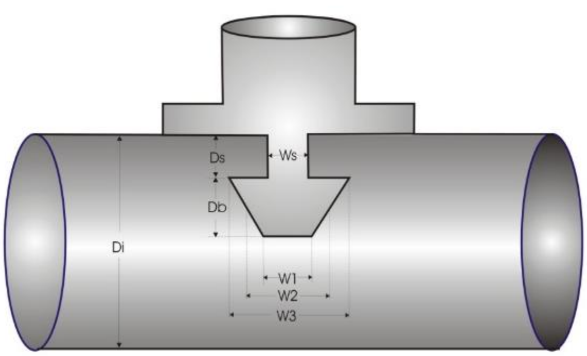

Figure 2. Pipe section with emitter barb insertion

Table 1. General specification of selected emitters with barb dimensions

Model	*Turbo Key (E1)*	*Key Clip (E2)*	*Spray Jet (E3)*	*Micro-tubes for 12.5 mm lateral pipe*		*Micro-tubes for 16.0 mm lateral pipe*	
				Ø1.3mm (E4)	*Ø2mm (E5)*	*Ø1.3mm (E4)*	*Ø2mm (E5)*
Total barb depth D_t (mm)	10.85	9.65	11.5	12.5	12.5	16	16
Barb depth D_b (mm)	6.07	5.95	6.73	12.5	12.5	16	16
Effective seat depth D_s (mm)	2.48	1.40	2.47	-	-	-	-
Seat width W_s (mm)	4.35	5.33	5.1	-	-	-	-
Barb face width W_b = (W1+W2+W3)/3 (mm)	4.23	5.51	4.67	1.9	3.4	1.9	3.4
Barb face area A_b (mm2)	36.5	40.27	44.05	16.0	26	20	33

At first, each lateral pipe was tested without emitters. Time of operation at the start of electric pump was 3 minutes for the stability of fluctuation of water and to release air in the selected lateral pipe length. The each lateral took 45 minutes for one time test run. A similar procedure was repeated for each type of lateral pipe with sealed emitters, assuming the discharge from the emitters equal to the flow rate collected at the end of the laterals. Emitters were inserted on laterals at 1 meter apart. This was followed by conducting two trials on each lateral pipe including emitter insertion. Only one pipe was tested in four trials due to two micro-tubes. Maximum lateral pressure for reading was 50 psi (35 m) with an increment of 5 psi (3.5 m). All trials were run for three times. Maximum and minimum temperature were recorded as an average of 30.5^{o}C and 21.8^{o}C during the data collection in the laboratory. Relative humidity was also recorded and the mean value found was 72.6 %, respectively. Flow rate (Q) was measured with the help of MC propeller flow meter (range of 10^{-3} to 10^3 M^3). The volume of water passed through the meter was noted at the desired pressure with respect to time for each lateral pipe. Volumetric method was used to calculate flow rate. Frictional head losses (H_L), to know changes due to manufacturing variability, were calculated by subtracting pressure head at inlet and pressure head at outlet simply. The head losses (H_L) caused by emitter's protrusion were also obtained by subtracting the value of head loss in the lateral pipe without emitters from the value of head loss with emitters. Thus, head drop for each single emitter was then taken by dividing the losses to the number of emitters punched. Practically flow rate varies depends upon the crop to be irrigated, so the analysis was done on design flow velocity of 1.5m/**s (FAO, 2007) to** check the variation in losses due to each type of emitters. An empirical equation developed by Hazen-William [1,6,19] was used to calculate the losses as equivalent lengths,

$$\boldsymbol{H_L} = \frac{\boldsymbol{KL\left(^{Q}/_{C}\right)^{1.852}}}{\boldsymbol{D_i^{4.87}}} \qquad (1)$$

H_L = Friction head loss in pipes (m/100m);
K = Conversion constant (1.212 x10^{12}) for metric unit;
L = Lateral length (m);
Q = Flow rate in the pipe (*l*/s);
C = Hydraulic roughness coefficient (147 to 150); Di = Internal diameter of lateral pipe (mm);

RESULTS

Hydraulic characteristics observed for the lateral pipes without emitters and with emitters at different pressure heads are presented in Figure 3 and Figure 4, respectively. The value of flow rate was upto 0.27*l*/s with head loss of 10.8 m for smaller diameter lateral pipe whereas flow rate upto 0.56*l*/s with head loss of 17 m for larger diameter lateral pipe without emitters at the same pressure head (m). However, it was 0.24*l*/s with head loss of 11.3 m and 0.53*l*/s with head loss of 16 m after inserting emitters in the lateral pipes. The results were non-significant at the start but showed significant differences at higher pressure head.

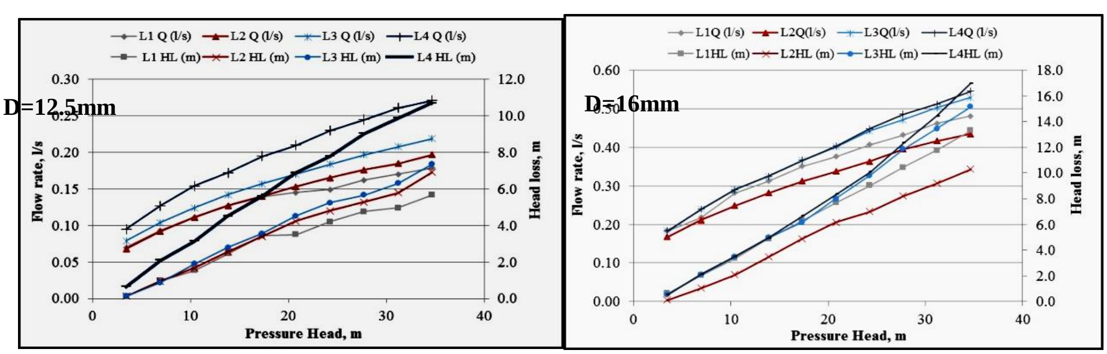

Figure 3. Hydraulic characteristics of the lateral pipes without emitters

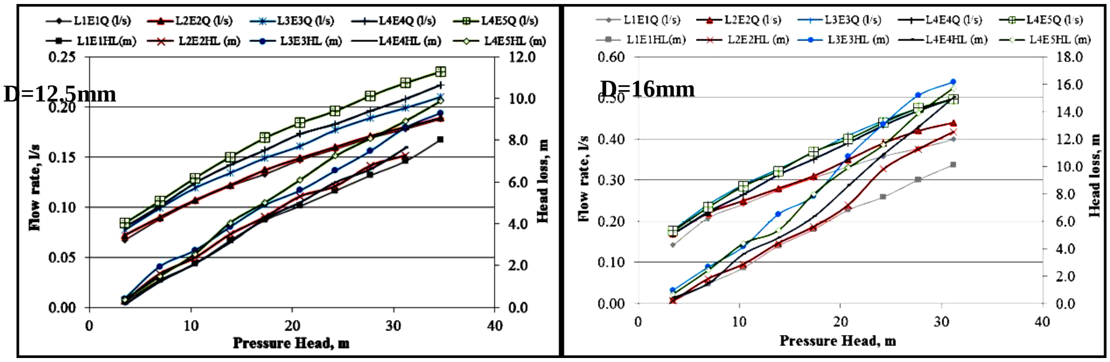

Figure 4. Hydraulic characteristics of the lateral pipes with emitters

The hydraulic differences were evaluated in the lateral pipes due to manufacturing variations without emitters and variation in hydraulic parameters with emitters. Losses were estimated at recommended design flow velocity of 1.5 m/s shown in Figure 5 and Figure 6.

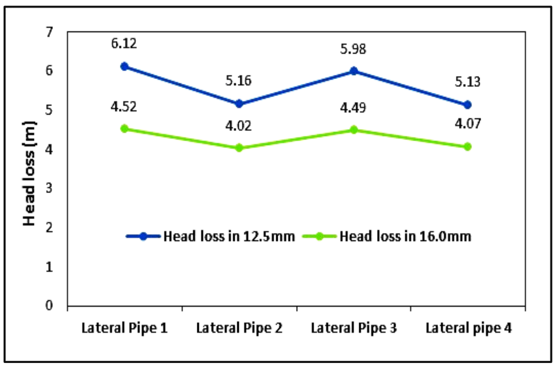

Figure 5. Head loss in the lateral pipes at design flow velocity of 1.5m/s

It is cleared from the results that head loss decreases with the increase of pipe diameter. Due to variations in the pipes during manufacturing, show a clear difference not only in different pipe of diameter but also among the same diameter pipes.

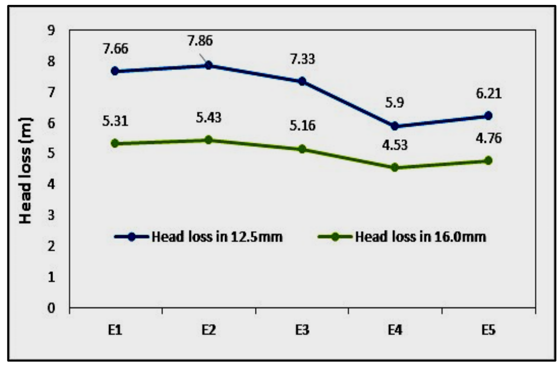

Figure 6. Head loss in the lateral pipes with emitters at design flow velocity of 1.5 m/s.

Considerable increase in head loss was observed due to obstruction in the path of flow caused by emitter's connection. The results showed that losses were different for each type of emitter. It varied due to change in the area of their barbs across the flow pipe. These head losses were due to twenty five numbers of emitter's projected in the pipes (Figure7). It means increasing emitter's number on the laterals will definitely affect the losses in the pipe and vice versa.

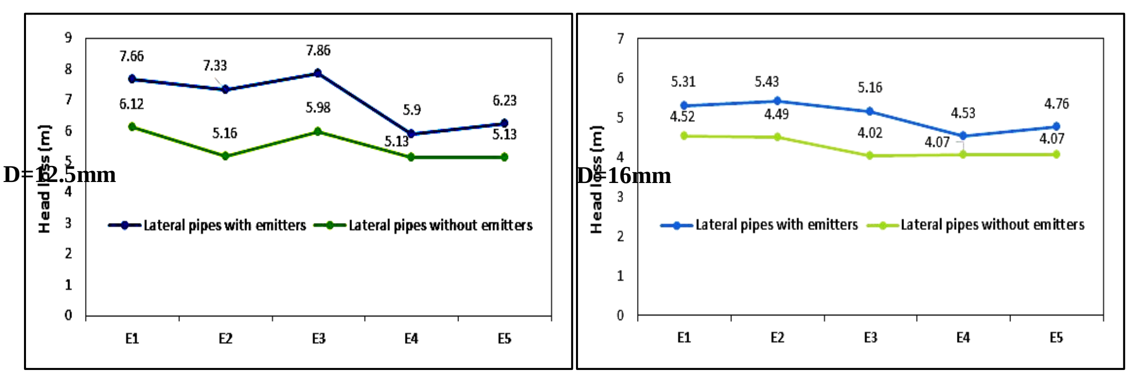

Figure 7. Influence of emitters

An expected percentage of head losses was found as compared to plain lateral pipes. Percentage head loss is counted more in small diameter laterals came with 37% compared to smaller barbs for large diameter pipe comprises only 12.2% as shown in Fig. 7. This was also due to more obstruction in flow stream lines due to large barb area, because emitter barbs affected more in small diameter pipes. Losses due to single emitter intrusion was estimated varying from 0.03 m to 0.09 m for barb face area of 15.63 mm2 to 44.05 mm2 in small diameter laterals. Similarly, losses were assessed from 0.026 m to 0.049 m for barb face area of 20.0

mm^2 to 44.05 mm^2 in large diameter lateral as shown in Figure 8 and Figure 9.

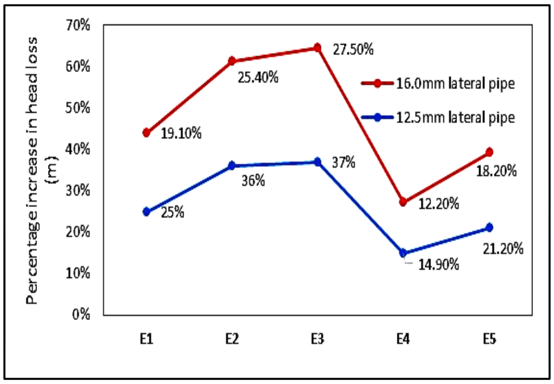

Figure 8. Percentage increase in head loss

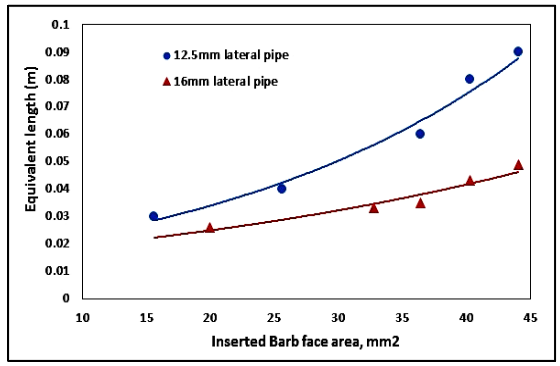

Figure 9. Effect of emitter barb areas

On the basis of polynomial equations derived from the flow rate and head loss curves, losses were calculated for each single emitter. It was observed, maximum losses are up to 0.23 m in small diameter pipe against flow rate of 0.35 *l*/s, whereas0.09 m in large diameter against 0.43 *l*/s flow rate due to key clip emitter as shown in **Figure 10**.

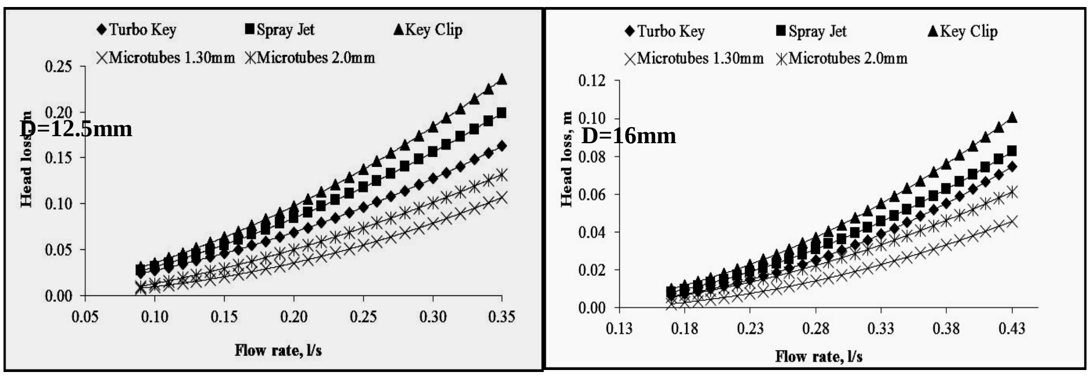

Figure 10. Influence of flow rate on head losses for various emitters

In designing drip irrigation system, it is very helpful to add losses as equivalent lengths in the system. The designer can easily sum up losses from emitter barbs area and from length of lateral pipes. In order to incorporate emitter head loss equivalent length was calculated for each emitter using Hazzen-William equation.

$$L_e = \frac{H_e D^{4.87}}{K\left(^{Q}/_{C}\right)^{1.852}} \qquad (2)$$

L_e = equivalent length of pipe per emitter (m)

H_e = head loss per emitter (m)

The calculated values of equivalent length and head loss per emitter in the conducted study vary from 0.020 m to 0.09 m and 0.17 m to 0.53 m for the 12.5 mm and 16 mm diameter lateral pipes, respectively. Equivalent length was found in the range of 19 cm to 53 cm in small diameter lateral, whereas its range from 0.17 m to 0.43 m and head loss 0.02 m to 0.049 m was determined in large diameter lateral as shown in Figure 11.

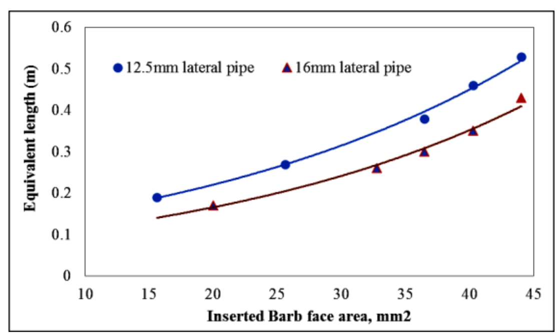

Figure 11. Losses as an equivalent length for laterals of 12.5mm and 16mm diameter

DISCUSSION

In this research study, hydraulic parameters were calculated in two different framework. First, plain lateral pipes were tested to check the losses due to variability in the lateral pipes without inserting emitters that results in 5.13 m to 6.12 m. Second, emitters were inserted and the losses due to emitter's insertion were measured, show a significant increase in the values from 5.90 m to 7.66 m as compared to the plain lateral pipes measured at specific design flow velocity of 1.5m/s. It was also observed that the losses were different for each type of emitter. The percentage increase in head losses were found varying from 14.9% to 37% in small diameter pipe and 12.2% to 27.5% in large diameter pipe. These losses for the design purposes are converted as an equivalent length. Results show the lengths between 19 cm to 53 cm for 12.5mm laterals and 17 cm to 46 cm for 16 mm lateral pipes. For the sake of convenience of designer, losses for each emitter were also determined with respect to the barbs area rather than depth. However, this will also help in calculating losses directly by measuring the barb area and reading from the chart.

CONCLUSION

Research analysis on losses found in lateral pipes without emitters shown that there are considerable variations due to the manufacturing variabilities. Moreover, significant losses were observed due to emitter barbs protrusion, more for larger barbs area. For the same emitter higher loss was observed in small diameter lateral as compared to large diameter. Within the lateral pipes having same diameters, losses were significant at high pressure and showed a considerable value for small diameter pipe.

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