# CHARACTERIZATION OF DRIP EMITTERS AND COMPUTING DISTRIBUTION UNIFORMITY IN A DRIP IRRIGATION SYSTEM AT LOW PRESSURE UNDER UNIFORM LAND SLOPES

A Thesis

by

DEBA PRASAD DUTTA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2008

Major Subject: Biological & Agricultural Engineering

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# ABSTRACT

Characterization of Drip Emitters and Computing Distribution Uniformity

in a Drip Irrigation System at Low Pressure under Uniform Land Slopes.

(December 2008)

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Characteristics of emitters under low pressure are essential for designing drip irrigation systems. Low pressure data for drip emitters are not available from manufacturers. A laboratory test was conducted to evaluate the performance of five types of newly manufactured drip tapes, especially under a low pressure distribution system. The five drip products that were tested were (i) Toro Drip in PC (PCS 1810-18-100), (ii) T-Tape (TT15-1245-0100), (iii) Mister_LS (MLD-HDT100), (iv) Mister_PS (MLD-1PC 25), and (v) Netafim (Techline CV 560 050). Drip tapes tested in this study have design discharge rates of 4.00 L/hr @ 206.84 Kpa (1.06 gph @ 30 psi), 1.02 L/hr @ 55.16 Kpa (0.27 gph @ 8 psi), 3.785 L/hr @ 172.37 Kpa (1.00 gph @ 25 psi), 3.785 L/hr @172.37 Kpa (1.00 gph @ 25 psi), and 0.984 L/hr @ 206.84 Kpa (0.26 gph @ 20psi), respectively. All of them, except T-Tape, were pressure compensating (PC) emitters; the T-Tape was non-pressure compensating (NPC). For all products, except Toro, the emitter spacing was 0.305 m (12 inches) and for Toro, it was 0.46 m (18 inches). Mister_PS (MLD-1PC 25) was the point source (PS) emitter and all others were

line source emitters. Drip products were tested with 15 different operating pressures ranging from 5.97 KPa (0.87 psi) to 344.74 KPa (50.00 psi).

From an evaluation of 60 emitters from each product, the Toro brand showed an average uniformity coefficient (UC) of 91.24 %, with a coefficient of variation ($C_v$) of 0.06, T-Tape drip products showed an average UC of 96.63 % with a $C_v$ of 0.04, Mister_ LS showed an average UC of 93.12 % with a $C_v$ of 0.08, Mister_PS showed an average UC of 96.33 % with a $C_v$ of 0.04, and Netafim showed an average UC of 97.92 % with a $C_v$ of 0.02. Flow rate vs. pressure head (Q-H) curves were also developed for each drip emitter tested. From emitter exponent values it was observed that all of the pressure compensating (PC) products behaved like NPC emitters at low pressures, although they behaved like PC emitters under normal operating pressures. From statistical analysis, it was determined that except for Netafim product, all other tested products were effective under low operating pressures as were under high operating or recommended pressures. Netafim product had no emission under low pressures.

Using the measured average emission rate and developed Q-H curves, the distribution uniformities of all products except Netafim were calculated under low pressure ranges of 5.97 KPa (0.87 psi) to 23.88 KPa (3.50 psi ) for different lengths of laterals and under 0%, 1%, 2% & 3% uniform land slopes. The range of distribution uniformity (DU) was from about 70% to 99%, which can be classified as “good” to “excellent”.

# DEDICATION

This thesis is dedicated to my deceased father Advocate D. L. Dutta, who would always inspire me in higher education and who is still I believe behind all my good works and it is also dedicated to my beloved mother, Namita Rani Dutta.

# ACKNOWLEDGMENTS

I would like to express my gratitude to all those who provided their sincere support and inspiration to write this thesis. I express my sincere gratitude to my committee co-chair, Dr. Bruce J. Lesikar, for providing me the great opportunity of conducting research and who always encouraged my work and guided me to explore the corner of the unknown world, to become detailed oriented and to develop independence of thinking. The experience of learning from him was quite impressive.

I am deeply indebted to my co-chair, Dr. V. P. Singh, whose help, inspiration, stimulating suggestions and encouragement helped me all the time during the research and writing of the thesis. He deserves my respect for spending most precious time reviewing my thesis and giving encouragement to go ahead with the thesis and makes it a success.

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# CHAPTER I

# INTRODUCTION

About 75% of the global freshwater is used for agricultural irrigation. Most of the water is applied by conventional surface irrigation methods. According to US Census Bureau 2002, in the year 2003, out of the total irrigated land of 52,583,431 acres in the US, only 2,988,101 acres of land was irrigated by drip/trickle irrigation, which is about 5.68%. If the percentage of acreage under drip irrigation can be increased, water, one of the most valuable and limited natural resources, can be saved substantially. In addition to substantial water saving, the advantage of drip irrigation is that water can be applied where it is most needed in a controlled manner according to the requirements of crops. Drip irrigation has advantages over conventional furrow irrigation as an efficient means of applying water, especially where water is limited. Vegetables with shallow root systems and some crops like cotton respond well to drip irrigation with increased yield and substantially higher fruit or fiber quality with smaller water applications, justifying the use of drip over furrow irrigation (Camp, 1998). However, high initial investment costs of these systems need to be offset by increased production to justify investment over furrow irrigation systems. The main components of a drip irrigation system are the drip polyethylene tubes with emitters attached to the inside wall and equally spaced 0.3 to 0.6 meters apart along the lateral lengths, pump, filtration system, mail lines, manifold pressure regulators, air release valves, fertigation equipment. A pump is needed to provide the necessary pressure for emission of water. Pumps can be driven by several

This thesis follows the style and format of the *Transactions of the American Society of Agricultural & Biological Engineers.*

types of energy: gas, diesel, solar etc. Sometimes, there is no electricity available for pumping. Gravity flow, instead of electricity or diesel energy, as shown in Figure 1-1, can be used if the elevation difference between the canal or elevation tank and the field is enough to supply water to the emitters with needed pressure.

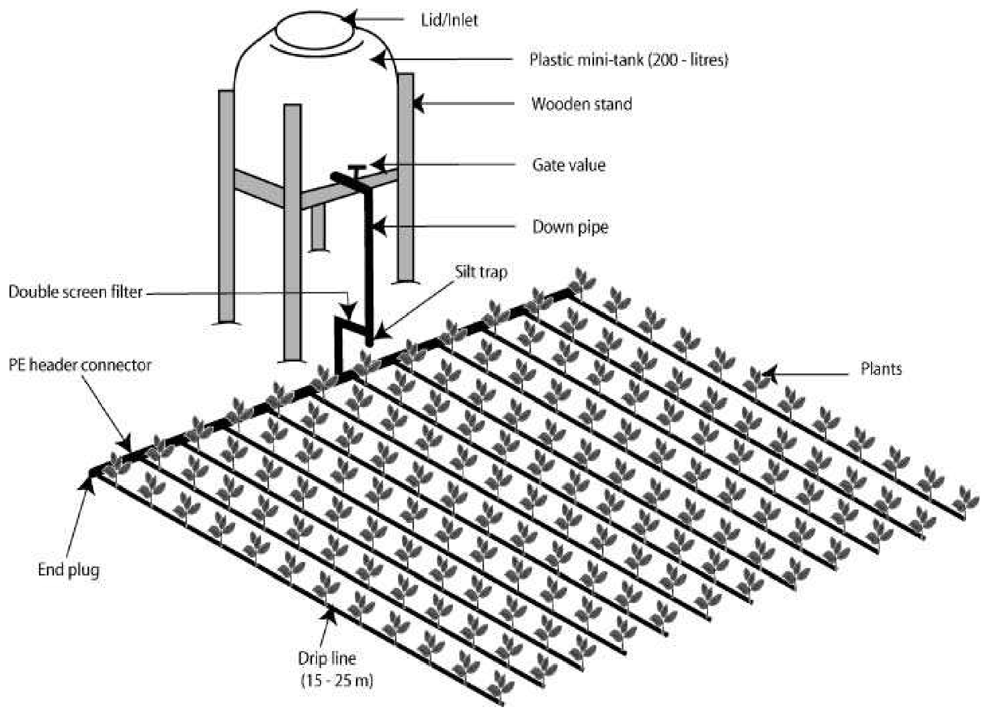


**Figure 1-1 Schematic view of a low pressure drip irrigation system (Ngigi, 2008)**

Characteristics of emitters under low pressure are essential for the design of gravity drip irrigation systems. Few data is provided by the manufacturers for drip emitter operating under low pressures. No guidelines regarding the optimum combination of operating pressure head, lateral length and land slope are available either. The inlet pressure head gained by the attractive flow should be balanced by the total head loss due to friction and emitter insertions along the drip line. If the inlet pressure head becomes greater than the required pressure head at the lateral for uniform emitter flows through the lateral, it may cause back-flow from the lateral downstream closed end to the inlet upstream. On the other hand, if the inlet pressure head becomes lower than the total required pressure head along the lateral, it may yield negative pressure at the emitters at any section of the lateral and it will affect the distribution uniformity. The friction loss within the lateral which is a function of the inlet pressure, diameter of laterals, spacing of emitters, and slope of laterals, plays a vital role in the distribution uniformity in drip systems.

The distribution uniformity of water is one of the important parameters to characterize drip emitters and design of a drip irrigation system. It is a measure of the uniformity of water application to the area being irrigated, expressed as a percentage between 0 and 100%, although it is practically impossible to attain 100%. DU of less than 70% is considered as poor, 70 - 90% is good, and greater than 90% as excellent (Rain Bird, 2008). A greater DU, equates better system performance. Low DU means that either more water is applied than required, increasing unnecessary expense; or too little water is applied, causing poor yield. The most common measure of DU is the low quarter DU, which is the ratio of the average of the lowest quarter of samples to the average of all samples. For purposes of accurately determining the total amount of water requirement for irrigation, distribution efficiency plays a vital role. Distribution Uniformity in a drip irrigation system is dependent upon manufacturing variation of emitters, operating pressure head, lateral length and land slope. In order to obtain a better

DU when designing an efficient drip irrigation system, the combination of operating pressure, lateral length and land slope must be considered. Therefore, all of these factors should be included in designing a drip irrigation system in order to have acceptable distribution uniformity within a certain length of the lateral.

***Objectives of Study***

The overall objective of this study was to evaluate the performance of existing high head operating pressure drip products under low head operating pressures with the goal of developing appropriate distribution efficiency in a low-head drip irrigation system. The specific objectives were:

1. To evaluate water emission rates of five types of drip emitters at different pressures ranging from 5.97 KPa (0.87 psi /2ft) to 344.74 KPa (50 psi /115.50 ft).
2. To evaluate and classify several drip emitter products according to the coefficient of variation $C_v$ and uniformity coefficient (UC).
3. To characterize the flow-pressure relationship for each emitter and classify the emitters as pressure compensating and non pressure compensating based on exponent coefficients (x) of emitters.
4. To determine the effect of water supply head, land slope and lateral length on distribution uniformity along the lateral.
5. To compute distribution uniformity for different products under low pressures at various uniform land slopes.

# CHAPTER II

# HYDRAULICS OF WATER FLOW IN DRIP LATERALS

## *Introduction*

Drip irrigation systems are used to uniformly distribute water in agricultural fields. If water can be applied efficiently in an irrigation field, water is saved and both crop quantity and quality are increased. Drip irrigation has advantages over conventional furrow irrigation as an efficient means of applying water, especially where water is limited. Vegetables with shallow root systems and some crops like cotton respond well to drip irrigation with increased yield and substantially higher fruit or fiber quality with smaller water application, thus justifying the use of drip over furrow irrigation. Several issues have emerged concerning the adaptation of the drip technology (Camp, 1998). One is that pressure is needed for filtering water and to provide pressure to overcome friction and other losses and produce enough pressure for the emitters. Filtration is needed to protect the drip line from clogging, which reduces water application uniformity. In some places, water comes from canals; the potential for clogging is high due to algae and trash in the canal. Ravina et al., 1992 found that different types of emitters had different susceptibilities to clogging, but for any particular type of emitter, clogging sensitivity was inversely proportional to the discharge of the emitter. They suggested maintaining turbulent flow in the laterals to prevent sedimentation.

Smajstrla and Clark, 1992 investigated hydraulic characteristics of five commercial drip tapes and found that they varied widely as a function of emitter design. Normally, a pump is used to develop the necessary operating pressure for the emission of water and also to protect the drip tapes from clogging. But in case of non-availability of electricity or to save energy, elevation difference between the canal or elevation tank and the field can be used to develop the necessary inlet pressure.

Some of the factors in designing drip irrigation are inlet pressure, friction loss due to velocity of the water, the local head loss due to insertions of emitters and changes in water temperature in the lateral. Inlet pressure is one of the most important factors in drip irrigation. If the inlet pressure head becomes greater than the required pressure head; it may cause back-flow and if the inlet pressure head becomes lower than the total required pressure head, it may create negative pressures at the lateral which will affect the distribution uniformity. Consequently, to avoid both these problems, the inlet pressure head must be determined precisely to balance the energy gain due to inlet flow and the total required pressure head within the lateral. Hathoot et al., 1993 and Yildirim and Agiralioglu, 2008 attempted a mathematical approach to calculate the inlet pressure head. Friction loss due to velocity of water can be determined using Darcy- Weisbach equation. Another factor to be considered is the local head loss due to emitter insertions, which introduce additional turbulence into the pipe flow. Although a single emitter generally produces a small local loss, due to the high number of emitters installed along a lateral, the total amount of local losses can become a significant fraction of the total energy loss.

Two alternative procedures have been applied for computing local losses. One is using some relations to evaluate the local loss coefficient α, expressing local losses as a fraction of the ratio between emitter and pipe diameters (Provenzano and Pumo, 2004;

Provenzano et al., 2005b; Yildirim, 2006a, 2007). The second approach is incorporating the equivalent length, $l_e$, to account for local pressure losses into the Darcy-Weisbach friction loss formula (Hathoot et al., 2000; Juana et al., 2002a; Yildirim, 2006b).

Another factor influencing the emission of emitters is water temperature; as temperature changes affect the viscosity of irrigation water and the emitter geometry (Clark et al., 2005). Theoretical and experimental analyses of the dependence of emitter discharge sensitivity on water temperature variations have been reported by Clark et al., 2005. The results of a recent experiment investigated by Sinobas et al.,1999 at the temperature range of 20 to $40^0$ C showed that discharge variations due to temperature changes depended on the emitter type. For instance, helical long-path emitters increased their flow with increasing temperature, in contrast to vortex emitters. Furthermore, the dependence of the behavior of pressure-compensating emitters on temperature changes was not significant at the temperature ranges of their investigation. Von Bernuth, 1990 shows that the failure to correct for viscosity differences can lead to a significant error when determining friction losses. For example, a $20^0$C change in temperature would lead to an 11% error in the friction loss, if viscosity changes were ignored (Sinobas et al., 1999 and Von Bernuth, 1990).

A low pressure drip irrigation was installed and evaluated by Texas Agrilife Extension service at the Weslaco Agrilife Research and Extension Center on a cotton field during the spring of 2006. In preliminary field trials conducted by Extension indicates that the minimum head should be about 3 psi (6.9 ft of water head). Netafim (2004) proposed the use of this low pressure irrigation system by using a screen filter with low friction losses (80 mesh) and special drip emitters to avoid clogging. The idea is to have longer laterals and to sacrifice distribution uniformity in order to reduce the initial cost. The energy costs will also be avoided by using gravity flow. This new irrigation technology may promote water savings and increase economic returns in agricultural production.

The distribution uniformity of water is one of the main criteria for designing an efficient drip irrigation system. However, due to the lack of knowledge of distribution uniformity of water under low pressure, this system is still facing problems of supplying water uniformly throughout the field.

Emitter manufacturer's variation, emitter clogging, slope variation and pressure variation are most important factors that affect the application uniformity. A laboratory test was conducted by Bralts et al., 1981 to determine the statistical and distribution uniformity of the emitter flow rate as a function of emitter variation, operating pressure, and length of the run. The statistical uniformity coefficient was recommended for use in determining the drip irrigation lateral line design uniformity including manufacturing variation. Toro design manual stated $C_v$ values less that 5% under operating pressure range from 15-60 psi. T-tape design and installation manual stated the coefficient of variation of just 3.50 % under recommended pressure range from 8-15 psi. Mister and Netafim both stated the coefficient of variation of 5 % under recommended pressure range from 10-60 psi and 15-70 psi, respectively.

***Flow Theory and Types of Drip Emitters***

The main device of a drip irrigation system is emitter. It is used to dissipate pressure and to discharge a small uniform flow or trickle of water at a constant rate at several points along a lateral. It is designed in such a way that the flow rate does not vary significantly with minor changes in pressure across the lateral. The properties of emitters that play a vital role in designing a drip irrigation system are: discharge variation due to manufacturing tolerance, closeness of discharge-pressure relationship to design specifications, emitter discharge exponent, operating pressure range, pressure loss in laterals due to insertions of emitters and stability of the discharge-pressure relationship over a long period of time. Emitters are classified according to their incorporation in the lateral, flow rate, form of pressure dissipation, and construction (Enciso et al., 2005 and Keller and Bliesner, 1990).

*Classification according to incorporation in the lateral*

1. Point source emitters:

   The emitters that are inserted directly into the lateral are called point source emitters. The point source emitters are suitable for irrigating trees, bushes and other similarly managed plants. A single emitter can be inserted according to plant requirements. The main types of point source emitters are single drip emitters, bubblers, micro sprinklers, and spray emitters.

2. Line source emitters:

   When emitters are integrated into the laterals, they are called line source emitters. They consist of drip tubing with supply orifices to meter water before it enters the emitter. The water then passes through a labyrinth of flow paths to dissipate or compensate for pressure and exits to one or more distribution orifices.

*Classification according to flow rate*

1. Pressure compensating (PC) emitters:

These emitters are constructed in such a way as to provide almost constant emission over a wide range of operating pressures. A resilient material is used in the flow path in order to have a desired constant flow rate. Due to the characteristics of materials, the flow cross section decreases as the pressure increases in the laterals assuring a constant flow rate over a wide range of pressures. But the main disadvantage of the PC emitters is that over a period of time, the materials may distort, causing gradual squeeze of flow, even though pressure remains constant. PC emitters are identified by the exponent value “x” of 0 to 0.1, which is an indirect measure of the sensitivity of flow rate to changes in pressure. A lower value of “x” indicates lower sensitivity and a higher value indicates higher sensitivity.

2. Non pressure compensating (NPC) emitters:

These emitters yield a variety of flow rates due to the variation of pressure in the laterals, usually the flow rate increases at a certain rate with the increase of pressure and decreases according to the flow pressure head characteristics of emitters.

*Classification according to pressure dissipation and construction*

As the water flows from laterals into the atmosphere, the emitter dissipates the pressure in the pipe distribution network. The pressure is dissipated either by individual small diameter orifices, a series of such orifices, vortex chambers, short tubes or tortuous flow paths.

1. Long-path emitters:

In these types of emitters, pressure is dissipated through a smooth long path, where flow is laminar. The head loss through emitters is directly proportional to the length of the path and inversely proportional to the diameter of the flow path. Hence, diameter plays an important role for determining the head loss and flow length. The characteristics of the emitter head loss deviate significantly due to any spiral effects and other irregularities in long path emitters.

2. Tortuous path emitters:

These types of emitters have relatively longer flow paths. The pressure head is lost by a combination of wall friction, sharp bends, contractions, and expansions.

3. Short-path emitters:

In these emitters, flow path is relatively shorter as the entrance characteristics dominate the flow regime causing pressure loss. Most of the short-path emitters are pressure compensating.

4. Orifice emitters:

In these types of emitters, water flows through a small diameter opening or series of openings where most of the pressure head is lost. Orifice emitters include many drip and spray emitters and also single chamber line-source tubing.

5. Vortex emitters:

A circular flow is generated in the vortex emitters due to the flow path containing a round cell. Water enters tangentially to the outer wall causing the circular motion. This produces a fast rotational motion creating a vortex at the center of the cell. Both the resistance to flow and the head loss in the vortex emitter are greater than for a simple orifice having the same diameter.

***Parameters Used to Evaluate Drip Emitters***

The following parameters were used to evaluate different drip irrigation products operating under high and low pressure head:

1. Average emitter discharge rate ($q_a$)
2. Standard deviation of emitter flow rate ($S_q$)
3. The variation coefficient of emitter flow ($C_v$)
4. Uniformity coefficient (UC)
5. Emission uniformity (EU)
6. Distribution uniformity (DU)

Computations followed the methodology proposed by Keller and Bliesner, 1990 and Kang and Nishiyama, 1996. The average emitter discharge rate, $q_a$ ($m^3/s$), can be expressed as:

$$q_a = \frac{1}{n}\sum_{i=1}^{n} q_i \tag{2.1}$$

where $q_i$ is the flow rate of the emitter $i$ ($m^3$/s) and $n$ is the total number of emitters.

The standard deviation of emitter flow rate, $S_q$, (ASABE, 2008R) can be written as:

$$S_q = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(q_i - q_a)^2} \tag{2.2}$$

The coefficient of variation of emitter flow, $C_{v,}$ (ASABE, 1999) evaluates the variability of flow and is computed by dividing the standard deviation by mean. Manufacturers usually publish the coefficient of variation for each of their products and the system designer must consider this source of variability. $C_v$ can be expressed as:

$$C_v = \frac{S_q}{q_a} \tag{2.3}$$

Another major important factor is the uniformity of water application. Christiansen's UC (%) evaluates the mean deviation, which is represented in ASABE standards as:

$$UC = 100\left[1 - \frac{1}{nq_a}\sum_{i=1}^{n}\left|q_i - q_a\right|\right] \tag{2.4}$$

Other frequently used uniformity measures in the irrigation system are the emission uniformity EU (%) and low quarter distribution uniformity DU (%).

The measure of emission uniformity EU (ASABE, 2008R) is used in trickle irrigation, while it is applied to sprinkler irrigation under the name of pattern efficiency is expressed as:

$$EU = \left[1.0 - \frac{1.27C_v}{\sqrt{n}}\right] \times \left(\frac{q_n}{q_a}\right) \times 100 \qquad (2.5)$$

where $q_n$ is the minimum flow rate of the sampling group emitters.

Low quarter distribution uniformity (DU) (Marriam and Keller, 1978) as applied to all types of irrigation systems can be expressed as:

$$DU = 100\left(\frac{q_m}{q_a}\right) \qquad (2.6)$$

where $q_m$ is the average flow rate of the emitters in the lowest quartile.

The average coefficient of variation of flow rates for each emitter through three times of sampling is known as $C_{ve}$ and is expressed as:

$$C_{ve} = \frac{S_{qe}}{q_{ae}} = \frac{\sqrt{\frac{1}{n-1}\sum_{i=n}^{n}(q_{ie} - q_{ae})^2}}{\frac{1}{n}\sum_{i=1}^{n} q_{ie}} \qquad (2.7)$$

A micro-irrigation system uniformity classification was developed to characterize the emitters based on UC and $C_v$ and is summarized in Tables 2-1 & 2-2, respectively.

**Table 2-1 Micro-irrigation system uniformity classification based on the coefficient of variation ***

| Emitter type | $C_v$ range | Classification |
|---|---|---|
| Point - source | < 0.05 | Excellent |
| | 0.05 – 0.07 | Average |
| | 0.07 – 0.11 | Marginal |
| | 0.11 – 0.15 | Poor |
| | >0.15 | Unacceptable |
| Line source | < 0.10 | Good |
| | 0.10 – 0.20 | average |
| | >0.20 | Marginal to unacceptable |

*Adopted from ASABE Standards EP405.1, 2008R

**Table 2-2 Micro-irrigation system uniformity classification based on uniformity coefficient***

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

*Adopted from ASABE Standards EP 458, 1999

***Emitter Flow Rate and Pressure Head Relationship***

A basic component of emitter characteristics is the flow rate (Q) vs. pressure head (H) relationship. 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 constant value C were derived using polynomial regression in Microsoft Excel.

An emitter flow rate and pressure head relationship was established as:

$$Q = CH^x$$

(2.8)

where $Q$ is the emitter flow rate, $m^3/s$ ; $C$ is the emitter Coefficient, 1/second; $H$ is the pressure head in the lateral at the location of emitters, m; and $x$ is the exponent characteristics of emitters, unitless.

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 to 1.0, where a lower value indicates a lower sensitivity and a higher value indicates a higher sensitivity. For PC emitters the value should be less than 0.1 and should approach 0. For NPC emitters, it should approach 0.5 (Cuenca, 1989).

***Validation of Measured Data with Calculated Data***

The emission rate for 60 emitters tested for each product was calculated theoretically using the following procedure.

The head loss due to friction and insertion of emitters was calculated and then the pressure head at every emitter was determined. The emission from every emitter was calculated using the characteristic equation developed for pressure head vs. discharge for each product.

*Head loss due to friction*

The head loss due to friction was calculated using the Darcy-Weisbach equation:

$$h = f\left(\frac{L}{D}\right)\times\left(\frac{v^2}{2g}\right) \qquad (2.9)$$

where $h$ = head loss, m; $f$ = friction factor ; $L$ = length of pipe, m; $D$ = inner diameter of pipe work, m; $v$ = velocity of fluid, m/s; $g$ = acceleration due to gravity, m/s².

Friction factor can be expressed as:

$$f = \frac{64}{R_e} \qquad \text{(For } R_e \leq 2000\text{)} \qquad (2.10)$$

$$f = 0.32\times R_e^{-0.25} \qquad \text{(For } R_e \geq 2000\text{)} \qquad (2.11)$$

where $Re$ = Reynolds' number, which can be expressed as:

$$R_e = \frac{vD}{\upsilon} \qquad (2.12)$$

where $v$ = fluid velocity, m/sec; $D$ = Internal pipe diameter of lateral, m; and $v$= kinematic viscosity of water = $1 \times 10^{-6}$ m$^2$/sec, at 20 $^0$C.

Velocity $v$ can be expressed as:

$$v = \frac{Q}{A} \tag{2.13}$$

where, $Q$ = lateral flow rate (average flow rate per emitter × number of emitters), and $A$= cross sectional area of lateral.

*Head loss due to insertion of emitter*

Head loss due to the insertions of emitters was calculated as described by the methodology of Provenzano and Pumo, 2004. The schematic view of flow contraction and subsequent enlargement for on-line and integrated in-line emitters is shown in Figure 2-1.

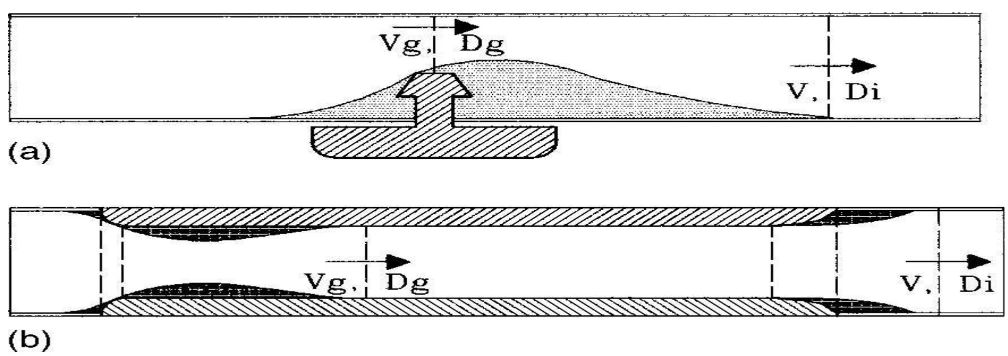


**Figure 2-1 Schematic view of flow for (a) on-line and (b) integrated in-line emitters (Provenzano and Pumo, 2004)**

The head loss due to insertion of emitters was calculated as:

$$\lambda = \alpha \times v^2 / 2g \tag{2.14}$$

where $\lambda$ = Head loss due to insertion of emitter, m ; $\alpha$ = coefficient; $v$ = velocity of water, m/s; and $g$ = acceleration due to gravity, m/s$^2$. Coefficient $\alpha$ can be expressed as:

$$\alpha = 0.056 \times \left[ \left( \frac{D_i}{D_g} \right)^{17.83} - 1 \right] \quad (2.15)$$

where $Di$ = internal diameter of pipe, mm; and $D_g$ = internal diameter due to emitter, mm

Total head loss at the i^th emitter, $h_i = (h + \lambda)$ (2.16)

Head at the i^th emitter $H_i = [H - (h + \lambda)]$ (2.17)

Discharge at the i^th emitter, $Q_i = CH_i^x$ (2.18)

where $Q_i$ = emitter flow rate for the i^th emitter, $m^3/s$; $C$= emitter coefficient, 1/sec; $H_i$= pressure head in the lateral at the i^th emitter, m; and $x$ = the exponent characteristics of emitters, unitless.

The calculated emission rates were then compared with the measured values to see the differences between them.

***Computing Distribution Uniformity***

The distribution uniformity (DU) of water was computed along a lateral for four products under a low pressure range of 0.60 m (2 ft), 1.20 m (4 ft), 1.80 m (6 ft) and 2.40 m (8 ft) of pressure head. DU for Netafim product could not be computed as this product had no emission under low pressure.

First, the emission from each emitter was calculated for a particular length of lateral using the methodology stated above. Then the average flow was determined for all emitters. After that, the average flow of the lowest quartile was determined and for a particular product for various lateral lengths, the distribution uniformity was calculated as:

$$DU = 100\left(\frac{q_m}{q_a}\right) \tag{2.19}$$

where $DU$ = distribution uniformity, %; $q_m$ = the average flow rate of the emitters in the lowest quartile, $m^3/s$; and $q_a$ = the average flow rate of all emitters under test, $m^3/s$.

# CHAPTER III

# EXPERIMENTAL SET UP

## ***Methodology***

### *Testing apparatus*

A laboratory based experiment was set up for this study. The apparatus used in this test to determine emitter flow rates has been described by Duan (2006). Ten lines of drip tubing each 3.04 meter (10 ft) long were attached between a supply and return manifold system as shown in Figure 3-1. In order to maintain the same pressure in each different lateral, even if one line plugged, the laterals were separated from each other using ball valves located before each to isolate the plugged line. A sketch of the testing apparatus used in this study is shown in Figure 3-1.

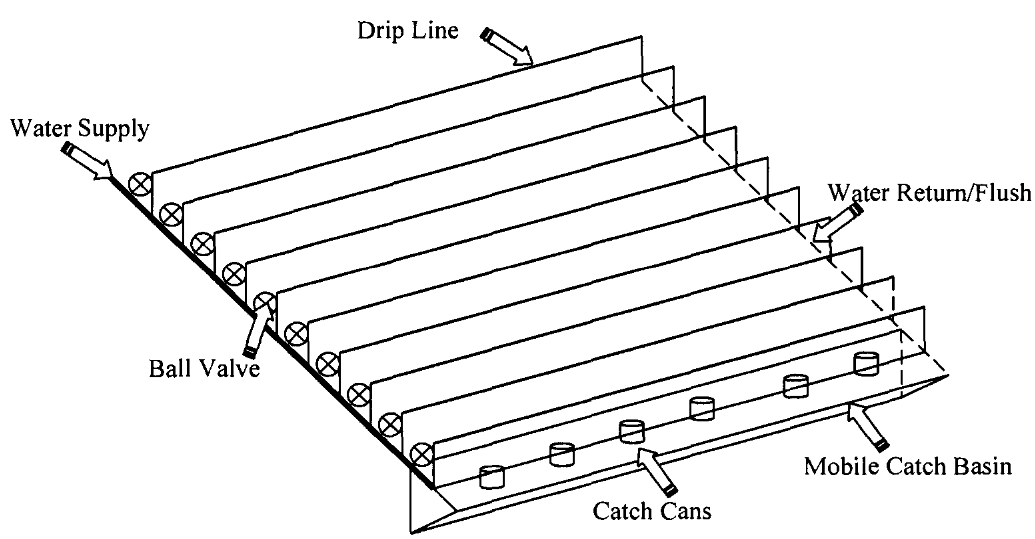


**Figure 3-1 Layout of the test apparatus for emitter testing (Duan, 2006)**

In order to avoid any kind of probable effects of biological growth, clean tap water was used for the experiment. First, water from the tap was collected in a tank of volume 0.85 $m^3$ (225 gallon) and then supplied to the laterals by using a 373 watt (0.5 HP) high head pump. The pump was a GOULDS pump which is a 4 inch submersible pump featuring ½ HP, 4.543 $m^3$/hour (20 GPM). Different pressures were generated by two control valves installed between the pump and the ball valves. A pressure gauge was plugged in at the ball valve before each lateral to monitor inlet pressure in the system. The supply water temperature was monitored by a -20 to + 80 $^0$ C floating thermometer suspended at the tank. Water temperature was maintained at 20 $^0$ C (±2$^0$C) by adding cold water as needed. The catch-can method of uniformity testing, as described by the American Society of Agricultural and Biological Engineers (ASABE, 1999) was used to collect water samples. In order to minimize any kind of loss of discharged water and to collect water directly into the catch cans located in a mobile catch-can basin, small pieces of cotton strings were attached to individual emitters. Each string was saturated with water before collecting each sample. The water samples collected in containers were weighted in an electric balance with a measurement accuracy of + 0.01 gm and were converted to volume. The lab setup system for emitter discharge collection is shown in Figure 3-2.

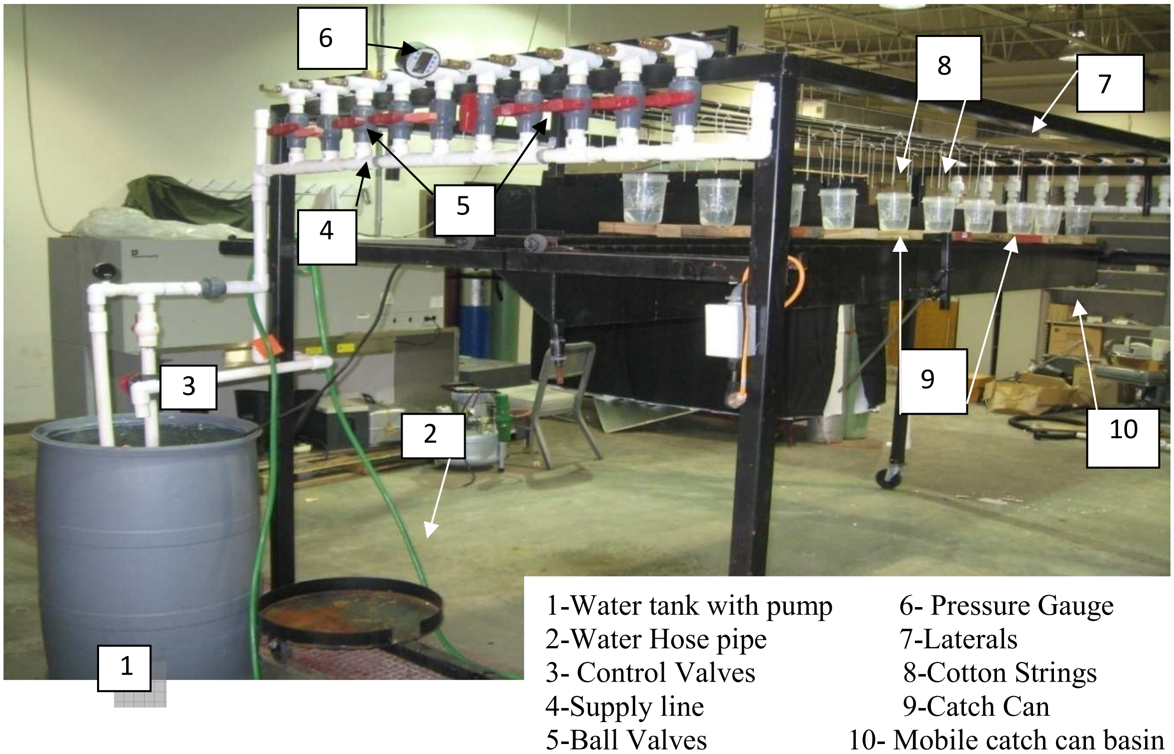


**Figure 3-2 Lab setup for collecting discharge from drip emitters**

*Emitter and tubing models*

The laboratory test was conducted with five different types of drip products to represent a generally used drip irrigation system (Table 3-1).

**Table 3-1 Manufacturer's parameters of selected drip tubing**

| | Make and Model | Type | Inside Diameter (mm) | Emitter Spacing (m) | Nominal flow rate (L/hr @Kpa) | Recommended operating pressure (Kpa) |
|---|---|---|---|---|---|---|
| 1 | Toro Drip in PC (PCS 1810–18–100) | PC/ LS | 16 (0.62 inch) | 0.46 (18 inch) | 4.00 @ 206.84 (1.06 gph @ 30 psi) | 68.95 – 413.68 (10 – 60 psi) |
| 2 | T-Tape (TT1–1245–0100) | NPC/ LS | 15 (0.59 inch) | 0.305 (12 inch) | 1.02 @ 55.16 (0.27gph @ 8psi) | 27.58 – 103.42 (4 – 15 psi) |
| 3 | Mister_LS (MLD-HDT100) | PC/ LS | 12.7 (0.50 inch) | 0.305 (12 inch | 3.785 @ 172.37 (1.00 gph @ 25 psi) | 68.95 – 413.68 (10 – 60 psi) |
| 4 | Mister_PS (MLD-1PC 25) | PC/ PS | 12.7 (0.50 inch) | 0.305 (12 inch | 3.785 @ 172.37 (1.00 gph @ 25 psi) | 68.95 – 413.68 (10 – 60 psi) |
| 5 | Netafim Techline CV 560 050 | PC/ LS | 14 (0.56 inch) | 0.305 (12 inch | 0.984 @ 206.84 0.26 gph @ 30 psi | 103.42 - 482.63 (15 – 70 psi) |

* PC = Pressure Compensating, NPC = Non-pressure Compensating, LS = Line source, PS = Point source

Some of the tested emitters are shown in Figure 3-3.

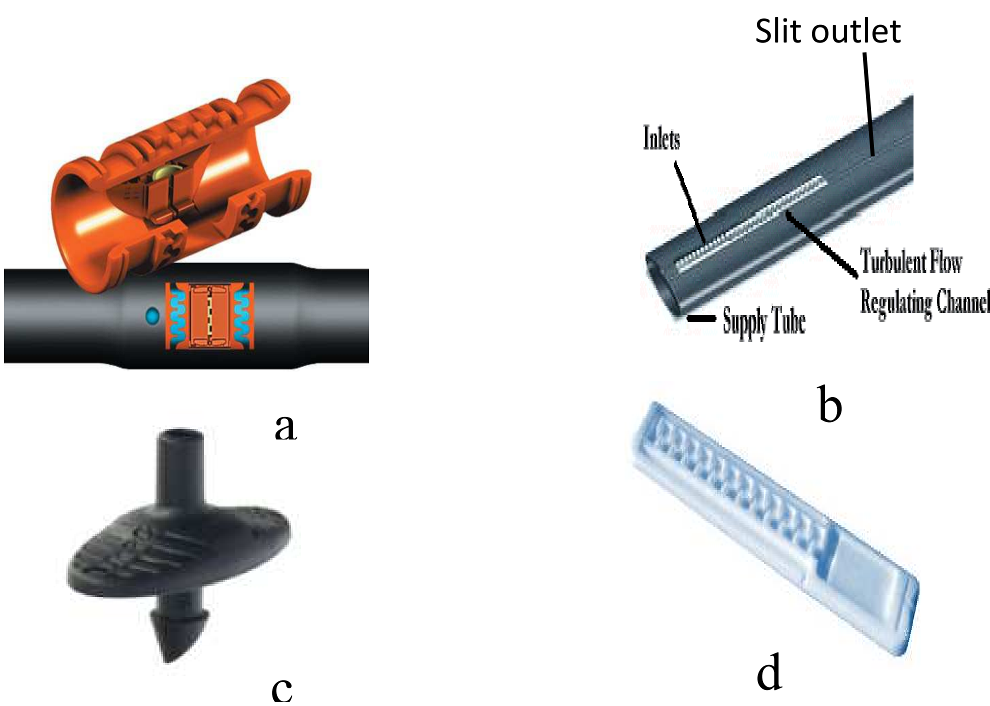


**Figure 3-3 Pictures of Toro (a), T-Tape (b), Mister-PS (c) and Netafim (d) emitters**

*Sampling protocol*

A. Sampling process:

In this experiment, each sampling event for Toro brand drip products was conducted by connecting 9 individual 3.05 m long of tubing to the testing apparatus. $1^{st}$, $5^{th}$ and $6^{th}$ laterals had 6 emitters on each lateral and other 6 laterals had 7 emitters at each lateral allowing for evaluating a group of 60 emitters at one time. All other brands of drip products were conducted by connecting 6 individual 3.05 m long of tubing to the testing apparatus. Each lateral had 10 emitters allowing evaluating a group of 60 emitters at one time. A continuous dripping of three hours were performed with every new drip product for conditioning before collecting samples. On the other hand, after turning on the pump, emitters were allowed to drip for approximately 3 minutes to allow for air to escape from the tubing. Samples were collected only after making sure that no air was exiting from the tubes. Water collection period was set in such a way that approximately 100 to 300 ml water samples could be collected to calculate discharge rate per minute. For each type of tubing, sampling on each lateral was repeated three times consecutively to minimize any kind of experimental error, including a measurement technique with starting and stopping time. After weighing, the weighted containers were emptied and wiped with a paper towel before collecting another new sample.

B. Tested operating pressures:

Samples were collected under various pressures: 5.97 KPa (0.87 psi /2ft), 11.94 KPa (1.73 psi /4 ft), 17.91 KPa (2.60 psi /6 ft), 23.88 KPa (3.50 psi / 8.00 ft), 35.82 KPa (5.20 psi /12 ft), 55.16 (8.00 psi /18.48 ft), 62.05 KPa (9.00 psi /20.79 ft), 68.95 KPa

(10.00 psi /23.10 ft), 82.74 KPa (12.00 psi /27.72 ft), 96.53 KPa (14.00 psi /32.34 ft), 117.21 KPa (17.00 psi /39.27 ft), 137.90 KPa (20.00 psi /46.20 ft), 172.37 KPa (25.00 psi/57.75 ft) , 206.84 KPa (30.00 psi /69.30 ft) and 344.74 KPa (50.00 psi /115.50 ft). A standard test on the emitter discharge rate in response to pressure (ASABE, 2008R) was conducted to develop sample data and for comparison with manufacturer's provided performance data.

# CHAPTER IV

# CALCULATIONS, RESULTS AND DISCUSSIONS

***Relationship between Emitter Flow Rate and Pressure Head***

The flow rate versus pressure head relationship plays a vital role in the characterization of emitters. It is one of the key factors in selecting an emitter and system design. In this study, a relationship between flow rate and pressure head was developed using polynomial regression in Microsoft excel and the emitter exponent x and constant value C were found from the equations derived. From the exponent x value, it was found that at a higher pressure or at manufacturer's recommended pressure range, the PC emitters behaved like PC emitters, but at a low pressure range, the PC emitters behaved like NPC emitters. In order to study the characteristics of emitters more precisely, the flow pressure curve was studied separately under low and high or normal operation pressure ranges. For Toro product, the lower pressure range was from 0.60-6.93 m (0.87-10 psi) and the normal pressure range was from 6.93-34.65 m (10-50 psi). For T-Tape, the lower pressure range was from 0.60-5.54 m (0.87-8 psi) and the normal pressure range was from 5.54-34.65 m (8-50 psi). For Mister_LS product, the lower pressure range was from 0.60-8.32 m (0.87-14 psi) and the normal pressure range was from 8.32-34.65 m (14-50 psi). For Mister_PS product, the lower pressure range was from 0.60-11.78 m (0.87-17 psi) and the normal pressure range was from 11.78-34.65 m (17- 50 psi). For Netafim product, the lower pressure range was from 3.00-5.54 m (4.33-8 psi) and the normal pressure range was from 5.54-34.65 m (8- 50 psi).

*Characterization of Emitters*

The average measured flow rate at a specified pressure was close to the manufacturer's published value for all products, but the measured coefficient of variation differed greatly in the case of Mister_LS product. Comparison is shown in Table 4-1.

**Table 4-1 Comparison of tested data with the manufacturer's published data**

| Make and Model | Inside Diameter (mm) | Emitter Spacing (m) | *Nominal flow rate (L/hr @ Kpa) | Tested flow rate (L/hr @ Kpa) | *Manufac turer coefficient of variation | Tested Coeffi cient of variation |
|---|---|---|---|---|---|---|
| Toro Drip in PC (PCS 1810–8–100) | 16 (0.62 inch) | 0.46 (18 inch) | 4.00 @ 206.84 (1.06 gph @ 30 psi) | 4.00 @ 206.84 (1.06 gph @ 30 psi) | 5 % | 6 % |
| T-Tape (TT15–1245–0100) | 15 (0.59 inch) | 0.305 (12 inch) | 1.02 @ 55.16 (0.27 gph @ 8psi) | 1.06 @ 55.16 (0.28 gph @ 8 psi) | 3.5 % | 3 % |
| Mister_LS (MLD-HDT100) | 12.7 (0.50 inch) | 0.305 (12 inch) | 3.785 @ 172.37 (1.00 gph @ 25psi) | 4.16 @ 172.37 (1.10 gph @ 25 psi) | 5 % | 8 % |
| Mister_PS (MLD-1PC 25) | 12.7 (0.50 inch) | 0.305 (12 inch) | 3.785 @ 172.37 (1.00 gph @ 25psi) | 4.50 @ 172.37 (1.19 gph @ 25 psi) | 5 % | 4 % |
| Netafim Techline CV 560 050 | 14 (0.56 inch) | 0.305 (12 inch) | 0.984 @ 206.84 (0.26 gph @ 30 psi) | 1.02 @ 206.84 (0.27 gph @ 30psi) | 5% | 2% |

*Adopted from manufacturers' manual of Toro, T-Tape, Mister and Netafim

The results of statistical analysis for all of the emitters are summarized in Table 4-2. To verify the error associated with manual operation, the average coefficient of variation $C_{ve}$ for all emitters through 3 replications of sampling was computed (Table 5). The $C_{ve}$ value was found around 0 % which assures that the experimental methodology had no significant influence on statistical results and emitter's real condition was represented properly by experiments.

**Table 4-2 Summary of statistical analysis on tested emitters***

| Sl no | Make & Model | UC (%) | $C_v$ | EU (%) | DU (%) | $C_{ve}$ |
|---|---|---|---|---|---|---|
| 1 | Toro Drip in PC (PCS 1810 – 18 – 100) | 91.24 | 0.06 | 82.44 | 92.13 | 0.0057 |
| 2 | T-Tape (TT15 – 1245 – 0100) | 96.63 | 0.04 | 84.61 | 94.35 | 0.0054 |
| 3 | Mister_LS (MLD-HDT100) | 93.12 | 0.08 | 74.20 | 86.24 | 0.0053 |
| 4 | Mister_PS (MLD-1PC 25) | 96.33 | 0.04 | 89.83 | 94.43 | 0.0107 |
| 5 | Netafim Techline CV 560 050 | 97.92 | 0.02 | 93.36 | 96.53 | 0.0066 |

*Note : Mean values under all pressures

According to ASABE standards (2008R and 1999), five tested drip tapes were classified on the basis of uniformity coefficient and coefficient of variation. The results are presented in Table 4-3.

**Table 4-3 Micro irrigation system classifications of tested emitters based on uniformity coefficient (UC) and coefficient of variation ($C_v$)**

| Sl no | Make and model | UC (%) | Classification | $C_v$ | Classification |
|---|---|---|---|---|---|
| 1 | Toro Drip in PC (PCS 1810–18 –100) | 91.24 | Excellent | 0.06 | Marginal |
| 2 | T-Tape (TT15 –1245– 0100) | 96.63 | Excellent | 0.04 | Excellent |
| 3 | Mister_LS (MLD-HDT100) | 93.12 | Excellent | 0.08 | Marginal |
| 4 | Mister_PS (MLD-1PC 25) | 96.33 | Excellent | 0.04 | Excellent |
| 5 | Netafim Techline CV560 050 | 97.92 | Excellent | 0.02 | Excellent |

The test results are illustrated below for the five products under testing.

*Toro Drip-in-PC (PCS 1810-18-100)*

The tested flow rate at different pressures and the calculated parameters are shown in Table 4-4. It was observed that the Toro Drip-in-PC (PCS 1810-18-100) had an emission rate of 3.48E-07 $m^3/s$ to 1.09E-06 $m^3/s$ for a pressure range of 0.60 m to 34.65 m. The tested average emission rate for Toro product 4.00 l/hr at 206.84 KPa (1.06 gph@30 psi) was the same as the manufacturer's published average flow rate at that pressure. The tested coefficient of variation was 6%, whereas the manufacturer's coefficient of variation was 5%. The emission rate increased rapidly up to a pressure of 6.93 m (10 psi) and then followed a relatively constant emission rate up to 34.65 m (50 psi) of the pressure head.

**Table 4-4 Emitter characterization of Toro Drip in PC (PCS 1810-18-100 )**

| Pressure (m) | $q_a$ ($m^3/s$) | $S_q$ ($m^3/s$) | UC (%) | $C_v$ | EU (%) | DU (%) | $C_{ve}$ |
|---|---|---|---|---|---|---|---|
| 0.60 | 3.55E-07 | 4.08E-08 | 91.62 | 0.12 | 78.97 | 87.13 | 0.02 |
| 1.20 | 5.12E-07 | 4.77E-08 | 92.98 | 0.10 | 79.59 | 87.95 | 0.01 |
| 1.80 | 5.95E-07 | 5.55E-08 | 92.22 | 0.10 | 79.24 | 88.76 | 0.01 |
| 2.40 | 7.27E-07 | 5.48E-08 | 81.79 | 0.08 | 65.05 | 89.51 | 0.00 |
| 3.60 | 8.87E-07 | 6.28E-08 | 67.03 | 0.07 | 76.78 | 90.13 | 0.00 |
| 5.54 | 1.08E-06 | 7.17E-08 | 94.37 | 0.07 | 82.34 | 90.47 | 0.01 |
| 6.24 | 1.13E-06 | 7.67E-08 | 94.43 | 0.07 | 81.37 | 90.43 | 0.00 |
| 6.93 | 1.16E-06 | 6.90E-08 | 91.67 | 0.06 | 85.44 | 91.58 | 0.01 |
| 8.32 | 1.16E-06 | 8.27E-08 | 94.44 | 0.07 | 91.99 | 97.95 | 0.00 |
| 9.70 | 1.15E-06 | 9.07E-08 | 93.53 | 0.08 | 93.97 | 99.90 | 0.00 |
| 11.78 | 1.12E-06 | 8.23E-08 | 93.94 | 0.07 | 92.90 | 98.62 | 0.00 |
| 13.86 | 1.11E-06 | 7.58E-08 | 94.32 | 0.07 | 83.23 | 90.44 | 0.00 |
| 20.79 | 1.14E-06 | 7.08E-08 | 95.02 | 0.06 | 83.61 | 91.29 | 0.01 |
| 34.65 | 1.10E-06 | 6.92E-08 | 100.00 | 0.06 | 79.69 | 95.62 | 0.01 |
| Average | | | 91.24 | 0.07 | 82.44 | 92.13 | 0.005 |

*$q_a$, average emitter discharge rate ; $S_q$, standard deviation of emitter flow rate ; UC, Christiansen's uniformity coefficient ; $C_v$, Variation coefficient of emitter flow rate; EU, Emission uniformity; DU, Low quarter distribution uniformity,$C_{ve}$ average variation coefficient among three sampling events.

The flow rate vs. pressure head relationship for the whole pressure range is shown in Table 4-5 and the developed Q-H curve is shown in Figure 4-1.

**Table 4-5 Flow rate vs. pressure head relationship of Toro Drip in PC (PCS 1810-18-100 )**

| Q-H | Total pressure range 0.60-34.65 m (0.87-50 psi) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Q = 5E\text{-}07H^{0.2999}$ | | | | | | | | | | | | | |
| H (m) | 0.60 | 1.20 | 1.80 | 2.40 | 3.60 | 5.54 | 6.24 | 6.93 | 8.32 | 9.70 | 11.78 | 13.86 | 20.79 | 34.65 |
| Q ($m^3/s$) | 3.48 E-07 | 5.2 E07 | 5.83 E-07 | 7.12 E-07 | 8.70 E-07 | 1.05 E-06 | 1.11 E-06 | 1.14 E-06 | 1.14 E-06 | 1.12 E06 | 1.10 E-06 | 1.08 E-06 | 1.11 E-06 | 1.09 E-06 |

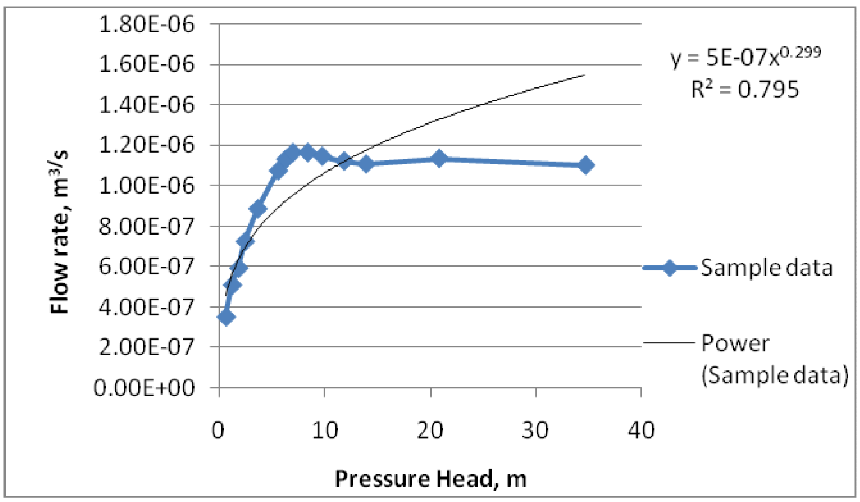


**Figure 4-1 Q-H Curve of Toro Drip in PC PCS 1810-18-100 (0.60-34.65 m/0.87-50 psi)**

For the total pressure range, the $R^2$ value was 0.7952 and the flow-pressure relationship was $Q = 5E - 07H^{0.2999}$. From the $R^2$ value, it can be said that the developed flow rate vs. pressure head relationship did not describe the emitter accurately. The emitter exponent value was 0.299. So, for the whole pressure range, the emitter did not behave like fully pressure compensating as for PC emitters this value should be between

0 to 0.1. For a non pressure compensating emitter, this value should be around 0.5. Thus, it can be said that the emitter behaved like partially pressure compensating for the whole pressure range. In order to describe the characteristics of the tested emitter, the flow pressure curve was divided into two pressure ranges, (i) 0.60 – 6.93 m (0.87-10 psi) and (ii) 6.93-34.65 m (10-50 psi). The Q-H curves are shown in Figures 4-2 and 4-3, respectively.

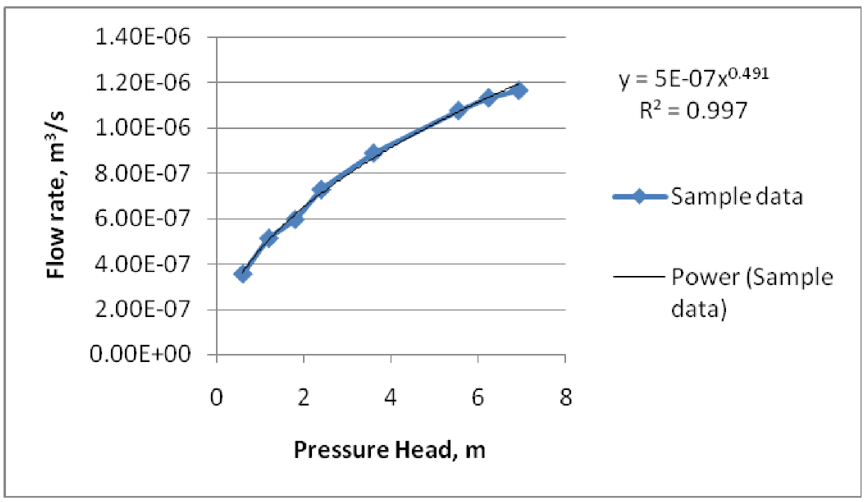


**Figure 4-2 Q-H Curve of Toro Drip in PC PCS 1810-18-100 (0.60-6.93 m/0.87-10 psi)**

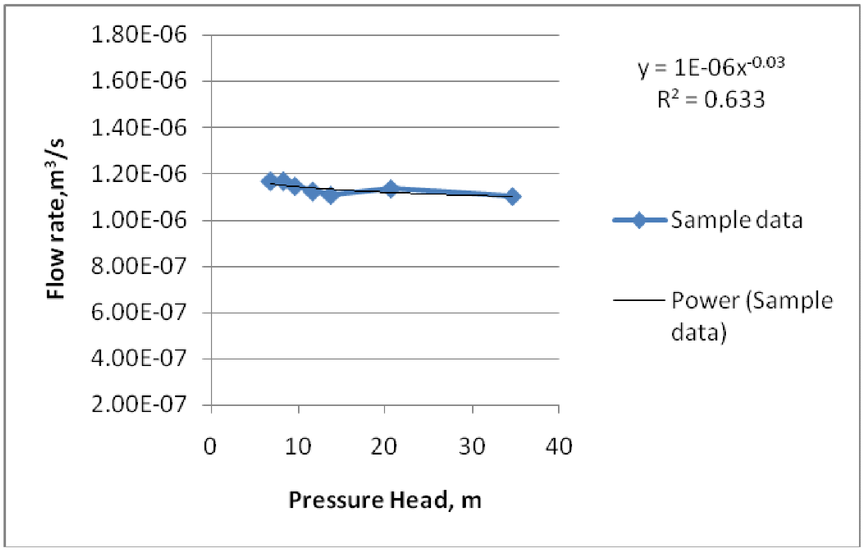


**Figure 4-3 Q-H Curve of Toro Drip in PC PCS 1810-18-100 (6.93-34.65 m/10-50 psi)**

At the low pressure range, the Q-H equation exhibited an $R^2$ value of 0.9973 (Figure 4-2). Thus, it can be said, this equation accurately described the flow-pressure relationship. The emitter exponent value was 0.4918 which confirmed that the emitter behaved like non-pressure compensating at a lower pressure range, although it is a pressure compensating emitter. No manufacturer's data is available at low pressure ranges. At the normal operating pressure ranges (from 10-50 psi), the emitter exponent value was 0.032, which is less than 0.1 and approximately equals 0. Hence, it can be said, the emitter behaved as a fully PC emitter at the suggested operating pressure range. At the normal operating pressure range, the $R^2$ value of 0.6334 fairly represented the flow-pressure relationships (Figure 4-3). It is also observed that there was a slight reduction in flow rate at higher pressures.

*T-Tape (TT15-1245-0100)*

The tested flow rate at different pressures and the calculated parameters for T-Tape are shown in Table 4-6. It was observed that the T-Tape (TT15-1245-0100) had an emission rate range of 0.78E-07 $m^3/s$ to 6.73E-07 $m^3/s$ for a pressure range of 0.60 m to 34.65 m. The tested average emission rate for T-Tape product 1.06 L/hr at 55.16 KPa (0.28 gph @ 8 psi) was very close to the manufacturer's published average flow rate of 1.02 L/hr (0.27 gph) at that pressure. The emission rate increased rapidly up to a pressure of 6.93 m (10 psi) and then followed a relatively constant emission rate up to a pressure head of 34.65 m (50 psi). The tested coefficient of variation was 3%, which was also close to the manufacturer's coefficient of variation of 3.5 %.

**Table 4-6 Emitter characterization of T_Tape (TT15-1245-0100**

| Pressure (m) | $q_a$ ($m^3/s$) | $S_q$ ($m^3/s$) | UC (%) | $C_v$ | EU (%) | DU (%) | $C_{ve}$ |
|---|---|---|---|---|---|---|---|
| 0.60 | 0.78E-07 | 6.33E-09 | 94.34 | 0.08 | 61.76 | 88.87 | 0.01 |
| 1.20 | 1.08E-07 | 1.00E-08 | 92.74 | 0.09 | 82.60 | 89.14 | 0.01 |
| 1.80 | 1.53E-07 | 7.17E-09 | 96.08 | 0.05 | 88.87 | 94.26 | 0.01 |
| 2.40 | 1.82E-07 | 8.67E-09 | 96.40 | 0.05 | 88.21 | 94.77 | 0.01 |
| 3.60 | 2.27E-07 | 7.00E-09 | 97.34 | 0.03 | 71.29 | 92.71 | 0.00 |
| 5.54 | 2.91E-07 | 8.50E-09 | 97.30 | 0.03 | 91.37 | 96.33 | 0.00 |
| 6.93 | 3.23E-07 | 1.00E-08 | 97.45 | 0.03 | 93.35 | 95.94 | 0.00 |
| 9.70 | 3.74E-07 | 1.75E-08 | 97.20 | 0.05 | 71.10 | 95.07 | 0.02 |
| 13.86 | 4.40E-07 | 1.42E-08 | 97.56 | 0.03 | 92.12 | 96.02 | 0.00 |
| 20.79 | 5.28E-07 | 1.33E-08 | 98.00 | 0.03 | 94.37 | 96.78 | 0.00 |
| 34.65 | 6.73E-07 | 1.18E-08 | 98.56 | 0.02 | 95.63 | 97.96 | 0.00 |
| Average | | | 96.63 | 0.04 | 84.61 | 94.35 | 0.005 |

*$q_a$, average emitter discharge rate; $S_q$, standard deviation of emitter flow rate; UC, Christiansen's uniformity coefficient; $C_v$, Variation coefficient of emitter flow rate; EU, Emission uniformity; DU, Low quarter distribution uniformity; $C_{ve}$ average variation coefficient among three sampling events.

The flow rate vs. pressure head relationship for the whole pressure range is shown in Table 4-7 and the developed Q-H curve is shown in Figure 4-4.

**Table 4-7 Flow rate vs. pressure head relationship of T-Tape (TT15-1245-0100)**

| Q-H | Total pressure range 0.60-34.65 m (0.87-50 psi) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Q= 1E\text{-}07H^{0.5366}$ | | | | | | | | | | |
| H (m) | 0.60 | 1.20 | 1.80 | 2.40 | 3.60 | 5.54 | 6.93 | 9.70 | 13.86 | 20.79 | 34.65 |
| Q ($m^3/s$) | 0.78 E-07 | 1.08 E-07 | 1.53 E-07 | 1.82 E-07 | 2.27 E-07 | 2.91 E-06 | 3.23 E-06 | 3.74 E06 | 4.40 E-06 | 5.28 E-06 | 6.73 E-06 |

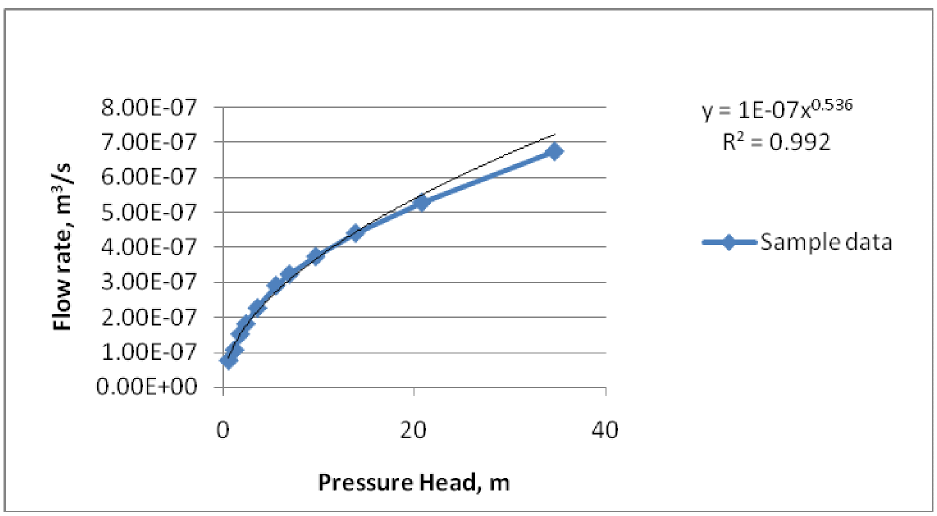


**Figure 4-4 Q-H Curve of T-Tape TT15-1245-0100 (0.60-34.65 m/0.86-50 psi)**

For the total pressure range, the $R^2$ value was 0.9921 and the flow pressure relationship was $Q = 1E - 07H^{0.5366}$. From the $R^2$ value, it can be said that the developed flow rate vs. pressure head relationship accurately described the emitter. The emitter exponent value was 0.5366. Thus for the whole pressure range the emitter behaved like non-pressure compensating as for NPC emitters this value should be around 0.5. In order to describe the characteristics of the tested emitter more accurately, flow pressure curve was divided into two pressure ranges, (i) 0.60 – 5.54 m (0.87-8 psi) and (ii) 5.54-34.65 m (10-50 psi). The Q-H curves are shown in Figures 4-5 and 4-6, respectively.

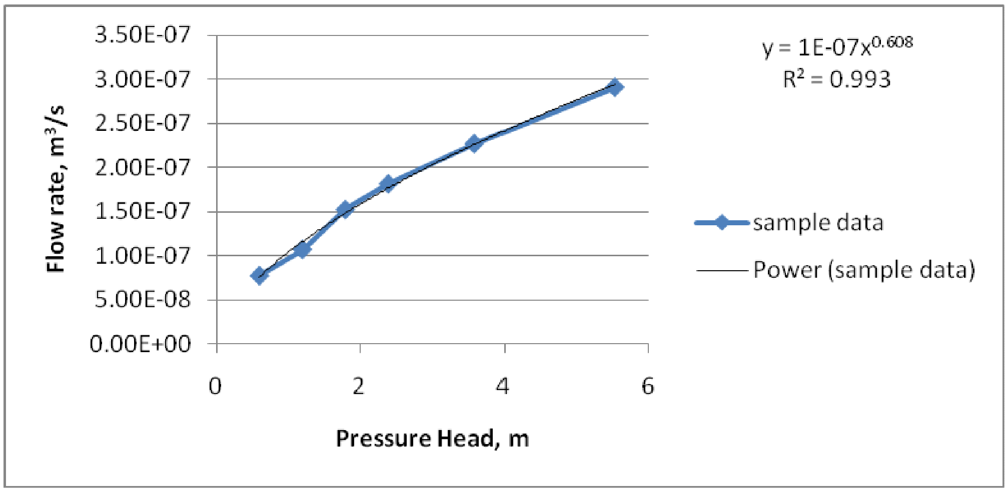


**Figure 4-5 Q-H Curve of T-Tape TT15-1245-0100 (0.60-5.54 m/0.86-8 psi)**

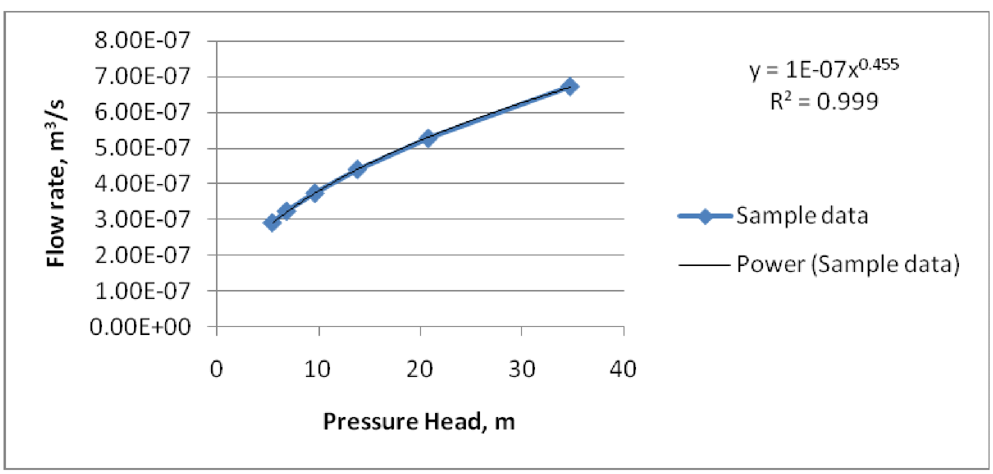


**Figure 4-6 Q-H Curve of T-Tape TT15-1245-0100 (5.54-34.65 m/8-50 psi)**

At the low pressure range, the Q-H equation exhibited an $R^2$ value of 0.9933 (Figure 4-5). At the normal operating pressure range, the $R^2$ value was 0.9998 (Figure 4-6). It can be said that both equations accurately described the flow pressure relationship under low and high pressure ranges. The emitter exponent value was 0.6087 at the low pressure range and 0.455 at the high pressure range. Thus it can be said that the emitter behaved perfectly like non-pressure compensating both at lower and higher pressure ranges. No manufacturer's data is available at low pressure ranges. An increasing tendency in flow rate with the increase of pressure was also observed throughout the whole pressure range.

*Mister_LS (MLD-HDT100)*

The tested flow rate at different pressures and the calculated parameters for Mister_in (MLD-HDT100) are shown in Table 4-8. It was observed that Mister_LS had an emission rate range of 3.87E-07 $m^3/s$ to 1.19E-06 $m^3/s$ for a pressure range of 0.60 m to 34.65 m (0.87-50 psi). The tested average emission rate for this product was 4.16 L/hr at 172.37 KPa (1.10 gph @ 25 psi), close to the manufacturer's published average flow rate of 3.78 L/hr (1.00 gph) at that pressure. The emission rate increased rapidly up to a pressure of 8.32 m (12 psi) and then followed a relatively constant emission rate up to a pressure head of 34.65 m (50 psi). The tested coefficient of variation of 8% was significantly greater than the manufacturer's coefficient of variation of 5 %.

**Table 4-8 Emitter characterization of Mister_LS (MLD-HDT100)**

| Pressure (m) | $q_a$ ($m^3/s$) | $S_q$ ($m^3/s$) | UC (%) | $C_v$ | EU (%) | DU (%) | $C_{ve}$ |
|---|---|---|---|---|---|---|---|
| 0.60 | 3.87E-07 | 4.00E-08 | 91.81 | 0.10 | 72.02 | 85.41 | 0.01 |
| 1.20 | 5.24E-07 | 4.67E-08 | 92.86 | 0.09 | 74.26 | 87.39 | 0.01 |
| 1.80 | 6.28E-07 | 5.58E-08 | 92.67 | 0.09 | 73.62 | 81.51 | 0.00 |
| 2.40 | 6.67E-07 | 5.98E-08 | 92.70 | 0.09 | 69.38 | 76.83 | 0.00 |
| 3.60 | 8.13E-07 | 6.15E-08 | 93.90 | 0.08 | 75.44 | 93.32 | 0.00 |
| 5.54 | 1.03E-06 | 8.17E-08 | 93.55 | 0.08 | 77.49 | 88.22 | 0.01 |
| 6.93 | 1.13E-06 | 9.58E-08 | 93.13 | 0.08 | 70.31 | 80.11 | 0.01 |
| 8.32 | 1.22E-06 | 9.18E-08 | 93.95 | 0.08 | 75.21 | 89.05 | 0.00 |
| 9.90 | 1.22E-06 | 9.60E-08 | 93.91 | 0.08 | 74.72 | 88.52 | 0.01 |
| 11.78 | 1.21E-06 | 1.13E-07 | 92.71 | 0.09 | 75.38 | 89.52 | 0.00 |
| 13.86 | 1.19E-06 | 1.11E-07 | 92.60 | 0.09 | 73.21 | 86.18 | 0.00 |
| 17.33 | 1.19E-06 | 1.04E-07 | 93.23 | 0.09 | 75.64 | 87.23 | 0.01 |
| 34.65 | 1.19E-06 | 9.52E-08 | 93.49 | 0.08 | 77.88 | 87.66 | 0.01 |
| Average | | | 93.12 | 0.08 | 74.20 | 86.24 | 0.0053 |

The flow rate vs. pressure head relationship for the whole pressure range is shown in Table 4-9 and the developed Q-H curve is shown in Figure 4-7.

**Table 4-9 Flow rate vs. pressure head relationship of Mister_LS (MLD-HDT100)**

| Q-H | Total pressure range 0.60-34.65 m (0.87-50 psi) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Q= 5E\text{-}07H^{0.316}$ | | | | | | | | | | | | |
| H (m) | 0.60 | 1.20 | 1.80 | 2.40 | 3.60 | 5.54 | 6.93 | 8.32 | 9.90 | 11.78 | 13.86 | 17.33 | 34.65 |
| Q ($m^3/s$) | 3.87 E-07 | 5.24 E-07 | 6.2 E-07 | 6.67 E-07 | 8.13 E-07 | 1.03 E-06 | 1.13 E-06 | 1.22 E-06 | 1.22 E06 | 1.21 E-06 | 1.19 E-06 | 1.19 E-06 | 1.19 E-06 |

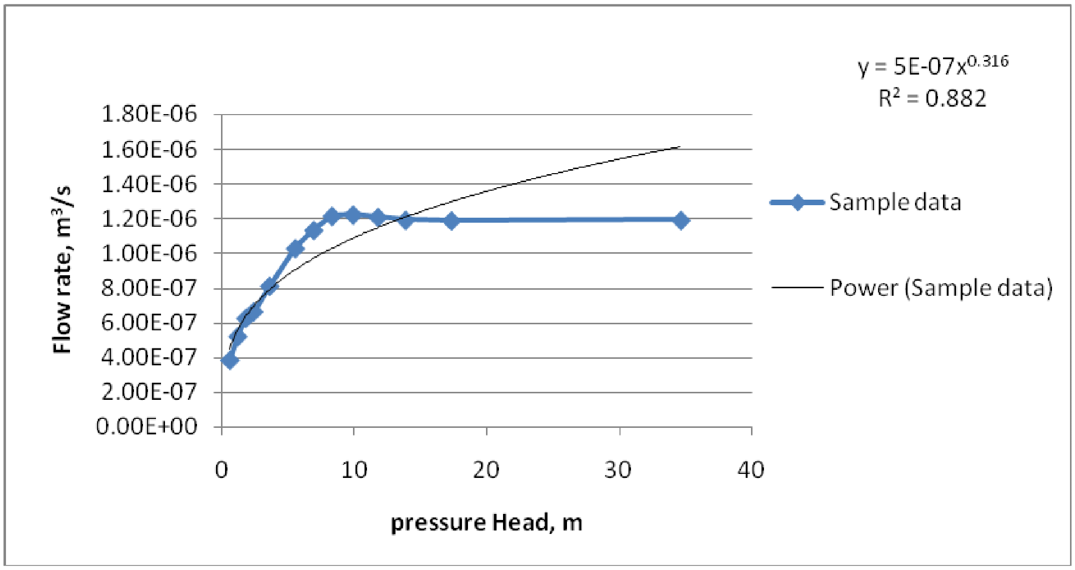


**Figure 4-7 Q-H Curve of Mister_LS MLD-HDT100 (0.60-34.65 m/0.87-50 psi)**

For the total pressure range, the $R^2$ value was 0.8823 and the flow pressure relationship was $Q = 5E - 07H^{0.316}$. From the $R^2$ value, it can be said that the developed flow rate vs. pressure head relationship did not accurately describe the emitters. The emitter exponent value was 0.316. So, for the whole pressure range, the emitter did not behave like fully pressure compensating, as for PC emitters this value should be less 0 to 0.1. For non-pressure compensating emitters, this value should be around 0.5. Thus, it can be said that the emitter behaved like partially pressure compensating. In order to describe the characteristics of the tested emitter more precisely, the flow pressure curve was divided into two pressure ranges, (i) 0.60 – 8.32 m (0.87-12 psi) and (ii) 8.32-34.65 m (12-50 psi). The Q-H curves are shown in Figure 4-8 and 4-9, respectively.

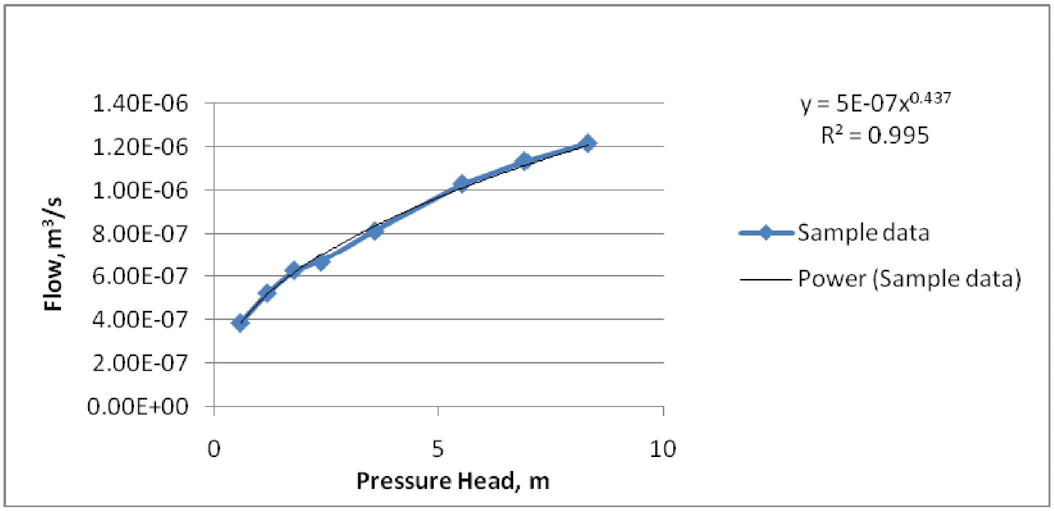


**Figure 4-8 Q-H Curve of Mister_LS MLD-HDT100 (0.60-8.32 m/0.87-12 psi)**

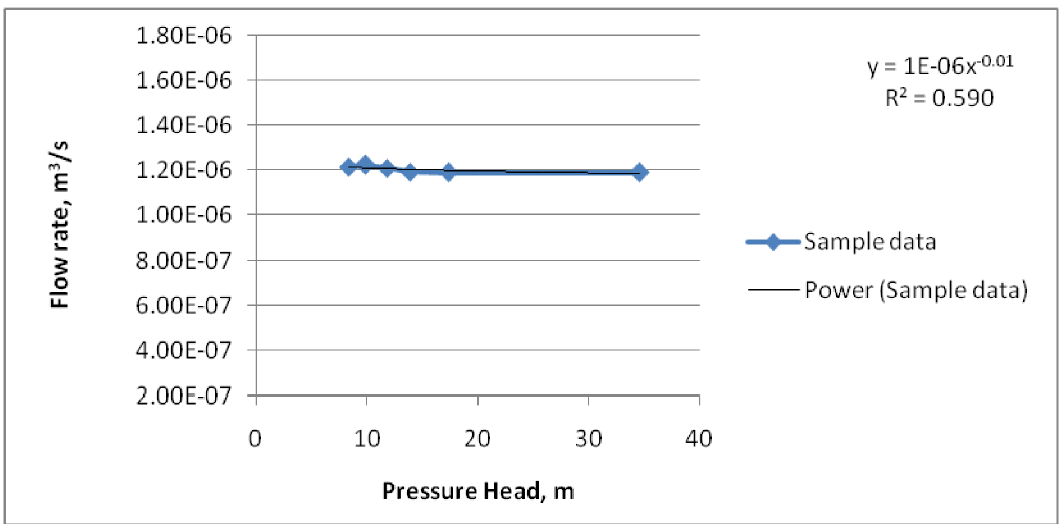


**Figure 4-9 Q-H Curve of Mister_LS MLD-HDT100 (8.32-34.65 m/12-50 psi)**

At a low pressure range of 0.60-8.32 m (0.87-12 psi), the Q-H equation exhibited an $R^2$ value of 0.9959 (Figure 4-8). So, it can be said that this equation accurately described the flow pressure relationship. The emitter exponent value was 0.4378, and the emitter behaved like non-pressure compensating at the lower pressure range, although in the manufacturer literature, it is a pressure-compensating emitter. No manufacturer's data is available at low pressure ranges. At the normal operating pressure range of 8.32-34.65 m (12-50 psi), the emitter exponent value was 0.018, which is less than 0.1 and approximately equals to 0. Hence, it can be said that the emitter behaved as fully PC emitter at the suggested operating pressure range. At the normal operating pressure range, the $R^2$ value of 0.5903 reasonably represented the flow-pressure relationship (Figure 4-9). It was also observed that there was a slight reduction in the flow rate at higher pressures of 13.86 to 34.65 m (17-50 psi).

*Mister_PS (MLD-1PC 25)*

For this product, manufacturers supplied the tape and emitters separately. The emitters were inserted to the PVC tube from outside manually at a spacing of 0.3 m (12 inch). The tested flow rate at different pressures and calculated parameters for Mister_on (MLD-1PC 25) are shown in Table 4-10. It was observed that the Mister_on had an emission rate range of 2.94E-07 $m^3$/s to 1.26E-06 $m^3$/s for a pressure range of 0.60 m to 34.65 m. The tested average emission rate for this product was 4.50 l/hr at 172.37 KPa (1.19 gph @ 25 psi), close to the manufacturer's published average flow rate of 3.79 l/hr (1.00 gph) at that pressure. The emission rate increased rapidly and uniformly up to a pressure of 11.78 m (17 psi) and then followed a concave increasing path up to 17.33 m (25 psi). After that a constant emission rate was observed up to a pressure head of 34.65 m (50 psi). The tested coefficient of variation of 4% was close to the manufacturer's coefficient of variation of 5 %.

**Table 4-10 Emitter characterization of Mister_PS (MLD-1PC 25)**

| Pressure (m) | $q_a$ ($m^3/s$) | $S_q$ ($m^3/s$) | UC (%) | $C_v$ | EU (%) | DU (%) | $C_{ve}$ |
|---|---|---|---|---|---|---|---|
| 0.60 | 2.94E-07 | 2.95E-08 | 92.10 | 0.10 | 81.02 | 87.47 | 0.01 |
| 1.20 | 3.94E-07 | 1.00E-08 | 97.92 | 0.03 | 94.77 | 96.67 | 0.01 |
| 1.80 | 4.78E-07 | 1.82E-08 | 96.76 | 0.04 | 91.30 | 95.52 | 0.01 |
| 2.40 | 5.50E-07 | 1.73E-08 | 97.48 | 0.03 | 91.58 | 96.17 | 0.01 |
| 3.60 | 6.66E-07 | 2.10E-08 | 97.51 | 0.03 | 91.89 | 96.16 | 0.01 |
| 5.54 | 8.40E-07 | 3.17E-08 | 97.05 | 0.04 | 92.74 | 95.22 | 0.01 |
| 6.93 | 9.40E-07 | 4.17E-08 | 96.37 | 0.04 | 87.41 | 94.55 | 0.01 |
| 8.32 | 9.95E-07 | 2.67E-08 | 97.74 | 0.03 | 92.81 | 96.54 | 0.01 |
| 9.90 | 1.09E-06 | 4.98E-08 | 96.02 | 0.05 | 90.86 | 94.20 | 0.01 |
| 11.78 | 1.15E-06 | 6.43E-08 | 95.43 | 0.06 | 85.47 | 93.43 | 0.01 |
| 13.86 | 1.17E-06 | 6.78E-08 | 95.20 | 0.06 | 83.01 | 92.83 | 0.02 |
| 15.94 | 1.20E-06 | 6.18E-08 | 95.66 | 0.05 | 90.88 | 93.03 | 0.01 |
| 17.33 | 1.26E-06 | 4.80E-08 | 96.79 | 0.04 | 93.36 | 95.78 | 0.01 |
| 34.65 | 1.26E-06 | 5.32E-08 | 96.62 | 0.04 | 90.51 | 94.46 | 0.01 |
| Average | | | 96.33 | 0.04 | 89.83 | 94.43 | 0.01 |

The flow rate vs. pressure head relationship for the whole pressure range is shown in Table 4-11 and the developed Q-H curve is shown in Figure 4-10.

**Table 4-11 Flow rate vs pressure head relationship of Mister_on (MLD-1PC 25)**

| Q-H | Total pressure range 0.60-34.65 m (0.87-50 psi) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Q = 4E\text{-}07^{0.4086}$ | | | | | | | | | | | | | |
| H (m) | 0.60 | 1.20 | 1.80 | 2.40 | 3.60 | 5.54 | 6.93 | 8.32 | 9.90 | 11.78 | 13.86 | 15.94 | 17.33 | 34.65 |
| Q ($m^3/s$) | 2.94 E-07 | 3.94 E-07 | 4.78 E-07 | 5.50 E-07 | 6.66 E-07 | 8.40 E-06 | 9.40 E-06 | 9.95 E-06 | 1.09 E-06 | 1.15 E06 | 1.17 E-06 | 1.20 E-06 | 1.26 E-06 | 1.26 E-06 |

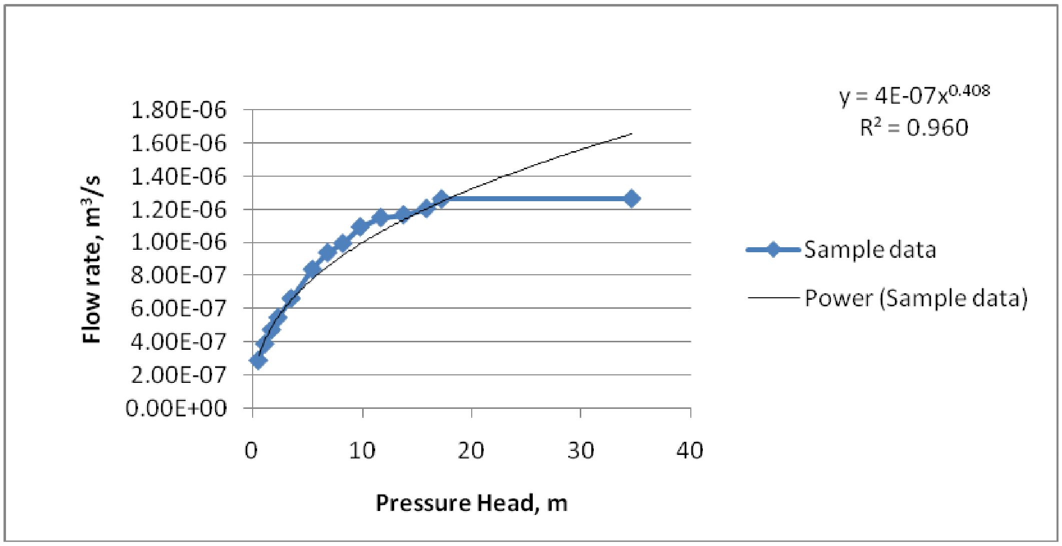


**Figure 4-10 Q-H Curve of Mister_PS MLD-1PC 25 (0.60-34.65 m/0.87-50 psi)**

For the total pressure range, the $R^2$ value was 0.9620 and the flow-pressure relationship was $Q = 4E - 07H^{0.4086}$. From the $R^2$ value it can be said that the developed flow rate vs. pressure head relationship described the emitter well. The emitter exponent value was 0.4086, so for the whole pressure range, the emitter did not behave like pressure compensating as for PC emitters this value should be less 0 to 0.1. It can be said that the emitter behaved like non-pressure compensating at the low pressure range. In order to accurately describe the characteristics of the tested emitter, the flow pressure curve was divided into two pressure ranges: (i) 0.60 – 11.78 m (0.87-17 psi) and (ii) 11.78-34.65 m (17-50 psi). The Q-H curve is shown in Figures 4-11 and 4-12, respectively.

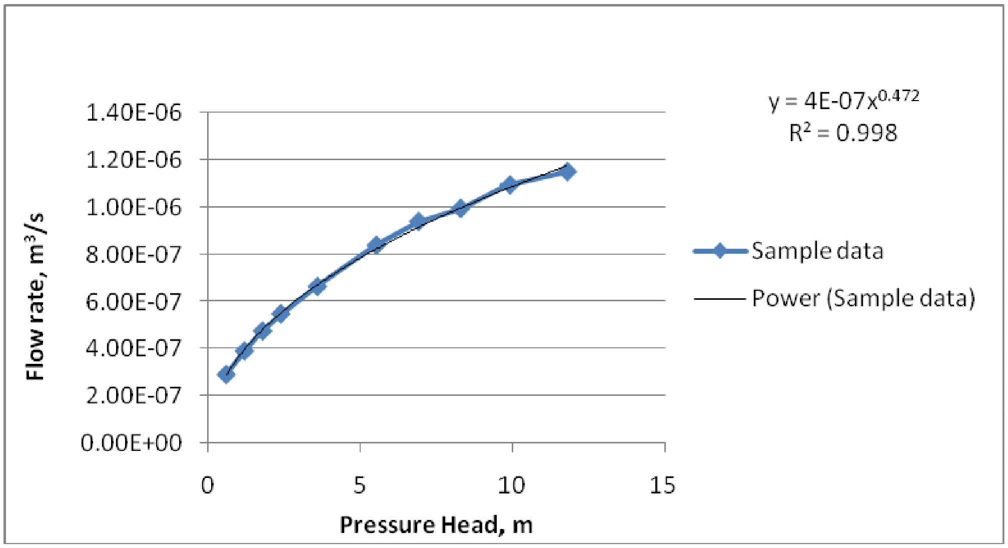


**Figure 4-11 Q-H Curve of Mister_PS MLD-1PC 25 (0.60-11.78 m/0.87-17 psi)**

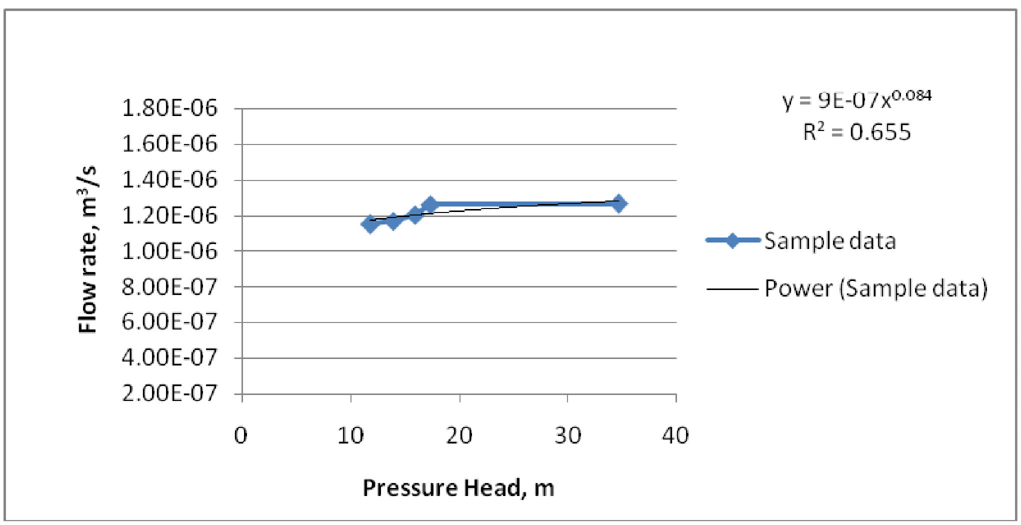


**Figure 4-12 Q-H Curve of Mister_PS MLD-1PC 25 (11.78-34.65 m/17-50 psi)**

At a low pressure range of 0.60 – 11.78 m (0.87-17 psi), the Q-H equation exhibited an $R^2$ value of 0.9987 (Figure 4-11). Thus, it can be inferred that this equation accurately described the flow pressure relationship. The emitter exponent value of

0.4727 confirmed that the emitter behaved like non-pressure compensating at a lower pressure range, although in the manufacturer's literature, it is a pressure compensating emitter. No manufacturer's data is available at low pressure ranges. At the higher operating pressure range of 11.78-34.65 m (17-50 psi), the emitter exponent value was 0.0846, which is less than 0.1 and approximately equals 0. So it can be said that the emitter behaved as fully PC emitter at the higher operating pressure range. At the normal operating pressure range, the $R^2$ value of 0.6558 fairly represented the flow pressure relationship (Figure 4-12). It is also observed that there was a slight reduction in the increasing tendency of flow rate from 11.78 (17 psi) up to 17.33 (25 psi) and then followed a constant emission rate up to a pressure head of to 34.65 m (50 psi).

*Netafim Techline (CV 560 050)*

The tested flow rate at different pressures and the calculated parameters for Netafim are shown in Table 4-12. It was observed that the Netafim Techline CV 560 050 had an emission rate range of 2.60E-07 $m^3/s$ to 2.90E-07 $m^3/s$ for a pressure range of 3.00 m to 34.65 m. This product had no emission at all, less than a pressure head of 3.00 m (10ft/23.1 psi). The tested average emission rate for this product was 1.02 L/hr at 206.84 KPa (0.27 gph @ 30 psi), very close to the manufacturer's published average flow rate of 0.984 L/hr (0.26 gph) at that pressure. The emission rate increased slightly at a pressure of 3.00 m (23.10 psi) to 5.54 m (8 psi) and then followed a relatively constant emission rate up to a pressure head of 34.65 m (50 psi). The tested coefficient of variation was 2%, which was lower than the manufacturer's published value of 5%.

**Table 4-12 Emitter characterization of Netafim Techline CV 560 050**

| Pressure (m) | $q_a$ ($m^3$/s) | $S_q$ ($m^3$/s) | UC (%) | $C_v$ | EU (%) | DU (%) | $C_{ve}$ |
|---|---|---|---|---|---|---|---|
| 3.00 | 2.60E-07 | 1.08E-08 | 96.77 | 0.04 | 90.78 | 94.80 | 0.00 |
| 3.60 | 2.80E-07 | 5.17E-09 | 98.50 | 0.02 | 95.72 | 97.68 | 0.00 |
| 5.54 | 2.86E-07 | 5.50E-09 | 98.47 | 0.02 | 94.62 | 97.37 | 0.01 |
| 13.86 | 2.87E-07 | 6.17E-09 | 98.27 | 0.02 | 94.46 | 97.12 | 0.01 |
| 20.79 | 2.85E-07 | 7.00E-09 | 98.12 | 0.02 | 93.00 | 96.65 | 0.01 |
| 34.65 | 2.90E-07 | 9.50E-09 | 97.36 | 0.03 | 91.59 | 95.54 | 0.01 |
| Average | | | 97.92 | 0.02 | 93.36 | 96.53 | 0.0066 |

The flow rate vs. pressure head relationship for the whole pressure range is shown in Table 4-13 and the developed Q-H curve is shown in Figure 4-13.

**Table 4-13 Flow rate vs. pressure head relationship of Netafim Techline CV 560 050**

| Q-H | Total pressure range 0.60-34.65 m (0.87-50 psi) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Q= 3E\text{-}07^{0.029}$ | | | | | | | | | | | | | |
| H (m) | 0.60 | 1.20 | 1.80 | 2.40 | 3.60 | 5.54 | 6.93 | 8.32 | 9.90 | 11.78 | 13.86 | 15.94 | 17.33 | 34.65 |
| Q ($m^3$/s) | 2.94 E-07 | 3.94 E-07 | 4.78 E-07 | 5.50 E-07 | 6.66 E-07 | 8.40 E-06 | 9.40 E-06 | 9.95 E-06 | 1.09 E-06 | 1.15 E06 | 1.17 E-06 | 1.20 E-06 | 1.26 E-06 | 1.26 E-06 |

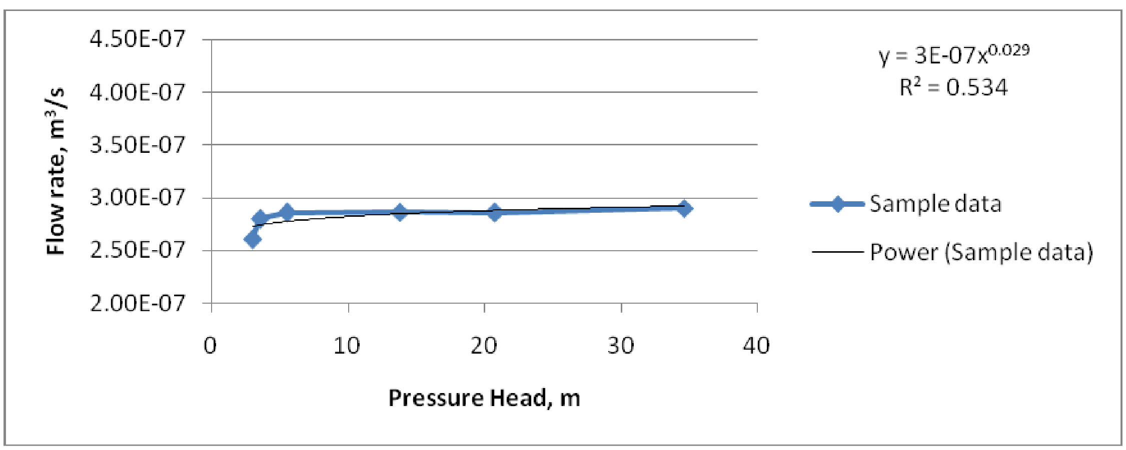


**Figure 4-13 Q-H Curve of Netafim Techline CV 560 050 (3.00-34.65 m/23.10-50 psi)**

For the total pressure range, the $R^2$ value was 0.5341 and the flow pressure relationship was $Q = 3E - 07H^{0.029}$. From the $R^2$ value, it can be said that the developed flow rate vs. pressure head relationship did not accurately describe the emitters. The emitter exponent value was 0.029, so for the whole pressure range, the emitter behaved like pressure compensating, as for PC emitters this value should be between 0 to 0.1. In order to describe the characteristics of the tested emitter more precisely, the flow pressure curve was divided into two pressure ranges, (i) 3.00 – 5.54 m (4.33-8 psi) and (ii) 5.54-34.65 m (8-50 psi). The Q-H curves are shown in Figures 4-14 and 4-15, respectively.

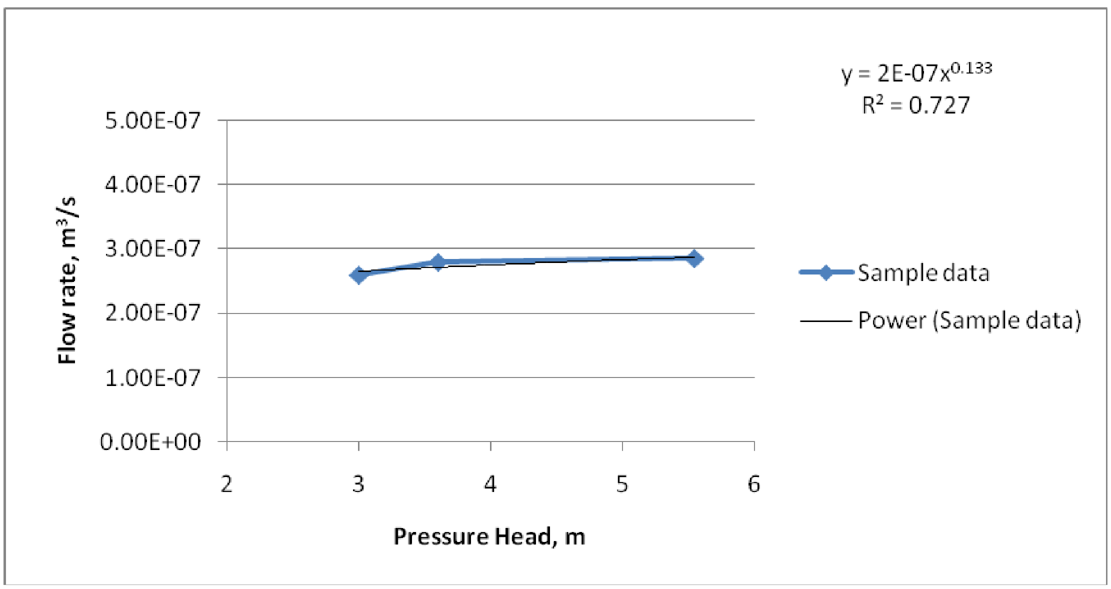


**Figure 4-14 Q-H Curve of Netafim Techline CV 560 050 (3.00-5.54 m/4.33-8 psi)**

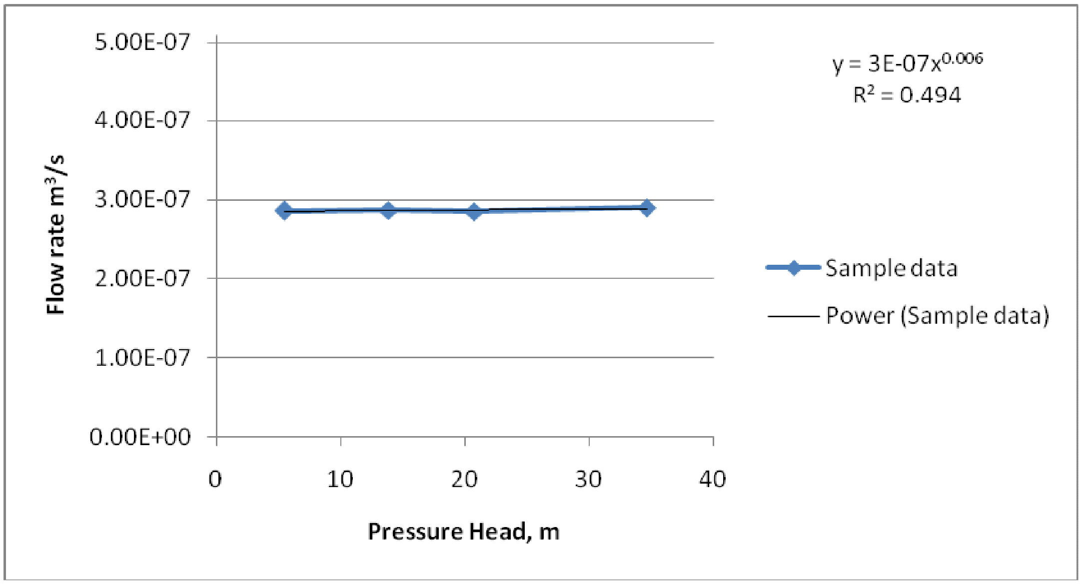


**Figure 4-15 Q-H Curve of Netafim Techline CV 560 050 (5.54-34.65 m/8-50 psi)**

At the low pressure range of 3.00 – 5.54 m (4.33-8 psi), the Q-H equation exhibited an $R^2$ value of 0.7277 (Figure 4-14). Thus, it can be said that this equation described the flow pressure relationship fairly well. The emitter exponent value was 0.1331 and the emitter behaved like pressure compensating at the lower pressure range. No manufacturer's data is available at low pressure ranges. At the higher operating pressure range of 5.54-34.65 m (8-50 psi), the emitter exponent value was 0.0067 which is less than 0.1 and approximately equals 0. So, it can be said that the emitter behaved as a fully PC emitter at the suggested operating pressure range. At the normal operating pressure range, the $R^2$ value of 0.494 fairly represented the flow pressure relationship (Figure 4-15).

***Summary of Experimental Results***

According to the exponent value derived from flow rate vs. pressure relationship, all the tested emitters were classified as PC or NPC at all pressure ranges and are presented in Table 4-14.

**Table 4-14 Classification of emitters on the basis of exponent values under different pressure range**

| | Classification factors and results | Toro_ Drip_In PC(PCS 1810-18-100) | T-Tape (TT15-1245-0100) | Mister_LS (MLD-HDT 100) | Mister_PS (MLD-1PC 25) | Netafim Techline CV560 050 |
|---|---|---|---|---|---|---|
| Low pressure range | Exponent x | 0.4918 | 0.6087 | 0.4378 | 0.4727 | 0.1331 |
| | Classification | NPC | NPC | NPC | NPC | Partially PC |
| Normal pressure range | Exponent x | 0.032 | 0.455 | 0.018 | 0.0846 | 0.0067 |
| | Classification | PC | NPC | PC | PC | PC |
| Whole pressure range | Exponent x | 0.2999 | 0.5366 | 0.316 | 0.4086 | 0.029 |
| | Classification | Partially PC | NPC | Partially PC | NPC | PC |

From the classification, the only NPC product T-Tape worked as NPC at all pressure ranges. But all of the four PC products behaved as fully PC emitters at the normal range. At the lower pressure range, all except Netafim acted as NPC, and Netafim acted as partially PC. Hence, for lower pressures the PC emitters were no more defined as PC; they acted like partially or non- pressure compensating emitters.

***Comparison of Measured Emission Rate with the Calculated Emission Rate***

The emission rates for 60 emitters from each of the five products were calculated using the methodology described in chapter II. Then the differences between the calculated and measured value were determined to assess the experimental error.

The calculations for Mister_LS (MLD-HDT 100) brand have been performed below. A schematic diagram of the positions of emitters in the laterals is shown in Figure 4-16.

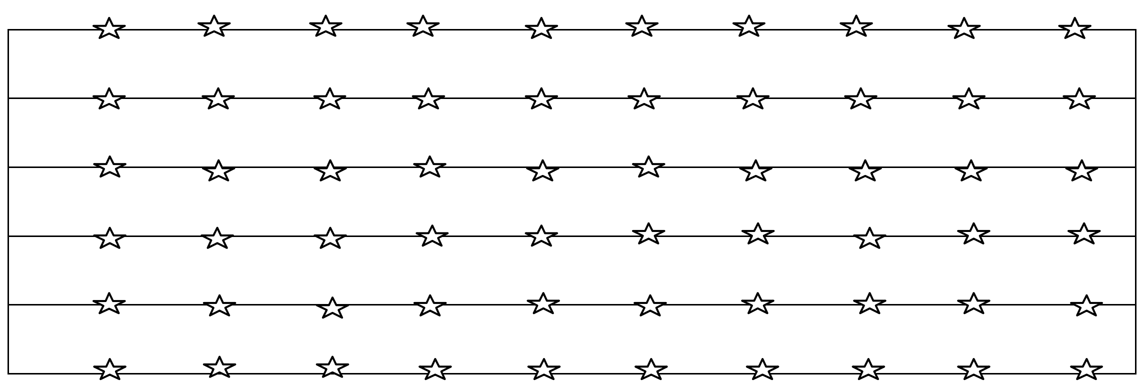

**Figure 4-16 Schematic diagram of position of emitters at laterals of Mister_LS product**

A. Head loss due to friction:

Initial Head is 0.60 m (2ft/0.87 psi)

Inside diameter of lateral = 0.0127 m (0.50 inch)

Number of emitters = 10

Average discharge per emitter at 0.60 m = 3.87E-07 $m^3/s$ (Table 4-8)

Q= Lateral Flow Rate

= 3.87E-07 × 10 $m^3/s$ (For 10 emitters) = 0.00000387 $m^3/s$

A= $\pi \times r^2 = \pi \times (0.0127/2)^2$ $m^2$ = 0.000127 $m^2$

V= 0.00000387 /0.0001267 m/sec = 0.030566 m/sec

$R_e = v \times D / \upsilon$ = 0.030566 × 0.0127 /1 ×$10^{-6}$ ft/sec × ft ×sec/$ft^2$ = 388

For Laminar flow, where, $R_e < 2000$,

Friction factor f = 64/$R_e$ = 64/388 = 0.16487

Head loss due to friction at the1st emitter of the1st lateral, $h_1 = f\,(L/D) \times (v^2/2g)$ m

= (0.16487×0.305/0.0127 × $0.030566^2$/2×9.80)= 0.000189 m

B. Head loss due to insertions of emitter:

$$\alpha = 0.056 \times \left[ (D_i / D_g)^{17.83} - 1 \right]$$

= 0.056* $(12.7/10.7)^{17.83}$-1) = 1.132764

where, α = coefficient, $D_i$ = Internal Diameter of pipe = 12.7 mm,$D_g$ = Internal diameter due to emitter = 10.7 mm

$$\lambda = \alpha \times v^2 / 2g$$

= 1.132764 × $0.030566^2$/2*9.80 = 0.00005 m

where, $\lambda$ = head loss due to insertion of emitter, m; v = velocity of water = 0.030566 m/s, g = Acceleration due to gravity = 9.80 $m/s^2$

Total head loss at the 1st emitter = (0.000189 + 0.00005) = 0.000243 m

Head at the1st emitter, $H_1$ = (0.60-0.000243) = 0.599757 m

Discharge at the1st emitter, $Q_1 = CH_1^x$

= 0.0000005 × $0.599757^{0.43}$ = 0.0000004 $m^3/s$ = 23.98385 ml/min

Discharges at other 9 emitters for the 1st lateral and for other 50 emitters at 5 other laterals were calculated using Microsoft Excel. Accordingly, the emission for all 60 emitters for the pressure of 1.20 m (4 ft), 1.80 m (6 ft ) and 2.40 m (8 ft) were calculated and compared with measured value. The results are shown in Table 4-15.

**Table 4-15 Comparison of measured vs. calculated emission rate for Mister_LS**

| Pressure (m) | Measured emission rate (ml/min) | Calculated emission rate (ml/min) | Differences (%) |
|---|---|---|---|
| 0.60 (2 ft) | 23.21 | 23.96 | -3.23 |
| 1.20 (4 ft) | 31.41 | 32.46 | -3.34 |
| 1.80 (6 ft) | 37.70 | 38.78 | -2.86 |
| 2.40 (8 ft) | 40.00 | 43.99 | -9.97 |

The discharges for Mister_PS, Toro and T-Tape brand were calculated using the same procedure using Microsoft Excel. The results are shown in Tables 4-16, 4-17 and 4-18, respectively.

**Table 4-16 Comparison of measured vs. calculated emission rate for Mister_PS**

| Pressure (m) | Measured emission rate (ml/min) | Calculated emission rate (ml/min) | Differences (%) |
|---|---|---|---|
| 0.60 (2 ft) | 17.64 | 18.62 | -6.56 |
| 1.20 (4 ft) | 23.61 | 25.87 | -9.65 |
| 1.80 (6 ft) | 28.66 | 31.34 | -9.50 |
| 2.40 (8 ft) | 33.02 | 35.91 | -8.86 |

**Table 4-17 Comparison of measured vs. calculated emission rate for Toro**

| Pressure (m) | Measured emission rate (ml/min) | Calculated emission rate (ml/min) | Differences (%) |
|---|---|---|---|
| 0.60 (2 ft) | 20.86 | 23.33 | -13.22 |
| 1.20 (4 ft) | 30.10 | 32.81 | -9.97 |
| 1.80 (6 ft) | 34.99 | 40.05 | -15.49 |
| 2.40 (8 ft) | 42.75 | 46.13 | -8.50 |

**Table 4-18 Comparison of measured vs. calculated emission rate for T_Tape**

| Pressure (m) | Measured emission rate (ml/min) | Calculated Emission rate (ml/min) | Differences (%) |
|---|---|---|---|
| 0.60 (2 ft) | 4.68 | 4.39 | 5.31 |
| 1.20 (4 ft) | 6.46 | 6.70 | -4.59 |
| 1.80 (6 ft) | 9.16 | 8.58 | 6.07 |
| 2.40 (8 ft) | 10.91 | 10.22 | 6.11 |

Among all products, Mister_PS showed the lowest differences between calculated vs. measured data, whereas; in case of Toro, the differences were highest. Except for 0.60 m and 1.80 m of pressure head for Toro, the differences were within 10%, which can be treated as acceptable range stating calculation methodology was fair.

***Computing Distribution Uniformity***

The distribution uniformity (DU) of water was computed along a lateral with 0%, 1 %, 2%, 3 % down slope for four products under the low pressure range of 0.60 m (2 ft), 1.20 m (4 ft), 1.80 m (6 ft) and 2.40 m (8 ft) of pressure head. DU for Netafim product could not be computed as the product had no emission under low pressure. First, the emission from each emitter was calculated for a particular length of lateral using the methodology stated in Chapter II. Then the average flow was determined for all emitters for that particular length. After that, the average flow of the lowest quartile was determined and the distribution uniformity was computed for a particular product for various lateral lengths using equation 2.19.

The calculations for Mister_LS product are shown below.

The distribution uniformity with 0% slope was calculated as follows.

A. Head loss due to friction:

Initial Head is 0.60 m (2ft/0.87 psi),

Lateral length = 15.25 m (50 ft)

Emitter spacing = 0.305 m (1ft)

Number of emitters = 49

Inside diameter of lateral = 0.0127 m (0.50 inch)

Average discharge per emitter at pressure head of 0.60 m = 3.87E-07 $m^3/s$

Q= lateral flow rate

= 3.87E-07 × 49 $m^3/s$ (For 49 emitters) = 0.000018963 $m^3/s$

$A = \pi \times r^2$

$= \pi \times (0.0127/2)^2 \ m^2 = 0.000127 \ m^2$

V= 0.000018963 /0.000126613 m/sec = 0.149771765 m/sec

$R_e = v \times D / \upsilon$

V= fluid velocity = 0.149771765 m/sec

D = internal pipe diameter = 0.0127 m

ν = kinematic viscosity = $1 \times 10^{-6}$ $m^2$/sec, at 20 $^0$C

$R_e = 0.149771765 \times 0.0127 / 1 \times 10^{-6}$ ft/sec × ft ×sec/ft$^2$ = 1902

For Laminar flow, where, $R_e < 2000$,

Friction factor $f = 64/R_e = 64/1902 = 0.033647$

Head loss due to friction at the 1st emitter of 1st lateral,

$$h = f(L/D) \times (v^2/2g)$$

$$= (0.033647 \times 0.305/0.0127 \times 0.149771765^2/2\times 9.80) \text{ m} = 0.001332 \text{ m}$$

B.Head loss due to insertions of emitter:

$$\alpha = 0.056 \times [(D_i/D_g)^{17.83} - 1]$$

$$= 0.056^* (12.7/10.7)^{17.83} - 1)$$

$$= 1.132764$$

$$\lambda = \alpha \times v^2/2g$$

$$= 0.549 * 0.149771765^2 /2*9.80 = 0.001296 \text{ m}$$

Total Head loss at the 1st emitter = (0.001332 + 0.001296) = 0.002628 m

Head at the 1st emitter, $H_1$ = (0.60-0.002628) = 0.597372 m

Discharge at the 1st emitter, $Q_1 = CH^x = 0.0000005 \times 0.597372^{0.4378}$

= 3.99034E-07 m$^3$/s

Discharge at other 48 emitters for the 15.25 m (50 ft) lateral has been calculated using Microsoft Excel.

Average discharge for all emitters = 3.79781E-07 m$^3$/s

Average lowest quartile discharge = 3.64445E-07 m$^3$/s

DU = 100 × (3.64445E-07/ 3.79781E-07) = 95.96 %

Accordingly, DU for various lengths of lateral at pressure heads of 0.60 m (2ft), 1.20 m (4 ft), 1.80 m (6 ft) and 2.40 m (8 ft) were calculated.

The distribution uniformity with 1% slope was calculated as follows.

Head gained at the1st emitter by down slope = 0.01 × 0.035 m = 0.00305 m

$H_1$ = (0.60 - 0.002628 + 0.00305) = 0.600422 m

$Q_1 = CH^{0.4378}$

$= 0.0000005 \times (0.600422)^{0.4378}$

$= 0.0000004\ m^3/s$

Accordingly, discharges at other 48 emitters were calculated using Microsoft Excel and DU was determined.

Average discharge for all emitters = 4.03E-07 $m^3/s$

Average lowest quartile discharge = 4.01E-07 $m^3/s$

DU = 100 × (4.01E-07/ 4.03E-07) = 99.44 %

DU for 1 %, 2 % and 3% slopes at various lengths of laterals for various pressure heads of 0.60 m (2ft),1.20 m (4 ft), 1.80 m (6 ft ) and 2.40 m (8 ft) were calculated in Microsoft Excel and are summarized in Table 4-19.

**Table 4-19 Distribution uniformity of Mister_LS (MLD-HDT-100) at lower pressure range**

| Pressure (m) | Lateral Length (m) | Distribution Uniformity (%) at slope | | | |
|---|---|---|---|---|---|
| | | 0% | 1% | 2% | 3% |
| 0.60 (2 ft) | 15.25 (50 ft) | 95.96 | 99.44 | 95.42 | 92.90 |
| | 24.40 (80 ft) | 69.84 | --- | --- | --- |
| | 26 (85 ft) | 64.51 | --- | --- | --- |
| | 27.35 (90 ft) | --- | 78.07 | --- | --- |
| | 28.36 (93 ft) | --- | 71.36 | --- | --- |
| | 30.50 (100 ft) | --- | --- | 84.18 | --- |
| | 32.33 (106 ft) | --- | --- | 70.44 | --- |
| | 35.00 (115 ft) | --- | --- | --- | 80.16 |
| | 35.99 (118 ft) | --- | --- | --- | 71.31 |
| 1.20 (4 ft) | 15.25 (50 ft) | 96.50 | 98.89 | 99.03 | 97.19 |
| | 24.40 (80 ft) | 77.95 | --- | 92.93 | --- |
| | 25.01 (82 ft) | 71.07 | --- | --- | --- |
| | 26 (85 ft) | --- | 80.40 | --- | --- |
| | 27.45 (90 ft) | --- | 72.53 | --- | --- |
| | 29.89 (98 ft) | --- | --- | 70.16 | --- |
| | 30.50 (100 ft) | --- | --- | --- | 81.40 |
| | 32.02 (105 ft) | --- | --- | --- | 70.13 |
| 1.80 (6 ft) | 15.25 (50 ft) | 96.74 | 98.35 | 99.81 | 98.86 |
| | 24.40 (80 ft) | 77.05 | 83.69 | 88.63 | --- |
| | 25.32 (83 ft) | 70.76 | --- | --- | --- |
| | 26 (85 ft) | --- | 76.62 | --- | --- |
| | 26.84 (88 ft) | --- | 70.39 | --- | --- |
| | 29.5 (90 ft) | --- | --- | 75.72 | 83.78 |
| | 28.36 (93 ft) | --- | --- | 69.27 | --- |
| | 29.58 m ( 97 ft) | --- | --- | --- | 71.05 |
| 2.40 (8 ft) | 15.25 (50 ft) | 97.31 | 98.49 | 99.36 | 99.60 |
| | 24.40 (80 ft) | --- | 89.04 | --- | --- |
| | 26 (85 ft) | 70.97 | --- | --- | --- |
| | 29.5 (90 ft) | 66.40 | --- | 81.47 | 86.20 |
| | 28.36 (93 ft) | --- | 68.99 | | --- |
| | 29.58 (97 ft) | --- | --- | 68.79 | --- |
| | 30.50 (100 ft) | --- | --- | --- | 70.82 |

Plots of lateral length vs. distribution uniformity for 0%, 1%, 2% and 3 % and at different pressure heads are shown in Figures 4-17, 4-18, 4-19 and 4-20, respectively.

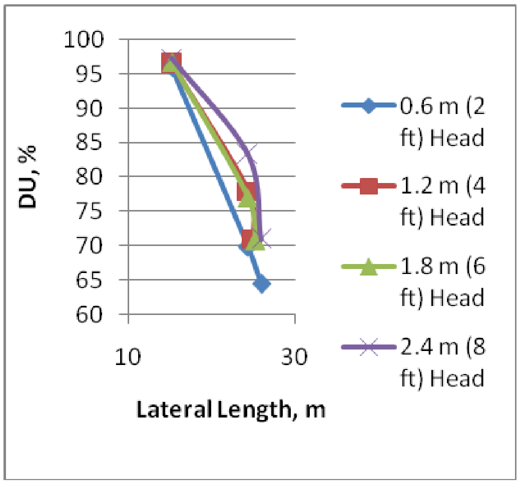


**Figure 4-17 Distribution uniformity vs. lateral length for 0% slope (Mister_LS)**

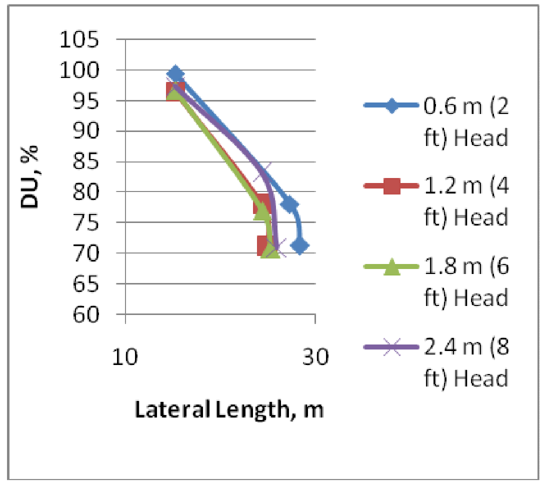


**Figure 4-18 Distribution uniformity vs. lateral length for 1% slope (Mister_LS)**

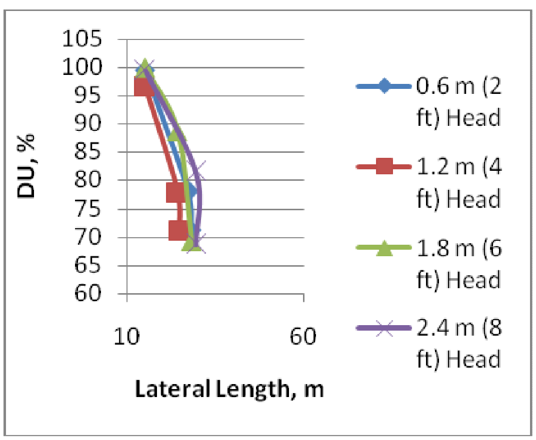


**Figure 4-19 Distribution uniformity vs. lateral length for 2% slope (Mister_LS)**

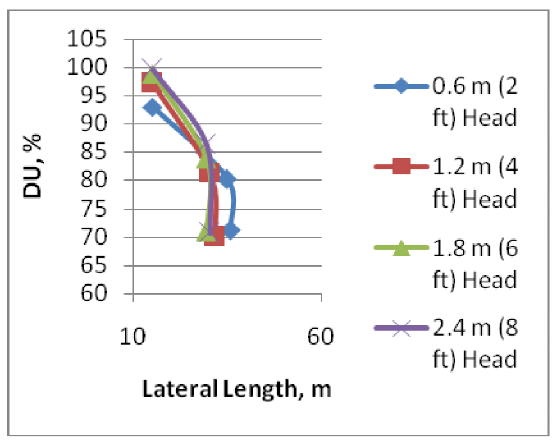


**Figure 4-20 Distribution uniformity vs. lateral length for 3% slope (Mister_LS)**

The distribution uniformities of Mister_PS, Toro and T-Tape brand were calculated by following the same procedure and the results are summarized in Tables 4-20, 4-21 and 4-22, respectively.

**Table 4-20 Distribution uniformity of Mister_PS (MLD-1PC25) at lower pressure range**

| Pressure (m) | Lateral Length (m) | Distribution Uniformity (%) at Slope | | | |
|---|---|---|---|---|---|
| | | 0% | 1% | 2% | 3% |
| 0.60 (2 ft) | 15.25 (50 ft) | 93.32 | 98.89 | 96.89 | 93.47 |
| | 20.74 (68 ft) | 71.58 | --- | --- | --- |
| | 21.35 (70 ft) | 64.84 | 88.55 | --- | --- |
| | 23.79 (78 ft) | --- | 69.33 | --- | --- |
| | 24.40 (80 ft) | --- | --- | 86.53 | 97.53 |
| | 26.53 (87 ft) | --- | --- | 69.68 | --- |
| | 30.50 (100 ft) | --- | --- | --- | 73.48 |
| 1.20 (4 ft) | 15.25 (50 ft) | 96.88 | 99.37 | 98.46 | 96.52 |
| | 24.40 (80 ft) | --- | 88.06 | 88.74 | 94.45 |
| | 26 (85 ft) | 71.00 | --- | --- | --- |
| | 28.36 (93 ft) | --- | 69.46 | --- | --- |
| | 30.50 (100 ft) | --- | --- | 70.24 | --- |
| | 32.64 (107 ft) | --- | --- | --- | 70.74 |
| 1.80 (6 ft) | 15.25 (50 ft) | 96.78 | 98.72 | 99.75 | 97.83 |
| | 18.30 (60 ft) | 81.07 | --- | --- | --- |
| | 22.87 (75 ft) | 70.47 | --- | --- | --- |
| | 18.30 (80 ft) | --- | --- | 90.78 | 94.40 |
| | 26 (85 ft) | --- | 81.27 | --- | --- |
| | 29.5 (90 ft) | --- | 72.60 | --- | --- |
| | 28.79 (95 ft) | --- | --- | 72.53 | --- |
| | 30.50 m ( 100 ft) | --- | --- | --- | 72.83 |
| 2.40 (8 ft) | 15.25 (50 ft) | 96.82 | 98.11 | 99.32 | 99.56 |
| | 24.40 (80 ft) | 80.92 | 85.30 | --- | --- |
| | 26 (85 ft) | 69.24 | --- | --- | --- |
| | 27.45 (90 ft) | --- | 70.57 | 77.94 | 83.47 |
| | 28.67 (94 ft) | --- | --- | 69.98 | --- |
| | 29.89 (98 ft) | --- | --- | --- | 69.26 |
| | 48.80 (160 ft) | --- | --- | --- | --- |

**Table 4-21 Distribution uniformity of Toro (PCS 1810-18-100) at lower pressure range**

| Pressure (m) | Lateral Length (m) | Distribution Uniformity (%) at slope | | | |
|---|---|---|---|---|---|
| | | 0% | 1% | 2% | 3% |
| 0.60 (2 ft) | 15.25 (50 ft) | 99.24 | 96.41 | 92.88 | 93.87 |
| | 45.75 (150ft) | 74.85 | 96.85 | 91.21 | 98.35 |
| | 48.80 (160 ft) | 71.53 | --- | --- | --- |
| | 56.43 (185 ft) | --- | 71.66 | --- | --- |
| | 70.15 (230 ft) | --- | --- | 69.26 | --- |
| | 81.43 (267 ft) | --- | --- | --- | 72.06 |
| 1.20 (4 ft) | 15.25 (50 ft) | 97.69 | 98.38 | 96.34 | 97.05 |
| | 27.45 (90 ft) | 80.26 | --- | --- | |
| | 29.58 (97 ft) | 70.38 | --- | | |
| | 30.50 (100 ft) | --- | --- | 96.25 | --- |
| | 45.75 (150ft) | --- | 85.43 | --- | 82.60 |
| | 48.48 ( 160 ft) | --- | 69.54 | --- | --- |
| | 57.34 (188 ft) | --- | --- | 70.35 | --- |
| | 63.74 (209 ft) | --- | --- | --- | 69.94 |
| 1.80 (6 ft) | 15.25 (50 ft) | 99.43 | 99.02 | 97.05 | 98.04 |
| | 30.50 m ( 100 ft) | 94.81 | --- | --- | 98.71 |
| | 38.12 (125 ft) | --- | --- | --- | --- |
| | 45.75 (150ft) | 70.27 | 84.43 | 77.40 | --- |
| | 50.32 ( 165 ft) | --- | 71.69 | --- | --- |
| | 55.51 (182 ft) | --- | --- | 70.38 | --- |
| | 60.00 (197 ft) | --- | --- | --- | 71.20 |
| 2.40 (8 ft) | 15.25 (50 ft) | 99.40 | 99.43 | 98.32 | 98.96 |
| | 30.50 (100 ft) | 94.07 | --- | --- | 96.38 |
| | 44.22 (145 ft) | 71.62 | --- | --- | --- |
| | 45.75 (150ft) | --- | 77.31 | 86.15 | --- |
| | 47.27 (155 ft) | --- | 72.64 | --- | --- |
| | 51.24 (168 ft) | --- | --- | 69.31 | --- |
| | 54.29 (178 ft) | --- | --- | --- | 72.48 |

**Table 4-22 Distribution uniformity of T-Tape (TT1-1245-0100) at lower pressure range**

| Pressure (m) | Lateral Length (m) | Distribution Uniformity (%) at slope | | | |
|---|---|---|---|---|---|
| | | 0% | 1% | 2% | 3% |
| 0.60 (2 ft) | 15.25 (50 ft) | 99.81 | 95.02 | 90.83 | 87.40 |
| | 30.50 (100 ft) | --- | --- | 84.66 | --- |
| | 45.75 (150ft) | --- | --- | --- | 74.55 |
| | 91.50 (300 ft) | 92.11 | 81.20 | --- | --- |
| | 113.32 (365 ft) | 70.83 | --- | --- | --- |
| | 208.92 (685 ft) | --- | 71.61 | --- | --- |
| | 213.50 (700 ft) | --- | --- | 71.63 | --- |
| | 228.75 (700ft) | --- | --- | --- | 70.94 |
| 1.20 (4 ft) | 15.25 (50 ft) | 99.85 | 97.42 | 94.99 | 92.80 |
| | 30.50 (100 ft) | --- | --- | --- | --- |
| | 45.75 (150ft) | --- | --- | --- | --- |
| | 57.95 (200 ft) | --- | --- | --- | --- |
| | 70.15 (250 ft) | 94.00 | 92.23 | 83.88 | 78.15 |
| | 117.42 (385 ft) | 69.87 | --- | --- | --- |
| | 152.50 (500 ft) | --- | --- | 76.48 | --- |
| | 170.80 (560 ft) | --- | 70.79 | --- | --- |
| | 213.50 (700 ft) | --- | --- | 71.56 | |
| | 221 (725 ft) | --- | --- | --- | 68.62 |
| 1.80 (6 ft) | 15.25 (50 ft) | 99.92 | 98.27 | 96.56 | 94.97 |
| | 70.15 (250 ft) | 97.47 | 95.22 | --- | --- |
| | 91.50 (300 ft) | --- | --- | 90.03 | 83.74 |
| | 109.80 (360 ft) | 68.73 | --- | --- | --- |
| | 131.15 (430 ft) | --- | 72.35 | --- | --- |
| | 172.32 (565 ft) | --- | --- | 69.46 | --- |
| | 201.30 (660 ft) | --- | --- | --- | 70.23 |
| 2.40 (8 ft) | 15.25 (50 ft) | 99.89 | 98.70 | 97.39 | 96.14 |
| | 57.95 (200 ft) | --- | 97.87 | 93.12 | 89.23 |
| | 70.15 (250 ft) | 92.22 | --- | --- | --- |
| | 106.75 (350 ft) | 71.86 | --- | --- | --- |
| | 131.15 (430 ft) | --- | 71.05 | --- | --- |
| | 155.55 (510 ft) | --- | --- | 69.61 | --- |
| | 175.37 (575 ft) | --- | --- | --- | 75.66 |

Plots of lateral length vs. distribution uniformity for different pressure head for Mister_PS, Toro and T-Tape at 0%, 1%, 2% and 3 % are shown in Figures 4-21, 4-22, 4-23, 4-24, 4-25, 4-26, 4-27, 4-28, 4-29, 4-30, 4-31 and 4-32, respectively.

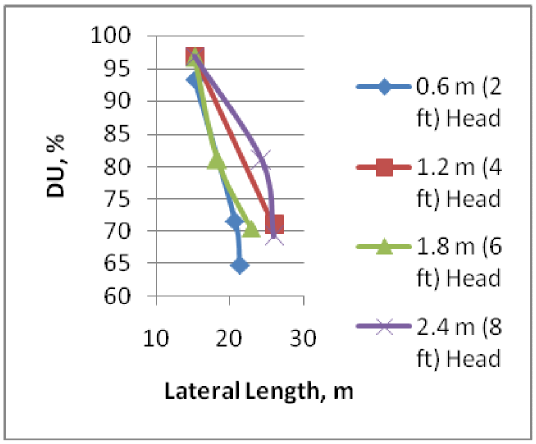


**Figure 4-21 Distribution uniformity vs. lateral length for 0% slope (Mister_PS)**

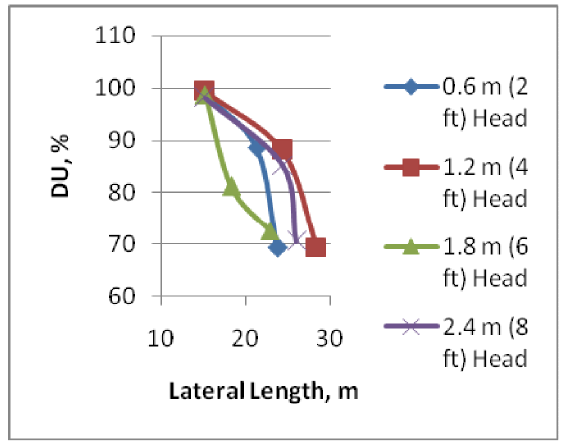


**Figure 4-22 Distribution uniformity vs. lateral length for 1% slope (Mister_PS)**

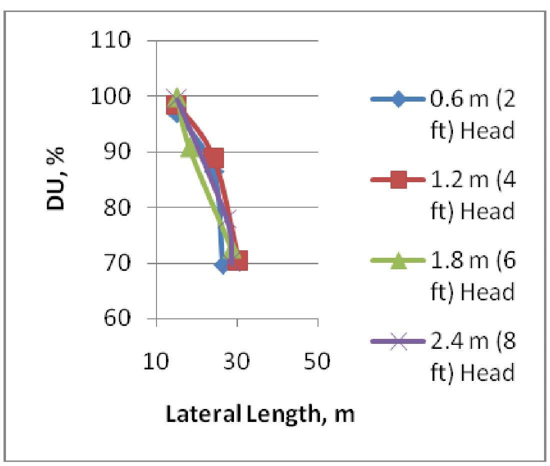


**Figure 4-23 Distribution uniformity vs. lateral length for 2% slope (Mister_PS)**

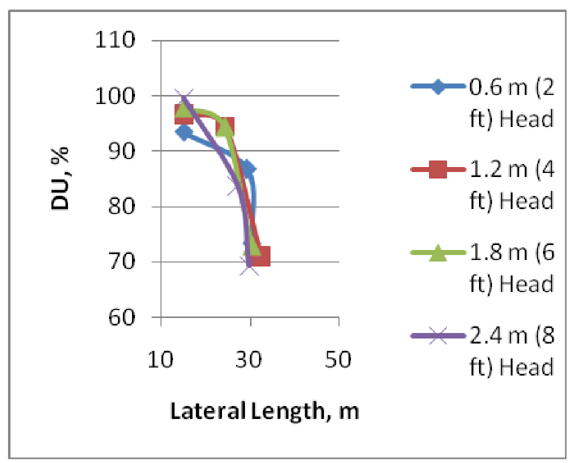


**Figure 4-24 Distribution uniformity vs. lateral length for 3% slope (Mister_PS)**

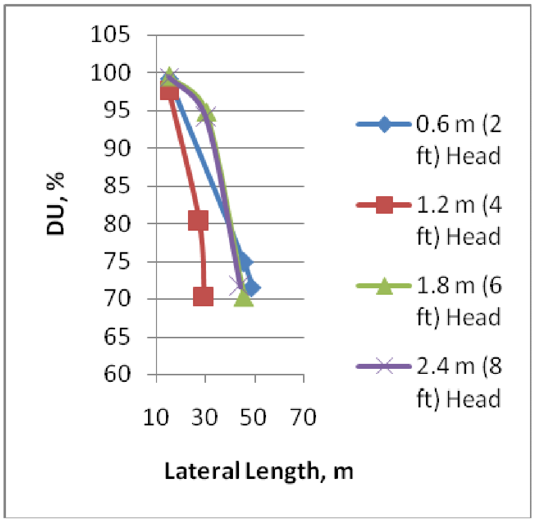


**Figure 4-25 Distribution uniformity vs. lateral length for 0% slope (Toro)**

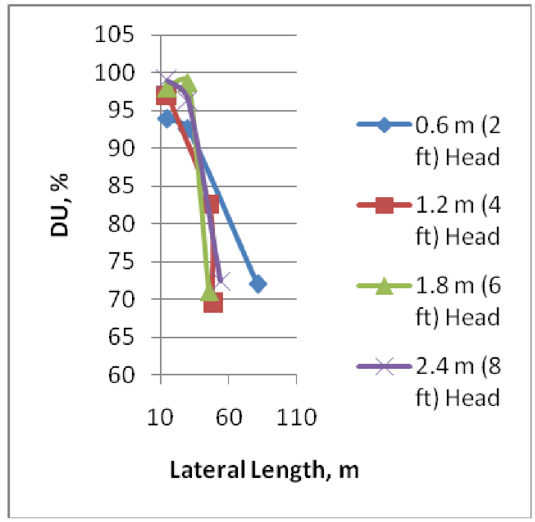


**Figure 4-26 Distribution uniformity vs. lateral length for 1% slope (Toro)**

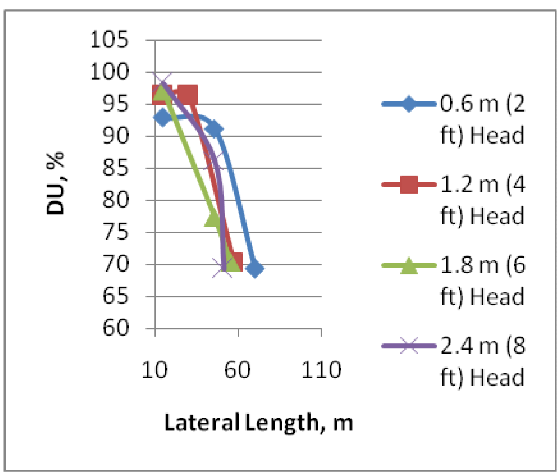


**Figure 4-27 Distribution uniformity vs. lateral length for 2% slope (Toro)**

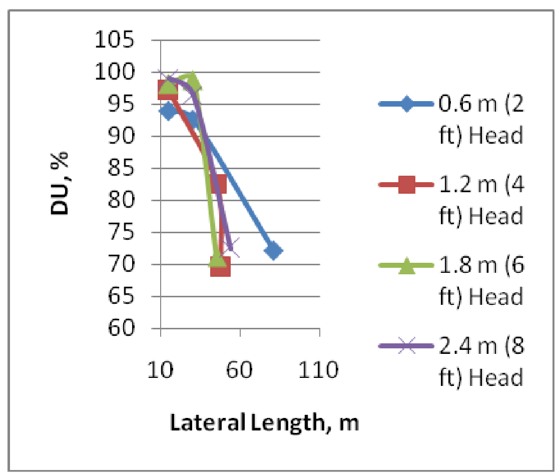


**Figure 4-28 Distribution uniformity vs. lateral length for 3% slope (Toro)**

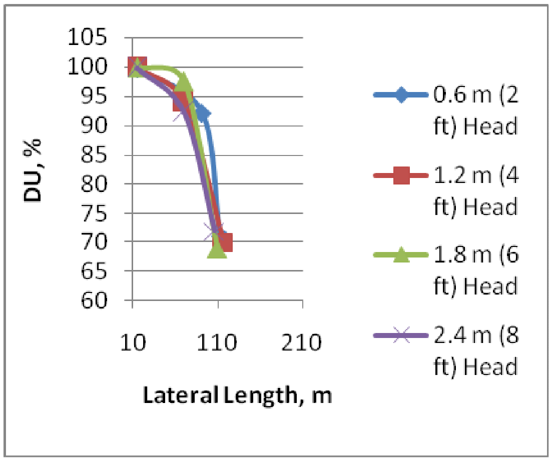


**Figure 4-29 Distribution uniformity vs. lateral length for 0% slope (T-Tape)**

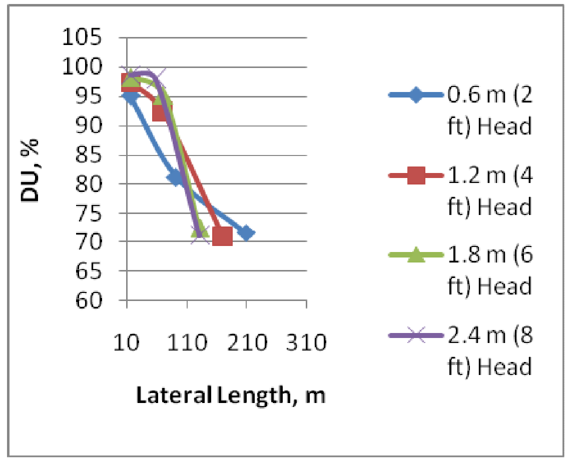


**Figure 4-30 Distribution uniformity vs. lateral length for 1% slope (T-Tape)**

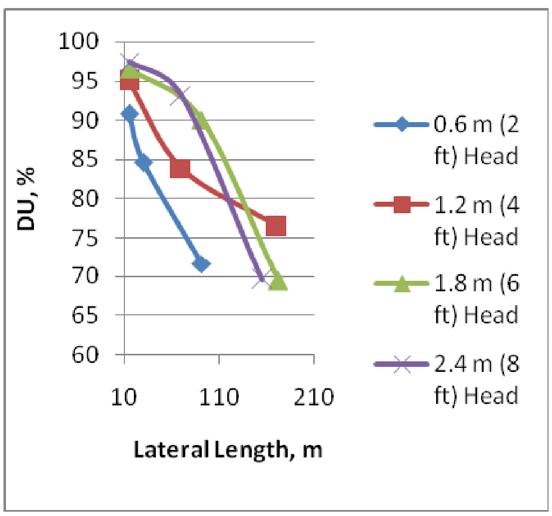


**Figure 4-31 Distribution uniformity vs. lateral length for 2% slope (T-Tape)**

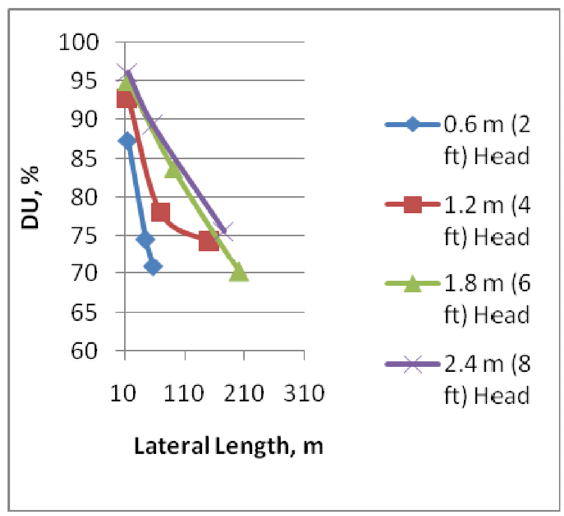


**Figure 4-32 Distribution uniformity vs. lateral length for 3% slope (T-Tape)**

***Summary of Lateral Length Obtained for DU of 70%***

For a particular product, it was observed that for a particular slope, the DU decreases as the lateral length increases and increases with the increase of land slopes. The maximum lateral length obtained for a distribution uniformity of about 70% for different products at different operating pressures are summarized in Table 4-23.

**Table 4-23 Maximum lateral length obtained for about 70% DU at different land slopes and at different operating pressures**

| Product | Pressure Head(m) | Maximum lateral length (m) at slope | | | |
|---|---|---|---|---|---|
| | | 0% | 1% | 2% | 3% |
| Mister-LS | 0.60 (2 ft) | 24.40 (80 ft) | 28.36 (93 ft) | 32.33 (106 ft) | 35.99 (118 ft) |
| | 1.20 (4 ft) | 25.01 (82 ft) | 27.45 (90 ft) | 29.89 (98 ft) | 32.02 (105 ft) |
| | 1.80 (6 ft) | 25.32 (83 ft) | 26.84 (88 ft) | 28.36 (93 ft) | 29.58 (97 ft) |
| | 2.40 (8 ft) | 26.00 (85 ft) | 28.36 (93 ft) | 29.58 (97 ft) | 30.50 (100 ft) |
| Mister-PS | 0.60 (2 ft) | 20.74 (68 ft) | 23.79 (78 ft) | 26.53 (87 ft) | 29.28 (96 ft) |
| | 1.20 (4 ft) | 25.92 (85 ft) | 28.36 (93 ft) | 30.50 (100 ft) | 32.64 (107 ft) |
| | 1.80 (6 ft) | 22.87 (75 ft) | 27.45 (90 ft) | 28.97 (95 ft) | 30.50 (100 ft) |
| | 2.40 (8 ft) | 26.53 (87 ft) | 27.45 (90 ft) | 28.67 (94 ft) | 29.89 (98 ft) |
| Toro | 0.60 (2 ft) | 48.80 (160 ft) | 56.43 (185 ft) | 70.15 (230 ft) | 81.43 (267 ft) |
| | 1.20 (4 ft) | 44.22 (145 ft) | 48.48 (160 ft) | 57.34 (188 ft) | 63.75 (209 ft) |
| | 1.80 (6 ft) | 45.75 (150 ft) | 50.32 (165 ft) | 55.51 (182 ft) | 60.00 (197 ft) |
| | 2.40 (8 ft) | 44.22 (145 ft) | 47.27 (155 ft) | 51.24 (168 ft) | 54.29 (178 ft) |
| T-Tape | 0.60 (2 ft) | 113.32 (365ft | 208.92 (685 ft) | 213.50 (700 ft) | 228.75 (750 ft) |
| | 1.20 (4 ft) | 117.42 (385 ft) | 170.80 (560 ft) | 213.50 (700 ft) | 221.00 (725 ft) |
| | 1.80 (6 ft) | 109.80 (360 ft) | 131.15 (430 ft) | 172.32 (565ft) | 201.30(660 ft) |
| | 2.40 (8 ft) | 106.75 (350 ft) | 131.15 (430 ft) | 155.55 (510ft) | 177.51 (582ft) |

Among all products, for 0% slope, Mister-PS showed a minimum lateral length of 20.74 m (68 ft) at the operating pressure of 0.60 m and T-Tape showed the maximum lateral length of 117.42 m (385 ft) at the operating pressure of 1.20 m. T-Tape showed the maximum lateral length at all slopes and at all operating pressures. The reason behind its best performance was its design criteria. Like the other products, the emitter was not inserted into the lateral. So, there was no pressure loss due to insertion of emitters, causing water to flow smoothly inside the lateral, which ultimately increased the lateral length for a particular range of distribution efficiency.

The maximum lateral lengths obtained for Mister_LS, Mister-PS, Toro and T-Tape products at different low pressure heads and at different slopes are shown in Figures 4-33, 4-34, 4-35 and 4-36, respectively.

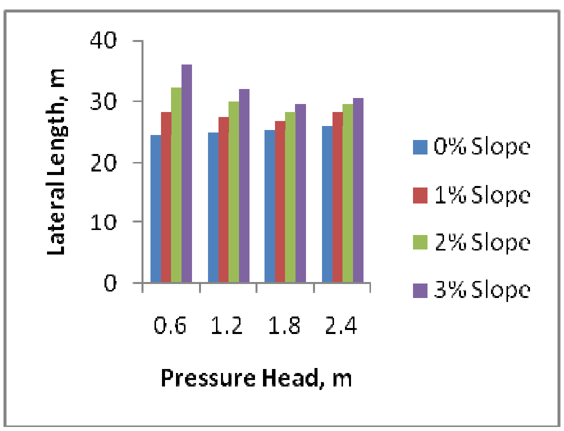


**Figure 4-33 Pressure head vs. lateral length for Mister_LS**

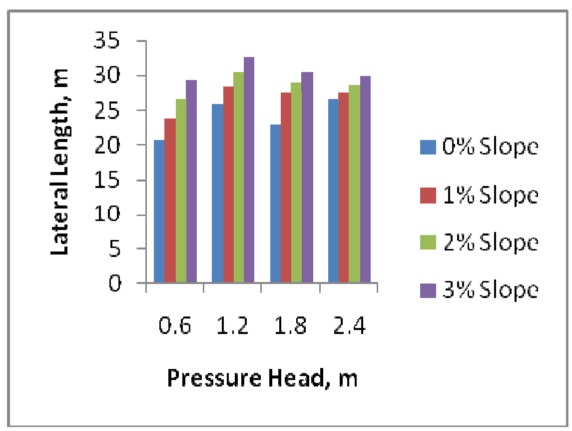


**Figure 4-34 Pressure head vs. lateral length for Mister_PS**

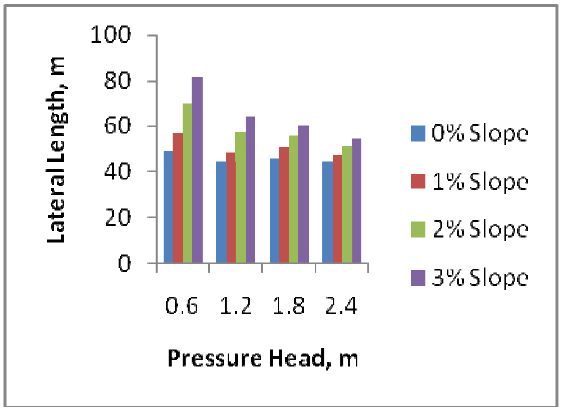


**Figure 4-35 Pressure head vs. lateral length for Toro**

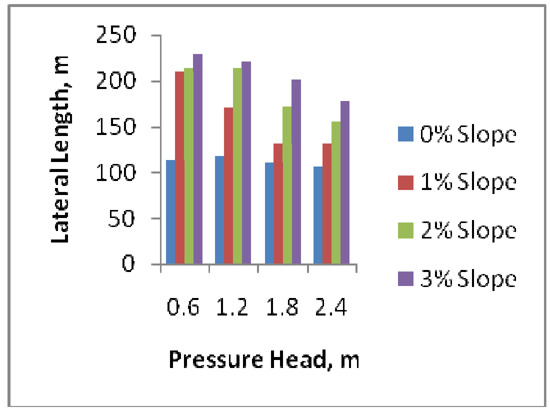


**Figure 4-36 Pressure head vs. lateral length for T-Tape**

***Sample Design and Cost Analysis for Low and High Pressure Drip Irrigation Systems***

Two low and one high pressure drip irrigation systems have been designed for a cotton field located at Rangerville, Cameron County, Texas, using the methodology described above. Geographical and other data have been collected from Texas AgriLife Research and Extension Center, Weslaco, Texas. The picture of the farm and its location on the Texas map are shown in Figures 4-37(a) and 4-37(b), respectively.

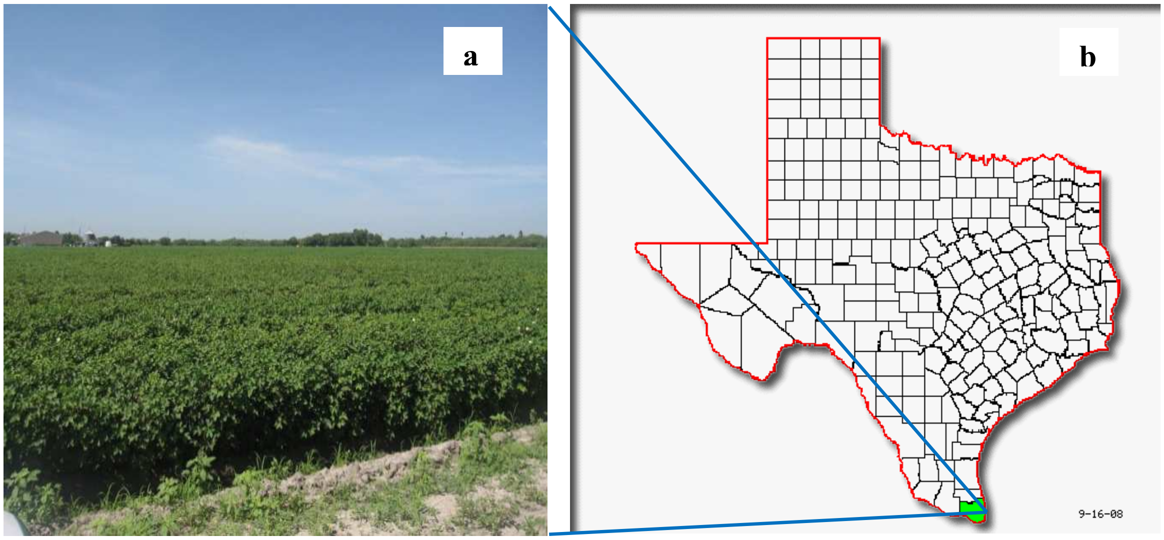


**Figure 4-37 (a) Picture of L. Simmons cotton field, Cameron County, Texas and (b) Location of L. Simmons cotton field in Texas Map**

*Location and description of the field*

# Name and location:

L. Simmons field, Rangerville, Cameron County, Texas. Coordinates: N26.08039 / W97.42847

# Length and width:

Field length 1,200 feet

Field width 700 feet

Area 840000 ft$^2$ (19.28 acres)

# Slope: 1% down slope

# Type of crop: Cotton on 40-inch rows

# Crop water requirement: Maximum daily amount of 0.32 inches

# Water source : Natural canal at the upstream side

*Design of low pressure system with one manifold*

Following the methodology described in chapter IV, the following calculations have been performed.

Drip product: T-Tape (TT15-1245-0100)

Lateral length with 55.48 % DU = 700 ft (for 1% of uniform land slope)

Operating pressure: 0.6 m (2ft).

Length of the field is 700 ft;

The width of the field is 1200 ft.

Row spacing is 40 inches = 3.33 ft

Number of laterals = (1200/3.33)-1 = 359

Total Length of laterals = 359×700 = 251300 ft

Number of emitters = 699×359 = 250941

Total flow = $7.8\times10^{-8}\times250941 = 0.19573398\ m^3/s$= 0.019573398 ×264×60 gpm

= 310 gpm

Crop water requirement = (0.32/12) ×840000 $ft^3$

= 2240 $ft^3$ = 2240× 7.5 gallon = 168,000 gallon

Time required for daily irrigation = (168000/310)/60 hr = 9 hr

The main will be connected at the middle of each lateral.

So the total flow 310 gpm will be divided into two equal flows of 310/2 = 155 gpm

Pipe diameter:

V = 5 ft/s (assumed)

$$Q = AV = 3.14 \times r^2 \times V$$
$$r^2 = \frac{Q}{3.14 \times V} = \frac{0.34}{3.14 \times 5} = 0.0217$$
$$r = 0.15 ft = 1.7659 inch$$
$$D = 3.53 inch$$

For 4 inch PVC pipe, friction loss per 100 ft for 155 gpm flow = 1.81 ft

(Table A.2. Training manual of CIDWT, 2007)

For 600 ft, friction loss = 1.81/100*600 = 10.86 ft.

Friction loss in main line = 5.69/100 × 20 = 1.13 ft (assume length of main line = 20 ft)

So, the inlet pressure required = 2.00 + 1.13 + 10.86 = 14 ft = 6 psi

Assuming water source is 5 ft below pump,

Total Head = 14 + 5 = 19 ft.

$$HP = \frac{Q \times H}{3960 \times E_f} = \frac{310 \times 19}{3960 \times 0.90} = 1.65$$

Energy cost = 1.65×0.7×9 = 10.41 Kwh

Electricity cost = 10.41×0.11 = $1.14

Using the excel sheet, hourly electricity cost = $0.3155 (@ $0.11/kwh)

Cost for 9 hrs (daily) = $ 2.83

For 8 days in a month the cost = $22.64

For 3 month, cost = 22.64×3 = $68.00

Cost for diesel (Using the excel sheet)

Hourly fuel cost for 310 gpm and 19 ft of head = $2.11 (@ $4.00 per gallon)

Cost for 9 hrs = 2.11×9= $18.99

For 8 days in a month, total cost = 18.99×8 = $152.00

For 3 month, cost = 152.00×3 = $456.00

The low head drip system has been designed based on the methodology described in Chapter II and the results found in Chapter IV. The total field has been considered as a single zone. A 3 HP pump will be used to supply water to the manifold. A gate valve will be fitted after the tank to control the water supply. Pressure regulators will also be fitted just after the pump. Pressure gauges will also be provided at the end of each manifold to observe the operating pressure in the system. Water will be supplied to the supply manifold by a 4 inch diameter PVC pipe. All the accessories are made of 4 inch diameter polyethylene (PE) pipes and PVC connectors. Laterals will be connected to the manifold by the connectors. The connectors will be directly fitted to the supply manifold at 3.33 ft spacing. The connector is fitted with removable end plugs for flushing any silt that may pass through the filter. At the end of each manifold, an air relief valve will be fitted to relieve the air from the laterals when the system is stopped. The drawing of the design is shown in Figure 4-38.

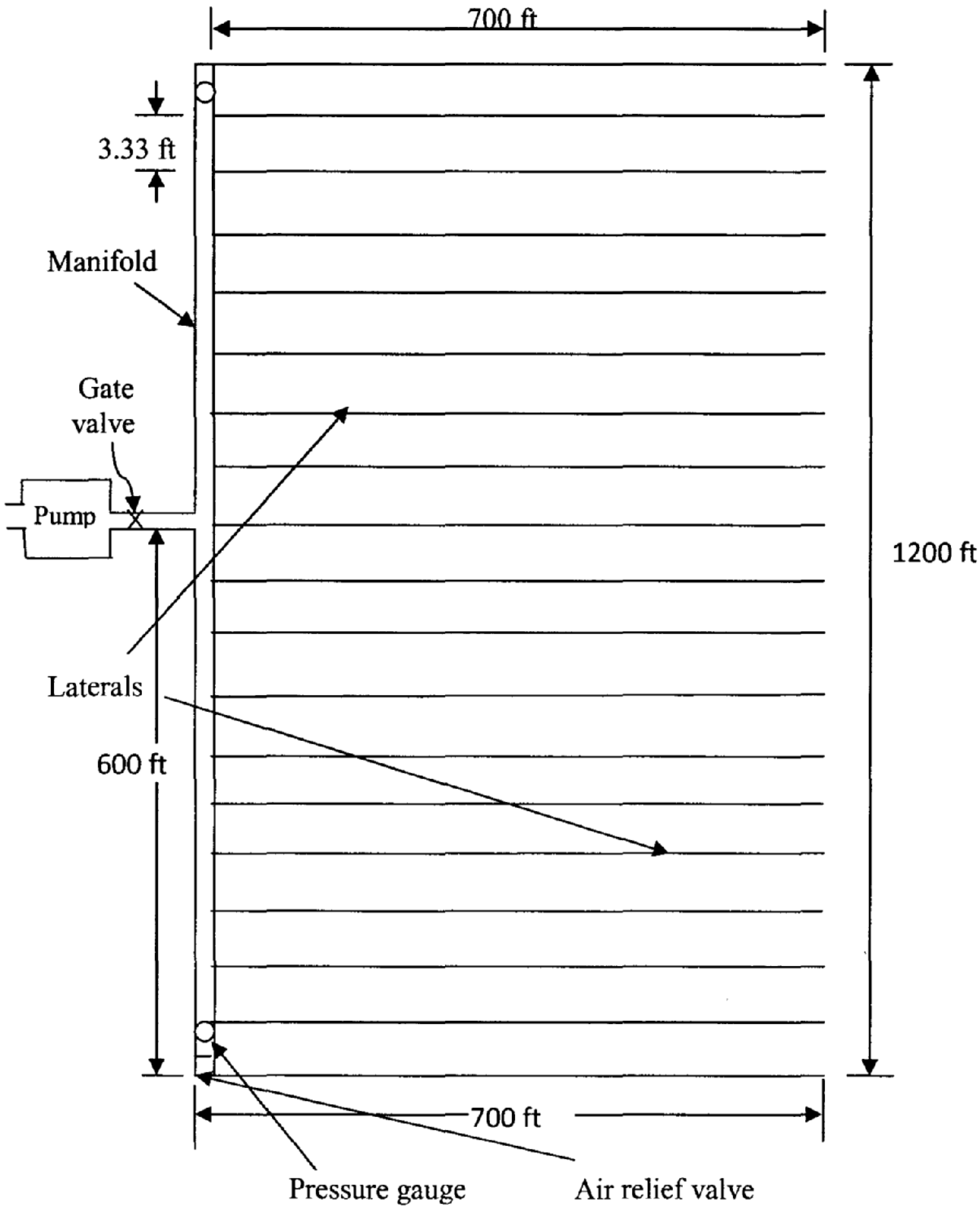


**Figure 4-38 Design of the low pressure drip irrigation system with one manifold**

A list of necessary materials for the construction of the system is provided in Table 4-24.

**Table 4-24 List of the materials and approximate cost for the low pressure drip system with one manifold**

| Description | Quantity | Unit price * ($) | Approximate cost ($) |
|---|---|---|---|
| 3 HP centrifugal pump | 1 | 3330.00 | 3330.00 |
| Gate valve | 1 | 89.00 | 89.00 |
| 4 inch PVC Pipe | 1220 ft | $183/100ft | 2232.00 |
| T-Tape Drip product (TT1-1245-0100 | 61 roll @ 4100 ft | $174.11 | 10621.00 |
| Connectors (FT0500TT005) | 359 | 1.00 | 359.00 |
| Air relief valves | 1 | 20.00 | 20.00 |
| Pressure Gauge | 2 | 35.00 | 70.00 |
| PVC fittings | Tee-2<br>End plug- 2 | 31.00<br>10.00 | 82.00 |
| Labor | 5 days*8= 40 hrs | 250.00 | 1000.00 |
| Other | | | 1000.00 |
| Total fixed cost | | | 18803.00 |
| Variable cost (electricity) | | | 68.00 |
| Variable cost (diesel) | | | 456.00 |

*Price of pump and T-Tape has been collected from ATS Irrigation, Inc. Brenham, TX 77834; other prices have been collected from internet.

*Design of low pressure system with two manifolds*

Following the methodology described in chapter IV, the following calculations have been performed.

Drip product: T-Tape (TT15-1245-0100)

Lateral length with 83.15 % DU = 350 ft (for 1% of uniform land slope)

Operating pressure: 0.6 m (2ft).

Length of the field is 700 ft;

The width of the field is 1200 ft.

Row spacing is 40 inches = 3.33 ft

The field is divided into 2 zones each of 350 ft length and 1200 ft width.

Number of laterals per zone = (1200/3.33)-1 = 359

Number of emitters per zone = 349×359 = 125291

Total flow per zone = $7.8\times10^{-8}$×125291 = 0.00977 $m^3/s$= 0.00977 ×264×60 gpm

= 155 gpm

Total flow for 2 zone = 155×2 = 310 gpm

Crop water requirement = (0.32/12) ×840000 $ft^3$

= 2240 $ft^3$ = 2240× 7.5 gallon = 168,000 gallon

Time required for daily irrigation = (168000/310)/60 hr = 9 hr

The main will be connected at the middle of each manifold.

From earlier calculations, pressure required at the middle of 2nd$^{t}$ manifold = 14 ft

Pressure required at the 1$^{st}$ manifold = 14 + 1.81/100×350 + 0.53/100×600= 23.51 ft

Total head = 5 + 23.51 = 28.51 ft

$$HP = \frac{Q \times H}{3960 \times E_f} = \frac{310 \times 28.51}{3960 \times 0.90} = 2.48$$

Energy cost = 2.04 ×0.7× 9 = 12.85 Kw

From excel sheet, electricity cost per hr = $0.4311

Total cost for electricity = 0.4311×9×8×3=$93.11

Diesel cost per hr = $2.42

Total cost for diesel = 2.42×9×8×3=$522.72

The low head drip system has been designed based on the methodology described in Chapter II and the results found in Chapter IV. The total field has been divided into 2 subzones. A 5 HP pump will be used to supply water to the two manifolds. One gate valve will be fitted before first manifold; another will be fitted before second manifold to schedule irrigation. Pressure regulators will also be fitted just after the pump. Pressure gauges will also be provided at the both end of each manifold to observe the operating pressure in the system. Water will be supplied to the supply manifolds by a 4 inch diameter PVC pipe. All the accessories are made of 4 inch diameter polyethylene (PE) pipes and PVC connectors. Laterals will be connected to the manifold by the connectors. The connectors will be directly fitted to the supply manifold at 3.33 ft spacing. The connector is fitted with removable end plugs for flushing any silt that may pass through the filter. At the end of each manifold, an air relief valve will be fitted to relieve the air from the laterals when the system is stopped. The drawing of the design is shown in Figure 4-39.

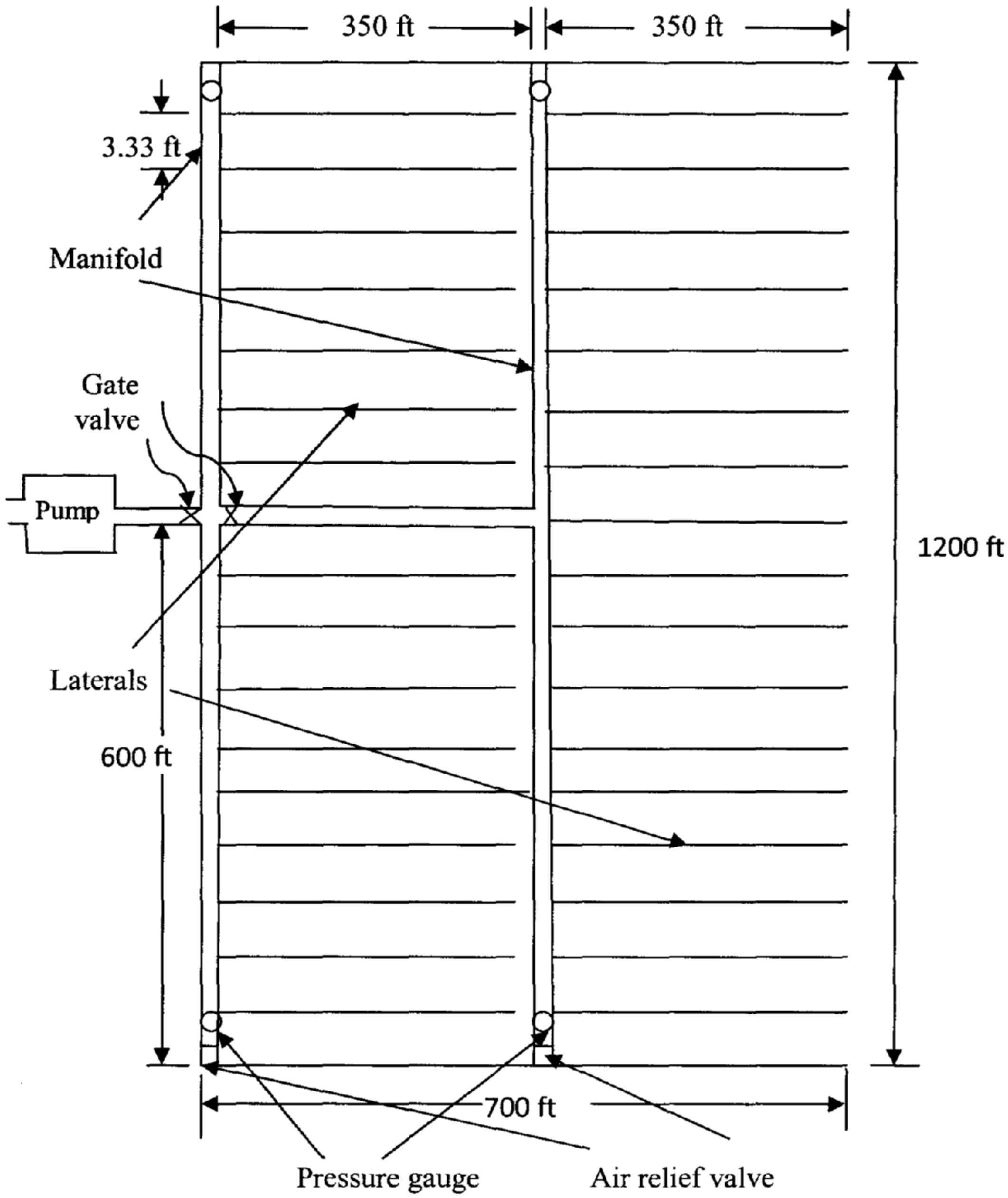


**Figure 4-39 Design of the low pressure drip irrigation system with two manifolds**

A list of necessary materials for the construction of the system is provided in Table 4-25.

**Table 4-25 List of the materials and approximate cost for the low pressure drip irrigation system with two manifolds**

| Description | Quantity | Unit price * ( $) | Approximate cost ( $) |
|---|---|---|---|
| 5.00 HP centrifugal pump | 1 | 3365.00 | 3365.00 |
| Gate valve | 2 | 89.00 | 178.00 |
| 4 inch PVC Pipe | 2420 ft | $183/100ft | 4428.00 |
| T-Tape Drip product (TT1-1245-0100 | 61 roll @ 4100 ft | $174.11 | 10621.00 |
| Connectors (FT0500TT005) | 359*2=718 | 1.00 | 718.00 |
| Air relief valves | 2 | 20.00 | 40.00 |
| Pressure Gauge | 4 | 35.00 | 140.00 |
| PVC fittings | Tee-4<br>End plug- 4 | 31.00<br>10.00 | 164.00 |
| Labor | 7 days*8= 56 hrs | 25.00 | 1400.00 |
| Other | | | 1000.00 |
| Total fixed cost | | | 22054.00 |
| Electricity cost | | | 93.11 |
| Diesel cost | | | 522.72 |

*Price of pump and T-Tape has been collected from ATS Irrigation, Inc.Brenham, TX 77834, other prices have been collected from internet.

*Design of high pressure system with one manifold*

Following the methodology described in chapter IV, the following calculations have been performed.

Drip product: T-Tape (TT15-1245-0100)

Lateral length with 90 % DU = 700 ft (for 1% of uniform land slope)

Operating pressure: 8 psi = 18.48 ft

Length of the field = 700 ft;

The width of the field = 1200 ft.

Row spacing is 40 inches = 3.33 ft

Number of laterals = (1200/3.33)-1 = 359

Number of emitters = 699×359 = 250941

Total flow = 0.0000002×250941 = 0.05 $m^3$/s= 0.019573398 ×264×60 gpm

= 795 gpm

Crop water requirement = (0.32/12) ×840000 $ft^3$

= 2240 $ft^3$ = 2240× 7.5 gallon = 168,000 gallon

Time required for daily irrigation = (168000/795)/60 hr = 3.52 hr

Head required = 40 psi = 92.40 ft

$$HP = \frac{Q \times H}{3960 \times E_f} = \frac{795 \times 92.4}{3960 \times 0.90} = 20.61$$

Energy = 20.61×0.7×3.52 = 50.78 Kw

Electricity cost per hr = $3.09

Total electricity cost = 3.09×3.52×8×3=$261.04

Diesel cost per hr = \$11.50

Total cost for diesel = $11.50 \times 3.53 \times 8 \times 3$ = \$974.28

The high head drip system has been designed based on the methodology described in Chapter II and the results found in Chapter IV. The total field has been considered as a single zone. A 15 HP pump will be used to generate necessary pressures and to supply water to the manifold. A gate valve will be fitted after the tank to control the water supply. After that the filtration system will be established. The pressure regulator will also be fitted just after the pump. Pressure gauges will also be provided at the both end of manifold to observe the operating pressure in the system. Water will be supplied to the supply manifold by a 4 inch diameter PVC pipe. All the accessories are made of 4 inch diameter polyethylene (PE) pipes and PVC connectors. Laterals will be connected to the manifold by the connectors. The connectors will be directly fitted to the supply manifold at 3.33 ft spacing. The connector is fitted with removable end plugs for flushing any silt that may pass through the filter. At the end of each manifold, an air relief valve will be fitted to relieve the air from the laterals when the system is stopped. The drawing of the design is shown in Figure 4-40.

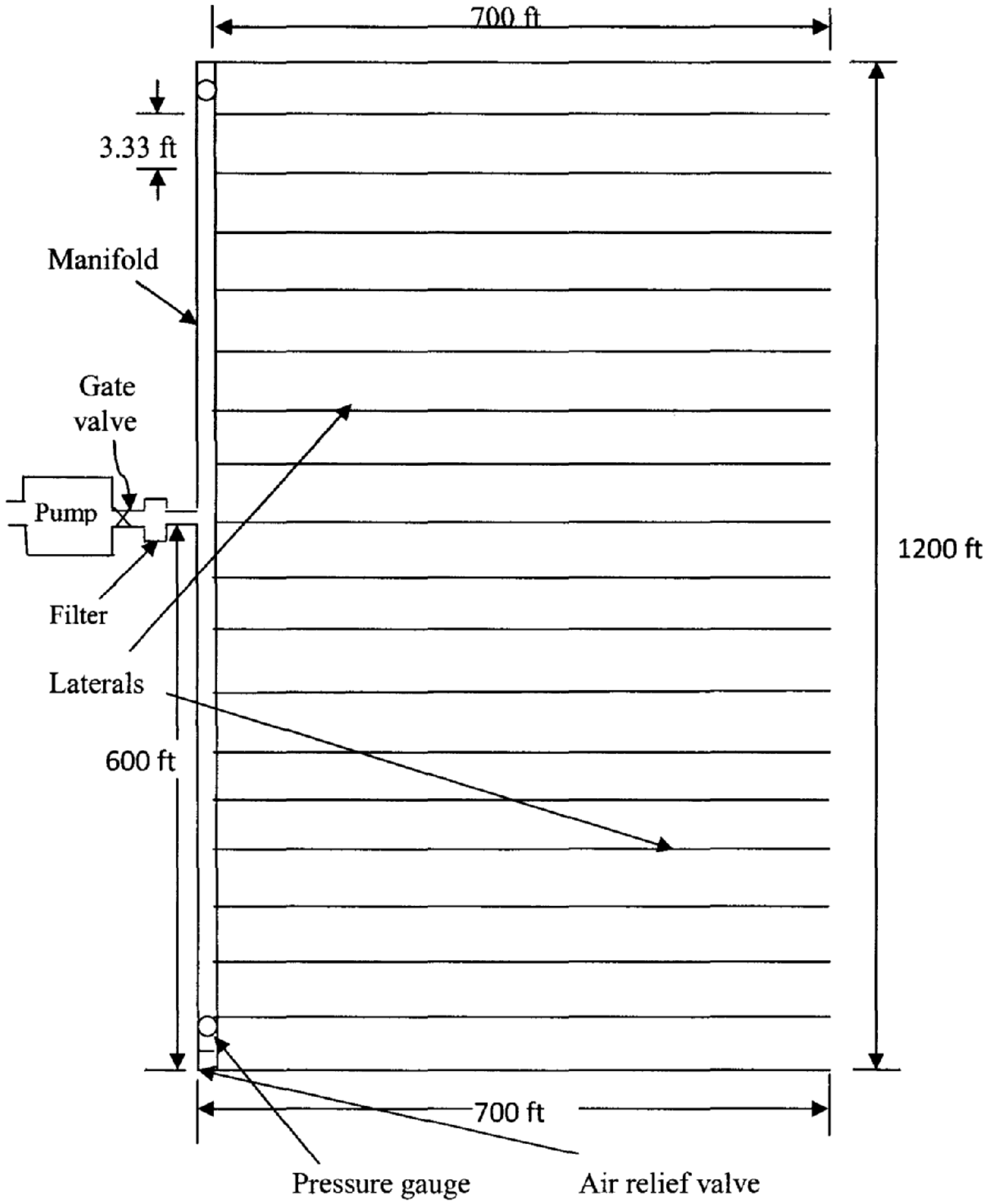


**Figure 4-40 Design of the high pressure drip irrigation system with one manifold**

A list of necessary materials for the construction of the system is provided in Table 4-26.

**Table 4-26. List of the materials and approximate cost for the high pressure drip irrigation system with one manifold**

| Description | Quantity | Unit price, ($) | Approximate cost, ($) |
|---|---|---|---|
| 15 HP centrifugal pump | 1 | 4220.00 | 4220.00 |
| Filtration system | 1 | 10000.00 | 10000.00 |
| Gate valve | 1 | 89.00 | 89.00 |
| 4 inch PVC Pipe | 1220 ft | $183/100ft | 2232.00 |
| T-Tape Drip product (TT1-1245-0100 | 61 roll @ 4100 ft | $174.11 | 10621.00 |
| Connectors (FT0500TT005) | 359 | 1.00 | 359.00 |
| Air relief valves | 1 | 20.00 | 20.00 |
| Pressure Gauge | 2 | 35.00 | 70.00 |
| PVC fittings | Tee-2<br>End plug- 2 | 31.00<br>10.00 | 82.00 |
| Labor | 5 days*8= 40 hrs | 25.00 | 1000.00 |
| Other | | | 1000.00 |
| Total fixed cost | | | 29693.00 |
| Electricity cost | | | 261.04 |
| Diesel cost | | | 380.00 |

*Price of pump, T-Tape and Filtration systems has been collected from ATS Irrigation, Inc. Brenham, TX 77834; other prices have been collected from internet.

*Comparison of cost analysis of three systems*

The comparison of cost analysis between three designed drip irrigation system in summarized in Table 4-27.

**Table 4-27 Comparison of the cost analysis of three systems**

| Items | Types of drip irrigation systems | | |
|---|---|---|---|
| | Low Pressure (2 ft of water head) | | High pressure (40 psi for filtration, 8 psi operating pressure) |
| | One manifold | Two manifolds | |
| HP | 1.65 | 2.48 | 20.61 |
| DU (%) | 55.48 | 83.15 | 90 |
| Fixed Cost ($) | 18803.00 | 22054 | 29693.00 |
| Variable Cost Electricity ($) | 68.00 | 93.11 | 261.04 |
| Variable Cost Diesel ($) | 456.00 | 522.72 | 974.28 |
| Water requirement for cotton (3 ft) | 4.32×19.28 = 83.28 acre-ft | 3.51 ×19.28 = 67.67 acre-ft | 3.3 × 19.28 = 63.62 acre-ft |

*Analysis and feasibility of the systems*

Among the three systems, one manifold low pressure system is suitable in respect to both fixed and variable cost, but it requires highest water. Two manifold low pressure system requires higher fixed and variable cost than one manifold system, but it requires less water than one manifold system. Also, in comparison with the high pressure system, it has got lower fixed and variable cost, but higher water requirement. The high pressure system needs both higher fixed and variable cost in comparison with the low pressure systems. But in respect to water saving, it requires lowest water among the three systems. From the above design, it seems that the initial investment in drip irrigation is comparatively higher than would be in the traditional surface irrigation system due to material cost. Primarily, a lower return from drip irrigation may be expected because of high sensitivity to initial investment. However, the initial investment can be minimized by introducing low pressure drip irrigation systems instead of high pressure systems. The low pressure system may be a suitable substitute for furrow irrigation because of limited water supply and in terms of yield. Cotton yields were greater with drip irrigation than with furrow on a silt soil but not for a sandy soil (Phene et al., 1992a) and were equal in another study (DeTar et al., 1994); however, in both cases much less water (~40% less) was required by drip irrigation. Another study by Henggeler (1995) reported a cotton yield increase of about 20% for drip over furrow irrigation for several counties in western Texas. Henggeler et al. (1996) also reported increased profitability for cotton because of higher yield and distribution of fixed costs over a larger area. Knapp (1993) stated that general recommendations regarding the best irrigation system are not appropriate but are dependent on many physical, biological, and economic factors, which can be managed best through the development and use of appropriate computer programs and databases suitable for the site. Another factor affecting the profitability of irrigation is the water resource and its availability and cost with time. The competition for the water resource is consistently increasing, especially in arid areas, so it is not possible to accurately predict long-term availability and cost. Hence, economic analyses are very difficult, at least for long time periods. Water conservation and application uniformity must be increased as water supplies for agriculture is diminishing day by day, which increases the relative importance of low pressure drip irrigation systems. In low pressure drip irrigation system, losses of water from deep percolation, evaporation and runoff are minimum, water application is uniform, even with variable slope and soil texture; problems with salinity of soil. Also the system facilitates automation of water and fertilizer application. Low pressure drip irrigation is more suitable in terms of saving energy where there is availability of some kind of natural elevated water source or other elevated water source like rainwater harvesting tank. Considering all these factors, despite high initial cost, low pressure drip irrigation may be widely used, particularly where water is expensive or scarce.

# CHAPTER V

# RECOMMENDATIONS

This study provided some new information regarding drip emitter characterization at low operating pressures. Also this study provided information regarding lateral length to achieve an acceptable DU under low pressures at different uniform land slopes. Except for the Netafim product, all other tested products can be used effectively under low operating pressures as under high operating or recommended pressures without significantly affecting their performance. The study was completely lab based and was limited to using new tubing and clean water at a controlled temperature of $20^0$C ($\pm2^0$C). So, further study can be conducted incorporating variation of emitter flow due to emitter clogging, water temperature, variety of emitter spacing and under complex land slopes. Also a field scale experiment can be conducted in a real field at larger scale in order to validate the methodology and to have field data in order to better design the system.

# CHAPTER VI

# CONCLUSIONS

A laboratory based experiment was conducted to test five different popular brands of drip products from several manufacturers which are used for drip irrigation. The manufacturers were Toro, T-Tape, Mister and Netafim. Among the products, T-Tape was NPC and all others were PC emitters. All of the products tested were new and unused, allowed 3 hours of running before starting collecting data.

1. This experiment characterized five types of drip products by measuring their emission rates at a water temperature of $20^0$ C ($\pm 2^0$ C) under a pressure range of 0 to 344.74 KPa (50.00 psi /115.50 ft). From evaluation of 60 emitters from each product, the Toro brand showed an average uniformity coefficient (UC) of 91.24 %, with a coefficient of variation ($C_v$ ) of 0.06, T-Tape drip products showed average UC of 96.63 % with a $C_v$ of 0.04, Mister_LS showed an average UC of 93.12 % with a $C_v$ of 0.08, Mister_PS showed an average UC of 96.33 % with $C_v$ of 0.04 and Netafim showed an average UC of 97.92 % with a $C_v$ of 0.02. But the Netafim brand had no emission under a low pressure range of 5.97 to 24.13 KPa (0.87 to 3.50 psi), it started emission only at 29.85 KPa (4.33 psi/10.00 ft).

2. As per micro-irrigation drip system classification guidelines (ASABE, 1999; ASABE, 2008R), all of the five products tested were classified as “excellent” on the basis of UC and according to the $C_v$ value, T-Tape, Mister_LS and Netafim were classified as “excellent”, Toro and Mister_LS brand were classified as “marginal”.

3. Flow rate vs. pressure curves (Q-H curves) were also developed for each drip emitter tested. Q-H curves were fitted to the data resulting in $R^2$ values ranging from 0.5341 to 0.9998. For the whole pressure range of 5.57 Kpa to 344.74 KPa, Toro and Mister_LS product acted as partially pressure compensating, whereas T-Tape and Mister_PS product acted as non pressure compensating and and Netafim products acted as pressure compensating.

4. The Q-H curves were studied separately under low pressure and normal operating pressure ranges to better understand their characteristics. Under the lower pressure ranges (5.57 KPa-68.95 KPa for Toro, 0-55.16 KPa for T-Tape, 5.57 KPa-82.74 KPa for Mister_LS, 5.57 KPa-117.21 for Mister_PS and 5.57 KPa-55.16 KPa for netafim), except for Netafim, the emitter exponent values were greater than 0.1, meaning all of the four pressure compensating (PC) products behaved like NPC emitters at low pressures, Netafim behaved like a partially PC emitter. An exponent value of less than 0.1 was observed (except for T-Tape) when tested within manufacturer's suggested operating pressure range (68.95 – 413.68 KPa for Toro, 27.58-103.42 KPa for T-Tape, 68.95 - 413-68 KPa for Mister_LS and Mister_PS and 103.42-482.63KPa for Netafim), that means they behaved like PC emitters under normal operating pressures.

5. The distribution uniformity was computed under low pressure conditions for four products, Mister_LS, Mister_PS, Toro, and T-Tape. The distribution uniformity for Netafim product was not computed because no emission was measured at low pressures. It was observed that the DU decreased as the lateral length increased and land slope decreased and DU increased as lateral length decreased and land slope increased, but it

did not increase or decrease proportionally as operating pressure increased or decreased for a particular slope. The maximum lateral length was also determined for approximately the minimum DU of 70% for all products at 0%, 1%, 2% and 3% of uniform land slopes. Among the maximum lateral lengths four products, Mister_PS showed a minimum lateral length of 20.74 m (68 ft) at the operating pressure of 0.60 m and at 0% slope, whereas, T-Tape showed the maximum lateral length of 228.75 m (750 ft) at the operating pressure of 1.20 m and at 3% slope. T-Tape showed the maximum lateral length at all slopes and at all operating pressures.

6. From statistical analysis, it was determined that except for the Netafim (PC) product, all other tested products were as effective under low operating pressure as under high operating or recommended pressures without significantly affecting their performance.

# CHAPTER VII

## SUMMARY

This study characterized five types of drip products that are being commonly used now a days for drip irrigation. The operating pressure range was 5.57 KPa-344.74 KPa (0.87 psi - 50 psi). A lab experiment was set up to measure the emission rate at different operating pressures. Using the collected emission rates, seven statistical parameters were calculated which were used to determine the performance of the tested emitters. The flow rate vs. pressure head relationship for each emitter type was established for both low and suggested or high operating pressure ranges. On the basis of the exponent values obtained from the relationships, the emitters were classified as pressure compensating or non-pressure compensating at both low and high pressure ranges. From emitter exponent values it was observed that all of the pressure compensating (PC) products behaved like NPC emitters at low pressures, although they behaved like PC emitters under normal operating pressures. All of the five products tested were classified as "excellent" on the basis of UC and T-Tape, Mister_PS and Netafim were classified as "excellent", Toro and Mister_LS brand were classified as "marginal" according to the $C_v$ value. From statistical analysis, it was determined that the except for the Netafim product, all other tested products were as effective under low operating pressures as were under high operating or recommended pressures.

Using the measured average emission rate and developed Q-H curves, the distribution uniformities of four products were computed under low pressure ranges of 5.97 KPa (0.87 psi /2.00ft), 11.94 KPa (1.73 psi /4.00 ft), 17.91 KPa (2.60 psi /6.00 ft), and 23.88 KPa (3.50 psi/ 8.00 ft) for different lateral lengths and under 0%, 1%, 2% & 3% uniform land slopes. The range of DU was approximately from 70% to 99%, which can be classified as “good” to “excellent”. The maximum lateral lengths for a minimum acceptable amount of DU of around 70% for each of the four products were also obtained. It was observed that DU increased with the decrease in lateral length and decreased with the increase in lateral length and increased with the increase in land slopes for all products. But the effect operating pressure on DU was not uniform. So, these factors should be considered carefully when designing a drip irrigation system.

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# APPENDIX A

Appendix A shows the average flow rates of emitters with their locations in the laterals

**Table A-1 Average flow rates of T-Tape TT15-1245-0100 (ml/min)**

| Pressure (KPa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 5.97 (0.87psi) | 1 | 4.84 | 4.87 | 4.71 | 4.69 | 4.64 | 4.73 |
| | 2 | 4.98 | 4.11 | 4.31 | 4.29 | 4.22 | 4.91 |
| | 3 | 4.84 | 4.40 | 4.71 | 3.69 | 2.93 | 4.80 |
| | 4 | 4.80 | 4.71 | 4.87 | 4.60 | 4.53 | 4.87 |
| | 5 | 4.73 | 5.02 | 5.02 | 4.40 | 4.33 | 5.02 |
| | 6 | 4.69 | 4.93 | 4.49 | 4.73 | 4.31 | 5.11 |
| | 7 | 5.11 | 5.16 | 4.69 | 4.84 | 4.76 | 5.11 |
| | 8 | 4.27 | 5.18 | 4.84 | 4.62 | 4.02 | 4.93 |
| | 9 | 4.67 | 5.09 | 4.76 | 4.87 | 4.16 | 4.76 |
| | 10 | 4.91 | 4.96 | 4.89 | 4.89 | 4.80 | 4.71 |
| 11.94 (1.73 psi) | 1 | 6.16 | 7.04 | 6.47 | 6.44 | 5.78 | 7.16 |
| | 2 | 5.42 | 6.44 | 5.78 | 5.69 | 5.64 | 7.07 |
| | 3 | 6.07 | 6.27 | 5.73 | 6.13 | 6.44 | 7.67 |
| | 4 | 6.11 | 5.76 | 6.11 | 6.38 | 6.76 | 7.51 |
| | 5 | 5.80 | 6.38 | 5.98 | 6.18 | 6.73 | 7.31 |
| | 6 | 6.42 | 5.96 | 5.98 | 6.40 | 6.87 | 7.56 |
| | 7 | 5.56 | 6.40 | 6.22 | 6.51 | 7.09 | 7.51 |
| | 8 | 6.09 | 6.47 | 6.62 | 6.40 | 6.24 | 7.47 |
| | 9 | 5.98 | 6.96 | 6.47 | 6.47 | 6.73 | 7.64 |
| | 10 | 5.53 | 6.42 | 5.80 | 6.73 | 7.09 | 7.73 |
| 17.91 (2.60 psi) | 1 | 9.13 | 9.47 | 9.80 | 9.83 | 9.10 | 8.60 |
| | 2 | 8.50 | 9.77 | 9.40 | 9.47 | 8.97 | 9.47 |
| | 3 | 9.40 | 9.13 | 9.43 | 8.87 | 9.13 | 9.50 |
| | 4 | 9.00 | 8.77 | 9.47 | 9.53 | 8.57 | 8.97 |
| | 5 | 8.90 | 9.00 | 9.20 | 9.60 | 8.67 | 9.47 |
| | 6 | 8.87 | 8.83 | 9.43 | 10.13 | 8.37 | 9.30 |
| | 7 | 8.93 | 9.20 | 9.73 | 9.77 | 9.37 | 8.97 |
| | 8 | 8.83 | 9.00 | 10.00 | 9.90 | 8.27 | 8.87 |
| | 9 | 8.73 | 9.03 | 9.60 | 9.43 | 8.20 | 9.03 |
| | 10 | 8.90 | 8.60 | 8.93 | 8.90 | 8.80 | 9.30 |
| 23.88 (3.46 psi) | 1 | 10.10 | 11.00 | 10.90 | 11.20 | 10.77 | 10.53 |
| | 2 | 12.90 | 11.23 | 10.60 | 11.10 | 10.40 | 10.67 |
| | 3 | 11.13 | 10.70 | 10.63 | 11.00 | 10.70 | 11.07 |
| | 4 | 10.33 | 10.43 | 10.60 | 11.57 | 10.60 | 11.03 |
| | 5 | 10.50 | 10.93 | 10.60 | 11.20 | 10.50 | 10.90 |

**Table A-1 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 6 | 10.70 | 10.30 | 10.50 | 11.63 | 11.07 | 11.67 |
| | 7 | 9.70 | 11.03 | 10.70 | 11.60 | 11.20 | 11.20 |
| | 8 | 10.00 | 10.63 | 11.57 | 11.67 | 10.50 | 11.10 |
| | 9 | 10.33 | 10.93 | 11.50 | 11.37 | 11.00 | 11.23 |
| | 10 | 10.30 | 10.67 | 10.80 | 10.87 | 11.80 | 11.27 |
| 35.82 (5.20 psi) | 1 | 13.83 | 13.73 | 13.57 | 14.00 | 13.30 | 13.43 |
| | 2 | 13.43 | 14.27 | 13.20 | 13.53 | 13.10 | 13.53 |
| | 3 | 14.17 | 13.40 | 13.73 | 13.33 | 13.23 | 14.03 |
| | 4 | 13.70 | 12.90 | 13.80 | 14.03 | 13.20 | 13.77 |
| | 5 | 13.67 | 13.23 | 13.67 | 13.40 | 12.93 | 13.80 |
| | 6 | 14.00 | 13.17 | 13.87 | 14.50 | 13.20 | 14.20 |
| | 7 | 13.33 | 13.53 | 13.90 | 14.30 | 13.53 | 13.87 |
| | 8 | 13.40 | 13.13 | 14.27 | 14.17 | 12.73 | 13.93 |
| | 9 | 13.90 | 13.43 | 14.53 | 14.13 | 12.93 | 14.10 |
| | 10 | 13.70 | 13.03 | 13.40 | 13.30 | 13.57 | 14.07 |
| 55.16 (8.00 psi) | 1 | 18.00 | 17.53 | 17.20 | 17.20 | 17.00 | 17.00 |
| | 2 | 17.07 | 17.97 | 17.20 | 17.23 | 16.47 | 17.23 |
| | 3 | 18.27 | 17.07 | 17.43 | 16.83 | 17.07 | 17.97 |
| | 4 | 17.80 | 16.63 | 17.70 | 17.77 | 17.00 | 17.57 |
| | 5 | 17.73 | 17.37 | 17.40 | 17.03 | 16.57 | 17.47 |
| | 6 | 18.03 | 17.20 | 17.67 | 18.40 | 17.20 | 18.07 |
| | 7 | 17.53 | 17.50 | 17.60 | 18.17 | 17.40 | 17.87 |
| | 8 | 17.40 | 17.03 | 18.20 | 18.10 | 16.03 | 17.77 |
| | 9 | 17.67 | 17.40 | 18.27 | 18.13 | 16.83 | 17.93 |
| | 10 | 17.37 | 16.60 | 17.27 | 17.20 | 17.93 | 18.10 |
| 68.95 (10.00 psi) | 1 | 20.13 | 19.40 | 19.20 | 19.40 | 19.80 | 18.60 |
| | 2 | 19.47 | 19.60 | 19.07 | 19.20 | 18.60 | 19.20 |
| | 3 | 20.60 | 18.93 | 19.20 | 18.80 | 18.73 | 19.53 |
| | 4 | 19.80 | 18.20 | 19.60 | 19.93 | 18.60 | 19.40 |
| | 5 | 19.87 | 18.73 | 19.20 | 18.93 | 18.47 | 19.33 |
| | 6 | 20.33 | 18.60 | 19.53 | 20.47 | 18.73 | 19.80 |
| | 7 | 19.80 | 19.27 | 19.60 | 20.20 | 19.00 | 19.53 |
| | 8 | 19.80 | 18.73 | 20.53 | 20.13 | 18.93 | 19.73 |
| | 9 | 20.07 | 19.20 | 20.40 | 20.07 | 18.33 | 19.87 |
| | 10 | 19.93 | 18.20 | 19.40 | 19.07 | 19.20 | 19.80 |
| | 1 | 23.20 | 22.53 | 22.33 | 22.60 | 22.13 | 21.93 |
| | 2 | 22.47 | 22.80 | 22.13 | 22.40 | 21.60 | 22.40 |

**Table A-1 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 96.53 (14.00 psi) | 3 | 23.47 | 22.00 | 22.53 | 22.00 | 21.93 | 23.00 |
| | 4 | 22.67 | 21.33 | 22.73 | 22.73 | 22.00 | 22.67 |
| | 5 | 22.93 | 21.87 | 22.40 | 22.20 | 21.53 | 22.80 |
| | 6 | 23.20 | 21.87 | 23.27 | 23.67 | 22.00 | 23.13 |
| | 7 | 22.60 | 22.13 | 23.20 | 23.40 | 22.47 | 22.93 |
| | 8 | 22.27 | 21.33 | 24.00 | 23.40 | 21.07 | 16.07 |
| | 9 | 22.93 | 21.93 | 23.40 | 23.33 | 21.67 | 23.40 |
| | 10 | 22.80 | 21.73 | 22.60 | 22.40 | 23.13 | 22.87 |
| 137.9 (20.00 psi) | 1 | 27.00 | 26.40 | 26.40 | 27.27 | 25.60 | 25.47 |
| | 2 | 26.00 | 26.93 | 25.80 | 27.07 | 25.07 | 26.07 |
| | 3 | 26.67 | 26.00 | 26.00 | 26.67 | 25.53 | 26.60 |
| | 4 | 26.73 | 25.07 | 26.67 | 27.53 | 25.33 | 26.87 |
| | 5 | 26.60 | 25.80 | 26.20 | 26.80 | 25.47 | 26.40 |
| | 6 | 27.13 | 25.53 | 26.73 | 28.60 | 25.60 | 26.60 |
| | 7 | 26.27 | 26.13 | 26.80 | 28.40 | 26.07 | 26.47 |
| | 8 | 26.20 | 25.60 | 28.20 | 27.93 | 24.47 | 26.47 |
| | 9 | 26.60 | 26.07 | 27.67 | 28.00 | 25.13 | 26.87 |
| | 10 | 26.27 | 25.13 | 26.27 | 27.00 | 26.53 | 26.60 |
| 206.84 (30.00 psi) | 1 | 32.60 | 32.00 | 31.67 | 31.73 | 31.27 | 30.73 |
| | 2 | 31.67 | 32.40 | 30.93 | 31.40 | 30.33 | 31.33 |
| | 3 | 32.87 | 31.20 | 31.40 | 30.93 | 30.87 | 32.07 |
| | 4 | 32.20 | 30.20 | 31.93 | 32.07 | 31.27 | 31.80 |
| | 5 | 32.47 | 31.13 | 31.33 | 31.07 | 31.13 | 31.60 |
| | 6 | 32.80 | 30.67 | 32.00 | 33.20 | 31.60 | 32.40 |
| | 7 | 31.73 | 31.60 | 32.00 | 32.73 | 30.27 | 31.87 |
| | 8 | 31.80 | 30.73 | 33.53 | 32.60 | 30.00 | 31.93 |
| | 9 | 32.20 | 31.40 | 33.13 | 32.53 | 30.33 | 32.13 |
| | 10 | 32.13 | 30.27 | 31.40 | 31.07 | 32.00 | 31.93 |
| 344.74 (50.00 psi) | 1 | 41.20 | 40.73 | 39.93 | 40.13 | 40.73 | 39.73 |
| | 2 | 40.00 | 40.80 | 39.00 | 40.20 | 39.93 | 40.07 |
| | 3 | 41.40 | 40.00 | 40.07 | 39.53 | 40.20 | 41.07 |
| | 4 | 40.60 | 38.73 | 40.07 | 40.73 | 40.20 | 40.60 |
| | 5 | 40.67 | 39.80 | 39.67 | 39.93 | 40.07 | 40.73 |
| | 6 | 41.33 | 39.40 | 40.27 | 41.67 | 40.60 | 41.53 |
| | 7 | 40.07 | 40.07 | 40.40 | 41.40 | 41.33 | 40.07 |
| | 8 | 40.07 | 39.60 | 41.73 | 41.40 | 39.53 | 40.73 |
| | 9 | 40.67 | 40.27 | 41.87 | 41.20 | 39.87 | 40.07 |
| | 10 | 40.33 | 38.93 | 39.87 | 40.00 | 41.40 | 40.87 |

**Table A-2 Average flow rates of Mister_LS MLD-HDT100 (ml/min)**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 5.97 (0.87psi) | 1 | 24.73 | 24.20 | 20.07 | 24.33 | 24.60 | 22.93 |
| | 2 | 25.40 | 20.47 | 24.40 | 24.47 | 25.93 | 24.00 |
| | 3 | 25.13 | 24.13 | 24.53 | 24.13 | 25.60 | 23.87 |
| | 4 | 25.20 | 24.67 | 24.00 | 22.87 | 25.67 | 21.33 |
| | 5 | 22.20 | 25.07 | 24.87 | 22.33 | 22.53 | 23.73 |
| | 6 | 24.93 | 18.40 | 18.73 | 22.20 | 17.87 | 23.00 |
| | 7 | 25.33 | 18.40 | 27.00 | 20.00 | 22.27 | 19.47 |
| | 8 | 24.27 | 24.47 | 28.80 | 21.20 | 25.20 | 20.87 |
| | 9 | 22.80 | 23.80 | 22.47 | 17.00 | 25.93 | 20.00 |
| | 10 | 24.07 | 23.60 | 23.00 | 21.33 | 26.00 | 22.60 |
| 11.94 (1.73 psi) | 1 | 33.40 | 32.73 | 26.60 | 33.53 | 32.07 | 32.20 |
| | 2 | 33.67 | 27.93 | 32.33 | 33.40 | 33.40 | 33.80 |
| | 3 | 33.53 | 32.73 | 32.47 | 32.80 | 29.87 | 34.13 |
| | 4 | 33.13 | 32.80 | 31.73 | 31.40 | 32.80 | 30.73 |
| | 5 | 29.27 | 33.80 | 33.33 | 30.60 | 29.67 | 34.40 |
| | 6 | 33.13 | 25.87 | 24.67 | 30.00 | 27.33 | 33.93 |
| | 7 | 32.93 | 25.53 | 36.20 | 27.53 | 32.33 | 28.93 |
| | 8 | 32.73 | 25.93 | 36.20 | 29.20 | 32.13 | 30.87 |
| | 9 | 30.73 | 33.20 | 29.93 | 23.67 | 35.47 | 29.80 |
| | 10 | 32.07 | 32.67 | 30.73 | 29.80 | 33.40 | 33.40 |
| 17.91 (2.60 psi) | 1 | 40.07 | 39.40 | 32.07 | 39.93 | 38.80 | 38.47 |
| | 2 | 40.40 | 33.67 | 39.20 | 40.40 | 40.53 | 40.20 |
| | 3 | 40.20 | 39.40 | 38.93 | 39.47 | 34.67 | 40.80 |
| | 4 | 40.33 | 39.27 | 38.20 | 37.93 | 39.60 | 36.53 |
| | 5 | 35.33 | 40.87 | 40.07 | 36.93 | 34.53 | 40.73 |
| | 6 | 39.60 | 30.60 | 29.73 | 36.13 | 33.33 | 40.20 |
| | 7 | 40.60 | 30.40 | 43.00 | 33.27 | 38.93 | 34.53 |
| | 8 | 39.60 | 40.80 | 42.73 | 35.67 | 32.53 | 36.80 |
| | 9 | 36.93 | 39.47 | 33.00 | 28.80 | 40.47 | 35.33 |
| | 10 | 38.80 | 39.27 | 37.20 | 36.27 | 40.33 | 40.87 |
| 23.88 (3.46 psi) | 1 | 42.47 | 41.80 | 34.93 | 42.47 | 40.67 | 41.47 |
| | 2 | 43.13 | 35.47 | 41.60 | 42.93 | 42.47 | 43.53 |
| | 3 | 42.87 | 42.07 | 41.80 | 41.73 | 35.53 | 44.07 |
| | 4 | 42.73 | 41.67 | 41.00 | 39.93 | 41.33 | 39.53 |
| | 5 | 37.93 | 42.93 | 42.93 | 39.13 | 35.53 | 44.20 |
| | 6 | 42.27 | 32.27 | 31.67 | 38.27 | 35.20 | 43.13 |
| | 7 | 43.40 | 32.53 | 45.07 | 35.07 | 40.67 | 37.60 |
| | 8 | 41.73 | 42.33 | 43.73 | 37.47 | 34.13 | 39.73 |

**Table A-2 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 9 | 39.53 | 42.07 | 34.20 | 30.20 | 41.27 | 38.40 |
| | 10 | 41.33 | 42.07 | 39.60 | 38.53 | 42.20 | 44.33 |
| 35.82 (5.20 psi) | 1 | 52.20 | 48.47 | 44.53 | 52.00 | 50.27 | 50.53 |
| | 2 | 52.60 | 46.00 | 50.47 | 52.33 | 52.47 | 52.73 |
| | 3 | 52.33 | 51.13 | 50.27 | 50.80 | 43.87 | 53.33 |
| | 4 | 50.27 | 51.47 | 50.27 | 49.27 | 51.20 | 48.13 |
| | 5 | 47.73 | 48.07 | 47.07 | 48.00 | 43.87 | 53.27 |
| | 6 | 51.87 | 39.47 | 43.40 | 46.93 | 43.47 | 52.93 |
| | 7 | 52.73 | 43.33 | 53.67 | 43.27 | 50.27 | 45.67 |
| | 8 | 50.47 | 51.33 | 48.87 | 46.33 | 42.27 | 48.27 |
| | 9 | 49.13 | 51.33 | 43.47 | 37.27 | 50.53 | 46.73 |
| | 10 | 50.53 | 48.20 | 48.20 | 47.27 | 52.20 | 53.00 |
| 55.16 (8.00 psi) | 1 | 65.60 | 64.80 | 53.07 | 65.00 | 63.00 | 62.73 |
| | 2 | 66.00 | 55.60 | 64.13 | 65.67 | 65.47 | 65.47 |
| | 3 | 65.67 | 65.33 | 64.07 | 64.20 | 62.20 | 66.13 |
| | 4 | 65.60 | 64.73 | 63.27 | 62.20 | 64.13 | 60.13 |
| | 5 | 58.13 | 66.53 | 65.47 | 60.47 | 55.33 | 66.60 |
| | 6 | 64.47 | 50.80 | 48.53 | 58.93 | 54.53 | 65.87 |
| | 7 | 66.93 | 50.33 | 68.73 | 54.33 | 62.33 | 57.67 |
| | 8 | 64.00 | 65.67 | 66.93 | 58.47 | 53.27 | 60.40 |
| | 9 | 61.60 | 65.47 | 52.20 | 56.87 | 63.47 | 58.87 |
| | 10 | 62.40 | 65.87 | 61.07 | 59.80 | 65.47 | 66.80 |
| 68.95 (10.00 psi) | 1 | 72.56 | 71.11 | 59.11 | 73.00 | 70.67 | 70.11 |
| | 2 | 72.89 | 58.22 | 70.67 | 72.22 | 72.89 | 72.22 |
| | 3 | 73.22 | 71.78 | 71.44 | 70.78 | 61.44 | 71.89 |
| | 4 | 72.11 | 71.00 | 69.89 | 69.33 | 71.44 | 66.89 |
| | 5 | 64.33 | 73.00 | 72.33 | 67.56 | 61.89 | 73.56 |
| | 6 | 71.56 | 55.89 | 54.11 | 65.11 | 60.22 | 70.44 |
| | 7 | 73.67 | 55.22 | 75.44 | 60.89 | 69.56 | 63.44 |
| | 8 | 71.11 | 72.11 | 73.78 | 65.22 | 59.89 | 67.11 |
| | 9 | 66.78 | 72.22 | 58.56 | 52.56 | 70.89 | 66.00 |
| | 10 | 68.56 | 72.56 | 68.22 | 66.78 | 72.44 | 74.22 |
| 82.74 (12.00 psi) | 1 | 77.78 | 76.78 | 67.33 | 78.44 | 75.33 | 75.22 |
| | 2 | 77.67 | 63.78 | 75.11 | 76.67 | 77.89 | 75.89 |
| | 3 | 78.22 | 77.56 | 76.22 | 75.89 | 66.11 | 76.33 |
| | 4 | 77.56 | 76.11 | 76.00 | 74.78 | 76.00 | 71.56 |
| | 5 | 69.00 | 71.67 | 71.00 | 72.89 | 65.89 | 78.67 |
| | 6 | 77.44 | 58.89 | 65.33 | 69.89 | 63.44 | 78.56 |

**Table A-2 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 7 | 79.11 | 64.33 | 80.44 | 65.44 | 74.33 | 69.56 |
| | 8 | 76.89 | 77.56 | 73.56 | 70.33 | 63.89 | 72.22 |
| | 9 | 73.11 | 77.89 | 66.11 | 55.56 | 74.89 | 70.56 |
| | 10 | 72.00 | 73.33 | 73.44 | 71.78 | 78.33 | 80.00 |
| 96.53 (14.00 psi) | 1 | 78.78 | 77.00 | 67.78 | 79.67 | 76.22 | 75.67 |
| | 2 | 78.67 | 73.44 | 75.11 | 76.78 | 79.11 | 75.22 |
| | 3 | 79.11 | 77.78 | 77.22 | 76.11 | 66.67 | 75.67 |
| | 4 | 78.33 | 75.89 | 76.78 | 75.56 | 76.11 | 71.89 |
| | 5 | 69.33 | 71.00 | 72.00 | 74.11 | 64.89 | 77.56 |
| | 6 | 78.89 | 57.78 | 66.00 | 70.11 | 62.44 | 80.00 |
| | 7 | 79.89 | 63.22 | 81.33 | 65.78 | 74.33 | 68.89 |
| | 8 | 78.22 | 77.33 | 74.00 | 69.56 | 63.56 | 73.11 |
| | 9 | 74.56 | 77.89 | 66.33 | 54.22 | 74.56 | 70.67 |
| | 10 | 72.56 | 73.78 | 74.22 | 72.89 | 79.44 | 78.89 |
| 117.21 (17.00 psi) | 1 | 78.11 | 75.89 | 63.56 | 78.33 | 74.33 | 75.56 |
| | 2 | 78.44 | 62.89 | 72.56 | 75.78 | 78.11 | 74.89 |
| | 3 | 79.11 | 77.11 | 77.33 | 75.56 | 65.22 | 75.56 |
| | 4 | 78.44 | 74.44 | 74.11 | 75.67 | 75.33 | 71.44 |
| | 5 | 78.00 | 75.44 | 77.11 | 73.67 | 64.22 | 78.89 |
| | 6 | 79.33 | 58.67 | 56.22 | 69.11 | 61.44 | 79.33 |
| | 7 | 79.67 | 55.11 | 81.00 | 66.00 | 73.33 | 69.33 |
| | 8 | 78.11 | 75.33 | 76.44 | 67.00 | 62.44 | 72.44 |
| | 9 | 75.44 | 76.00 | 60.89 | 53.56 | 73.33 | 70.00 |
| | 10 | 71.78 | 77.22 | 71.44 | 72.67 | 78.78 | 78.11 |
| 137.9 (20.00 psi) | 1 | 77.44 | 75.11 | 64.00 | 75.44 | 72.89 | 73.22 |
| | 2 | 77.11 | 61.67 | 70.89 | 74.22 | 77.22 | 73.00 |
| | 3 | 77.78 | 75.67 | 77.67 | 76.00 | 64.44 | 71.22 |
| | 4 | 76.78 | 74.44 | 75.33 | 75.89 | 72.56 | 69.56 |
| | 5 | 67.89 | 76.11 | 78.33 | 73.00 | 63.67 | 75.33 |
| | 6 | 77.00 | 58.00 | 56.56 | 69.11 | 59.89 | 78.00 |
| | 7 | 79.56 | 53.22 | 80.89 | 63.33 | 71.11 | 66.67 |
| | 8 | 76.33 | 75.22 | 77.00 | 68.00 | 61.56 | 71.67 |
| | 9 | 73.44 | 76.56 | 61.33 | 55.33 | 72.22 | 69.22 |
| | 10 | 69.44 | 77.11 | 73.33 | 73.89 | 78.00 | 78.56 |
| 172.37 (25.00 psi) | 1 | 78.00 | 74.22 | 63.89 | 77.78 | 70.89 | 73.89 |
| | 2 | 77.89 | 59.11 | 70.67 | 75.00 | 75.33 | 72.89 |
| | 3 | 78.78 | 76.56 | 76.44 | 73.56 | 65.11 | 72.11 |
| | 4 | 76.89 | 74.44 | 73.67 | 73.44 | 71.78 | 69.44 |

**Table A-2 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 5 | 69.67 | 75.44 | 75.44 | 71.89 | 64.78 | 74.89 |
| | 6 | 78.67 | 59.33 | 59.44 | 69.78 | 57.78 | 76.00 |
| | 7 | 79.44 | 54.78 | 76.67 | 63.56 | 71.67 | 69.22 |
| | 8 | 78.44 | 72.67 | 75.89 | 67.44 | 62.56 | 70.78 |
| | 9 | 76.22 | 74.67 | 61.56 | 56.67 | 70.67 | 68.78 |
| | 10 | 71.56 | 76.78 | 72.78 | 71.00 | 77.44 | 77.00 |
| 344.74 (50.00 psi) | 1 | 77.67 | 73.44 | 66.22 | 77.00 | 71.89 | 75.00 |
| | 2 | 75.89 | 75.33 | 61.33 | 73.11 | 76.78 | 75.67 |
| | 3 | 77.22 | 76.78 | 74.11 | 74.67 | 67.56 | 75.00 |
| | 4 | 76.00 | 74.89 | 74.33 | 75.22 | 74.11 | 72.00 |
| | 5 | 64.67 | 76.00 | 77.00 | 74.33 | 67.78 | 73.89 |
| | 6 | 76.89 | 63.00 | 61.33 | 72.11 | 57.89 | 76.78 |
| | 7 | 75.78 | 56.44 | 71.22 | 66.11 | 72.44 | 69.44 |
| | 8 | 76.22 | 74.22 | 75.78 | 64.11 | 65.44 | 73.11 |
| | 9 | 73.89 | 76.22 | 63.89 | 58.00 | 73.22 | 70.33 |
| | 10 | 60.78 | 75.89 | 63.78 | 72.56 | 73.56 | 76.11 |

**Table A-3 Average flow rates of Mister_PS MLD-1PC 25 (ml/min)**

| Pressure (Kpa) | Emitter Locations | Lateral Index | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 5.97 (0.87psi) | 1 | 17.87 | 20.20 | 20.07 | 14.80 | 20.33 | 16.93 |
| | 2 | 17.53 | 14.67 | 20.27 | 16.73 | 17.27 | 15.87 |
| | 3 | 14.60 | 17.27 | 17.40 | 17.93 | 17.93 | 15.80 |
| | 4 | 16.67 | 17.53 | 20.20 | 20.00 | 20.47 | 17.60 |
| | 5 | 20.13 | 18.93 | 18.53 | 20.13 | 15.47 | 16.40 |
| | 6 | 20.33 | 20.20 | 15.80 | 15.93 | 17.40 | 16.60 |
| | 7 | 21.00 | 17.60 | 20.40 | 17.07 | 15.53 | 16.47 |
| | 8 | 17.73 | 19.13 | 18.60 | 17.60 | 15.67 | 17.67 |
| | 9 | 17.93 | 18.87 | 17.27 | 17.60 | 15.13 | 16.27 |
| | 10 | 18.00 | 17.60 | 17.67 | 16.20 | 14.53 | 15.20 |
| 11.94 (1.73 psi) | 1 | 23.60 | 23.60 | 23.93 | 23.67 | 23.73 | 23.60 |
| | 2 | 23.27 | 23.13 | 24.00 | 24.00 | 23.80 | 22.60 |
| | 3 | 23.40 | 22.47 | 23.07 | 22.80 | 24.33 | 22.47 |
| | 4 | 22.80 | 22.53 | 23.80 | 23.73 | 24.20 | 24.67 |
| | 5 | 24.27 | 22.87 | 23.87 | 23.67 | 22.93 | 23.47 |
| | 6 | 24.53 | 23.40 | 24.27 | 24.20 | 24.53 | 23.20 |
| | 7 | 24.60 | 23.67 | 24.33 | 23.93 | 23.07 | 24.07 |

**Table A-3 Continued**

| Pressure Kpa | Emitter Locations | Laterals A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|
| | 8 | 28.07 | 28.40 | 28.07 | 27.33 | 27.87 | 30.53 |
| | 9 | 28.33 | 28.13 | 30.53 | 27.53 | 27.47 | 29.67 |
| | 10 | 28.47 | 27.67 | 27.80 | 26.87 | 27.53 | 26.33 |
| 23.88 (3.46 psi) | 1 | 32.73 | 33.40 | 34.60 | 33.00 | 33.87 | 33.60 |
| | 2 | 32.40 | 32.67 | 34.67 | 32.07 | 32.73 | 31.40 |
| | 3 | 30.40 | 32.07 | 32.67 | 33.13 | 34.33 | 31.20 |
| | 4 | 31.80 | 32.53 | 34.80 | 33.40 | 34.20 | 34.27 |
| | 5 | 33.07 | 32.53 | 34.47 | 35.20 | 32.60 | 32.67 |
| | 6 | 33.13 | 33.07 | 32.27 | 31.47 | 33.93 | 32.33 |
| | 7 | 33.53 | 33.07 | 34.53 | 32.33 | 32.00 | 33.60 |
| | 8 | 32.33 | 33.20 | 34.27 | 34.33 | 31.93 | 34.33 |
| | 9 | 32.73 | 33.27 | 34.80 | 32.00 | 31.87 | 33.33 |
| | 10 | 33.27 | 32.87 | 32.60 | 31.27 | 32.53 | 32.73 |
| 35.82 (5.20 psi) | 1 | 39.89 | 40.44 | 40.67 | 38.44 | 41.67 | 41.44 |
| | 2 | 39.89 | 39.67 | 40.33 | 38.67 | 39.22 | 38.56 |
| | 3 | 39.33 | 38.78 | 39.44 | 38.89 | 40.78 | 38.44 |
| | 4 | 39.00 | 39.00 | 40.56 | 40.44 | 43.33 | 41.78 |
| | 5 | 40.56 | 40.11 | 40.11 | 41.44 | 38.44 | 39.89 |
| | 6 | 41.11 | 40.11 | 36.89 | 37.78 | 42.56 | 39.89 |
| | 7 | 41.67 | 39.78 | 40.67 | 38.78 | 39.11 | 41.44 |
| | 8 | 39.89 | 40.11 | 40.33 | 38.44 | 39.00 | 40.78 |
| | 9 | 40.44 | 40.22 | 43.11 | 39.22 | 38.44 | 40.67 |
| | 10 | 40.78 | 40.22 | 39.89 | 38.00 | 38.89 | 38.56 |
| 55.16 (8.00 psi) | 1 | 50.11 | 52.33 | 51.00 | 51.67 | 52.00 | 50.33 |
| | 2 | 50.44 | 48.67 | 52.56 | 48.33 | 49.33 | 47.11 |
| | 3 | 47.00 | 47.78 | 49.00 | 50.78 | 51.56 | 47.33 |
| | 4 | 47.44 | 51.56 | 51.11 | 52.78 | 52.78 | 50.56 |
| | 5 | 51.89 | 50.33 | 50.22 | 53.44 | 48.33 | 51.33 |
| | 6 | 52.44 | 52.22 | 50.11 | 47.00 | 53.22 | 48.78 |
| | 7 | 56.11 | 50.11 | 51.56 | 47.89 | 49.11 | 49.78 |
| | 8 | 51.00 | 50.22 | 50.11 | 51.11 | 49.11 | 51.67 |
| | 9 | 50.78 | 50.56 | 53.78 | 50.89 | 48.44 | 49.33 |
| | 10 | 52.22 | 49.33 | 49.67 | 47.22 | 50.11 | 49.11 |
| 68.95 (10.00 psi) | 1 | 59.33 | 59.44 | 58.56 | 49.67 | 59.33 | 56.44 |
| | 2 | 57.78 | 56.33 | 59.11 | 53.78 | 55.22 | 56.00 |
| | 3 | 55.33 | 53.89 | 54.78 | 55.56 | 58.33 | 53.22 |
| | 4 | 52.67 | 57.56 | 58.22 | 58.89 | 62.33 | 56.33 |
| | 5 | 60.78 | 56.78 | 59.00 | 58.22 | 54.44 | 57.56 |

**Table A-3 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 6 | 60.56 | 59.33 | 54.33 | 53.78 | 58.00 | 54.44 |
| | 7 | 60.00 | 56.78 | 58.00 | 53.22 | 54.44 | 56.44 |
| | 8 | 56.44 | 60.11 | 58.00 | 55.56 | 54.67 | 57.67 |
| | 9 | 57.11 | 55.56 | 53.33 | 57.78 | 54.11 | 54.67 |
| | 10 | 56.22 | 54.67 | 55.22 | 52.78 | 52.00 | 54.67 |
| 82.74 (12.00 psi) | 1 | 60.67 | 60.56 | 62.44 | 59.00 | 58.56 | 59.22 |
| | 2 | 59.44 | 60.89 | 60.56 | 59.00 | 58.67 | 57.56 |
| | 3 | 59.56 | 57.89 | 58.22 | 58.22 | 61.44 | 57.44 |
| | 4 | 56.78 | 61.78 | 60.11 | 61.33 | 61.11 | 59.44 |
| | 5 | 61.78 | 58.67 | 61.11 | 60.11 | 58.11 | 59.56 |
| | 6 | 60.67 | 61.22 | 58.11 | 57.00 | 60.56 | 59.11 |
| | 7 | 61.56 | 60.56 | 59.00 | 57.78 | 58.56 | 60.44 |
| | 8 | 59.44 | 61.78 | 59.89 | 59.33 | 59.00 | 60.33 |
| | 9 | 61.44 | 61.89 | 62.89 | 61.33 | 58.89 | 60.78 |
| | 10 | 62.11 | 58.67 | 60.89 | 56.89 | 55.67 | 58.00 |
| 96.53 (14.00 psi) | 1 | 65.78 | 67.33 | 68.78 | 60.67 | 70.22 | 64.78 |
| | 2 | 66.11 | 62.67 | 68.67 | 62.56 | 62.67 | 62.11 |
| | 3 | 60.11 | 62.22 | 68.11 | 63.44 | 71.56 | 62.11 |
| | 4 | 61.67 | 67.78 | 67.56 | 70.22 | 70.89 | 63.00 |
| | 5 | 69.89 | 69.89 | 68.22 | 68.56 | 64.00 | 64.00 |
| | 6 | 67.67 | 67.33 | 66.11 | 61.00 | 68.56 | 63.78 |
| | 7 | 68.11 | 68.78 | 68.56 | 61.33 | 62.89 | 68.00 |
| | 8 | 64.33 | 66.33 | 68.11 | 66.78 | 64.56 | 68.44 |
| | 9 | 67.33 | 67.11 | 63.78 | 66.00 | 64.78 | 66.22 |
| | 10 | 66.44 | 63.33 | 62.78 | 60.78 | 62.33 | 62.89 |
| 117.21 (17.00 psi) | 1 | 70.33 | 75.33 | 72.00 | 61.11 | 70.00 | 66.11 |
| | 2 | 70.11 | 64.89 | 73.56 | 66.78 | 64.11 | 66.78 |
| | 3 | 59.56 | 65.56 | 69.89 | 67.67 | 73.44 | 66.22 |
| | 4 | 65.44 | 72.44 | 74.44 | 74.00 | 72.78 | 66.22 |
| | 5 | 75.67 | 71.78 | 71.56 | 71.22 | 67.56 | 66.22 |
| | 6 | 70.89 | 70.22 | 65.44 | 64.78 | 69.89 | 67.78 |
| | 7 | 77.33 | 73.11 | 70.78 | 66.67 | 65.89 | 68.56 |
| | 8 | 68.67 | 70.56 | 77.22 | 67.78 | 67.22 | 69.11 |
| | 9 | 71.56 | 71.44 | 67.11 | 67.22 | 66.89 | 67.78 |
| | 10 | 76.00 | 66.00 | 70.33 | 64.67 | 61.67 | 67.44 |
| 137.9 (20.00 psi) | 1 | 73.67 | 74.11 | 73.89 | 61.89 | 72.33 | 66.33 |
| | 2 | 72.78 | 68.11 | 66.78 | 68.00 | 68.00 | 69.11 |
| | 3 | 61.56 | 66.67 | 65.89 | 69.22 | 75.44 | 69.00 |

**Table A-3 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 4 | 67.78 | 74.33 | 71.89 | 71.78 | 75.44 | 66.33 |
| | 5 | 75.11 | 74.11 | 72.78 | 58.67 | 70.89 | 77.00 |
| | 6 | 74.67 | 75.56 | 67.56 | 66.11 | 67.44 | 72.56 |
| | 7 | 77.89 | 72.11 | 75.56 | 69.56 | 66.67 | 70.44 |
| | 8 | 71.44 | 73.33 | 73.67 | 66.11 | 68.22 | 68.00 |
| | 9 | 69.89 | 72.00 | 67.56 | 66.89 | 68.33 | 68.33 |
| | 10 | 70.22 | 67.78 | 75.44 | 65.00 | 62.56 | 70.67 |
| 158.58 (23.00 psi) | 1 | 74.56 | 74.33 | 77.89 | 70.00 | 74.33 | 69.11 |
| | 2 | 73.44 | 67.67 | 75.67 | 68.89 | 66.22 | 69.22 |
| | 3 | 69.89 | 67.56 | 72.56 | 71.56 | 74.33 | 70.89 |
| | 4 | 67.89 | 71.67 | 75.67 | 78.00 | 79.11 | 68.00 |
| | 5 | 74.89 | 80.44 | 79.33 | 73.67 | 71.00 | 71.11 |
| | 6 | 75.33 | 78.56 | 72.56 | 66.56 | 71.22 | 74.00 |
| | 7 | 75.89 | 77.22 | 74.33 | 70.56 | 67.89 | 70.56 |
| | 8 | 70.00 | 76.33 | 77.78 | 71.44 | 67.00 | 68.56 |
| | 9 | 70.67 | 73.56 | 74.11 | 66.67 | 68.78 | 67.56 |
| | 10 | 73.67 | 73.44 | 73.56 | 66.78 | 68.78 | 73.11 |
| 172.37 (25.00 psi) | 1 | 79.56 | 78.56 | 76.56 | 75.44 | 72.78 | 72.22 |
| | 2 | 79.11 | 77.89 | 73.89 | 75.33 | 72.78 | 71.11 |
| | 3 | 78.89 | 77.67 | 77.33 | 75.56 | 73.22 | 73.33 |
| | 4 | 77.78 | 78.56 | 80.00 | 81.89 | 77.22 | 73.22 |
| | 5 | 78.89 | 81.78 | 77.56 | 73.33 | 73.22 | 74.00 |
| | 6 | 75.67 | 81.44 | 75.33 | 74.44 | 74.78 | 73.22 |
| | 7 | 80.33 | 80.11 | 77.44 | 71.56 | 75.56 | 71.89 |
| | 8 | 74.22 | 80.56 | 77.44 | 72.00 | 74.11 | 72.56 |
| | 9 | 75.56 | 73.67 | 75.89 | 72.33 | 73.33 | 73.33 |
| | 10 | 74.00 | 72.11 | 77.11 | 75.33 | 73.56 | 73.89 |
| 344.74 (50.00 psi) | 1 | 80.33 | 76.33 | 78.33 | 70.78 | 76.67 | 76.78 |
| | 2 | 78.67 | 74.44 | 72.56 | 74.67 | 69.56 | 78.78 |
| | 3 | 71.11 | 71.67 | 70.00 | 79.11 | 75.67 | 78.89 |
| | 4 | 75.56 | 73.44 | 78.22 | 77.33 | 78.67 | 73.11 |
| | 5 | 76.78 | 76.56 | 77.89 | 75.78 | 78.44 | 73.44 |
| | 6 | 80.78 | 81.11 | 73.44 | 71.78 | 78.22 | 79.89 |
| | 7 | 81.00 | 76.44 | 74.22 | 76.44 | 76.22 | 77.33 |
| | 8 | 73.33 | 78.89 | 76.00 | 75.67 | 74.56 | 81.89 |
| | 9 | 81.22 | 74.78 | 75.33 | 69.67 | 76.00 | 74.00 |
| | 10 | 74.00 | 71.56 | 75.78 | 73.33 | 69.11 | 78.44 |

**Table A-4 Average flow rates of Netafim Techline CV 560 050**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| 28.85 (4.33 psi) | 1 | 15.10 | 16.80 | 15.87 | 15.53 | 14.67 | 15.77 |
| | 2 | 15.40 | 16.57 | 15.87 | 15.60 | 14.67 | 15.67 |
| | 3 | 15.27 | 16.90 | 16.23 | 15.53 | 14.80 | 15.67 |
| | 4 | 15.10 | 16.47 | 16.07 | 15.73 | 14.73 | 15.57 |
| | 5 | 15.13 | 16.27 | 15.93 | 15.60 | 14.27 | 15.57 |
| | 6 | 15.07 | 16.43 | 15.73 | 15.20 | 14.77 | 15.70 |
| | 7 | 15.30 | 16.90 | 16.37 | 15.30 | 14.73 | 15.50 |
| | 8 | 15.17 | 16.57 | 15.83 | 15.57 | 14.67 | 15.53 |
| | 9 | 15.33 | 16.33 | 16.50 | 15.60 | 14.57 | 15.67 |
| | 10 | 15.40 | 17.03 | 15.97 | 15.27 | 14.53 | 15.80 |
| 35.85 (5.20 psi) | 1 | 16.57 | 17.10 | 16.33 | 17.03 | 17.17 | 17.10 |
| | 2 | 16.50 | 16.57 | 16.40 | 16.47 | 17.33 | 16.93 |
| | 3 | 16.77 | 17.03 | 16.83 | 16.73 | 17.40 | 17.10 |
| | 4 | 16.47 | 16.60 | 16.67 | 17.03 | 16.43 | 17.17 |
| | 5 | 16.63 | 16.80 | 16.63 | 17.03 | 16.77 | 17.03 |
| | 6 | 16.43 | 16.83 | 16.50 | 16.87 | 17.03 | 17.17 |
| | 7 | 16.13 | 17.10 | 16.87 | 16.77 | 17.60 | 16.87 |
| | 8 | 16.50 | 16.83 | 16.33 | 17.00 | 16.87 | 16.70 |
| | 9 | 16.43 | 16.40 | 16.87 | 16.57 | 17.10 | 17.10 |
| | 10 | 16.23 | 17.00 | 16.53 | 16.90 | 16.87 | 17.00 |
| 55.16 (8.00 psi) | 1 | 16.27 | 18.10 | 16.83 | 17.37 | 17.13 | 17.03 |
| | 2 | 17.03 | 17.57 | 16.60 | 16.63 | 17.33 | 17.47 |
| | 3 | 17.07 | 17.53 | 17.23 | 16.80 | 17.43 | 17.30 |
| | 4 | 16.63 | 17.10 | 17.43 | 17.30 | 16.60 | 17.50 |
| | 5 | 17.17 | 17.73 | 17.33 | 17.37 | 16.93 | 17.53 |
| | 6 | 17.10 | 17.17 | 16.93 | 17.30 | 17.03 | 17.23 |
| | 7 | 16.57 | 17.50 | 17.47 | 17.10 | 17.63 | 17.20 |
| | 8 | 17.17 | 17.17 | 16.70 | 17.30 | 16.97 | 17.00 |
| | 9 | 16.83 | 16.77 | 17.30 | 16.90 | 17.07 | 17.40 |
| | 10 | 16.53 | 17.23 | 16.97 | 17.30 | 16.93 | 17.30 |
| 137.9 (20.00 psi) | 1 | 16.43 | 17.73 | 16.67 | 17.80 | 17.27 | 17.20 |
| | 2 | 17.30 | 17.10 | 16.90 | 16.57 | 17.47 | 17.13 |
| | 3 | 17.03 | 17.63 | 17.27 | 17.10 | 17.33 | 17.47 |
| | 4 | 16.77 | 17.00 | 17.27 | 17.57 | 16.30 | 17.70 |
| | 5 | 17.57 | 17.67 | 17.30 | 17.60 | 16.93 | 17.47 |
| | 6 | 17.10 | 17.20 | 17.03 | 17.37 | 17.70 | 17.40 |
| | 7 | 16.77 | 17.40 | 17.17 | 17.17 | 17.67 | 17.60 |
| | 8 | 17.40 | 17.10 | 16.80 | 17.03 | 16.83 | 16.97 |

**Table A-4 Continued**

| Pressure Kpa | Emitter Locations | Laterals | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| | 9 | 16.80 | 16.57 | 17.20 | 16.60 | 17.33 | 17.83 |
| | 10 | 16.67 | 17.30 | 17.00 | 17.57 | 17.00 | 17.60 |
| 206.84 (30.00 psi) | 1 | 16.00 | 17.70 | 16.80 | 17.80 | 17.67 | 17.50 |
| | 2 | 16.27 | 17.23 | 16.93 | 16.73 | 17.53 | 17.00 |
| | 3 | 16.47 | 17.60 | 17.90 | 16.97 | 17.20 | 17.07 |
| | 4 | 16.47 | 17.13 | 17.17 | 17.30 | 16.60 | 16.60 |
| | 5 | 17.10 | 17.63 | 17.40 | 17.20 | 16.47 | 17.13 |
| | 6 | 17.00 | 17.33 | 17.27 | 17.40 | 17.07 | 17.13 |
| | 7 | 16.43 | 17.73 | 17.27 | 16.90 | 17.70 | 16.77 |
| | 8 | 17.10 | 17.47 | 17.07 | 17.13 | 16.93 | 16.97 |
| | 9 | 17.27 | 17.17 | 17.63 | 16.30 | 17.17 | 16.70 |
| | 10 | 17.13 | 17.93 | 17.40 | 17.57 | 17.30 | 17.23 |
| 344.74 (50.00 psi) | 1 | 17.27 | 18.13 | 17.33 | 17.83 | 16.37 | 17.77 |
| | 2 | 17.53 | 17.73 | 17.77 | 17.27 | 17.17 | 16.60 |
| | 3 | 17.27 | 18.10 | 17.20 | 16.63 | 18.03 | 16.63 |
| | 4 | 17.50 | 17.83 | 17.70 | 17.60 | 16.03 | 17.67 |
| | 5 | 18.13 | 17.80 | 18.10 | 18.17 | 17.13 | 18.17 |
| | 6 | 17.13 | 17.50 | 16.60 | 17.57 | 17.97 | 17.40 |
| | 7 | 17.23 | 17.40 | 17.10 | 18.10 | 17.60 | 17.87 |
| | 8 | 17.30 | 16.20 | 16.30 | 17.20 | 17.73 | 17.40 |
| | 9 | 17.03 | 17.33 | 16.60 | 16.80 | 17.90 | 18.27 |
| | 10 | 17.43 | 17.07 | 16.77 | 18.40 | 16.67 | 18.10 |

**Table A-5 Average flow rates of Toro Drip in PC PCS 1810-18-100 (ml/min)**

| Pressure (Kpa) | Emitter Locations | Lateral Index | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | I |
| 5.97 (0.87psi) | 1 | 22.07 | 20.13 | 23.60 | 20.47 | 26.80 | 20.20 | 21.20 | 20.93 | 21.40 |
| | 2 | 21.13 | 20.20 | 19.13 | 27.40 | 21.47 | 21.40 | 16.80 | 20.33 | 19.87 |
| | 3 | 20.67 | 19.13 | 24.40 | 21.47 | 21.00 | 19.60 | 17.73 | 25.40 | 17.53 |
| | 4 | 18.20 | 20.93 | 23.80 | 20.53 | 20.73 | 19.40 | 24.93 | 20.20 | 17.00 |
| | 5 | 19.53 | 20.60 | 24.53 | 18.33 | 21.00 | 21.47 | 21.33 | 20.33 | 21.40 |
| | 6 | 18.47 | 18.27 | 18.80 | 21.40 | 20.80 | 19.73 | 20.73 | 22.27 | 17.73 |
| | 7 | | 27.73 | 19.27 | 17.00 | 19.27 | 20.20 | 24.47 | | |
| 11.94 (1.73 psi) | 1 | 32.67 | 29.75 | 35.00 | 29.33 | 37.50 | 28.17 | 30.83 | 30.67 | 31.75 |
| | 2 | 30.17 | 29.17 | 29.33 | 30.58 | 32.33 | 30.25 | 24.33 | 29.67 | 29.42 |
| | 3 | 30.42 | 27.25 | 34.50 | 30.67 | 30.75 | 27.42 | 25.83 | 33.92 | 26.25 |
| | 4 | 26.33 | 29.83 | 33.08 | 29.58 | 30.58 | 27.58 | 34.33 | 30.00 | 25.67 |
| | 5 | 34.83 | 29.75 | 33.50 | 25.67 | 30.92 | 30.33 | 31.08 | 29.50 | 33.17 |
| | 6 | 26.83 | 26.42 | 28.92 | 30.25 | 37.17 | 27.67 | 30.17 | 33.00 | 27.17 |

**Table A-5 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | I |
| | 7 | | 30.42 | 29.75 | 24.50 | 30.58 | 28.33 | 31.00 | | |
| 17.91 (2.60 psi) | 1 | 37.63 | 33.13 | 39.63 | 34.79 | 38.46 | 31.67 | 35.46 | 37.96 | 39.00 |
| | 2 | 33.04 | 34.04 | 34.71 | 41.08 | 33.83 | 34.50 | 28.17 | 36.50 | 36.67 |
| | 3 | 33.04 | 31.54 | 39.67 | 35.00 | 33.04 | 30.58 | 29.92 | 38.42 | 32.42 |
| | 4 | 29.29 | 34.88 | 37.63 | 34.88 | 32.67 | 31.50 | 38.08 | 37.17 | 31.58 |
| | 5 | 37.92 | 34.71 | 41.29 | 30.79 | 33.00 | 34.83 | 36.25 | 36.54 | 39.42 |
| | 6 | 29.33 | 31.54 | 34.83 | 36.71 | 40.08 | 30.83 | 35.29 | 40.13 | 33.17 |
| | 7 | | 40.67 | 34.83 | 29.04 | 37.25 | 32.96 | 36.58 | | |
| 23.88 (3.46 psi) | 1 | 44.58 | 43.50 | 46.50 | 42.92 | 49.33 | 40.00 | 44.50 | 45.08 | 46.83 |
| | 2 | 43.00 | 42.83 | 42.83 | 45.42 | 45.00 | 43.17 | 35.67 | 43.92 | 44.42 |
| | 3 | 43.75 | 39.67 | 40.67 | 45.92 | 42.42 | 39.42 | 37.75 | 44.25 | 39.50 |
| | 4 | 37.92 | 43.92 | 40.92 | 43.58 | 43.25 | 39.33 | 46.83 | 45.17 | 38.08 |
| | 5 | 44.75 | 34.33 | 44.17 | 38.25 | 43.58 | 44.25 | 45.75 | 43.58 | 46.92 |
| | 6 | 39.33 | 39.92 | 42.75 | 44.67 | 48.67 | 39.08 | 44.33 | 49.17 | 39.92 |
| | 7 | | 46.50 | 43.83 | 37.25 | 43.08 | 40.83 | 38.50 | | |
| 35.82 (5.20 psi) | 1 | 55.67 | 53.44 | 54.22 | 51.67 | 57.67 | 49.56 | 55.11 | 55.89 | 56.89 |
| | 2 | 52.33 | 52.67 | 52.67 | 54.22 | 55.89 | 53.44 | 44.11 | 53.22 | 53.11 |
| | 3 | 54.11 | 49.22 | 49.89 | 54.33 | 52.22 | 49.00 | 46.89 | 52.78 | 47.67 |
| | 4 | 47.22 | 53.89 | 49.22 | 52.22 | 53.11 | 49.11 | 54.44 | 55.67 | 46.22 |
| | 5 | 53.89 | 40.56 | 54.33 | 45.89 | 53.89 | 54.89 | 56.22 | 53.33 | 55.56 |
| | 6 | 48.67 | 49.33 | 52.00 | 54.00 | 58.89 | 48.89 | 55.11 | 60.22 | 48.22 |
| | 7 | | 55.11 | 54.00 | 45.11 | 55.00 | 51.11 | 49.00 | | |
| 55.16 (8.00 psi) | 1 | 66.00 | 64.22 | 66.11 | 63.67 | 68.67 | 59.56 | 66.78 | 68.22 | 67.89 |
| | 2 | 64.44 | 63.67 | 64.11 | 66.67 | 66.11 | 63.78 | 54.11 | 65.33 | 63.33 |
| | 3 | 66.78 | 60.22 | 60.22 | 66.67 | 61.33 | 58.56 | 57.33 | 64.44 | 57.78 |
| | 4 | 58.22 | 65.78 | 58.33 | 64.33 | 63.33 | 58.33 | 66.11 | 67.89 | 56.56 |
| | 5 | 66.11 | 52.67 | 66.78 | 55.33 | 63.56 | 66.44 | 67.89 | 65.22 | 66.78 |
| | 6 | 60.22 | 60.11 | 63.78 | 66.56 | 68.00 | 58.44 | 66.67 | 73.56 | 58.11 |
| | 7 | | 67.33 | 66.67 | 55.22 | 63.89 | 61.00 | 59.78 | | |
| 62.05 (9.00 psi) | 1 | 62.56 | 67.11 | 68.78 | 67.44 | 73.56 | 63.56 | 70.89 | 72.22 | 71.22 |
| | 2 | 68.89 | 68.00 | 66.11 | 70.44 | 69.78 | 68.11 | 57.00 | 69.56 | 67.00 |
| | 3 | 60.44 | 62.33 | 62.56 | 69.56 | 65.89 | 63.11 | 60.89 | 68.22 | 59.11 |
| | 4 | 67.89 | 68.33 | 60.44 | 68.33 | 67.00 | 61.22 | 69.22 | 71.11 | 60.56 |
| | 5 | 67.11 | 54.78 | 68.89 | 58.11 | 67.11 | 72.11 | 70.89 | 67.89 | 70.78 |
| | 6 | 67.78 | 62.44 | 65.33 | 68.78 | 74.89 | 62.89 | 69.56 | 77.33 | 63.33 |
| | 7 | | 70.22 | 68.89 | 58.44 | 68.78 | 66.78 | 61.89 | | |
| 68.95 (10.00 psi) | 1 | 69.78 | 67.78 | 71.00 | 70.33 | 74.78 | 63.67 | 75.00 | 75.22 | 72.44 |
| | 2 | 69.67 | 69.22 | 66.78 | 71.78 | 70.78 | 70.11 | 59.67 | 72.33 | 67.89 |

**Table A-5 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | I |
| | 3 | 70.33 | 64.22 | 64.33 | 70.67 | 67.89 | 65.44 | 63.33 | 69.78 | 59.11 |
| | 4 | 61.78 | 68.56 | 65.11 | 67.00 | 68.89 | 61.56 | 72.44 | 72.78 | 61.22 |
| | 5 | 71.00 | 68.89 | 69.00 | 63.44 | 68.67 | 73.78 | 72.67 | 71.33 | 72.56 |
| | 6 | 68.33 | 63.11 | 67.89 | 67.89 | 77.89 | 63.11 | 71.78 | 68.89 | 64.78 |
| | 7 | | 71.00 | 71.22 | 65.67 | 73.22 | 68.33 | 62.56 | | |
| 82.74 (12.00 psi) | 1 | 63.78 | 68.33 | 72.44 | 72.44 | 73.00 | 65.44 | 72.78 | 76.22 | 71.89 |
| | 2 | 69.56 | 72.00 | 67.44 | 72.11 | 70.00 | 70.22 | 57.89 | 73.89 | 67.67 |
| | 3 | 61.11 | 63.67 | 65.22 | 71.11 | 67.00 | 65.56 | 63.11 | 69.89 | 58.78 |
| | 4 | 67.56 | 69.67 | 65.56 | 68.44 | 68.89 | 61.56 | 71.33 | 71.33 | 63.78 |
| | 5 | 69.22 | 54.22 | 69.67 | 62.22 | 70.89 | 75.67 | 73.44 | 68.56 | 74.00 |
| | 6 | 71.78 | 63.44 | 68.11 | 67.33 | 78.67 | 64.56 | 69.44 | 80.78 | 66.44 |
| | 7 | | 72.44 | 72.33 | 65.44 | 69.67 | 69.89 | 61.89 | | |
| 96.53 (14.00 psi) | 1 | 64.22 | 66.11 | 72.44 | 72.00 | 75.89 | 67.00 | 70.56 | 74.33 | 68.78 |
| | 2 | 76.22 | 71.44 | 67.56 | 72.89 | 70.78 | 69.67 | 56.00 | 72.00 | 64.89 |
| | 3 | 60.22 | 64.33 | 66.22 | 68.67 | 66.89 | 64.44 | 60.89 | 66.44 | 56.11 |
| | 4 | 67.67 | 70.22 | 62.78 | 73.56 | 68.67 | 60.22 | 69.33 | 68.00 | 60.56 |
| | 5 | 68.00 | 53.89 | 70.22 | 56.89 | 65.89 | 74.67 | 70.89 | 66.22 | 71.00 |
| | 6 | 71.44 | 63.44 | 65.11 | 70.00 | 77.22 | 61.78 | 65.11 | 76.78 | 64.67 |
| | 7 | | 73.33 | 72.22 | 59.78 | 70.56 | 69.44 | 59.89 | | |
| 117.21 (17.00 psi) | 1 | 62.11 | 64.56 | 67.89 | 70.11 | 73.33 | 58.33 | 72.33 | 73.33 | 69.11 |
| | 2 | 68.67 | 68.67 | 65.33 | 70.67 | 67.89 | 66.44 | 55.89 | 72.44 | 66.22 |
| | 3 | 59.00 | 62.33 | 64.11 | 66.78 | 65.00 | 63.67 | 60.67 | 67.11 | 60.44 |
| | 4 | 65.00 | 69.11 | 65.33 | 71.89 | 65.11 | 59.44 | 68.89 | 68.11 | 60.33 |
| | 5 | 68.11 | 52.67 | 69.56 | 56.11 | 63.00 | 71.11 | 71.33 | 66.78 | 71.22 |
| | 6 | 70.56 | 63.00 | 61.78 | 68.44 | 73.11 | 61.00 | 65.89 | 75.67 | 64.22 |
| | 7 | | 69.89 | 70.11 | 58.78 | 67.56 | 66.78 | 59.78 | | |
| 137.9 (20.00 psi) | 1 | 68.33 | 65.78 | 68.11 | 66.78 | 70.67 | 62.56 | 69.56 | 70.00 | 67.00 |
| | 2 | 67.22 | 69.44 | 62.11 | 68.67 | 66.22 | 67.00 | 56.78 | 70.56 | 63.78 |
| | 3 | 66.11 | 62.33 | 63.89 | 66.22 | 59.67 | 63.22 | 60.33 | 64.33 | 56.67 |
| | 4 | 59.22 | 67.44 | 61.33 | 67.00 | 66.44 | 60.44 | 68.44 | 67.78 | 59.56 |
| | 5 | 68.22 | 55.22 | 65.56 | 54.89 | 68.11 | 73.67 | 69.00 | 63.67 | 69.67 |
| | 6 | 64.11 | 63.67 | 58.33 | 66.89 | 72.00 | 61.89 | 64.89 | 76.11 | 63.00 |
| | 7 | | 69.11 | 69.22 | 57.67 | 68.33 | 67.00 | 60.33 | | |
| 206.84 (30.00 psi) | 1 | 69.11 | 67.44 | 71.00 | 67.11 | 73.56 | 61.56 | 74.22 | 69.00 | 72.00 |
| | 2 | 70.00 | 70.22 | 67.56 | 67.67 | 64.67 | 68.44 | 61.78 | 70.00 | 67.11 |
| | 3 | 67.56 | 64.56 | 67.00 | 68.78 | 59.89 | 58.67 | 58.67 | 66.89 | 60.11 |
| | 4 | 56.44 | 66.00 | 64.67 | 71.67 | 68.22 | 63.00 | 64.11 | 69.44 | 67.11 |
| | 5 | 69.89 | 67.44 | 68.67 | 60.00 | 69.11 | 66.00 | 65.67 | 63.11 | 72.00 |

**Table A-5 Continued**

| Pressure (Kpa) | Emitter Locations | Laterals | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | I |
| | 6 | 64.78 | 65.78 | 59.22 | 69.33 | 75.44 | 61.78 | 69.00 | 75.67 | 66.67 |
| | 7 | | 68.11 | 70.22 | 63.11 | 70.22 | 68.56 | 63.33 | | |
| 344.74 (50.00 psi) | 1 | 68.44 | 66.67 | 68.33 | 69.00 | 64.78 | 62.00 | 70.67 | 70.11 | 66.00 |
| | 2 | 65.78 | 67.67 | 65.33 | 67.22 | 55.44 | 66.56 | 61.33 | 71.22 | 64.67 |
| | 3 | 66.89 | 66.78 | 65.89 | 68.33 | 56.89 | 65.89 | 65.22 | 65.22 | 60.56 |
| | 4 | 52.22 | 65.67 | 64.44 | 65.00 | 68.33 | 61.56 | 63.44 | 67.11 | 60.56 |
| | 5 | 70.67 | 60.56 | 61.89 | 59.33 | 63.33 | 70.56 | 69.00 | 66.22 | 66.00 |
| | 6 | 65.89 | 61.78 | 58.78 | 63.22 | 66.56 | 59.44 | 63.00 | 70.33 | 64.11 |
| | 7 | | 62.11 | 72.89 | 64.56 | 69.44 | 62.67 | 56.67 | | |

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