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# DEVELOPMENT OF A SOFTWARE TO DETERMINE THE EMITTER CHARACTERISTICS AND THE OPTIMUM LENGTH OF NEW DESIGNED DRIP IRRIGATION LATERALS

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**Abstract-** An appropriate design of a drip irrigation system in order to increase the uniformity of water distribution with a high efficiency is of importance. The first step for the design is the determination of suitable length of laterals. In order to do this, the emitter characteristics and the friction losses of new designed laterals on which the emitters are placed must be known by laboratory experiments. On the other hand, mathematical models developed can also be used for the determination of friction losses in drip irrigation laterals.

In this study, a software in Visual Basic 6.0 programming language was developed and it helps analyzing the data from a new designed emitter in order to find out the main characteristics and friction losses and to obtain the optimum lateral length of the lateral in the shortest time with an acceptable accuracy in. The software included several options for the selection of in-line or on-line emitter type, pressure compensating or non-pressure compensating emitters. The software calculates the optimum lateral length based on the measurement and model equations and utilizes the step by step procedure. Optimum lateral length criterias in the software such as $C_u$ and $q_{var}$ for non-pressure compensating emitter and lateral end pressure for compensating emitter were used.

The comparison of optimum lateral lengths indicated a very good agreement between the experimentally obtained results and the results from the use of mathematical models for different criteria and different slope conditions. The differences in optimum lateral lengths between the experimental and calculated values obtained from the mathematical models ranged between -0.4 and 0.7%.
**Key Words-** Drip irrigation, uniform water distribution, optimum lateral length

## 1. INTRODUCTION

Drip irrigation is a technique that enables us to save water and energy while economical, less laborious and more efficient irrigation can be achieved. The success of drip irrigation is possible if the system is appropriately designed and managed. The first step in the design of drip irrigation system is to determine the optimum lateral lengths that will allow equal water distribution along the laterals. The characteristics emitters and the friction losses along the lateral for a new produced drip irrigation lateral are the main data for optimum lateral lengths.

There are significant differences in finding the frictional losses between the theoretical calculations using both the Darcy-Weisbach or Hazen-Williams equations and the data obtained in the laboratory [1], [2], [3]. For this reason, researchers try to attain the data in the laboratory and to determine the friction losses [4], [5], [6]. In addition to these, some studies using dimensional analysis were carried out recently in order to develop some empirical models for predicting the friction losses [7], [8], [9], [10]. The developed models in these studies help predicting the friction losses with high accuracy while they save time and labor since to determine the characteristics and the friction losses of a recently designed emitter and to find out the optimum lateral length.

There is already available software in the market for designing drip irrigation systems. However, there is no software in order to determine of technical properties of a new design emitter and lateral pipe based on experimental data. Hence, the objective of this study was to develop software that helps analyzing the data from a recently designed emitter in order to find out the main characteristics for emitters and friction losses in lateral between two emitters and to obtain the optimum lateral length in the shortest time with an acceptable accuracy.

## 2. MATERIAL AND METHODS

In this study, software called DRIPMOD was developed and written in Visual Basic 6.0 programming language. The flow chart of the software is given in Figure 1. The program was tested and verified against the data obtained in the test lab of the Department of Agricultural Machinery, Faculty of Agriculture at Ege University.

### 2.1. Determination of emitter properties

In general, the pressure and flow rate relationship of the emitter was described as,

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

where q is the emitter discharge rate (L $h^{-1}$) H is operating pressure (bar), k is emitter coefficient, and x is exponent depend on emitter characteristics [6], [11], [12].

In this section of the program, the k and x coefficients are calculated by regression analysis module based on the emitter flow data (the amount of water collected in certain time at the experiment) at a selected pressure. Additionally, the coefficient of manufacturing variation ($V_m$) of emitters is determined by using equation (2).

$$V_m = Sq / \bar{q} \tag{2}$$

where standard deviation of the flow rates (Sq) and the mean emitter flow rate ($\bar{q}$) [6], [11], [13]. Based on the value of $V_m$, the rank of the emitter based on ASAE standards [14] is determined.

### 2.2. Determination of the friction loss between two emitters based on the experimental measurements

As a first step, coefficients and constants of friction loss equation are achieved in order to determine the optimum lateral lengths based on the experimental measurements.

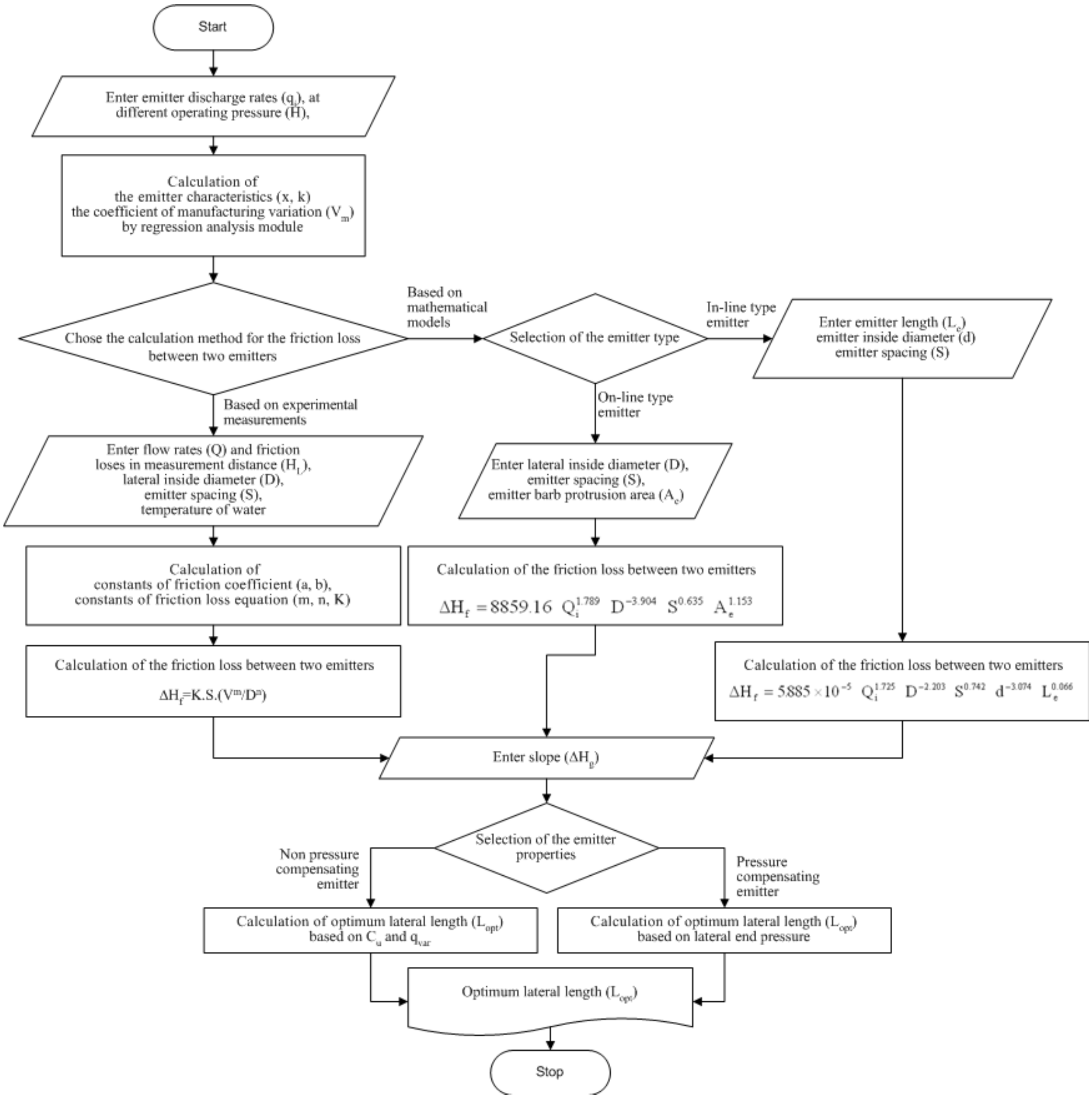



Figure 1. Flow chart of the software

The friction coefficient in Darcy-Weisbach equation is characterized by the Blasius equation for turbulent flow as [1], [5], [19];

$$f = 0.3164\, R_e^{-0.25} \qquad (4\,000 \le R_e \le 100\,000) \qquad (3)$$

As described in the introduction, drip irrigation laterals are not frictionless and cannot be assumed they are. Hence, the use of the Blasius equation is in error and for this reason, the friction coefficient and Reynolds number relationship is given below;

$$f = a\, Re^b = a \left( \frac{V\, D}{\nu} \right)^b \qquad (4)$$

where, a and b are the constants for given pipe size and flow regime; D is the pipe inside diameter in m; V is the velocity in m $s^{-1}$ and $\nu$ is the kinematic viscosity of water in $m^2\, s^{-1}$.

The coefficients a and b as given in the above equation is calculated by software for each irrigation pipe equipped with emitters at a specific spacing so that an equation for the friction losses can be developed. The friction loss ($\Delta H_f$) for the emitter spacing (S) can be written as;

$$\Delta H_f = \frac{a}{2g\,\nu^b} S \frac{V^{2+b}}{D^{1-b}} \tag{5}$$

where, g is the acceleration of gravity i.e. 9.81 m $s^{-2}$.
Assuming,

$$K = \frac{a}{2g\,\nu^b}\ ,\ m = 2+b \quad \text{and} \quad n = 1-b$$

Then, equation (5) can be simplified as;

$$\Delta H_f = K\,S\,\frac{V^m}{D^n} \tag{6}$$

where, $\Delta H_f$ is the friction loss between emitter i and emitter (i–1) in m; K is the constant; S is the emitter spacing in m; V is the velocity between emitter i and emitter i–1 in m $s^{-1}$; D is the lateral inside diameter in m.

For the calculations, the necessary variables such as lateral inside diameter in mm, emitter spacing in cm, measurement distance of the friction losses in m and the water temperature in Celsius degrees are entered. Using these values, the software calculates the K, m and n constants and employes these constants in the equation (6) results in $\Delta H_f$.

**2.3. Determination of the friction losses between two emitters based on the mathematical models**

The predictions of the friction losses between two emitters can also be made possible without testing friction losses in the laboratory by using the mathematical models. For this purpose, the models for in-line and on-line emitters developed by Demir et al. [9] was used in the software.

The friction loss model for between two emitters for in-line emitters is given below and it accounts for 98.53% of the variation in the data.

$$\Delta H_f = 5.885 \times 10^{-5}\ Q_i^{1.725}\ D^{-2.203}\ S^{0.742}\ d^{-3.074}\ L_e^{0.066} \tag{7}$$

where, $\Delta H_f$ is the friction loss in emitter spacing in m; $Q_i$ is the flow rate in lateral section in $m^3 s^{-1}$; D is the pipe inside diameter in m; S is the emitter spacing in m; d is the emitter inside diameter in m and $L_e$ is the emitter length in m.

The in-line friction loss model is valid for the following ranges; $0.2 \le S \le 1$ m, $12.53 \le D \le 13.77$ mm, $11.33 \le d \le 12.05$ mm, $31.53 \le L_e \le 68.68$ mm and $3591 \le R_e \le 23688$.

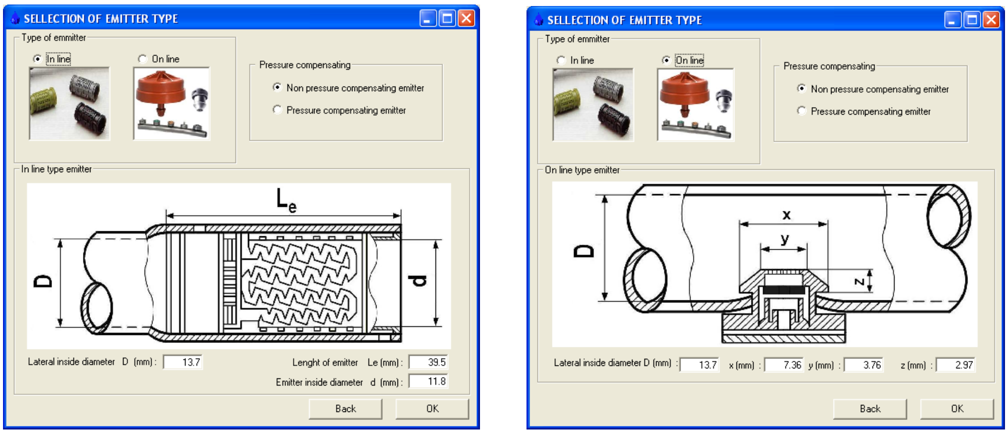
The friction loss model for between two emitters for on-line emitters is given below and this model accounts for 98.76% of the variation in the data.

$$\Delta H_f = 8859.16\ Q_i^{1.789}\ D^{-3.904}\ S^{0.635}\ A_e^{1.153} \tag{8}$$

where, $A_e$ is the emitter barb protrusion area ($A_e=(x+y)z/2$) in $m^2$ (Fig. 2b).

The on-line friction loss model is valid for $0.2 \le S \le 1$ m, $12.01 \le D \le 13.68$ mm, $27.51 \le A_e \le 36.06$ $mm^2$ and $4047 \le R_e \le 22215$.

As mentioned above, the software developed requires the selection of the emitter type as either in-line or on-line and this is achieved through the user interface (Fig. 2a, 2b)




(a) (b)

Figure 2. User interface window for sellection of emitter type (a: in line) (b: on line)

## 2.4. Determination of optimum lateral lengths

Drip irrigation laterals are not only smooth pipes but also have multiple outlets depending upon the emitter type and spacing. Since emitters discharge water along the lateral line, the total flow rate decreases and the pressure changes in the lateral line with respect to the length (Fig. 3). For this reason, pressure and flow rate relations are considered in order to determine the optimum lateral lengths and water distribution uniformity from the emitters along the lateral.

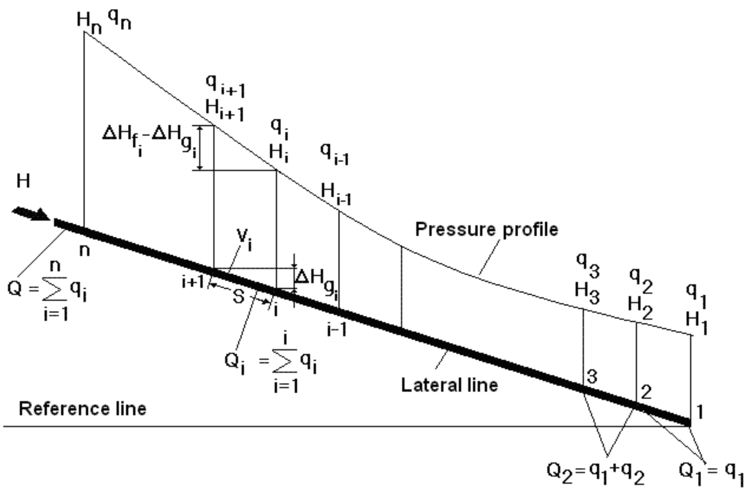



Figure 3. The pressure and flow rate distribution along the drip irrigation lateral line

The emitter flow rates along the lateral for each emitter are found by the following equation;

$$q_i = kH_i^x \tag{9}$$

In equation $q_i$ is the flow rate in emitter i in L $h^{-1}$ and the inlet pressure $H_i$ in the above equation is calculated as;

$$H_i = H_{i-1} + \Delta H_f \pm \Delta H_g \quad (10)$$

where, $H_i$ is the inlet pressure in $i^{th}$ emitter in m; $H_{i-1}$ is the inlet pressure in emitter i-1 in m; $\Delta H_f$ is the friction loss between emitter i and emitter i-1 in m; $\Delta H_g$ is the elevation between emitter i and emitter i-1 in m.

In the above calculations, the positive sign of $\Delta H_g$ indicates the uphill slope whereas the minus sign indicates the downhill. No effect of $\Delta H_g$ is taken into account where the slope is zero. In the calculations, the type of emitter and its features, the diameter of the laterals, slope and the flow conditions are considered.

Design criterias are computed simultaneously by the software. Several criterias are used to calculate the optimum length of the laterals in order to obtain uniform water distribution.

One of the criteria used for this purpose is the uniformity coefficient ($C_u$) as defined by Christiansen [15] for sprinkler irrigation and defined as:

$$C_u = 100\left(1 - \frac{\overline{\Delta q}}{\bar{q}}\right) \quad (11)$$

where, $\overline{\Delta q}$ is the mean absolute deviations from the mean emitter flow rate and $\bar{q}$ is the mean emitter flow rate [15], [11], [16].

Another criteria is emitter flow variation ($q_{var}$) and it is defined as [11], [17]:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} 100 \quad (12)$$

where, $q_{max}$ and $q_{min}$ are the maximum and minimum emitter flow along the line, respectively.

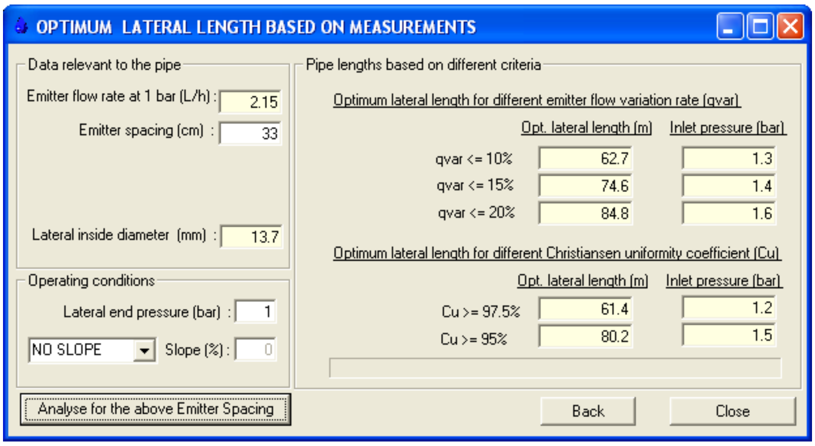
Several researchers suggest a uniformity coefficient of about 97.5% be equal a $q_{var}$ of 10%, and a uniformity coefficient of about 95% be equal a $q_{var}$ of 20% [18], [11], [17].

At this point, the pressure compensating or non-pressure compensating emitter option is selected. Depending upon this selection, the flow direction of the computations in order to determine the optimum lateral length changes (Figure 1)

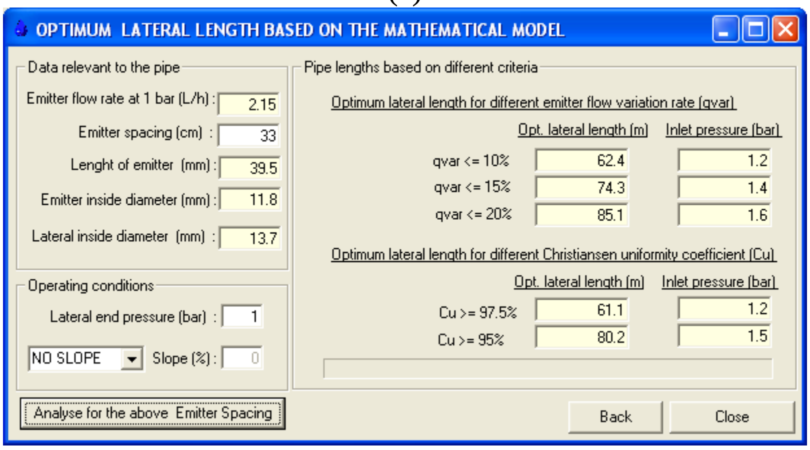
The friction losses in sequential emitters placed on the lateral are calculated at different lateral end pressure and slopes by using pressure-flow rate and friction loss equations. At the same time, the software calculates the optimum lateral length based on the measurement and model equations and utilizes the step by step procedure is followed in order to meet the limitations that $C_u \geq 97.5\%$ and $C_u \geq 95\%$ or $q_{var} \leq 10\%$, $q_{var} \leq 15\%$ and $q_{var} \leq 20\%$ (Fig. 4a, 4b).

In case of using pressure compensating emitters, the emitter flow rates become nearly constant along the irrigation line but pressure varies due to friction losses. For this reason, the pressure values at the start and the end of the lateral instead of $C_u$ and $q_{var}$ were considered.

The initial pressure at the inlet of the lateral can be calculated since the necessary calculations for the pressure of the emitters and emitter flow rates in sequential order can be made. The optimum lateral length calculations for the pressure compensating (PC) emitters differ since the inlet and outlet pressure instead of $C_u$ and $q_{var}$ values are needed.




(a)

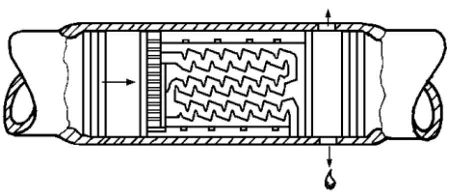



(b)

Figure 4. User interface window for the optimum lateral length based on the measurement (a) and model (b)

## 3. RESULTS AND DISCUSSION

Using the develop software, the necessary calculations in order to obtain the optimum lateral length of a new designed in-line emitter and lateral pipe are explained with an example. The calculated optimum lateral length results from experimental data and mathematical model are compared with each other. The technical properties of new produced emitter and lateral pipe used in this example are given in Fig. 5.



**Pipe Properties**

| | | |
|---|---|---|
| Pipe inside diameter (D) | : | 13.7 mm |
| Pipe thickness | : | 1.0 mm |

**Emitter Properties**

| | | |
|---|---|---|
| Emitter spacing (S) | : | 33.0 cm |
| Emitter length (Le) | : | 39.5 mm |
| Emitter inside diameter (d) | : | 11.8 mm |
| Emitter outside dimater | : | 16.0 mm |

Figure 5. Technical properties of new designed in-line emitter and lateral pipe

As a first step for the example, the amount of water collected in certain time at the experiment at a selected pressure in order to determine the technical properties of the new emitter are given in Table 1 and the data are then analyzed by using the developed software.

Table 1. Flow rate test results for a new designed emitter at different operating pressures

| Operating pressure $H_i$ (bar) | The amount of water collected in 6 minutes (ml) | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| 0.5 | 154 | 154 | 158 | 156 | 165 | 157 | 155 | 154 | 152 | 156 | 158 | 157 | 152 | 151 | 151 | 168 | 165 | 157 | 162 | 158 | 157 |
| 1.0 | 207 | 205 | 207 | 208 | 216 | 207 | 206 | 201 | 203 | 207 | 208 | 208 | 205 | 202 | 201 | 208 | 218 | 203 | 210 | 211 | 206 |
| 1.5 | 253 | 261 | 268 | 262 | 274 | 263 | 263 | 257 | 255 | 263 | 265 | 260 | 265 | 262 | 259 | 260 | 275 | 264 | 266 | 270 | 263 |
| 2.0 | 298 | 295 | 300 | 300 | 312 | 300 | 300 | 293 | 290 | 300 | 298 | 300 | 290 | 295 | 293 | 300 | 308 | 300 | 298 | 300 | 298 |
| 2.5 | 338 | 335 | 340 | 340 | 352 | 340 | 340 | 333 | 330 | 340 | 338 | 340 | 330 | 335 | 333 | 340 | 348 | 340 | 338 | 340 | 338 |

The results obtained from the analysis, average emitter flow rate was computed 2.15 L $h^{-1}$ at an operating pressure of 1 bar.. The k value and x coefficient are 2.1481 and 0.4806, respectively while the coefficient of manufacturing variation ($V_m$) is found to be 0.0207 for the same type 21 emitters at 5 different pressures. In this case, the emitter is ranked excellent since $V_m$<0.5. The coefficient of determination ($R^2$) is calculated to be 98.90 %.

In the second step, friction loss measurements in order to determine the friction losses between two emitters at different discharges at a measurement distance of 6 m in the laboratory were achieved The results from the measurements are given in Table 2 and used for further analysis by the developed software.

Table 2. Friction loss test results of a new designed lateral

| Number of runs | Discharge (L $s^{-1}$) | Friction loss (m) | Number of runs | Discharge (L $s^{-1}$) | Friction loss (m) |
|---|---|---|---|---|---|
| 1 | 0.0732 | 0.29 | 10 | 0.1735 | 1.35 |
| 2 | 0.0982 | 0.51 | 11 | 0.1827 | 1.48 |
| 3 | 0.1085 | 0.61 | 12 | 0.1854 | 1.52 |
| 4 | 0.1181 | 0.72 | 13 | 0.1952 | 1.66 |
| 5 | 0.1275 | 0.81 | 14 | 0.2033 | 1.77 |
| 6 | 0.1372 | 0.91 | 15 | 0.2167 | 1.99 |
| 7 | 0.1447 | 1.01 | 16 | 0.2251 | 2.14 |
| 8 | 0.1534 | 1.11 | 17 | 0.2391 | 2.39 |
| 9 | 0.1624 | 1.23 | 18 | 0.0547 | 0.17 |

According to the experiment results, for an irrigation pipe with an inner diameter of 13.7 mm and equipped with in-line emitters at equally spaced at 33 cm the coefficient a and b are found to be 0.4182 and –0.2322, respectively, and the determination of coefficient is 94.97%. Based on the experiments, the coefficient m, n and K are 1.7678, 1.2322 and 0.00086256, respectively. Using these values, optimum lateral length results based on experimental data are given in Fig. 4.a (lateral end pressure is assumed to be 1 bar). and the optimum lateral lengths of pipe is 62.7, 74.6 and 84.8 m for $q_{var}$≤10%,

$q_{var}$≤15% and $q_{var}$≤20%, respectively. The optimum lateral lengths that meet the conditions of $C_u$≥97.5% ve $C_u$ ≥95% are also found to be 61.4 and 80.2 m.

The results by using in-line mathematical model for the same drip irrigation pipe are given in Fig. 4.b. The optimum lateral length of pipe was computed to be 62.4, 74.3 and 85.1 m for 10%, 15% and 20% emitter flow variations, respectively. The optimum lateral lengths that meet the conditions of uniformity coefficients are also found to be 61.1 and 80.2 m.

Using the developed software, optimum lateral lengths for different criterias and slope conditions were computed by using experimental data and in-line model equation and results are given in Table 3.

Table 3. Optimum lateral length for different criterias and different slope condition

| Result type | Criteria | Optimum lateral length (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | No slope | Up slope (%) | | | Down slope (%) | | |
| | | 0 | 1 | 2 | 3 | 1 | 2 | 3 |
| Based on Experimental data | $q_{var}$≤10% | **62.7** | 67.7 | 71.9 | 75.9 | 56.8 | 51.5 | 46.2 |
| | $q_{var}$≤15% | **74.6** | 78.9 | 82.8 | 86.8 | 69.3 | 64.4 | 59.7 |
| | $q_{var}$≤20% | **84.8** | 89.1 | 92.7 | 96.4 | 80.2 | 75.6 | 71.3 |
| | Cu≥97.5% | **61.4** | 67 | 72.9 | 78.5 | 55.8 | 50.2 | 45.2 |
| | Cu≥95% | **80.2** | 84.8 | 89.4 | 94.4 | 75.6 | 71.3 | 67 |
| Based on Model | $q_{var}$≤10% | **62.4** | 67.7 | 71.9 | 76.2 | 56.4 | 51.2 | 45.9 |
| | $q_{var}$≤15% | **74.3** | 78.9 | 83.2 | 86.8 | 69.3 | 64.4 | 59.4 |
| | $q_{var}$≤20% | **85.1** | 89.4 | 93.1 | 96.7 | 80.2 | 75.6 | 71.3 |
| | Cu≥97.5% | **61.1** | 66.7 | 72.6 | 78.5 | 55.4 | 49.8 | 44.9 |
| | Cu≥95% | **80.2** | 84.8 | 89.8 | 94.4 | 75.6 | 71.3 | 67 |

The comparison of optimum lateral lengths indicates a very good agreement between the experimentally obtained results and the results from the use of mathematical models for different criterias and different slope condition. The differences in optimum lateral legths between the experimental and calculated values obtained from the mathematical models range between -0.4 and 0.7%.

## 4. CONCLUSIONS

In this study, the software called DRIPMOD was developed in Visual Basic 6.0 programming language. The software enables one to analyze the emitter related data obtained in the laboratory and allows determining the emitter characteristics and friction losses and optimum lateral length in a short time accurately.

The software also uses the models available in the literature and based on the emitter type and helps predicting the friction losses and optimum lateral lengths without a need for experimental data.

It is believed that the software developed in this study will help manufacturers and engineers in finding the characteristics of the emitters and optimum lateral lengths in a short time with certain accuracy.

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