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Assessment of drip lateral design methods based on uniformity coefficient

J. Ramachandran*, V. Ravikumar and R. Lalitha

Department of Soil and Water Conservation Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, Trichy-621 712, Tamil Nadu, India.
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ABSTRACT
In this paper, six drip lateral design methods were selected and a comparative assessment was done to find its practical applicability for finding accurate uniformity coefficient. Step-By-Step (SBS) method, Differential method (DM), Constant Discharge method (CDM), Variable discharge method (VDM), Outlet variation method (OVM) and Statistical method (STM) were the different methods assessed. The percentage relative error in calculating the uniformity coefficient by different methods were obtained as the difference between step-by-step method (true) value and alternate method (observed) value. These errors were tabulated. VDM and OVM method performed well with equal accuracy to SBS method at different slopes. For L=250m, DM method performed well. The STM performed good for down slope and lateral length of 250m with 6 per cent relative error. The method having lesser relative percentage error can be selected by the design engineers for designing the laterals from the relative percentage error tables.

Key words: Lateral design, Micro-irrigation, Uniformity coefficient.

INTRODUCTION

An important objective of any micro irrigation system is uniform distribution of water delivered through the emitters on the lateral line. Adequate analysis of trickle lateral hydraulics is very important for the design and evaluation of micro irrigation systems. The increasing progress in computer technology has led many researchers to propose new numerical methods for hydraulic analysis and lateral design. In earlier studies for trickle lateral hydraulic computation, the primary solution is based on a discharge that is uniform, although effects of the manufacturer's variability have been modeled based on the derived hydraulic profile. However, this basic assumption may cause significant errors in hydraulic computations. Recently, some new methods have been developed based on the assumption of a non-uniform emitter outflow profile. The errors caused by the basic assumption of spatial invariance of the emitter outflow are minimized when the new alternative approaches are used.

Initially Christiansen (1942) had developed an analytical approach introducing the concept of a friction factor to calculate the total friction head drop at the end of multiple outlet pipelines. Christiansen's approach is based on the application of a stepwise method in a pipeline having a finite number of operating outlets with equal discharge, equally spaced. Wu and Gitlin (1975) derived mathematical equations for total friction drop and expressed friction drop ratio for laminar flow, turbulent flow in smooth pipe and fully turbulent flow conditions. Flow in lateral pipe for a trickle-irrigation system is considered to be steady, spatially varied flow with decreasing emitter outflow in the downstream direction. Among the investigators who provided approximate solutions to the problem of trickle-irrigation design, Perold (1977), Gellespie *et al*., (1979) and Khatri *et al*., (1979) generally neglected the change in the velocity head and assumed an initial uniform emitter outflow. Anyoji and Wu (1987) developed a statistical approach based upon the coefficient of variation of pressure head along a lateral line and the variations of emitter outflow caused by the manufacturer. The equation of the coefficient of variation of pressure head along the lateral line is derived as the function of inlet pressure head and pressure head changes due to friction and slope. Warrick and Yitayew (1987) developed an analytical solution for flow in a manifold. Both velocity head losses and variable discharge along the manifold are considered in the fundamental analysis. The appropriate second order, nonlinear equation is solved for two flow regimes, laminar and fully turbulent. Valiantzas (1998) developed an accurate analytical approach. In the suggested analysis the emitter outflow is considered to be variable along the lateral. A simple equation is presented for direct calculation of lateral hydraulics. Numerical tests indicated that the suggested method gives results very close to the back-step accurate numerical method. Vallesquino and Luque-Escamilla (2001) presented a new approach for solving lateral hydraulic problem in laminar or turbulent flow by treating the outflow as a discrete variable event by means of Taylor polynomials used to calculate flow rates along the laterals. Valiantzas (2002a) proposed a new linear relationship describing the total flow rate variation along

*Corresponding author's e-mail: eeesurya.tnau@gmail.com

laterals. The suggested equation approaches a closer value to the actual flow rate values. Simple analytical equations describing friction head loss and velocity head variation along laterals in which the number of outlets is taken into account are developed. The proposed method is useful for sprinkle irrigation design as well as for manifold micro irrigation pipeline design where the effect of the number of outlets may be significant on the hydraulic computations.

Step-By-Step (SBS) method, Differential method (DM), Constant Discharge method (CDM), Variable discharge method (VDM), Outlet variation method (OVM) and Statistical method (STM) were the different methods considered for assessment. Uniformity coefficient estimated by six hydraulic calculation methods that differs based on the assumption of spatial variance of emitter outflow were analyzed and compared in this paper. It covers various combinations of design parameters, varying emitter discharge exponents, and different slope conditions.

MATERIALS AND METHODS

Step-By-Step Method (SBS): In this procedure, the average emitter discharge q_{av}, the corresponding pressure head H_{av}, the emitter discharge exponent y, the number of emitters N, the spacing between successive individual emitters s, the slope of the lateral line s_0 and the internal diameter of the lateral pipe D are taken as known quantities. Then for this input data, the pressure distribution and discharge from each emitter (q_n) are found out by trial and error method. It is highly accurate but tedious to do for different diameters and length of the lateral at each emitter. So computer assistance is needed to make the calculation easier (Kang and Nishiyama, 1996). The co-efficient of uniformity is calculated as

$$UC = 1 - \left[\frac{1}{Nq_{av}}\right] \sum_{1}^{N} |q_n - q_{av}| \qquad \text{... (1)}$$

Differential Method (DM): Warrick and Yitayew (1988) presented differential method in which the emitters are considered to be close enough for the lateral to be regarded as a homogeneous system of a main tube and a longitudinal slot. This method requires the numerical solution (Runge-Kutta numerical method) of a nonlinear, second-order, ordinary differential equation. Uniformity in terms of flow rate is given by

$$UC = 1 - \frac{2}{X_0}(X_0 - X_{div} - X_0 V_{div}) \qquad \text{.... (2)}$$

Where X_{div} and V_{div} are dimensionless coordinate and velocity at which $q/q_{avg} = 1.0$ and X_0 is dimensionless distance (length of lateral divided by characteristic length).

Constant Discharge Method (CDM): Valiantzas (1998) developed an analytical approach which is a modified form of energy-gradient line approach (Wu and Gitlin, 1975) for the direct design of laterals. The analytical determination of friction drop is based on the assumptions that emitter outflow is constant. There exists a uniform slope and a smooth flow in the pipe. UC is approximately calculated from the following equation as

$$UC = 1 - \frac{0.798}{H_S}\, y \left[\frac{H_{f0}^{\,2}}{(2m+3)(m+2)^2} - \frac{(S_0 L)^2}{12} + \frac{H_{f0} S_0 L}{(m+2)(m+3)}\right]^{0.5} \qquad \text{....(3)}$$

Where H_s is the design pressure head, H_{f0} is the total friction loss of a similar pipe transmitting the entire flow over its length, m is frictional flow exponent varying with different flow regimes and S_0 is reduced uniform slope of lateral line. In case of uniform slope laterals, the length of the lateral can be determined if the UC is known, just by rearranging the above equation. And for the laterals whose S_0 not equal to zero then it requires some iterative technique to find the length.

Variable Discharge Method (VDM): Valiantzas (1998) developed an alternative analytical approach—the power function form equation—which is an extension of the CDM method for direct calculation of lateral hydraulics based on the assumption that the emitter outflow is spatially variable. The Christiansen uniformity coefficient can be approximated by the following expression:

$$UC = 1 - \frac{0.798}{H_S}\, y \left[\frac{H_{f0}^{\,2}}{(2m_\alpha+3)(m_\alpha+2)^2} - \frac{(S_0 L)^2}{12} + \frac{H_{f0} S_0 L}{(m_\alpha+2)(m_\alpha+3)}\right]^{0.5} \qquad \text{....(4)}$$

Where m is replaced by m_α and α is empirical exponent that takes into account spatially variable outflow.

Outlet Variation Method (OVM): A continuous-uniform outflow approach that takes into account the effect of the number of outlets on the lateral hydraulics is presented (Valiantzas, 2002b). The continuous outlet discharge variation approach along the lateral length is applied by assuming that the lateral to consist of an infinite number of outlets. The Christiansen coefficient of uniformity (UC), is used here to express uniformity of outlet discharge which is as follow as

$$UC = 1 - 0.798 * y \left[\frac{H_{var}^{0.5}}{H_{av}}\right] \qquad \text{....(5)}$$

UC values are independent of the number of outlets n.

Statistical Method (STM): A statistical design technique was developed based upon theoretical development of equation of co-efficient of variation of pressure head along the lateral and the variations of emitter flow (Anyoji and Wu, 1987 and Ravikumar *et al.*, 2003). Co-efficient of variation of pressure head along the lateral line is derived is the function of inlet pressure head and pressure head changes due to friction and slope. And by using equation 5, coefficient of uniformity is calculated for this method. It differs the OVM in theoretical development aspect.

Comparison Test for Uniformity co-efficient: The problem formulated to find uniformity co-efficient was: emitter discharge exponent, y = 1.0, slope s_0 = 0% horizontal slope, 2% Upslope and 2% Down slope; Length = 50, 100, 150, 200, 250 m; internal diameter of the lateral, D = 14 mm; average outflow of emitter, q_{av} = 4.0 lph ($1.111*10^{-6}$ m^3s^{-1}); average pressure head, H_{av} = 9.631 m; and the spacing between successive emitters, s = 1.0 m. The maximum value of emitter discharge exponent was taken (y = 1) because the discharge variation with respect to the head variation is maximum at this case. The problem formulated was taken from Yildirim and Agıralioglu (2004) for the validation of calculation methods. Since SBS method is the accurate method, UC estimated by SBS method is taken as the true value and UC estimated by other methods is taken as observed value. The relative percentage error is calculated using the following formulae:

$$\text{Relative\_Percentage\_Error} = \frac{\text{True - Observed}}{\text{True}} \quad \ldots(6)$$

The relative percentage error in estimating the UC at different slope conditions are tabulated for different lengths.

RESULTS AND DISCUSSION

Uniformity coefficient was calculated for various lengths of lateral, ranging from 50 to 250 m for the emitter discharge exponent y = 1.0 and three different slope conditions. The SBS method is the accurate method and the other six methods were compared with it. Several studies also used SBS method as accurate method for comparison (Valiantzas (1998); Valiantzas, 2002b; Yildirim and Agıralioglu, 2004).

The Tables 1 to 3 show the relative percentage error for different lengths with respect to uniformity co-efficient estimated from different methods. At zero slope condition (Table 1) for smaller lateral length (L=50m) the analytical methods like CDM, VDM, OVM performed with good accuracy compared to SBS method. The OVM performed better from 50m to 200m with error percentage varying from 0.015 to 2.882%. This is because in OVM, effect of number of outlets variable discharge were taken into account. Valiantzas (2002b) also indicated that OVM was more accurate than other methods particularly when the number of outlets is relatively small. At length = 250m, the OVM showed high error because, the effect due to number of outlets was high at this longer length. But the DM method performed well at longer length. Yildirim and Agıralioglu (2004) also reported that DM method had the highest level of uniformity for an extended zone of the UC variation. At 250m length comparing CDM and VDM, the VDM performed well as it takes into account the variable outflow from emitter as indicated in Valiantzas (1998). Yildirim and Agıralioglu (2004) also reported that for emitter discharge exponent, y = 1.0, DM and VDM methods were almost identical with a little deviation, whereas the results of the CDM differed significantly from those of the other methods. When VDM and CDM was compared at 250m the VDM performs well at longer length. Valiantzas (1998) also presented graphically that for UC < 0.95, the constant discharge results deviated from the exact solution i.e. SBS method. While comparing the STM method with CDM, STM performs better with good accuracy because of its statistical method of development.

Table 1: Relative percentage error of UC for different lengths (Zero slope).

L (m)	CDM (%)	VDM (%)	OVM (%)	DM (%)	STM (%)
50	0.004	0.002	0.015	0.877	0.186
100	0.164	0.128	0.011	0.640	0.862
150	2.366	0.522	0.091	1.706	0.411
200	12.327	3.020	2.882	4.056	6.604
250	41.939	17.035	24.724	11.646	31.990

Table 2: Relative percentage error of UC for different lengths (2% Upslope).

L (m)	CDM (%)	VDM (%)	OVM (%)	DM (%)	STM (%)
50	0.183	0.213	0.277	3.208	0.375
100	0.048	0.587	0.572	3.791	1.022
150	3.258	1.447	1.089	2.507	0.288
200	16.551	5.499	6.152	4.367	10.316
250	54.965	26.146	39.016	23.741	43.949

Table 3: Relative percentage error of UC for different lengths (2% down slope).

L (m)	CDM (%)	VDM (%)	OVM (%)	DM (%)	STM (%)
50	0.168	0.184	0.153	0.889	0.688
100	0.109	0.109	0.073	4.405	3.932
150	2.101	0.915	1.790	11.318	3.348
200	8.789	0.647	0.274	20.570	1.872
250	31.652	9.399	13.575	39.664	6.920

When the laterals are to be laid at 2% upslope, the CDM performs well at smaller length (L = 50 to 100m). VDM and OVM also performs good equally from L=50 to 200m. For length L=250m VDM performs well with 26.146% relative error and DM method performs well with 23.741% relative error. Yildirim and Agıralioglu (2004) also pointed that the results of the CDM and VDM methods were in close agreement with the results of the SBS and DM methods for the emitter discharge exponent, y = 1.0.

When 2% down slope is provided OVM performed well for length 50m to 100m whereas VDM performed well for 250m lateral length. The STM performed good for down slope and lateral length of 250m with 6% relative error. This is because, coefficient of variation of pressure head along the lateral line in STM was derived as the function of inlet pressure head and pressure head changes due to friction and slope (Anyoji and Wu, 1987 and Ravikumar *et al*., 2003). The method having lesser relative percentage error can be selected by the design engineers for designing the laterals from the relative percentage error tables. Hence the simple direct analytical equations with good accuracy can be used for design purpose instead of tedious step by step method.

CONCLUSION

A comparative assessment of six lateral design methods was done. For lateral design in drip irrigation system, Step-By-Step method, Differential method, Constant discharge method, Variable discharge method, Outlet variation method and Statistical method were the different methods compared. Uniformity coefficient estimated from these methods was used to compare the performance of these methods. The percentage relative error for different methods was calculated by having the step-by-step method as true value and other method as observed value and the errors are tabulated. Outlet Variation Method and Variable discharge methods showed good performance at different lengths of lateral and different slopes. For laterals of longer length, Differential method also performed well in estimating the Uniformity coefficient. The relative percentage error tables for different slope condition proposed in this paper will be a design aid for engineers in designing drip laterals for different crops.

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