ANALYSIS AND DESIGN OF A MICROIRRIGATION LATERAL

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Manuscript received: April 18, 2005; Reviewed: May 31, 2005; Accepted for publication: September 13, 2005

ABSTRACT

Micro-irrigation systems are methods of applying water, nutrients and chemicals directly to the plant root area at a controllable rate, which allows maximum results and minimum use of water and energy. For these reasons, micro-irrigation systems are developed in arid countries with insufficiency water resources. It has expanded to many countries engaging in modern agricultural practices due to relatively high agricultural outputs and low energy expenses. For micro-irrigation to be profitable, system design's must be based on precise calculations and rigorous management. The precision with which micro-irrigation lateral and network's are designed is of fundamental importance to system operation, the uniformity of distribution of water and fertilizer, and the consumption of energy. The computation model presented in this paper is based on equations of mass and energy conservation within an elemental control volume on the lateral. Considering the variation of the out-flow regime leads to an algebraic, coupled and non-linear equation system whose resolution is based on the numeric methods to a defective analytic approach. In this work, the control volume method was selected due to its simplicity. A program of computation has been developed for this and applied to a lateral for the first time. Results from this simple model are precise and are similar to those from other validated models. Precision design increase efficiency of water and fertilizer distribution. This method can be applied to the design of micro-irrigation lateral's or network's.

KEY WORDS model, uniformity, lateral, design, emitter, micro-irrigation

INTRODUCTION

Micro-irrigation consists of the practice of accurately providing the right amount water and mineral nutrients to the plant's roots area. Herein, the goal was it to provide water most efficiently by applying it at the right rate. Irrigation efficiency is clearly a function of the uniformity of application. So, it depends mainly on the uniformity of emitter's discharge. This, in turn, depends on the variation in pressure, as well as on the uniformity of emitter operation. Proper design of micro-irrigation system consists in assuring a high uniformity of application. The emitter discharge is a function of the lateral pressure and variation pressure will be reduce to a minimum. Low discharges and low pressure heads in the distribution network allow to use of smaller pipes of lower pressure rating which reduces the costs. Since irrigations are slow and spread over along time, peak discharges are reduced, thus requiring smaller size pipes and pumps, causing less wear and longer life of network. The irregularity of this emitter discharge is essentially owed to variation of the pressure due to losses in laterals, but also to the land slope, and to the emitter's characteristics. The discharge of an emitter is also influenced by the water temperature and the always possible partial or complete plugging of emitters. When the network is installed, it's impossible to change its design. So, it's fundamental to assure precision of calculations.

The design of micro-irrigation lateral has been the subject of several studies published in recent years. In first, graphic methods or polyplot, have been used by Christiansen (1942) and Vermeiren (1983) according to the simplified diagrams, obtained by combining the analytical and an empirical methods. Their utilization stopped with the development of microcomputer program. Wu and Gitlin (1974) developed a computer model based on the average discharge, Solomon and Keller (1978) tried the calculation based on the piezometric curve. Keller and Karmeli (1974) formulated a computational model to calculate the pressure at any point along lateral by testing many values of emitter's exponent. Computations are considerably simplified by assuming that the emitter discharge is constant along lateral. In order to increase the efficiency of design, researchers become interested in the hydraulic analysis of micro-irrigation lateral. Mathematical models have been established using the law of continuity and conservation of energy. Perold (1977) used an iterative process based on the back step method. Warrick and Yitayew (1988), Yitayew and Warrick (1988) presented an alternative treatment including a spatially variable discharge function as part of the basic solution to micro-irrigation lateral design. They expound two evaluations: an analytical solution, and a Runge-Kutta numerical solution of non-linear differential equations. Design curves for different flow regimes are presented and verification of solution is also made by comparing the result with experimental measurements. Bralts and Segerlind (1985), Bralts et al. (1993) used the finite element method for numerical solution of non-linear second order differential equations. Their articles provide a detailed description of other methods. However, some

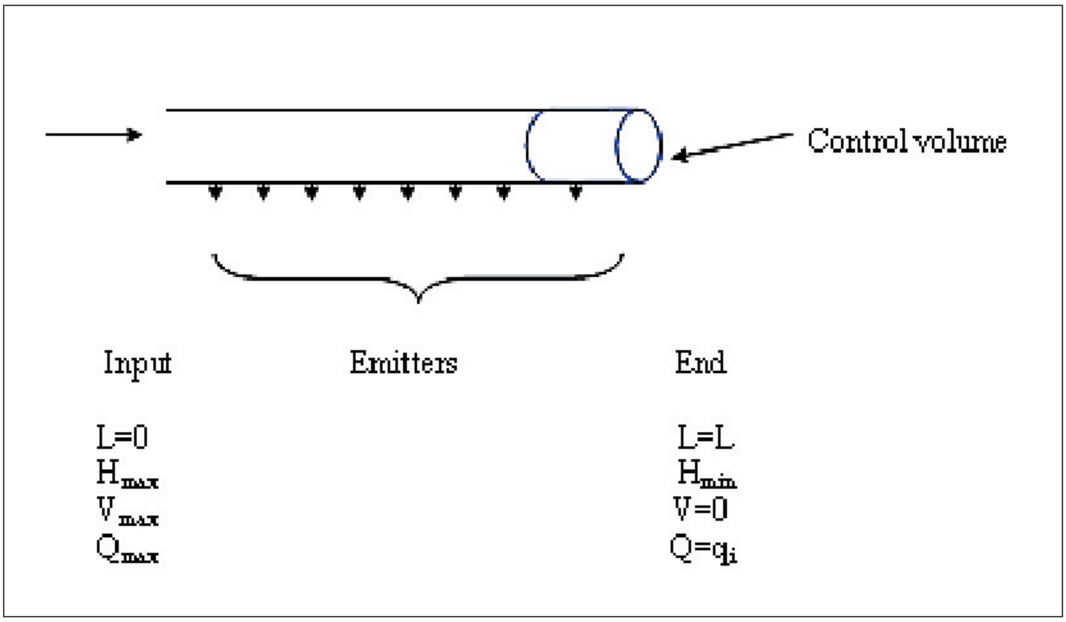

Figure 1. Microirrigation lateral with emitters

complications were encountered for the large micro-irrigation network where convergence was sometimes too slow, 70 seconds was computation time of lateral model, (Bralts et al., 1993). There in, the virtual emitter system method was developed, giving enough flexibility to handle these situations. Kang and Nishiyama (1994), Kang and Nishiyama (1996) used also the finite element method to analyse the pressure head and discharge distribution along lateral and submain pipe. The golden section search was applied to find the operating pressure heads of lateral corresponding to the required uniformity of water application. Valiantzas (1998) introduced a simple equation for direct calculation of lateral hydraulics. Computations are based on the assumption of a no uniform emitter outflow profile. The objective of this paper is to present a computer model based upon the back step procedure and the control volume method to simultaneously solve non-linear algebraic equations. An alternative iteration process is developed in this study which simplifies the model to design lateral of micro-irrigation system.

THEORITICAL DEVELOPMENT

Micro-irrigation lateral is considered at horizontal position (slope=0). Emitters are identical and fixed at an equal spacing. According the law of conservation of energy and continuity equation for an elemental control volume on the operating lateral, (fig. 1), the balance-sheet between the two extremity cross-area i and i+1, figure 2 expressed as follows (1) and (2).

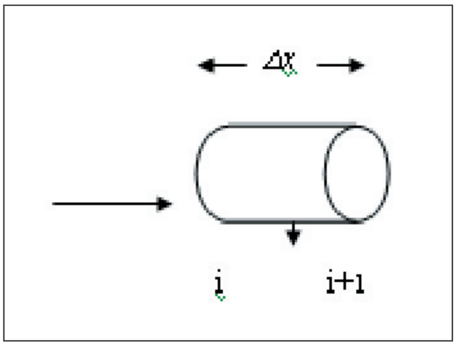

Figure 2. Elemental control volume

$$E_i = E_{i+1} + h_f \quad (1)$$

$$A\overline{V_i} = A\overline{V_{i+1}} + q_i \quad (2)$$

In these expressions, E_i and E_{i+1} are, respectively, input and output energy of water flow, hf is the head loss between i and i+1 along length Δx. In the second equation, A is the cross sectional area of lateral, and $\overline{V}$ is the average velocity between i and i+1, and q_i is the emitter discharge at the operating average pressure $\overline{H}$. A widely used formula for head loss in pipe is the Hazen-Williams formula represented by (3).

$$h_f = a\overline{V}^m \Delta x \quad (3)$$

$$q_i = \alpha \overline{H}_i^y \quad (4)$$

Equations (3) for simple pipe size and (4) describing emitter discharge can be defined as.

$$h_f = a\left(\frac{V_i + V_{i+1}}{2}\right)^m \Delta x \quad (5)$$

$$q_i = \alpha \frac{(H_i + H_{i+1})^y}{2} \quad (6)$$

The parameters a and m are defined in equations (13) and (14), α is a constant of emitter and y is an emitter exponent. According to (fig. 2), equations (1) and (2) become.

$$H_i + \frac{V_i^2}{2g} = H_{i+1} + \frac{V_{i+1}^2}{2g} + a\frac{(V_i + V_{i+1})^m}{2}\Delta x \quad (7)$$

$$V_i A = V_{i+1} A + \alpha\left(\frac{H_i + H_{i+1}}{2}\right)^y \quad (8)$$

or

$$H_{i+1} = H_i + \frac{1}{2g}(V_i^2 - V_{i+1}^2) - a\left(\frac{V_i + V_{i+1}}{2}\right)^m \Delta x \quad (9)$$

$$V_{i+1} = V_i - \frac{\alpha}{A}\frac{(H_i + H_{i+1})^y}{2} \quad (10)$$

According to fluid mechanic, the flow regime is characterized by the Reynolds number Re as follows.

$$Re = \frac{VD}{\mu} \quad (11)$$

$$A = \frac{\pi D^2}{4} \quad (12)$$

Table 1. Comparison of results from the new model and Bralts et al. (1993) model

Parameters	New model	Bralts et al. (1993)
H_t (m)	30	30
Q_t (m^3/s)	0.22	0.22
Cu_q (%)	94.21	94
Cu_H (%)	88.14	88
Time computer (s)	1	70
Number of iteration	2	15

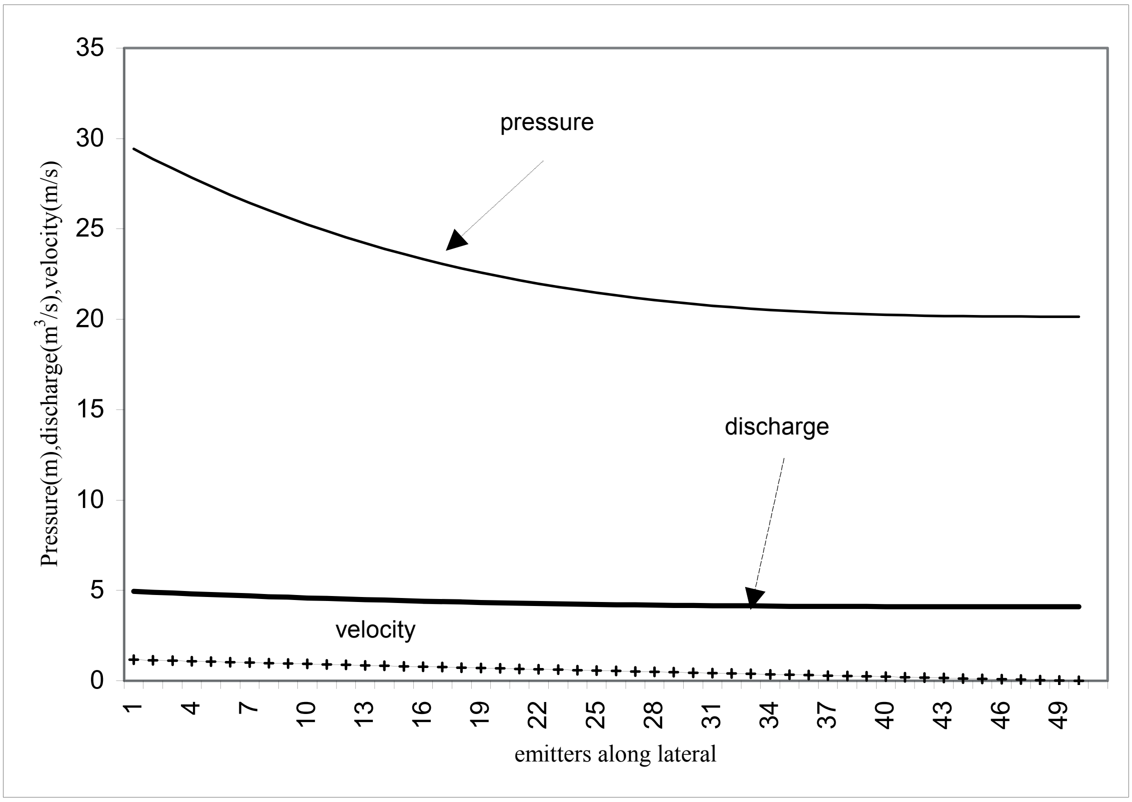

Figure 3. Distribution of pressure, velocity and emitter discharge along lateral.

where D is interior diameter of lateral and *μ is kinematic viscosity of water.*

In laminar flow regime, Re<2300, m=1 and the constant a is expressed as.

$$a = \frac{32\mu}{gD} \qquad (13)$$

In turbulent flow regime, Re>2300, m=1,852 and a is expressed as.

$$a = \frac{5{,}88}{C^m A^{0{,}5835}} \qquad (14)$$

C is the Hazen-Williams coefficient.

Uniformity equations:

$$q_{avg} = \frac{\sum q_i}{NG} \qquad (15)$$

where NG is the total emitter number in the lateral.

$$H_{avg} = \frac{\sum H_i}{NG} \qquad (16)$$

$$Cu_q = 100(1 - C_{vq}) \qquad (17)$$

$$Cu_H = 100(1 - C_{vH}) \qquad (18)$$

C_{vq}: coefficient of emitter flow variation, C_{vH}: coefficient of pressure variation,

C_{uq}: coefficient of emitter flow uniformity, C_{uH}: coefficient of pressure uniformity.

Iterative procedure:

Design model of micro-irrigation lateral is formed by non-linear algebraic equations (9)

and (10) which to formulate in a form suitable for computation on a digital computer as follows.

$$HS = H(I) + \frac{1}{2g}[V(I)^2 - VS^2] - a\Delta x\left[\frac{V(I)+VS}{2}\right]^m \qquad (19)$$

$$VS = V(I) - \frac{\alpha}{A}\left[\frac{HI + H(I)}{2}\right]^y \qquad (20)$$

HS is the following solution of pressure, H(I) is the previous solution of pressure, VS is the following solution of velocity, V(I) is the previous solution of velocity. The V_i values and H_i

are chosen and known before beginning calculation, the system, formed by the two

algebraic equations (9) and (10), coupled, non-linear, having two unknown V_{i+1} and H_{i+1} is

solved according to an iterative process according to the following procedure.

$$H_{i+1}^{k+1} = H_i^k + \frac{1}{2g}\left[\left(V_i^{k+1}\right)^2 - \left(V_{i+1}^{k+1}\right)^2\right] - a\left(\frac{V_i^{k+1} + V_{i+1}^{k+1}}{2}\right)^m \Delta x \qquad (21)$$

$$V_{i+1}^{k+1} = V_i^k - \frac{\alpha}{A}\left(\frac{H_i^k + H_{i+1}^k}{2}\right)^y \qquad (22)$$

with variable i from 1to NG.

H_i^k : previous solution of the pressure of the emitter i, H_{i+1}^{k+1} : following solution of the pressure

of the emitter i+1, V_i^k : previous solution of the velocity, V_{i+1}^{k+1} : following solution of the

velocity. Test of convergence is compute using conditions (23) and (24) where ε is the

precision imposed to the solution.

$$\left|\frac{H_i^{k+1} - H_i^k}{H_i^{k+1}}\right| \prec \varepsilon \qquad (23)$$

$$\left|\frac{V_i^{k+1} - V_i^k}{V_i^{k+1}}\right| \prec \varepsilon \qquad (24)$$

RESULTS

The example on which the model of calculation is applied, is the one of a micro- irrigation lateral in dark polyethylene of length L_r=250m and interior diameter D=15,2mm. The lateral is equipped with 50 identical emitters, spacing of 5m. The constant of the emitter are *α*=9,14 10^{-7} and y=0,5. The nominal discharge emitter is 17 l/h, what corresponds to an equal theoretical total outflow Q_t= 17.50=850 l/h or Q_t= 0,23611m³/s. The viscosity of water is 10^{-6} m²/s, C=150 and ε= 10^{-4}. For head pressure of 30m for example, the results as executing the program in "Fortran" on a PII microcomputer are regrouped in table 1. Distribution of the velocity, pressure and discharge along lateral is represented by figure 3.

Results expressed by the fig.3, show that the proposed model permits to calculate the distribution of the velocity, pressures and discharges along lateral length for any total discharge Q_t or head pressure H_t proposed for lateral. If the choice of the total discharge is fixed by the need peak of plants, the operating pressure is fixed according to the uniformity wanted for diameter or length lateral. Thus, the combination between Q_t, H_t, D and L that assures the more economic choice and most technical of the installation of the network is kept for the design. Results from this model of calculation are compared to those found by the model of Bralts et al. (1993) that used the numeric method of the finite elements, which results have been validated by his "exact" solution. The proposed model is simple and requires a small computation time compared to one other model in the literature.

CONCLUSION

The proposed model is based on algebraic non-linear equations of which the resolution by an elementary numeric approach proved to be more simple and precise that the complex models requiring some very effective numeric methods. The procedure of calculation can be applied from the two extremity of the lateral. With this procedure, it is possible to generalize the computation model to all the micro-irrigation network.

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