# ANALYSIS AND DESIGN OF A MICROIRRIGATION LATERAL

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**ABSTRACT**

*Microirrigation 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, microirrigation systems are developed in arid countries with insufficiency in water resources. They have expanded to many countries engaging in modern agricultural practices due to relatively high agricultural outputs and low energy expenses. For microirrigation to be profitable, system design's must be based on precise calculations and rigorous management. The precision with which microirrigation 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 equations 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 microirrigation lateral's or network's.*

***KEY WORDS:*** *model, uniformity, lateral, design, emitter*

# 1 INTRODUCTION

Microirrigation consists of the practice of accurately providing the right amount of 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 microirrigation system consists in assuring a high uniformity of application. The emitter discharge is a function of the lateral pressure and pressure variation will be reduced 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 a long 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 microirrigation 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 and Jobling (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) and Wu and Gitlin (1975) developed a computer model based on the average discharge but 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 microirrigation 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) and Yitayew and Warrick (1988) presented an alternative treatment including a spatially variable discharge function as part of the basic solution to microirrigation 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) and 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 complications were encountered for the large microirrigation 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) and Kang and Nishiyama (1996) used also the finite element method to analyze the pressure head and discharge distribution along lateral and submain. 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 non 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 microirrigation system.

# 2 THEORETICAL DEVELOPMENT

## 2.1 - Description of theoretical model

Microirrigation lateral is considered at horizontal position (slope=0). Emitters are identical and fixed at an equal spacing. According to 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 $i+1$, fig. 2 expressed as follows (1) and (2).

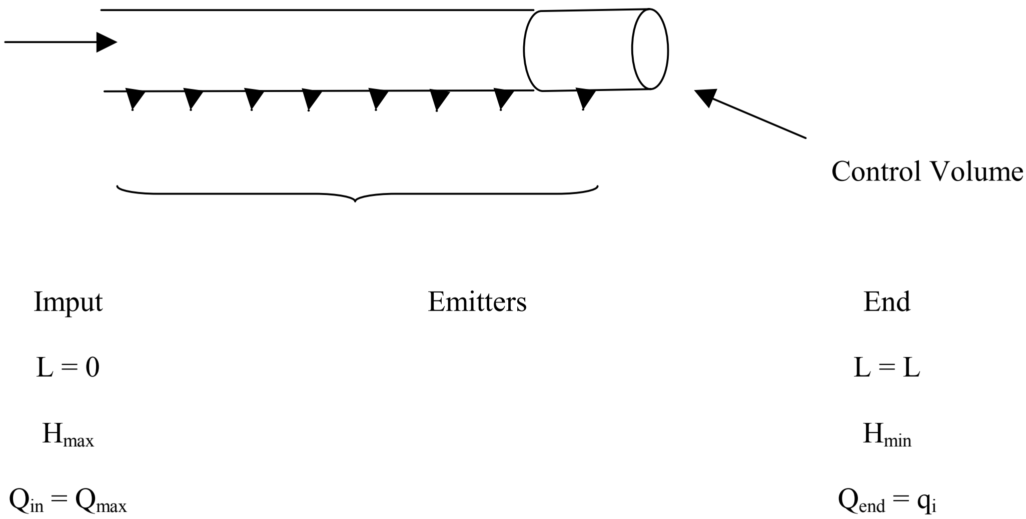



Figure 1. Microirrigation lateral with emitters

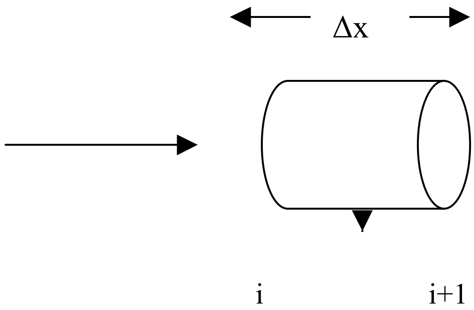



Figure 2. Elemental control volume

$$E_i = E_{i+1} + h_f \qquad (1)$$
$$A\overline{V}_i = A\overline{V}_{i+1} + q_i \qquad (2)$$

In these expressions, $E_i$ and $E_{i+1}$ are, respectively, input and output energy head of water flow, $hf$ is the head loss between $i$ and $i+1$ along length $\Delta x$. 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 formulation represented by (3).

$$h_f = a\overline{V}^m \Delta x \qquad (3)$$
$$q_i = \alpha \overline{H}_i^y \qquad (4)$$

In a circular orifice, q is proportional both to the square of the diameter represented in α and to $H^y$, α is a constant of emitter, it is found empirically and consists of the orifice area, the flow coefficient and units transformation. The parameters y and m are also empirical, the first for emitter exponent , the second for regime flow exponent. Equations (3) for simple pipe size and (4) describing emitter discharge can be defined by (5) and (6). The parameters $a$ and $m$ are defined in equations (13) and (14).

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

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

According to figure 2, equations (1) and (2) become.

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

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

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

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

In such a way, a lateral with emitters can be designed for constant discharge, taking into account pressure variation both due to the friction loss as well as to topographical differences.

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

$$Re = \frac{VD}{\nu} \qquad (11)$$

A cross area of lateral (A) is given by:

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

where *D* is interior diameter of lateral and $\nu$ is kinematic viscosity of water.In laminar flow regime, *Re* <2300, *m*=1 and the constant *a* is expressed as.

$$a = \frac{32\nu}{gD^2} \qquad (13)$$

In turbulent flow regime, *Re* >2300, *m*=1.852 and *a* is expressed after transformation as.

$$a = \frac{5.88}{C^m A^{0.5835}} \qquad (14)$$

*C* is the Hazen-Williams coefficient.

## 2.2 Uniformity equations

The average discharge corresponding to average pressure are the statistically given.

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

where *NG* is the total emitter number in the lateral.

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

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

$Cu_H = 100(1 - C_{vH})$ (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.

## 2.3 Numerical model and Iterative procedure

Design model of microirrigation lateral is formed by non linear algebraic equations (9) and (10) which are formulated in a form suitable for computation on a digital computer as follows.

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

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

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 unknowns $V_{i+1}$ 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 1 to $NG$. $H_i^k$ : 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 computed using conditions (23) and (24) where ε is the precision imposed to the solution.

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

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

# 3 RESULTS

According to Bralts et al., (1993), the example on which the model of calculation is applied, is the one of a microirrigation 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 $\alpha=9.14\times10^{-7}$ and $y$=0.5. The nominal discharge emitter is 17 *l/h*, which corresponds to an equal theoretical total outflow $Q_t$= 17X50=850 *l/h* or $Q_t$= 0.23611m$^3$/s. The viscosity of water is $10^{-6}$ m$^2$/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 table1. Distribution of the velocity, pressure and discharge along lateral is represented by fig. 3.

| Parameters | New model | Exacte solution by 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 of calculation (s) | 1 | 70 |
| Number of iteration | 2 | 15 |

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

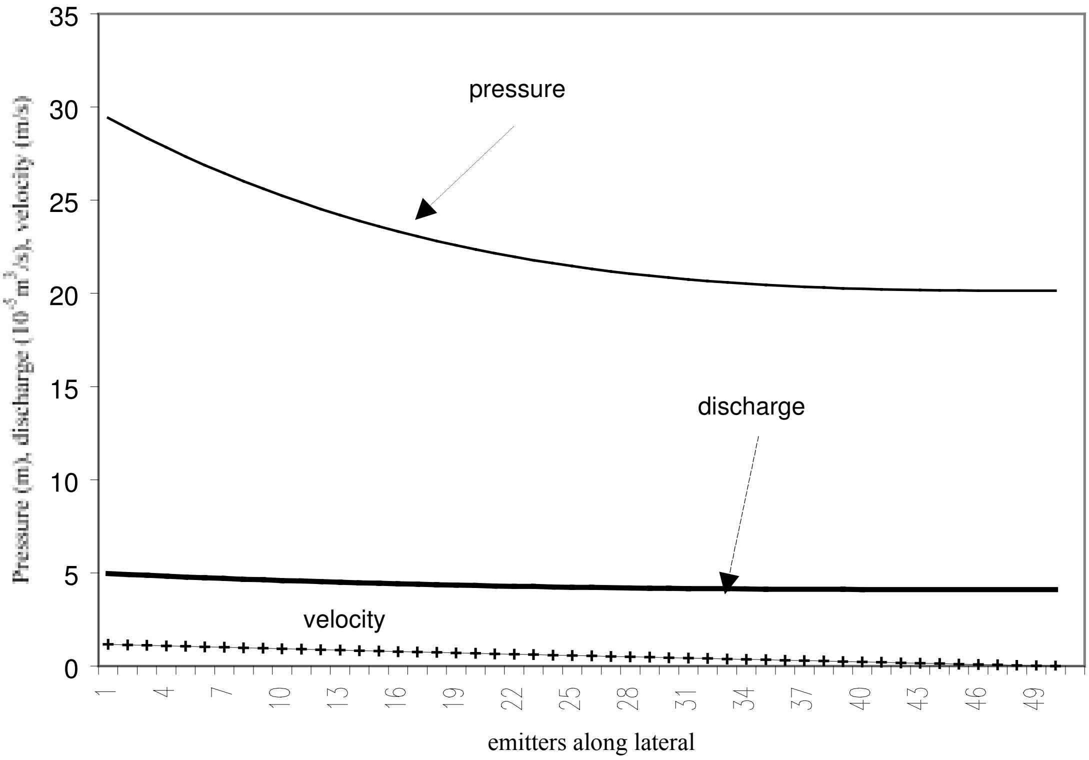
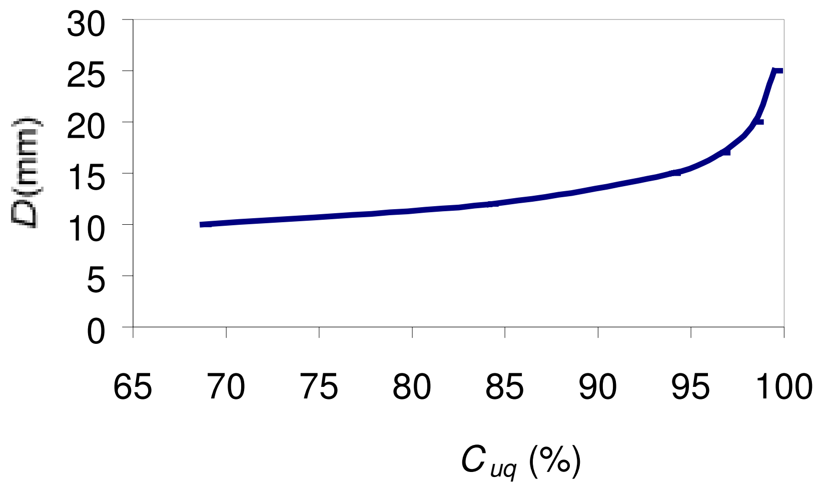



Figure 3. Distribution of pressure, velocity and emitter discharge

($H_{max}$=30m, D=15.2mm, L=250m, NG=50)

Results expressed by (fig. 3), show that the proposed new 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 calculated according to the uniformity wanted for diameter or length lateral.

Thus, the combination between $Q_t$, $H_t$, D and L (fig. 4) that assures the more economic choice (optimisation) and most technical of the installation of the network is kept for the design.



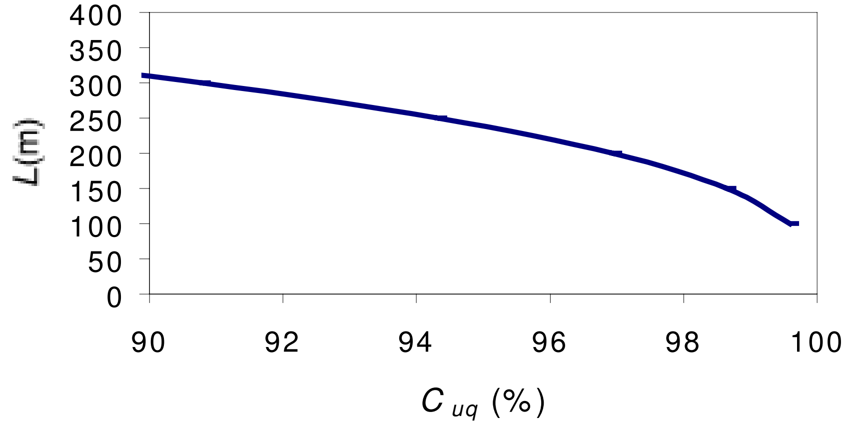




Figure 4. Relationship between length (L) and diameter (D) of lateral with uniformity 's discharge ($C_{uq}$)

In general, microirrigation lateral are plastic pipes. They are grated according to their test pressure. A pipe of grade 4, for example, has been tested at 40m pressure. In portable microirrigation and for buried pipes, sometimes grade 6 is specified for its higher structural strength and durability. An optimal design of microirrigation system must achieve uniformity of water application to the soil, so as to enable the application of the exact irrigation water requirement during the same time duration, throughout any part of the system that is operated as a single unit. In microirrigation system this means that all emitters controlled by the same valve will have as closely as possible the same discharge. Since emitters discharge is function of the lateral pressure, then if the same emitter is used throughout a single subunit the pressure variation will be reduced to a minimum, or at least remain within a specified range. The specification is generally given ( Solomon and Keller, 1978) in terms of the permissible range of discharges. In most cases it takes one of the following forms:

- "The discharges of all emitters operated simultaneously as a single unit should have a variation of not more than x percent."

- "The discharge of the emitters with the highest flow should not be more than x percent higher than that with the lowest flow."

- The discharges of all emitters operated as a single units should be within ±x/2 percent of the average discharge."

The discharge of emitter is also influenced by the temperature (air and water) but it seem that the effect is mostly negligible when the flow is turbulent, except perhaps in desert conditions. Microirrigation design should determine the dimensions of plot and network, so that the system will be as economically efficient as possible. Each case requires its own analysis and design nevertheless it's possible to give a few indications about the size of irrigation plots and their shape.

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 they "exact" solution. The proposed model is simple and requires a small computation time compared to one other model in the literature.

# 4 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 microirrigation network.

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