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# Hydraulic Design of Micro-irrigation Subunit Based on Genetic Algorithm

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ABSTRACT:

With the difference between average discharge and design discharge of emitter to be the objective function , a based-genetic-algorithm model for micro-irrigation subunit hydraulic design is established, which takes the node pressure in the submain end as a decision variable and applies bisection algorithms and back step method to handle the hydraulic calculation of submain and laterals. Simulation results show that the model and algorithm possess excellent solving efficiency, accuracy, and good versatility and practical value. In the meanwhile, it can be also obtained that discharge and pressure distribution of submain and laterals some characteristic value and their orifice location such as average discharge, maximum discharge and minimum discharge of emitter, determine pressure variation, discharge variation, uniformity and other indicators. This model can be applied to hydraulic analysis and design of the micro-irrigation subunit with non-uniform slope, varied-diameter, varied-spacing and so on, and also used to check or evaluate the micro-irrigation subunit which has been designed or completed.

Key words: micro-irrigation, subunit, hydraulic calculation, genetic algorithm

With the numerous emitters in the subunit and a large workload of calculation, micro-irrigation scholars have been exploring an accurate, simple and convenient design method. Nowadays, in the design of micro-irrigation subunits, the allowable differential pressure are usually allocated between the submain and the lateral, which are considered as the completely independent components. The submain and the lateral respectively are calculated and designed as the porous flow pipes. The porous pipes' design methods are mainly Porous Coefficient Method[1], Energy Gradient Line Method[2], Graphic Methods[3], Finite Element Method[4,5], Genetic Algorithm[6,7], and so on. However, the existing micro-irrigation subunit design either based on uniformly-spaced and uniformly-discharge assume or taking the submain and lateral as the two independent units to simplify the desigh, which destroy the integrity of subunit, bring some calculation errors and some difficulties to the applying to the design of non-uniform spaced emitters and slope with paired laterals. Meanwhile, it can not meet the average discharge of the emitter and irrigation uniformity appropriately required by the micro-irrigation system. Therefore, it is hard to reach the optimal state. Some scholars take subunit as a whole to optimize the design by taking empirical coefficient [8], Finite Element[9] and lateral flow formula[10,11]. The paper takes subunit as a whole to optimize the design, discarding the assumption that the submain and the lateral are uniformly-spaced and uniformly-discharge. Employing the genetic algorithm theories and methods, regarding the irrigation uniformity and design discharge of emitter as the constraints, the paper puts forward a convenient, speedy optimization design methods for the submain and lateral diameter in the micro-irrigation subunit.

# 1 Hydraulic Calculation in micro-irrigation subunit

As shown in Fig.1, submain nodes, submain pipe section, lateral orifice and lateral pipe section are respectively indexed. In the subunit, the pressure and flow on each submain notes and each lateral emitters, the average flow of the emitters and irrigation uniformity can be worked out by the following formulas and steps.

Step1: The pressure head, $Hs(0)$ of the $s(0)$ node, is produced randomly at the end of submain.

$$h_{c\,min} \le H_s(0) \le h_{c\,max}$$

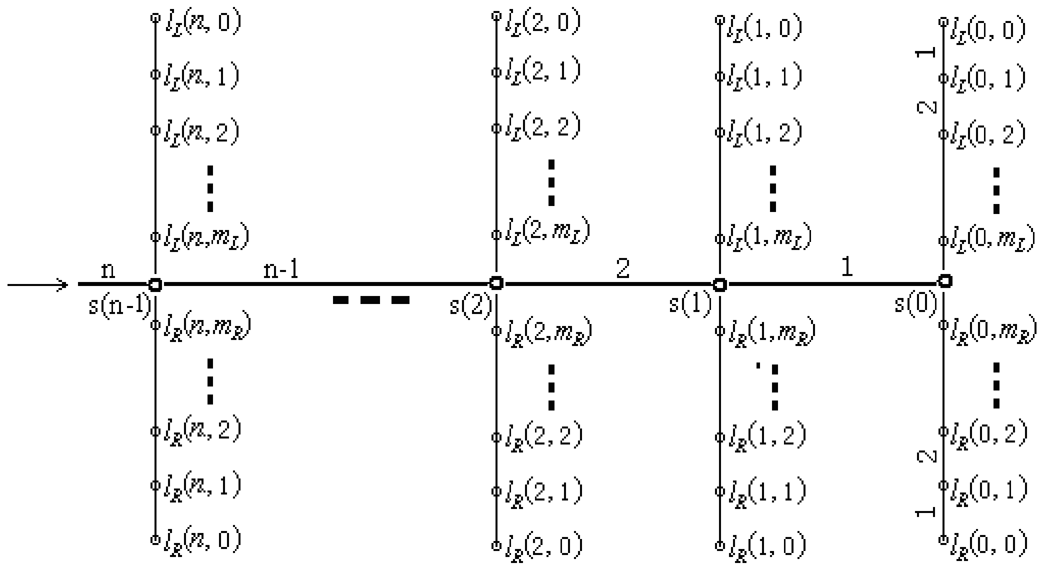


Fig. 1 Illustration for layout and serial number of subunit

Step2: Employing dichotomy, the left side lateral's discharge and pressure on the $s(0)$ node at the end of submain can be calculated.

(1) Supposed $Q_{l_L}(0,0) = 0$, $h' = h_{cmin}$, $h'' = h_{cmax}$

(2) Supposed $h_{l_L}(0,0) = \frac{1}{2}(h' + h'')$, then $q_{l_L}(0,0) = kh_{l_L}(0,0)^x$

(3) $Q_{l_L}(0,j) = Q_{l_L}(0,j-1) + q_{l_L}(0,j-1)$

 

$$\Delta h_{l_L}(0,j) = \alpha f \frac{Q_{l_L}(0,j)^{m}}{d_l^b} S_{l_L}(0,j) + S_{l_L}(0,j) I_{l_L}(0,j)$$

$$h_{l_L}(0,j) = h_{l_L}(0,j-1) + \Delta h_{l_L}(0,j) \quad ,$$

$$q_{l_L}(0,j) = k h_{l_L}(0,j)^{x}$$

$j$ =1, 2, …, $m_L$

(4)

$$H_{l_L}(0) = h_{l_L}(0,m_L) + \alpha f \frac{Q_{l_L}(0,m_L)^{m}}{d_l^b} S_{l_L}(0,m_L) + S_{l_L}(0,m_L) I_{l_L}(0,m_L)$$

(5) If $H_{l_L}(0) - H_s(0) \le \varepsilon$ , then the calculation of the left side lateral is figured out, or if $H_{l_L}(0) > H_s(0)$, then $h'' = h_{l_L}(0,0)$; if $H_{l_L}(0) < H_s(0)$, then $h' = h_{l_L}(0,0)$, repeat the steps of (2) ～ (4).

Step3: Employing the method of step 2, the right side lateral's discharge and pressure on the $s(0)$ node at the end of submain and emitters can be calculated.

Step4: Hydraulic Calculation of the s(1)~s(n) nodes on the submain

$$Q_{s(i)} = Q_{s(i-1)} + Q_{l_L(i-1,m_L)} + Q_{l_R(i-1,m_R)}$$

$$H_{s(i)} = H_{s(i-1)} + af \frac{Q_{s(i)^m}}{d_s^b} S_{s(i)} + S_{s(i)} \times I_{s(i)}$$

$i$ =1, 2, …, $n$, taking $H_s(i)$ as the $s(i)$ node's pressure head of the submain, employing the method of step 2, the lateral's discharge and pressure on both the left and right side on the $s(i)$ node of the submain can be frowned out.

Step5:

$$\bar{q} = \frac{1}{(n+1)(m_L + m_R + 2)} \sum_{i=0}^{n} \left[ \sum_{j=0}^{m_L} q_{l_L}(i,j) + \sum_{k=0}^{m_R} q_{l_R}(i,k) \right]$$

$$\Delta \bar{q} = \frac{1}{(n+1)(m_L + m_R + 2)} \sum_{i=0}^{n} \left[ \sum_{j=0}^{m_L} \left| q_{l_L}(i,j) - \bar{q} \right| + \sum_{k=0}^{m_R} q_{l_R} \left| (i,k) - \bar{q} \right| \right]$$

$$C_u = 1 - \frac{\Delta \bar{q}}{\bar{q}}$$

Repeat from step 1 to step 5 until $\bar{q} = q_d$, and then the calculate is over.

Where: $h_{l_L}(i,j)$ is the emitter pressure of the lateral on the left side, m; $h_{l_R}(i,j)$ is the emitter pressure of the lateral on the right side, m; $q_{l_L}(i,j)$ is the emitter discharge of the lateral on the left side, L/h; $q_{l_R}(i,j)$ is the emitter discharge of the lateral on the right side, L/h; $\Delta h_{l_L}(i,j)$ is the head loss of pipe section of the lateral on the left side, m; $\Delta h_{l_R}(i,j)$ is the head loss of pipe section of the lateral on the right side, m; ; $Q_{l_L}(i,j)$ is the pipe section discharge of the lateral on the left side, L/h; $Q_{l_R}(i,j)$ is the pipe section discharge of the lateral on the right side, L/h; $H_{l_L}(i)$ is the inlet pressure of the lateral on the left side, m; $H_{l_R}(i)$ is the inlet pressure of the lateral on the right side, m; $d_l^b$ is the diameter of the submain, mm; $d_s^b$ is the diameter of the lateral, mm; $H_s(i)$ is the orifice pressure of the submain, m; $Q_s(i)$ is the discharge of the submain pipeline, L/h; $C_u$ is the design irrigation uniformity; $\bar{q}$ is the average flow of the emitters; $\Delta\bar{q}$ is the average flow deviation of the emitter; $\alpha$ , $f$, $m$, $b$ is head loss calculation coefficient. $S_{lL}(i,j)$ is the length of the left pipe section of the lateral, m; $S_{lR}(i,j)$ is the length of the right pipe section of the lateral, m; $I_{l_L}(i,j)$ is the terrain slope on the left side lateral; $I_{l_R}(i,j)$ is the terrain slope on the right side of lateral; $S_s(i)$is the length of the $i$ pipe section of the submain, m; $I_s(i)$ is the terrain slope of the submain, $\varepsilon$ is the calculation accuracy; s(i) is the number of submain nodes; $l_L(i,j)$ is the number of the left lateral emitter; $l_R(i,j)$ is the number of the right lateral emitter; $m_L$ is the emitter number on the left side lateral; $m_R$ is the emitter number on the right side lateral.

Above the calculation, as long as the pressure Hs(0) on the end of submain nodes s(0) was known, through back-step derivation the hydraulic calculation can be completed, however, making sure the value of Hs(0) when $\overline{q} = q_d$ is difficult by applying routine algorithm. This paper makes $\overline{q}$ close $q_d$ step by step in order to achieve the irrigation subunit's hydraulic calculation by genetic algorithm and whole search ability.

## 2 Genetic Algorithm Model

(1) Establishing Fitness Function

With the hydraulic calculation of the irrigation subunit, the objective function can be constructed.

$$f[H_{s(0)}] = \mathbf{min}\,|\overline{q} - q_d| \qquad (1)$$

$$h_{cmin} \le H_{s(0)} \le h_{cmax}$$

Where: $q_d$ is the emitter design flow, L/h; $h_{cmin}$ is the allowed max emitter pressure, m; $h_{cmax}$ is the allowed min emitter pressure, m.

The above objective function is transformed into the maximization problem called for genetic algorithm, the fitness function is constructed as follows:

$$\mathbf{Fit} = \frac{1}{1 + f[H_{s(0)}]} \qquad (2)$$

(2) Coding.

$H_s(0)$ is a continuous real variable in the optimization variables of the Genetic Algorithm, the real encoding method is adopted

(3) Selection.

Two individuals are chosen randomly from the group, and the optimal one would be selected as the parent individual.

(4) Crossover.

Any two paired parent individuals $X_1$, $X_2$, two real $\lambda_1$, $\lambda_2$ are generated randomly between [0，1]，then both the $\lambda_1 X_1+(1-\lambda_1)X_2$ and $\lambda_2 X_1+(1-\lambda_2) X_2$ have the gene of the parent individual $X_1$, $X_2$, which can be regarded as the son individuals after the crossover, realizing the cross operation.

(5) Variation.

The individual and variable which are in need of variation are generated randomly. And in the variable's feasible region, the new value will be generated randomly which will replace the original variable's value.

(6) Algorithm Realization.

In the feasible [$H_{s(0)}$] region, [$h_{cmin}$, $h_{cmax}$], the initial group having a certain scale generates randomly as the first generation of genetic groups. According to the methods of step1 to step 5, the hydraulic calculation is carried through，then the individual fitness is figured out by using the formula (2). In accordance with the selection, crossover and variation operation of the design, the new generation groups will be generated. Repeat the procedure until the value of the individual fitness meets the accuracy requirement.

## 3 Examples Calculation

The example is calculated on the even slope, table 1 shows the basic data.

Adopting the genetic algorithms, the size of the population chosen is 30, the largest genetic algebra is 15, and the simulation calculation is carried out. As the large amounts of the emitters, the optimization results are only shown in table 3, and the curves of the submain and parts of the lateral's pressure are shown in Tab.2, Fig.2 and Fig.3.

Tab.1 Basic data

| | Pipe diameter(mm) | Orifice number(piece) | | Ground slope $I_{l_L}$ | Ground slope $I_{l_R}$ | Orifice space(m) | $q_d$ (l/h) | Flow formula |
|---|---|---|---|---|---|---|---|---|
| Lateral | 16 | 220 | 260 | 0.01 | -0.01 | 0.3 | 2.2 | $q=0.592h^{0.59}$ |
| Submain | 28.8 | 8 | | -0.005 | | 1.4 | | |

Tab.2 Computing result of subunit

| $S(i)$ | $H_{s(i)}$/ m | $Q_{s(i)}$/ (l/h) | $H_{l_L(i)}$/ m | $H_{l_R(i)}$/ m | $Q_{l_L(i)}$/ (l/h) | $Q_{l_R(i)}$/ (l/h) | $H_{l_L(i,m_L)}$/ m | $H_{l_L(i,0)}$/ m | $H_{l_R(i,m_R)}$/ m | $H_{l_R(i,0)}$/ m |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 9.7949 | 1027.2 | 9.7945 | 9.7947 | 467.63 | 559.60 | 9.7856 | 9.7860 | 7.9746 | 8.6719 |
| 1 | 9.8049 | 2055.1 | 9.8057 | 9.8044 | 467.96 | 559.91 | 9.7968 | 9.7957 | 7.9844 | 8.6797 |
| 2 | 9.8549 | 3086.1 | 9.8550 | 9.8551 | 469.40 | 561.55 | 9.8460 | 9.8463 | 8.0273 | 8.7207 |
| 3 | 9.9641 | 4123.7 | 9.9648 | 9.9637 | 472.59 | 565.07 | 9.9557 | 9.9548 | 8.1230 | 8.8086 |
| 4 | 10.1501 | 5172.7 | 10.1508 | 10.1496 | 477.97 | 571.05 | 10.1415 | 10.1405 | 8.2852 | 8.9590 |
| 5 | 10.4299 | 6238.7 | 10.4309 | 10.4297 | 485.99 | 579.97 | 10.4214 | 10.4203 | 8.5293 | 9.1855 |
| 6 | 10.8212 | 7328.0 | 10.8210 | 10.8209 | 497.01 | 592.29 | 10.8111 | 10.8111 | 8.8691 | 9.5020 |
| 7 | 11.3419 | 8447.9 | 11.3411 | 11.3428 | 511.45 | 608.44 | 11.3309 | 11.3324 | 9.3223 | 9.9238 |
| inlet pressure in the irrigation subunit $H_{s(n)}$* /m | | | 11.6768 | | | Irrigation uniformity $Cu$ | | 0.9656 | | |
| The emitter average flow $\bar{q}$ /(l/h) | | | 2.2000 | | | Flow deviation rate $q_v$ | | 0.2144 | | |

From the Tab.2, the maximum pressure of the submain is in the inlet, and the pressure will decrease gradually. The pressure will reach the minimum when it gets to the No.3 orifice at the end of the submain. The average flow is $\bar{q}$ =2.2l/h which is simple with $q_d$. The results show that the higher the calculation accuracy, the more the optimization results will meet the design requirements.

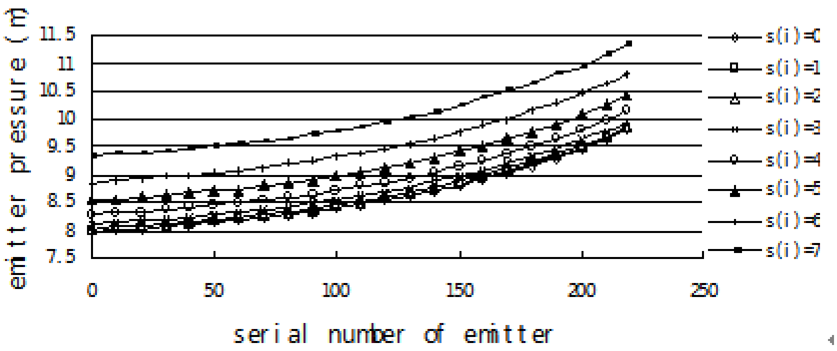


Fig. 2　Emitter pressure graph of left laterals

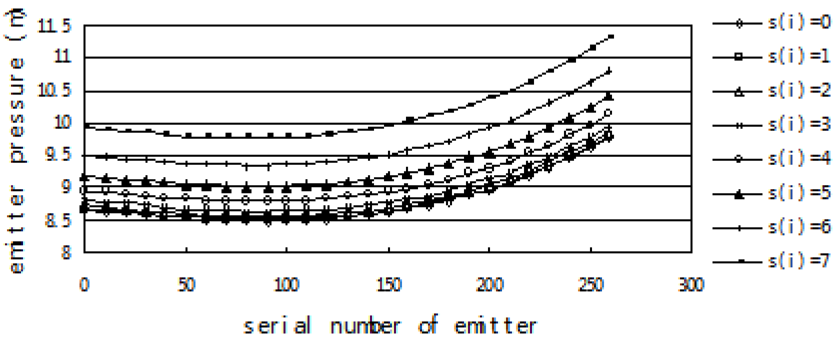


Fig. 3　Emitter pressure graph of right laterals

Tab.2, Fig.2 and Fig.3 show that the maximum pressure on the left lateral presents in the inlet lateral, and the minimum pressure is in the end lateral. The max pressure on the right lateral presents in the inlet lateral, and the min pressure is in the 88th orifice, it accords the hydraulic characters. There are eight diverge orifices, each one has 480 emitters on the left and right lateral. The discharge and pressure of 4000 or more nodes should be figured out in the algorithm procedure and the operation of the procedure lasts 26 seconds, which show that such algorithm has high solution efficiency.

Considering the disturb taken by random factor to algorithm's solving performance evaluation, the algorithm program run 100 times independently. Compare the emitter average flow with the emitter design one, and compare the inlet lateral pressure of every calculate results with the optimizing one, the relate deviate is shown in Tab.3. Among these the probability that the relate deviate is lower than 0.01% is higher 80%, the probability that the relate deviate is lower than 0.5% is 100%, which show that such algorithm has high solution efficiency.

Tab.3　Relative deviation of calculation result and superior solution

| relate deviat/% | | <0.001 | <0.005 | <0.01 | <0.05 | <0.5 |
|---|---|---|---|---|---|---|
| Times of appearance | $\overline{q}$ 与 $q_d$ | 62 | 78 | 82 | 91 | 100 |
| | $H_{s(n)}$ 与 $H_{s(n)}^*$ | 2 | 48 | 80 | 93 | 100 |

## 4 Conclusion and Discussion

The genetic model and algorithm put forward in this paper considers the subunit cost to the minimum as the goal and the irrigation uniformity and average discharge of emitters, the submain diameter, lateral diameter, emitter number of the lateral on the left side and the orifice pressure at the end submain as the constraints. This method not only optimizes the diameter of submain and lateral on the slope micro-irrigation subunit, determines inlet pressure of subunit and the best submain position, but also calculates every orifice's pressure and discharge on the submain and lateral. The method adopted in the paper can ensure lateral work in accordance with the requirements of the design, which can also enhance the economic and technical rationality of the design of lateral effectively. If only the known design conditions are input into the computer, the optimization result will be figured out by itself, which has both universal and practical value. The method is also applicable to the optimization of the micro-irrigation subunit with non-uniform slope, varied -diameter, varied -spacing and varied – emitter types.

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