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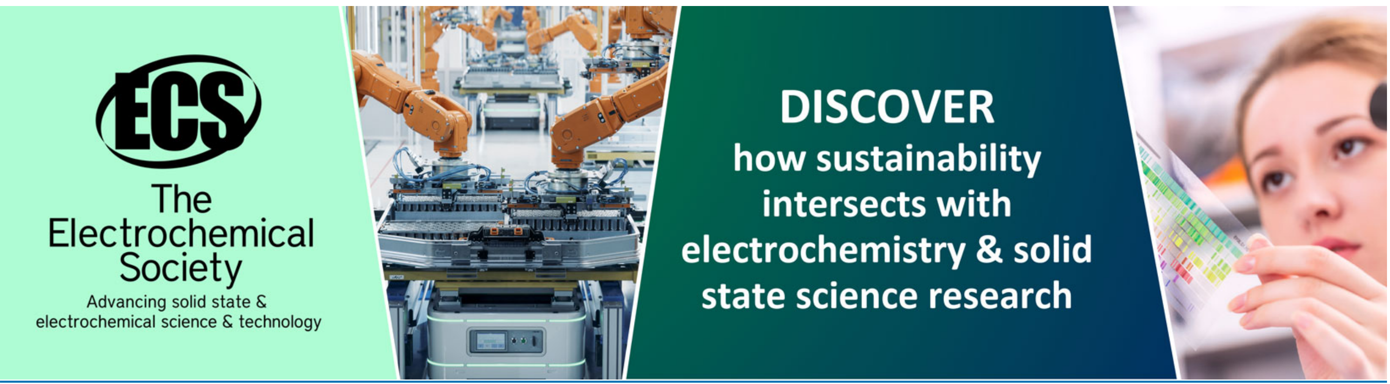

Static pressure distribution along the main current channel of drip irrigation pipe

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Abstract. Based on the conservation law of mass and momentum, a mathematical model of variable mass flow was established. Combined with the pressure test data, the expression of static pressure distribution along the main current channel of the drip irrigation pipe was obtained. The results show that the static pressure variation along the main current channel of the drip irrigation pipe depends on the frictional resistance and the momentum exchange. The frictional resistance term diminishes the static pressure, and the momentum exchange term makes the static pressure tend to increase. The pressure test shows that the axial flow velocity distribution index m of the drip irrigation pipe is independent of the dripper characteristic parameters and linear with the drip number N. Based on the theoretical analysis and experimental data regression, the expression of the momentum exchange coefficient k is obtained, and the equation is solved by the Blasius resistance formula. The calculated value of the static pressure agrees well with the measured value. In the static pressure distribution model, the influence factors of static pressure are attributed to the length-diameter ratio of the drip irrigation pipe and the Reynolds number Re_0 of the inlet, which is convenient for optimizing the structural design and determining the optimal operating conditions. This paper can provide a reference for the hydraulic calculation of drip irrigation pipe and the hydrodynamics study of porous pipes.

1. Introduction

As a precise irrigation technology, drip irrigation not only saves water effectively and significantly, but also saves labor and increases production. Therefore, it has been rapidly promoted and applied in agricultural production. Irrigation uniformity is the core index of drip irrigation quality assessment. Its influencing factors include the static pressure distribution of the main current channel, irrigator manufacturing deviation and blockage, but the most important factor is the static pressure distribution[1]. A specific exponential relationship between the dripper flow rate q and the static pressure hydraulic head h can be obtained by Darcy-Weisbach frictional head loss formula[2]:

$$q = Ch^y \tag{1}$$

Where q is the dripper flow rate, L/h; h is the static pressure hydraulic head of the main current channel in the drip irrigation pipe, m; C and y are the two characteristic parameters of the dripper, respectively called the flow coefficient and the flow index.

The rationality of equation (1) has been widely proved. It can be seen that the flow rate of the dripper is mainly dependent on the static pressure, except for its self-characteristic parameters C and y, and so the uniformity of irrigation mainly depends on the static pressure distribution along the main current channel of the drip irrigation pipe. Scholars at home and abroad have carried out a lot of research on this problem. In 1942 Christiansen first proposed the porous coefficient method to calculate the head loss of the porous pipeline, which laid a foundation for calculating the hydraulic head loss of the porous pipeline. Wu and Gitlin then put forward the energy gradient line method to determine the pressure hydraulic head along the drip irrigation pipeline [3-5]. Jain et al used existing empirical formulas to establish a model and qualitatively analyzed the model and took advantage of the Darcy-Weisbach formula to further calculate and analyze the hydraulic head loss of the drip irrigation pipe[6]. Kang, Nishiyam et al calculated and summarily drew the hydraulic characteristics law distribution map of the drip irrigation pipe by finite element method, and analyzed the variation law of hydraulic head loss along the drip irrigation pipe[7-9].

With the popularization of drip irrigation technology, there are more and more researches on the hydraulic performance and simplified calculation of drip irrigation pipes. These studies rely on the test results to directly perform regression analysis of multi-factor systems [10-15]. In addition, with the development of mathematical modeling methods and computer technology, some new algorithms have emerged, such as dichotomy [16], genetic algorithm [17], artificial neural network [18], CFD technology [19-21], etc., to study the porous pipes energy loss and flow characteristics of drip irrigation pipes.

Although the above research work utilizes different research means and methods, the same idea is based on the law of conservation of mechanical energy, which grounds on the constant total flow energy equation of the actual fluid, mainly by calculating the frictional head loss of the porous pipeline to determine the static pressure distribution along the porous pipeline, that is believing that the factor affecting the static pressure distribution is only the friction loss.

However, when this energy method is applied to the calculation of porous pipes such as drip irrigation pipes, two problems emerges:

First, the law of energy conservation is based on the conservation of total energy, while the energy equation is derived from the Bernoulli equation and the head loss formula. These formulas are all calculated in terms of unit mass, which is applicable to the independent flow systems that have no mass exchange with other systems. However, in the porous pipes, when the fluid in the main current channel flows through the lateral flow orifice, the fluid in the low energy boundary layer flows out through the orifice, and the relatively high energy fluid remains in the main current channel of the drip irrigation pipe to form a redistribution of energy. If the overall energy balance is calculated by the mechanical energy per unit mass in the main current channel, the fluid mechanical energy after the splitting is necessarily greater than that before the flow splitting (if the friction loss in the extremely short process is not considered), which obviously violates the law of conservation of energy.

Second, the total flow energy equation is obtained by integrating the Bernoulli equation in the flow section, while the Bernoulli equation is established by the streamline. For the porous pipe such as the drip irrigation pipe, the number of streamlines at different flow sections is different, which means that there are many possibilities of establishing an energy equation according to the streamline.

Therefore, the energy equation established by the unit mass fluid is not suitable for calculating the energy of the porous pipes. The porous outflow test by McNown showed that there is indeed a phenomenon of static pressure increased in the main current channel after splitting[22]. Du Tao considers that the phenomenon of the pressure rising at the end of the pipe is similar to the water hammer and calculates the pressure recovery value by the theory of direct water hammer[23].

For drip irrigation pipe, the quality of the fluid is continuously reduced during the flow process. For this flow behavior, the momentum analysis method can be used for research. In this study, the momentum conservation principle is utilized, and the momentum equation of variable mass flow with drip irrigation pipe as a typical example is established. The static pressure variation in the main current channel is attributed to the dual effects of momentum exchange and friction loss. The analytical solution of the static pressure distribution along the drip irrigation pipe is obtained by solving the momentum equation, which can provide the basis for the hydraulic design of the drip irrigation system and the study of variable mass flow behavior.

2. Theoretical model

2.1. Momentum equation of variable mass flow

The flow of the fluid in the drip irrigation pipe is a variable mass flow process, which can be simplified as a porous outflow as shown in the Figure1. A micro-element is taken as the control body before and after the orifice, shown as Figure 2, and the momentum equation of variable mass flow is established.

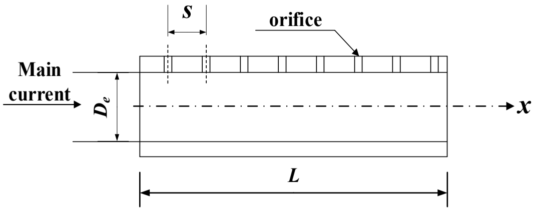


Figure 1. Simplified model of drip irrigation pipe.

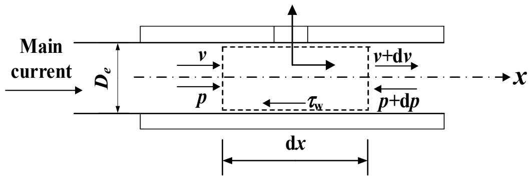


Figure 2. Micro-element control volume.

If the flow section area of the main flow channel of the drip irrigation pipe is A_e, the axial flow velocity at the interface indicated by the dotted line on the left side is v, the static pressure is p, after flowing a distance $\mathrm{d}x$ to the right dotted line, the axial flow velocity is $v+\mathrm{d}v$, and the static pressure is $p+\mathrm{d}p$, then the momentums of the fluid flowing through per unit time at the two sections are $\rho A_e v^2$ and $\rho A_e (v+\mathrm{d}v)^2$.

According to the momentum theorem, the increment of fluid momentum is the result of the axial force. On the micro-element $\mathrm{d}x$, the force acting on the control body has static pressure and wall friction. Therefore, the momentum equation can be written as:

$$-A_e \mathrm{d}p - \pi D_e \tau_w \mathrm{d}x = \rho A_e[(v+\mathrm{d}v)^2 - v^2] \tag{2}$$

For a circular pipe with equal sections, the frictional resistance of the pipe wall per unit area to the control body:

$$\tau_w = \rho\lambda(v^2/8) \tag{3}$$

substituted into the above formula and then tidied, obtaining:

$$\frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x} + \frac{\lambda}{2D_e}v^2 + 2v\frac{\mathrm{d}v}{\mathrm{d}x} = 0 \tag{4}$$

where: D_e is the inner diameter of the drip irrigation pipe; λ is the friction coefficient of the pipe wall.

It can be seen from the above formula that the axial static pressure variation depends on two items: $\lambda v^2/2D_e$, characterizing the frictional effect of the pipe wall, and $2v\mathrm{d}v/\mathrm{d}x$, characterizing the momentum transmission effect. Since the velocity distribution on the flow cross section of the main flow channel of the drip irrigation pipe is not uniform, the uneven distribution makes the fluid flow through the lateral flow orifice not strictly perpendicular to the axial direction. Considering that equation (4) is a momentum differential equation obtained on the basis of the assumption of the streamline perpendicular to the axis flowing out from the orifice, the axial momentum component carried away by the lateral orifice fluid, as well as the influence of the orifice on the boundary layer of the pipe, has not been considered.

Therefore, the momentum transmission item needs to be corrected. The correction method is to multiply the momentum transport item by a correction coefficient, called the momentum exchange coefficient, under the premise of ensuring the constant friction resistance term, that is:

$$\frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x}+\frac{\lambda}{2D_e}v^2+2kv\frac{\mathrm{d}v}{\mathrm{d}x}=0 \tag{5}$$

The processing method using the momentum exchange coefficient is simple in that it does not need to consider the specific flow details, but the errors caused by the simplification of the model are included in this correction coefficient, and the part of the axial momentum component carried away by the lateral flow orifice are directly corrected. Equation (5) shows that the static pressure variation in the main current channel of the drip irrigation pipe is affected by the dual influence of the frictional resistance and the momentum exchange.

Therefore, the static pressure solution comes down to determining the friction resistance coefficient λ and the momentum exchange coefficient k, which are described below.

2.2. Friction resistance coefficient λ

The porous coefficient method is based on energy balance, and it does not consider the variation along the path in the porous pipes, as an averaging and simplified treatment method. The commonly used expression of porous coefficient is Christiansen formula[10]:

$$F=\frac{1}{m+1}+\frac{1}{2N}+\frac{\sqrt{m-1}}{6N^2} \tag{6}$$

where F is the Christiansen porous coefficient; m is the flow index, and generally 1.75; N is the number of orifices.

The variable mass momentum equation used in this paper takes the micro-elements before and after the orifice as the analysis object in the derivation. The introduction of a friction coefficient refers to the actual friction coefficient value on the dx pipe segment, which is independent of the number of holes in the porous pipe, so it is not necessary to reduce it by the porous coefficient method but to utilize a continuous function that varies with the longitudinal flow velocity, which is more in line with the physical reality than the porous coefficient method. Strictly speaking, λ should be calculated according to the subareas of different flow states, but many studies[24-28] have shown, for the inner diameter less than 80 mm of the drip irrigation pipes made by PE material, there should be enough accuracy for calculation when the entire pipeline is uniformly treated according to the turbulent smooth zone, that is, the friction resistance coefficient of the drip irrigation pipe is calculated by the Blasius resistance formula:

$$\lambda=0.3164/\mathrm{Re}^{0.25} \tag{7}$$

where Reynolds number $\mathrm{Re}=vD_e/\nu$, D_e and ν are the inner diameter of the drip irrigation pipe and the kinematic viscosity of water, respectively.

2.3. Momentum exchange coefficient k

The momentum exchange coefficient is the key to solving the variable mass momentum equation. The equation derivation process shows that the role of the momentum exchange coefficient k is to correct the part of axial momentum component taken away by the lateral flow orifice.

The axial component of the orifice outflow causes the change of the main flow velocity and the main flow energy before and after the orifice. It is assumed that k is proportional to the relative kinetic energy difference in the main current channel before and after the splitting, i.e.

$$k\propto\frac{\Delta(v^2)}{v^2} \tag{8}$$

Then the mathematical expression of the relative kinetic energy difference becomes the key to the form of the function to derive k .Mathematical analysis is performed by:

$$\frac{v_{i+1}^2 - v_i^2}{v_i^2} = \frac{(v_i + v_{i+1})(v_{i+1} - v_i)}{v_i^2} = \frac{2v_\xi \Delta v}{v_i^2} \tag{9}$$

where $\Delta v = v_{i+1} - v_i$, $v_i + v_{i+1} = 2v_\xi$ is the median theorem.

Both sides are divided by Δx and the limitation is taken:

$$\lim_{\Delta x \to 0} \frac{v_{i+1}^2 - v_i^2}{v_i^2 \Delta x} = \lim_{\Delta x \to 0} \frac{2v_\xi}{v_i^2} \frac{\Delta v}{\Delta x} = \frac{2v'}{v} \tag{10}$$

That is,

$$[\frac{v_{i+1}^2 - v_i^2}{v_i^2}]' = 2\frac{v'}{v} \tag{11}$$

The equation (10) was integrated from 0 to *x*, and the function of the relative kinetic energy difference is obtained:

$$\frac{v_{i+1}^2 - v_i^2}{v_i^2} = \int_0^x 2\frac{v'}{v} = 2\ln\frac{v}{v_0} \tag{12}$$

where v_0 is the inlet flow velocity of the drip pipe.

It can be obtained from the simultaneous Equations（8）and（12）：

$$k \propto \ln\frac{v}{v_0} \tag{13}$$

It can be determined by equation (13) that k is related to the longitudinal flow velocity distribution of the pipeline, and the longitudinal velocity distribution of the drip irrigation pipe is a stepped piecewise function. In order to facilitate the mathematical processing, this paper simplifies the longitudinal flow velocity distribution of the main current channel of the drip irrigation pipe into a continuous function, and assumes the following exponential distribution form:

$$\frac{v}{v_0} = (1 - \frac{x}{L})^m = (1 - \overline{x})^m \tag{14}$$

where *x* is the length from the head of the pipe, m; *L* is the total length of the drip irrigation pipe, m; $\overline{x}$ is the relative coordinate of the pipe.

Combining equations (13) and (14), it can be known:

$$k \propto \ln(1 - \overline{x}) \tag{15}$$

Based on the above analysis, the functional formula for determining the momentum exchange coefficient k is as follows:

$$k = a + b\ln(1 - \overline{x}) \tag{16}$$

where *a* and *b* are undetermined parameters.

By integrating equation (5) between any two sections $A - A$ and $B - B$ of the main current channel, it can be obtained:

$$p_A - p_B = \rho g h_{f_{AB}} + \rho k(v_B^2 - v_A^2) \tag{17}$$

that is：

$$k = \frac{p_A - p_B - \rho g h_{f_{AB}}}{\rho(v_B^2 - v_A^2)} \tag{18}$$

where p_A and p_B are the static pressures of the two measuring points *A* and *B*, respectively; v_A and v_B are the axial flow velocity of the two measuring points of *A* and *B* respectively; $h_{f_{AB}}$ is the friction loss between the two measuring points of *A* and *B*.

According to equation (18), the momentum exchange coefficients k of different pipe sections under different working conditions are tested and measured, and the data regression is carried out according to the expression shown in equation (16).

2.4. Static pressure distribution along the path

The theoretical model of the variable mass momentum equation shows that the static pressure variation value of the porous pipe depends on the friction resistance coefficient λ and the momentum exchange coefficient k. In the above analysis and derivation process, the functional expression of λ and k has been determined. Therefore, the variable mass equation can be solved. The equation (7) of λ, the equation (16) of k and the equation (14) of the longitudinal flow velocity distribution of the drip pipe are substituted into the equation (5), achieving:

$$\frac{1}{\rho}\frac{\mathrm{d}p}{\mathrm{d}x} + \frac{0.1582\nu^{0.25}}{D_e^{1.25}} v_0^{1.75}(1-\bar{x})^{1.75m} + v_0^2[a + b\ln(1-\bar{x})]\frac{\mathrm{d}(1-\bar{x})^{2m}}{\mathrm{d}x} \tag{19}$$

$\Delta P = \frac{2(p_{\bar{x}} - p_0)}{\rho v_0^2}$ is constructed to be a dimensionless quantity, and ΔP is the relative static pressure difference at $\bar{x}$. $p_{\bar{x}}$ is the static pressure value at the position $\bar{x}$; p_0 presents the static pressure value at the head of the drip irrigation pipe; $\frac{1}{2}\rho v_0^2$ is the dynamic pressure value expressed by the axial flow velocity value v_0 at the drip irrigation pipe head.

Solution of equation (19) can acquire the relative static pressure difference at any relative coordinate $\bar{x}$ of the drip irrigation pipe:

$$\Delta P = a[1-(1-\bar{x})^{2m}] - \frac{0.058E}{\mathrm{Re}_0^{0.25}}[1-(1-\bar{x})^{2.75m}] - b[(1-\bar{x})^{2m}\ln(1-\bar{x}) - \frac{1}{2}\bar{x}(\bar{x}-2)] \tag{20}$$

where $E = L/D_e$ is length-diameter ratio of the drip irrigation pipe; $\mathrm{Re}_0 = v_0 D_e/\nu$ is the Reynolds number of the drip irrigation pipe head.

There are still three undetermined parameters in equation (20): *a* and *b* and the velocity distribution index *m*. It is necessary to determine the three undetermined parameters by the test of pressure measurement-flow measurement along the drip irrigation pipe to obtain a perfect static pressure distribution solution along the path.

3. Materials and methods

3.1. Experimental material

The six types of drip irrigation pipes (represented by A~F) were provided by Qinchuan Water-Saving Irrigation Company of Shaanxi Province. The basic characteristic parameters of the six drip irrigation pipes are given in Table 1.

Table 1. General parameters of tested drip pipes.

Drip pipe type	Drip pipe length L/m	Emitter spacing s/m	Pipe outer diameter D/mm	Emitter characteristic parameters		Pipe inner diameter D_e /mm		Cross section area A_e / mm^2
				Flow coefficient C / -	Flow index y/ -	Mean value	Standard deviation	
A	6,12,18,24	0.3	16	13.91	0.605	14.59	0.496	167.164
B	6,12,18,24	0.3	12	3.253	0.544	10.62	0.262	88.579
C	6,12,18,24	0.3	8	7.346	0.596	6.97	0.083	38.141
D	6,12,18,24	0.3	16	9.647	0.512	14.02	0.158	154.316
E	36,48,60	1.2,0.6,0.3,0.15	16	6.718	0.216	13.56	0.082	144.388
F	6,12,18,24	1.2,0.6,0.3,0.15	16	4.895	0.174	13.56	0.082	144.388

3.2. Test equipment and methods

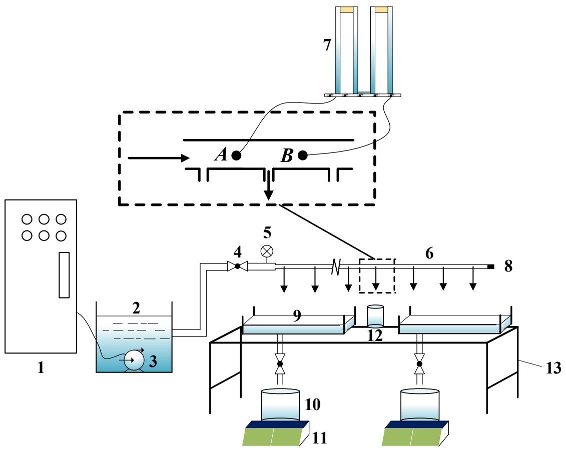
The main variation parameters in the test include the type of drip irrigation pipes (6 types), the distance s between the drippers, the total length L of the drip irrigation pipe and the pressure hydraulic head H_0 at the head. The levels of the type of the drip irrigation pipes, the distance between the drippers and the total length of the drip irrigation pipe are set and listed in Table 1. The pressure H_0 at the head is set to 0.02, 0.04, 0.06, 0.08, 0.10, 0.12 MPa through constant voltage variable frequency cabinet, a total of 240 sets of working conditions. The pressure measurement-flow measurement test equipment of the drip irrigation pipe is shown in Figure 3.

For each set of measurement conditions, the pressure measurement and flow measurement are started after the water flow is running smoothly. During the test, the water temperature of the storage tank is maintained at about 20 °C (the viscosity of the water is $\nu = 10^{-6}\,\text{m}^2/\text{s}$). Each group of working conditions is set with three valid repetitions by replacing the pipe.

The purpose of the pressure measurement-flow measurement is to regress and obtain the undetermined parameters *a* and *b* in the empirical expressions of the velocity distribution index m and k, and to verify the static pressure distribution model.

k is measured by the formula (18), wherein $p_A - p_B$, the static pressure difference between the two measuring points, can be directly read by the differential pressure gauge; $h_{f_{AB}} = s(\lambda_A v_A^2 + \lambda_B v_B^2)/4D_e g$ is the friction loss between the two points, the friction resistance coefficients λ_A and λ_B are obtained by the substitution of the flow velocities at points *A* and *B* into equation (7). Then, v_A and v_B are weighed after a certain period of time by cooperating with the beaker and the water collection tank, by the method of volume.

The longitudinal flow velocity distribution is obtained by the volumetric method measuring the flow rate (weighing the water collector). The measuring points are selected at intervals of 10% of the total length of the drip irrigation pipe, and the longitudinal flow velocity distribution profile of the drip irrigation pipe is obtained, followed by the regression of the equation (14), obtaining the value of m.



1. Variable frequency cabinet 2. Reservoir 3. Centrifugal pump 4. Globe valve 5. Pressure gauge 6. Drip pipe 7. Manometer 8. Plug
9. Water collecting channel 10. Bucket 11. Weighing machine 12. Measuring jug 13. Test-bed
Figure 3. Schematic diagram of test equipment.

4. Results and analysis

4.1. Longitudinal flow velocity distribution of main current channel

The longitudinal flow velocity distribution of the main current channel of the drip irrigation pipe is attributed to the regression of the flow velocity distribution index m . In the above analysis, the structural parameters (length-diameter ratio E) and flow parameters (Reynolds number Re_0 of the pipe head) of the drip irrigation pipe have been considered. Among other factors, the form of the flow velocity distribution may be related to the self-characteristic parameters of the dripper (flow coefficient *C*, flow state index *y*) and the number *N* of dripper installed.

Two-way analysis of variance was performed on m which is measured for the working conditions of each group. The two possible influence factors were the type of drippers (6 types) and the number of the drippers installed *N* (16 levels can be know from Table 1). The results of variance analysis show that when the significance level is 5%, the type of the drippers has no a significant effect on the flow velocity distribution index m , that is, under the same condition *N*, there is no statistically significant difference in the flow velocity distribution index corresponding to different types of drippers.

It can be considered that in the range of *C* and *y* involved in the test drippers, the longitudinal flow velocity distribution form of the drip irrigation pipe is independent of the dripper characteristic parameters, and linearly dependent to the number *N* of the drippers installed (Figure 4) significantly. The relationship between the two is:

$$m = 0.0036N + 1.19 \quad (5 \le N \le 400) \tag{21}$$

According to the equation (21), equation (14) can be written as:

$$v = v_0(1-\overline{x})^{0.0036N+1.19} \tag{22}$$

This is based on the longitudinal flow velocity distribution formula of the drip irrigation pipe obtained from the test.

4.2. Regression of momentum exchange coefficient

After measuring the variation law of k_i along the path under various working conditions, the regression is performed according to equation (16). The results show that there is no statistically significant difference between the values of a_i and b_i at different working conditions (significant level of 0.05), so the average value of a_i and b_i are a and b, with the substitution result into equation (16) as follows:

$$k = 0.83 + 0.14\ln(1-\overline{x}) \tag{23}$$

Figure 5 shows the variation law of the momentum exchange coefficient k of the drip irrigation pipe. If the equation (18) of k is substituted into the constant total flow energy equation, it can be obtained that $k = 0.5$. Therefore, applying the energy equation to solve the flows of the porous pipes can be regarded as a special solution method of the momentum equation, but the momentum exchange coefficient takes a constant of 0.5 and k is not considered. As the drip irrigation pipe discharges along the path, the hydrodynamic characteristics in the main current channel change continuously, and the momentum exchange at the orifice also inevitably changes. Consequently, compared with the energy equation method, the momentum equation method considering the variation k along the way is more in line with the physical reality.

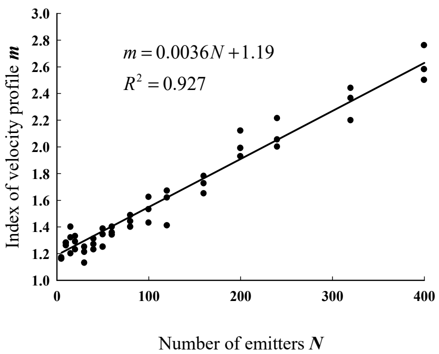


Figure 4. Relationship between m and N.

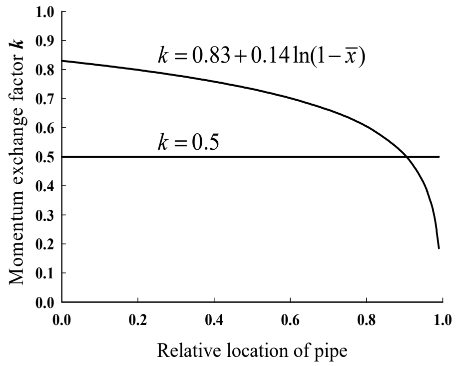


Figure 5. Axial variation of momentum exchange factor.

4.3. Static pressure distribution along the path

From the previous derivation formula and the empirical regression results of 3.1 and 3.2, the static pressure distribution along the drip irrigation pipe are obtained by the simultaneous equations (20), (21) and (23):

$$\Delta P = 0.83[1-(1-\overline{x})^{0.0072N+2.38}] - \frac{0.058E}{\mathrm{Re}_0^{0.25}}[1-(1-\overline{x})^{0.01N+3.27}] - 0.14[(1-\overline{x})^{0.0072N+2.38}\ln(1-\overline{x}) - \frac{1}{2}\overline{x}(\overline{x}-2)] \tag{24}$$

Equation (24) is a static pressure distribution model of the drip irrigation pipe obtained by regression of the pressure measurement-flow measurement data of the drip irrigation pipe according to the variable mass momentum equation. The model is given in dimensionless form.

Figure 6 shows the comparison between the measured values of the static pressure distribution of the drip irrigation pipe and the calculated value by the equation (24) under six typical conditions. It can be seen from the figure that the calculated results agree well with the measured results, that is, the equation (24) is used for the static pressure distribution along the drip irrigation pipe with certain accuracy.

The static pressure distribution curve of the working condition 6($L = 6\mathrm{m}$, $s = 1.2\mathrm{m}$, $H_0 = 0.05\mathrm{Pa}$) in Figure 6 is gradually increasing along the path, which indirectly proves the rationality of the variable mass momentum equation. There is indeed a momentum exchange effect that causes the static pressure to rise, and The Bernoulli equation based on fluid energy balance per unit mass cannot reflect this effect.

In the design of drip irrigation system, one of the ultimate objectives of hydraulic calculation is to determine the optimal combination of pipe diameter and pipe length. In the drip irrigation operation, the operating pressure at the head is the most important factor influencing the operating cost of the system. Equation (24) contains the length-diameter ratio E and the Reynolds number Re_0 of the pipe head, which are important control parameters in drip irrigation design and operation process, as the structure and flow parameters of the drip irrigation pipe.

Since the combination form $E/\mathrm{Re}_0^{0.25}$ of the two appears in the equation (24), the influence of the item on the static pressure distribution along the drip irrigation pipe is analyzed. Figure 7 shows the variation of the static pressure along the drip irrigation pipe with $E/\mathrm{Re}_0^{0.25}$, when $N=10$ （$L=6$m，s=0.6m）.

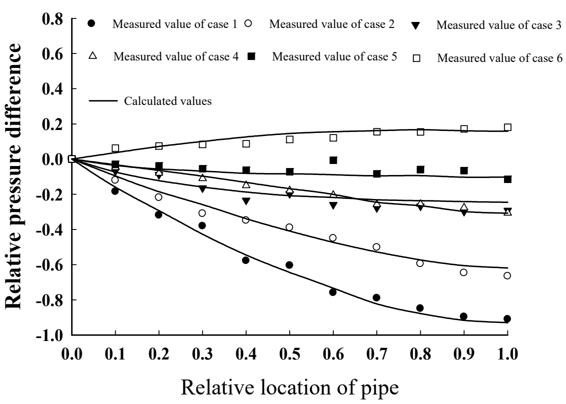


Figure 6. Comparison of longitudinal static pressure distribution between measured and calculated values.

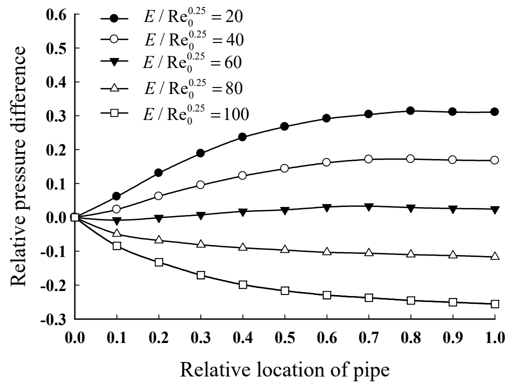


Figure 7. Relationship between $E/\mathrm{Re}_0^{0.25}$ and longitudinal static pressure distribution.

It can be seen from Figure 7 that the combined parameter $E/\mathrm{Re}_0^{0.25}$ has obvious influence on the form of static pressure distribution, and it can be considered that $E/\mathrm{Re}_0^{0.25}$ characterizes the relative strength of frictional resistance effect and momentum exchange, that is, the smaller $E/\mathrm{Re}_0^{0.25}$, the stronger the momentum exchange, and the weaker the frictional resistance, presenting the static pressure increase along the path. It can be inferred that for a certain Reynolds number of the pipe head, a length-diameter ratio always exists, making the friction resistance and momentum exchange basically balanced, and the static pressure is evenly distributed along the path; Conversely, for a certain length-diameter ratio, there must be a Reynolds number at the head of the pipe, which makes the static pressure along path evenly distributed. If the influences of the dripper manufacturing deviation and the flow channel blockage are not considered, the flow rate of the dripper is equal, so to achieve 100% irrigation uniformity is possible.

5. Conclusions

In this study the following conclusions are mainly obtained:

(1) The static pressure variation of the main current channel of the drip irrigation pipe depends on the frictional resistance term and the momentum exchange term. The frictional resistance makes the static pressure to tend to decrease, while the momentum exchange term causes the rising tendency of the static pressure, and the specific form of the static pressure distribution along the path depends on the relative strength of the two terms.

(2) The variance analysis of the longitudinal flow velocity distribution index of the drip irrigation pipe is carried out. The results show that m is not related to the self-characteristic parameters of the dripper but linearly dependent to the number N of the drippers installed.

(3) The functional form of the momentum exchange coefficient k is qualitatively analyzed, and the empirical expression of the momentum exchange coefficient of the drip irrigation pipe based on the regression of the flow test data is obtained; combined with the friction coefficient λ of the Blasius

formula, the momentum equation is solved, and the solution of the static pressure distribution along drip irrigation pipe was acquired.

(4) In the static pressure distribution model, the friction resistance and momentum exchange effects are classified and transformed into the controllable structural parameter E and the flow parameter Re_0, which is convenient for optimizing the structural design of the drip irrigation system and determining the optimal operating conditions.

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