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THEORETICAL AND EXPERIMENTAL STUDY ON DEVICE CHARACTERISTICS OF SPRINKLER IRRIGATION SYSTEM

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ABSTRACT

The resistance loss of sprinkler irrigation system is an important parameter, it has significance and practical value for studying its device characteristics. In this study, according to the selected materials and setting modes, both the pressure drop along the pipe and the local resistance loss were calculated out. The theoretical device characteristics of one sprinkler irrigation system was analyzed. A calculating schema has been carried out in order to apply the method to any sprinkling system. Experimental study was carried out for this system. Water distribution maps for the sprinklers were drawn using Matrix Laboratory (MATLAB). The hydraulic characteristics were as follow, 7.2, 3.0, 10.0 mm/h was the average, minimum, and maximum irrigated intensity, respectively. It supplied theoretical foundation for the reasonable application of sprinkler irrigation system for the future.

KEY WORDS:

Sprinkler irrigation system; Device characteristics; Resistance loss coefficient; CU

INTRODUCTION

Sprinkling systems in supplying water to crops has been widely used in recent years. This method is suitable for different kinds of crops including agricultural crop such as soybean, tea, coffee, sugarcane and vegetables. Sprinkling irrigation has also other advantages such as high homogeneity, simple control of water flow rate, possible combination with supplies of nutrition, fertilizer or pesticide. With this method, it is also possible to apply mechanization that would result in labor cost savings. Light-duty irrigation system is a typical unit in China. Because of the characteristics of simple and flexible, it is adapt to the rural development. The sprinkler irrigation system contains a lateral, risers and sprinklers. The accurate determination of water discharge and head at sprinklers requires complex calculations and long time. Of all the methods presented by investigators, the finite element method is the best one to use when considering a complete unit.

Pressurized pipelines with multiple outlets (laterals and manifolds) are extensively used to distribute water in irrigating areas under sprinkler irrigation systems. Adequate analysis of hydraulic design of multiple-outlet pipelines is important for the proper performance of these systems. A multiple-outlet pipeline is a hydraulic structure whose design is limited by the pressure head at the pipeline inlet, water application uniformity and, consequently by the total head losses due to friction. In previous solution is based on an outflow that is uniform, although ramifications 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. The objective of this paper is to present a theoretical procedure for calculating the resistance loss of system and develop a new method, which can produce accurate results in a short time.

HYDRAULIC ANALYSIS OF SPRINKLER IRRIGATION SYSTEMS

Hydraulic design of a multiple outlets pipelines is one of the important factors in the ultimate success or failure of sprinkler irrigation systems. A multiple outlets pipelines is a hydraulic structure whose design is limited by the operating inlet pressure head. In order to design an adequate irrigation system, it is important to perform accurate determination of water discharge and adjustment through each sprinkler. Christiansen put forward the factor F in 1942 as:

$$F = \frac{1}{m+1} + \frac{1}{2N} + \frac{(m-1)^{0.5}}{6N^2} \qquad (1)$$

Where F=Christiansen's factor F; m=velocity exponent in the formula used for the computation of head loss caused by friction; and N= the number of outlets along the pipeline.

The factor was developed assuming the first outlet is one outlet spacing from the inlet of the pipeline. Further, Christiansen assumed that the outlets along the pipeline have equal discharge. In a pipeline with multiple outlets, there will be energy losses caused by the coupler and structure of the outlets. However, there also is gradual reduction in velocity head as flow passes the outlet and this will cause an increase in pressure, which will balance losses caused by turbulence at outlet couplings. Hence exact procedures to calculate pressure losses in pipeline with multiple outlets can not be justified. The estimation of head loss caused by friction in pipelines with multiple outlets requires a stepwise analysis starting from the most downstream outlets, working upstream and computing the head loss caused by friction in each segment.

With the sprinkler irrigation system shown in Fig.1, it consists of a lateral, risers and sprinklers. In general, to facilitate the design and installation of irrigation system, identical risers and sprinklers are to be mounted. Therefore in this case, a sprinkler can be analyzed as a representation of the whole system. It is known that the discharge from the riser or emitter is a function of water pressure. In simple form

$$Q = K\sqrt{H} \qquad (2)$$

Where Q =sprinkler flow rate or discharge(m^3/s); H =working pressure head at the sprinkler (m); K =coefficient ($m^{2.5}/s$) (constant with each type of sprinkler).

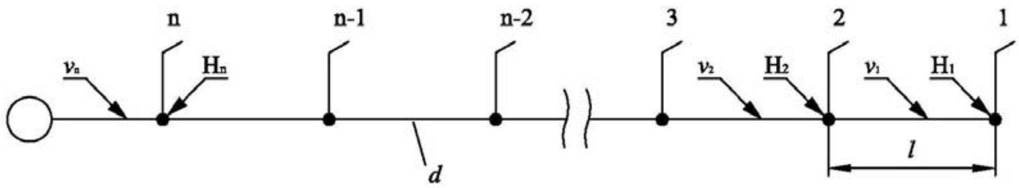

Fig.1 Layout of a sprinkler irrigation system

From the obtained values of Q and H, values of different discharge coefficient K for different types of sprinkler can be identified.

First of all, let us examine the farthest sprinkler at the lateral. Supposing that the flow through sprinkler 1 takes head H_1, with the value of discharge coefficient K given by the above experiment, discharge Q_1 through sprinkler 1 at the intersection of the last riser and second last riser can be determined as:

$$H_2 = H_1 + \lambda_1 \frac{l}{d}\frac{v_1^2}{2g} \qquad (3)$$

Where H_1 =pressure head at sprinkler 1 (m); H_2 =pressure head at sprinkler 2 (m); v_1 =velocity of section 1 (m/s); g =gravitational acceleration (m/s^2); d =diameter of lateral (m); l =spacing of sprinkler (m); λ_1 =friction factor in Darcy-Weisbach equation. In case that the lateral line is a smooth pipe,

$$\lambda_1 = 0.3164\left(\frac{dv_1}{\upsilon}\right)^{-0.25} \qquad (4)$$

Where υ = kinematical viscosity of water (m^2/s)

Similarly,

$$H_3 = H_2 + \lambda_2 \frac{l}{d}\frac{v_2^2}{2g} = H_1 + \lambda_1 \frac{l}{d}\frac{v_1^2}{2g} + \lambda_2 \frac{l}{d}\frac{v_2^2}{2g} \qquad (5)$$

$$H_n = H_1 + \lambda_1 \frac{l}{d}\frac{v_1^2}{2g} + \lambda_2 \frac{l}{d}\frac{v_2^2}{2g} + \cdots + \lambda_{n-1} \frac{l}{d}\frac{v_{n-1}^2}{2g} \qquad (6)$$

In general,

$$H_n = H_1 + \sum_{i=1}^{n-1} \lambda_i \frac{l}{d}\frac{v_i^2}{2g} \qquad (7)$$

Now the Eq.7 becomes

$$H_n = H_1 + 0.3164\frac{l}{2gd}\left(\frac{\upsilon}{d}\right)^{0.25} \sum_{i=1}^{n-1} v_i^{1.75} \qquad (8)$$

With the value of H_1, we can identify the value of q relatively at each sprinkler and total discharge at the lateral

$$Q_L = \sum_{i=1}^{n} q_i \qquad (9)$$

Where q_i =the sprinkler discharge

To express the relationship between the inlet discharge and the inlet pressure head of a lateral, Kang and Nishiyama (1996) presented the lateral discharge equation as:

$$Q_L = C_0 + C_1 H + C_2 H^2 + \cdots + C_n H^n \quad (10)$$

Where C_0 , C_1 , C_2 ,… C_n =coefficients, determined using the least squares method; Q_L =inlet discharge of the lateral; H =inlet pressure head of the lateral.

Using the same theory, relationship between the inlet pressure head and the velocity of the lateral can be expressed by the lateral pressure head equation as:

$$H = C_0 + C_1 v + C_2 v^2 \quad (11)$$

APPLICATION EXAMPLE

Distribution uniformity test were conducted in the laboratory at the Research Center of Fluid Machinery Engineering and Technology (Jiangsu, China). Fig.2 shows the photo of the sprinkler irrigation system experimental setup. A centrifugal pump typed 65ZB-40C supplied water to the lateral from a reservoir maintained at a constant level. The sprinklers model were 10 × 20PY impact sprinkler and the nozzle diameter was 4.5 mm. The sprinkler flow rate was 2600 L/h with an operating pressure of 250 kPa, which was controlled by a pressure regulator. To determine the sprinkler water distribution profile, the following standards were adopted: American Society of Agricultural Engineers (ASAE) S.330.1 (1985); ASAE S.398.1 (1985); and International Organization for Standardization (ISO) 7749-2 (1990), MOD GB/T 19795 (2005).

(a) centrifugal pump

(b) impact sprinkler

Fig.2 Sprinkler irrigation system

The sprinkler nozzle height was 1.2 m above ground and approximately 800 mm above the collector tops. The test duration was 1 h. The average volume readings at the end of the test (60 minutes) for each collector position were calculated out. Then, the CU was calculated. The parameters used in the analysis were Christiansen Uniformity Coefficient (CU) (Christiansen 1942):

$$CU = \left[1 - \frac{\sum_{i=1}^{n} |x_i - \bar{x}|}{n\bar{x}} \right] \times 100\% \quad (12)$$

where x_i = water depth collected by catch cans; $\bar{x}$ = mean water depth collected in all catch cans; n = total number of catch cans used in the evaluation

Matrix Laboratory (MATLAB) was used to establish computational program. The water depth of every interpolating point was worked out using mathematical model of cubic spline interpolating. CU was calculated out using equation 12. The water depth distribution map and contour map for the 20PY sprinklers are shown in Figs.3 and 4. Water depth at any point around the sprinkler can be visualized easily and conveniently.

It is notable in Fig. 4 that the water distribution was uniform around the rectangular irrigated control area. The average irrigated intensity was 7.2 mm/h. The minimum irrigated intensity was 3.0 mm/h near any single sprinkler. The maximum irrigated intensity was 10 mm/h between the two sprinklers.

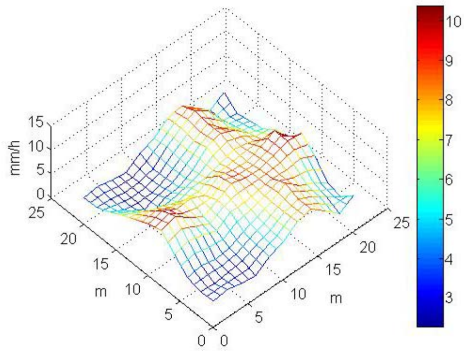

Fig. 3. Water distribution map

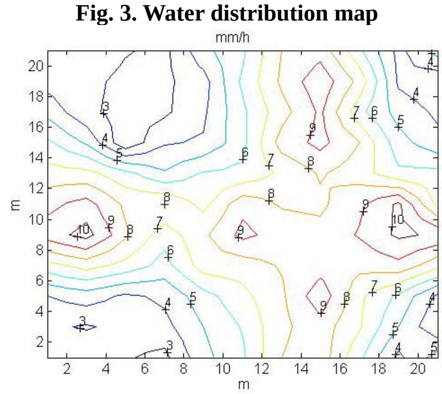

Fig. 4. Water distribution contour map

CONCLUSIONS

A new method has been developed that can be used to analyze and calculate sprinkler irrigation systems by means of combining the back step method, the lateral pressure head equation, the unsteady flow method and the forward step method. The calculating procedure can be programmed on computers in generalized form to design and calculate any different irrigation systems with its parameters easily changed when changing the input values of the program. The analyzing and calculating procedure is also simple, fast and accurate. MATLAB software platform was supplied to study the uniformity coefficient. A new evaluation method was developed to precisely calculate uniformity from catch-can test data. Distribution maps of water depth could also be generated. Three-dimensional and contour maps of water distribution in combined irrigation were figured out.

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