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Empirical and quantitative study of the velocity distribution index of the perforated pipe outflowing along a pipeline

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ABSTRACT

To study the distribution law of the flow velocity along perforated pipes, influence factors such as the pipe laying slope, the length diameter ratio and the orifice rate were considered by dimensional analysis, and the influence of the flow velocity distribution index on the velocity distribution along the perforated pipe was analyzed by combining theoretical calculations with experiments. A method of calculating the flow velocity distribution index was proposed, and experiments were carried out. The results show that the calculated values are in good agreement with the experimental results. When the flow velocity distribution index approaches 1.0, the relative deviation of discharge at each orifice along the perforated pipe is very small. Flow velocity distribution index decreases with the increase in the laying slope and increases with the increase in the length diameter ratio and the orifice rate. In the design of perforated pipes, the flow velocity distribution index approaches 1.0 by adjusting the laying slope, the length diameter ratio or the orifice rate of the perforated pipes to reduce the relative deviation in discharge from the orifices and achieve the goal of the same discharge size of each orifice along the perforated pipes.

1. Introduction

A perforated fluid distribution pipe (hereafter referred to as perforated pipes) is a device used to allow the main fluid along the axial direction of the pipe to outflow through the small lateral orifices evenly [1,2]. It consists of a main pipe and several rows of branch pipes, nozzles or pores that are connected to the side of the main pipe [3,4]. Perforated pipes are widely used in water-saving irrigation, petrochemical applications, water supply and drainage, ventilation and other fields [5–7]. The velocity distribution along the flow path is consistent with the flow distribution for a perforated pipe with uniform cross section. Studying the flow velocity distribution is helpful to understand the uniformity of the outflow from a perforated pipe along the pipeline, and the uniformity of outflow along the perforated pipe is one of the important parameters to evaluate for its engineering application; therefore, the calculation of flow velocity distribution along the perforated pipe is an important component of hydraulic calculations to consider in engineering applications [8–11].

Many scholars have studied outflow problems for perforated pipes from the point of view of an energy equation and momentum conservation. Myers et al. calculated the porous coefficient of the perforated pipe by using an energy equation and proposed a computer program method for the calculation [12,13]. Warrick et al. used perforated pipes for micro irrigation as the research object and presented a series of hydraulic calculation models for porous fluid problems [14,15]. Hathoot et al. proposed a method for calculating head loss between orifices of a perforated pipe on the basis of the study by Warrick et al. [16,17]. Roland et al. proposed a numerical calculation method for a hydraulic field such as flow, pressure and head loss in a micro irrigation field network and improved the efficiency in the design of perforated pipes [18,19]. Pedro et al. used Darcy's law to establish a new algorithm for calculating the head loss of perforated pipes [20]. Afrin et al. studied the hydraulic performance of the perforated pipe by means of experiments and built a numerical model for hydraulic calculations of perforated pipes [21–23]. Maynes et al. studied the head loss coefficient of the perforated pipe by experiments and proposed the theoretical calculation method for the head loss coefficient [24]. Dan et al. studied the pressure distribution along the perforated pipe by establishing a functional relationship between a certain position on the perforated pipe and the water head and proposed the optimal design method for an irregular micro irrigation field network [25,26]. Additionally, Edmar, Kang Yuehu, Jain and Ravikumar et al. also presented a series of empirical formulas for calculating hydraulic parameters such as pressure and flow of perforated pipes on the basis of an experiment and further improved aspects of hydraulic calculation for perforated pipes [27–30].

However, the preceding study does not involve the flow velocity

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distribution in the perforated pipe along the pipeline when it runs. The velocity distribution is very important for pipeline engineering, and there are many factors affecting the velocity distribution of pipelines [31–33]. In this paper, the main factors such as pipe laying gradient, ratio of length to diameter and perforating ratios were considered by dimensional analysis, and the flow velocity distribution law along the pipeline was studied by means of theoretical calculation and experiment. A method of determining the flow velocity index was proposed and validated by experimental data. The research can provide a theoretical basis for hydraulic calculation and the engineering application of perforated pipes.

2. Experimental survey

2.1. Experimental materials and devices

The experimental pipes were produced by the 148 regiment of the eighth Division in Xinjiang Production and Construction Corps. The pipe diameters are 8.0 cm, 7.5 cm, 5.5 cm and 5.0 cm. The water outlet orifice at each perforation position along the pipeline is perforated by a laser to form a pair of water outlet round holes, and the orifice diameter is 1.2 mm. The experimental device is shown in Fig. 1. The front of the experimental device is a constant-pressure water tank with an overflow plate, and the pressure head at the inlet of the pipeline can be controlled by adjusting the elevation of the overflow plate. The pipe laying surface is composed of aluminum alloy channel steel, and the lever support is set at intervals of 2.5 m as the slope control point of the aluminum alloy laying surface. The slope of the paved surface is controlled by adjusting the elevation of the support to adjust the pipe laying slope. The slope is checked with an automatic level. Before the experiment, pipes of different lengths and distances were acquired according to the requirements of the experiment, the pipes were blocked at the end, and the pressure heads and the slope values of the laying surface were adjusted. Fixed observation sections were established every 5 m from the first outlet position in the pipeline, and the pressure heads were observed with piezometric tubes. The single hole water yield at the entrance and the relevant section and the corresponding container water holding time are observed and recorded during the experiment. The pipe flow is measured by a TDS-100P portable flowmeter. The flow of each outlet orifice along the pipeline is measured by the volume method; the specific method considers that the vessels are adhibited to contain the water from each outlet orifice within the prescribed period of time. Then, the counting cup is adopted to measure the corresponding water volume, and the outlet flow is obtained after the volume is divided by the time. The outlet flow of water from each orifice within a certain section of the perforated pipe is added together, and then, the outlet flow along the section of the perforated pipe can be obtained.

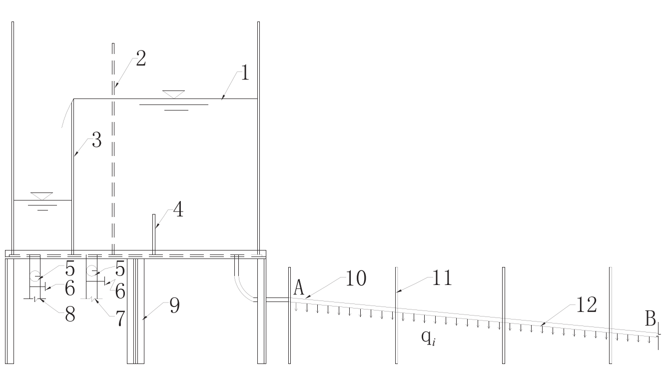

Fig. 1. Schematic diagram of the experimental equipment. 1 Water storage tank, 2 Grille plate, 3 Overflow plate, 4 Baffle, 5 Water meter, 6 Gate valve, 7 Inlet pipe, 8 Overflow pipe, 9 Tank support, 10 The conduit, 11 Regulating rod, 12 Aluminum alloy plate.

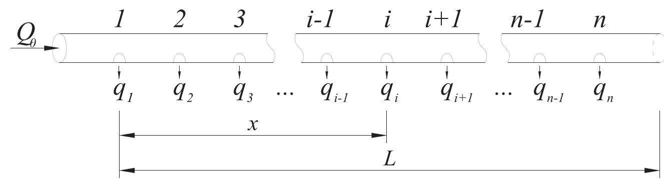

Fig. 2. Schematic diagram of the perforated pipe structure.

2.2. Experimental scheme

The experimental indexes mainly include pressure head (H), laying slope of pipes (I), outflow orifice diameter (d), and spacing of outlet orifices (S). The influence of a variable on the flow rate or flow velocity index was investigated by a single-factor experiment. The characteristic parameters of the hydraulic parameters of perforated pipes under different working conditions are obtained through the processing and analysis of the experimental data, and the experimental data can be applied to theoretical calculations and the verification of the results.

3. Determination of the velocity distribution index

3.1. Discussion of the velocity distribution index

The end of the perforated pipe is blocked, and the pipe diameter is not variable along the pipeline. Small equidistant orifices are drilled in the side of the main pipe, and water outflows from each orifice after it enters the main pipe. The schematic diagram of the perforated pipe is shown in Fig. 2. In Fig. 2, Q_0 is the inlet flow of the perforated pipe, m^3/s; i is the orifice number, $i = 1, 2, 3 \ldots\ldots n$; and q_i is the outflow flow for the ith orifice, m^3/s.

The reliability, economy and safety of the perforated outflow equipment largely depends on the uniformity of the fluid distribution. When a fluid passes through a perforated pipe and each fluid flows through a small orifice, the flow is redistributed once, and the quality of the fluid in the pipe decreases during this process. Therefore, the fluid moves according to variable mass flow, and the momentum, mass, pressure, and velocity of the fluid change along the pipeline. The outflow of a perforated pipe occurs under pressure. Accordingly, it belongs to the problem of pressurized pipe flow in hydraulics, and the velocity distribution in the perforated pipe is a key problem to be solved.

In general, the outflow q of the perforated pipe along each orifice is nonuniform; in other words, the variation in the flow velocity and flow in the perforated pipe along the pipeline is a function of the location x of the cross section of the pipe. The diameter D is unchanged along the pipeline, and the velocity is proportional to the flow due to the uniform section of the pipeline. Therefore, it is assumed that the flow velocity distribution in the perforated pipe has the following power function form [34,35].

$$v = \frac{Q_x}{A} = \frac{Q_0}{A}\left(1 - \frac{x}{L}\right)^z = v_0\left(1 - \frac{x}{L}\right)^z \tag{1}$$

where Q_x is the flow at the distance of the section x from the entrance of the perforated pipe, m^3/s; L is the length of the perforated pipe, m; v_0 and v are the flow velocity at the entrance of the perforated pipe and the velocity at the cross section x distance from the entrance, repectively, m/s; A is the cross-sectional area of perforated pipe, $A = \frac{1}{4}\pi D^2$, m^2; and z is the velocity distribution index.

By formula (1), we can see that the flow velocity in the perforated pipe is greatest at the inlet ($x = 0$) and equal to zero at the closed end. Transformation of Formula (1) can be obtained as follows:

$$\frac{v}{v_0} = \left(1 - \frac{x}{L}\right)^z \tag{2}$$

Take z > 1.0 (z = 1.2, z = 1.4, z = 1.6), z = 1.0 and z < 1.0 (z = 0.8, z = 0.6, z = 0.4) into Formula (2). The distribution curves of the