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Flow regime and head loss in a drip emitter equipped with a labyrinth channel*

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Abstract: Labyrinth channels are widely adopted in emitter designs to regulate the water flow. The flow regime and the head loss of labyrinth channels have significant impacts on the hydraulic performance of emitters. In this study, the flow behavior of water passing through an emitter channel is observed using the micro particle image velocimetry (PIV), and the head loss during the flow is analyzed for an emitter with a triangular labyrinth channel. The results show that the flow regime is consistent with the classical theory of hydraulics governing straight channels, even when the cross-sectional area is very small (as small as 0.5 mm×0.5 mm). The critical Reynolds number from laminar to turbulent flows in a labyrinth channel is approximately in a range between 43 and 94. The local head loss factor decreases as the Reynolds number increases for labyrinth channels with smaller cross-sectional areas, such as 0.5 mm×0.5 mm and 1.0 mm×1.0 mm. The local head loss factor is not related to the Reynolds number and is only a function of the boundary conditions of the labyrinth channel when the Reynolds number exceeds approximately 1 000 (for cross-sectional areas of 1.5 mm×1.5 mm and 2.0 mm×2.0 mm). The ratio of the local head loss to the total head loss $(h_j / h_{f_{\text{total}}})$ first increases and then remains nearly constant as the Reynolds number increases in the labyrinth channel. The head loss in the labyrinth channel is almost equal to the local head loss, and $(h_j / h_{f_{\text{total}}})$ is approximately 0.95 for cross-sectional areas of greater than 1.0 mm×1.0 mm. These results can be used for optimizing the design of emitter channels.

Key words: emitter, flow regime, labyrinth channel, head loss

Introduction

Emitters are key components of drip irrigation systems[1-3]. To allow the pressurized water in pipes to drip slowly into the soil, most emitter channels are small and in a complex structure[4,5]. The cross-sectional area of the channel is generally less than 1 mm^2, and a labyrinth structure is widely adopted to enable the emitter channel to regulate the water flow[6-9]. Mattar and Al-Amoud[10] indicated that the pressure loss during the flow is caused by the tortuous route of the emitter channel. With the small size and the complex structure of the emitter channel, it is impossible to observe the flow behavior of the water passing

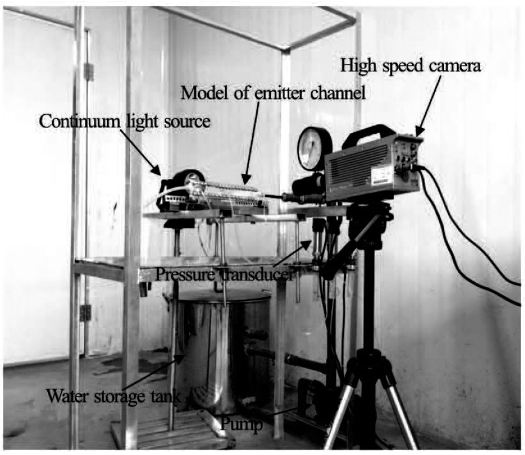

Fig.1 Experimental setup

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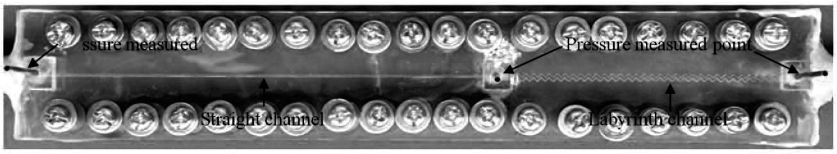

Fig.2 The emitter channel model used for testing

through an emitter channel before the micro particle image velocimetry (PIV) technology is developed. Many simulations were conducted for the emitter channel flow[11-13]. Wu et al.[14] used the standard k - ε model and the large eddy simulation (LES) method to analyze the flow characteristic in the drip irrigation emitter, and the results showed that the LES model was more effective to simulate the flow characteristics in the flow path of drip irrigation emitters. Under the condition of the turbulent flow in labyrinth channels, Wei et al. [15] calculated the distributions of the pressure and the velocity and the relationship between the pressure and the discharge rate for channels with three different shapes (triangular, rectangular, and trapezoidal) using the CFD method. Moreover, the results of the labyrinth channel simulation are well consistent with the experimental data. The CFD provides a promising tool for the design of emitter channels with fewer experimental channels and laboratory experiments.

According to the traditional hydrodynamics, the flow through labyrinth channels is typically laminar at the flow rates and the path dimensions for drip emitters. Nevertheless, some studies did show that the flow in labyrinth channels might be turbulent[16-19]. Thus, the question arises, "which type of flow model, the turbulent flow or the laminar flow, should be adopted in the CFD simulations for emitters with labyrinth channels". To answer this question, the flow behavior of water passing through an emitter channel is observed using the micro PIV and the head loss is analyzed during the flow for a triangular emitter labyrinth channel. The head loss includes the friction head loss and the local head loss. The friction head loss is the loss of energy that occurs in the flow due to the viscous effects generated by the surface of the emitter channel. The local head loss mainly occurs at the entrance and a single bend in the emitter channel. The results prove very valuable for optimizing the design of emitter channels.

1. Materials and methods

1.1 *Experimental design*

The experiments on the flow regime and the head loss of a drip emitter equipped with a labyrinth channel are conducted at the Irrigation Hydraulics Laboratory (IHL), Northwest A&F University, Yangling, China. The testing apparatus consists of a 90-l cylindrical stainless steel water storage tank, a vortex pump driven by an electric motor, the PVC pipe, valves, a model of an emitter channel, several pressure transducers, a plastic cup, a micro PIV instrument and other necessary equipment. The experimental setup is shown in Fig.1.

A model of an emitter channel is fabricated using two pieces of plexiglass. The emitter channel is carved on one piece, and the second piece is used to cover the first one. The two pieces of plexiglass are then fastened using 38 bolts to form a closed emitter channel. The emitter channel consists of a straight channel and a triangular labyrinth channel, both of square cross section, as shown in Fig.2. The length of the straight channel and the flow length of the labyrinth channel are both 16 cm. Four different square cross sectional areas are used in the emitter channels: 0.5 mm× 0.5 mm, 1.0 mm×1.0 mm, 1.5 mm×1.5 mm and 2.0 mm×2.0 mm, respectively. Each emitter channel model is tested at 5 kPa and 10 kPa and from 20 kPa to 360 kPa with an increment of 20 kPa.

Xi'an Xinming model CYB13 pressure transducers are installed at the inlet of the straight channel, the inlet of the labyrinth channel, and at the outlet of the labyrinth channel, for measuring pressures from 0 kPa to 400 kPa at ±0.1% accuracy. The transducers are calibrated at the IHL before the start of the experiments, and all three transducers are connected to a data logger, which is used to record the pressure at an interval of 5 s during each emitter test of 15 min. The average pressures at the inlet of the straight channel, the inlet of the labyrinth channel and the outlet of the labyrinth channel are calculated in each test. Then, the friction head loss for the straight channel and the total head loss for the labyrinth channel are calculated using the pressures measured at the inlet of the straight channel, the inlet of the labyrinth channel and the outlet of the labyrinth channel. Because the length of the straight channel and the length along the flow of the labyrinth channel are the same, the friction head loss for the labyrinth channel is equivalent to the friction head loss for the straight channel in each test. Therefore, the local head loss for the labyrinth channel is also calculated using the total and friction head losses for each test. The water exiting the emitter channel is collected in a plastic cup, and the weight of the water is measured using an ele-