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HYDRAULIC CHARACTERIZATIONS OF TORTUOUS FLOW IN PATH DRIP IRRIGATION EMITTER*

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ABSTRACT: At present, the tortuous emitter has the most advanced performances in drip irrigation. But the theories and methods for designing its flow path have been strictly confidential and the researches on the function of practical guidance have seldom been published. Seven types of most representative tortuous emitting-pipes currently used in agricultural irrigation regions of China were chosen for investigating the geometric parameters of the flow path by means of combining high-precision microscope and AutoCAD technology. By the measurement platform developed by the authors for hydraulic performances of emitters, the free discharge rates from the 7 types of emitters were measured at 9 pressure levels of 1.5 m, 3.0 m, 5.0 m, 7.0 m, 9.0 m, 10.0 m, 11.0 m, 13.0 m and 15.0 m. Then the discharge-pressure relationship, manufacturing variation coefficient, average velocity on the cross-section of flow path and the critical Reynolds number for the flow regime transformation within the paths were analyzed in detail. The results show that both pressure-ascending work pattern and pressure-descending work pattern have some impacts on the discharge rates of tortuous emitters, but the impact level is not significant. The target pressure could be approached by repetitive applications of the two work patterns during pressure regulation. The operation under low pressures has some impacts on the hydraulic performances of emitters, but the impact level is also not significant. The classical model of the discharge-pressure relationship is suitable for the pressure range of 1.5 m -15.0 m. The Reynolds number for fluids within the 7 types of tortuous emitters ranges from Re =105 to Re =930. The critical Reynolds number for the flow regime transformation is smaller than that for the routine dimension flow path. The variation coefficient of emitter discharge rates is slightly fluctuating around a certain value within the whole pressure range.

KEY WORDS: drip irrigation, emitters, tortuous flow path, hydraulic performances, flow characteristics

1. INTRODUCTION

The emitter is a device used to dissipate pressure and to discharge water at a constant rate by dissipating the energy when pressured water flows through its narrow and long internal path structure or micro-orifice. It is the main component of the drip irrigation system and it determines its characteristics [1-3]. The discharge rate per emitter is very small and it is usually only 1 L/h -8 L/h (more of 1 L/h -4 L/h). The width of the flow path of an emitter is much small and it is usually only about 0.6 mm-1.3 mm. The drip irrigation system can be easily deteriorated if the emitter is clogged by the pollutants in water. The structure and hydraulic performances of emitters have an important impact on the irrigation uniformity, anti-clogging capacity and life-span of the drip irrigation system. Since the drip irrigation technology was introduced, many researchers and manufacturers have spent plenty of endeavor and material to research and develope drip irrigation equipment [4]. In some countries such as in Israel, there have been mature design theories, production workmanship, product

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sales and adequate application experience. Especially, the design and production of emitters are relatively quick and the improved performances have been tested in practical applications [5]. Some famous international companies such as *Netafim* and *Rainbird* have their design institutes of drip irrigation emitters. But theories and methods for designing the flow paths have been strictly confidential and research papers on flow paths of emitters with the function of practical guidance have seldom been published.

Karmeli[6] investigated the flow regimes in the long flow path under the conditions of different Reynolds numbers (Re) and the results showed that as $Re < 2000$, the flow was laminar, as $2000 < Re < 4000$, the flow was partially turbulent, as $Re > 4000$, the flow was turbulent. With the Darcy-Weisbach formula the discharge- pressure relationship of emitters under different flow regimes was derived. Tal and Zur [7] studied the hydraulic performances of the helical long-path emitters. Their results showed that the Darcy- Weisbach formula could be used to solve the hydraulic problems within the long and straight flow path of emitters. But it could not explain the hydraulic phenomenon within the helical flow path of emitters because the centrifugal force enhaces the friction inside it. Gilaad et al. [8] pointed out that the hydraulic performances of emitters were determined by the flow path patterns, dimension and material, etc. Because the dimension of the flow path is rather small, the boundary viscous substrate accounts for a large proportion of the whole water flow. The dimension and shape of cross-section of the flow path continuously change, and local water head loss is the primary pattern of energy dissipation within the flow path. Ozekici and Sneed [9] showed that 90% of the water head loss occurred in the part of dentate structure. Fang et al. [10] studied the hydraulic performances of wafer-like dentate tortuous flow path emitters and the results showed that the traditional pipe flow regime theory could not explain the water flow phenomenon within the paths because of the rather narrow cross-section of the paths. From the general point of view, researches were basically restricted to the area of long capillary flow path of emitters. Currently, emitters of tortuous flow path are the most advanced drip irrigation emitters. Some researches were involved in this area, but the majority of them were only restricted to one certain type of flow path. Because of the complex structure of tortuous flow path, it is very difficult to measure its geometric parameters. There is a shortage of studies on the hydraulic performances and fluid movement mechanism for different types of emitters of tortuous flow path.

In this paper, seven types of most representative tortuous emitting-pipes currently used in agricultural irrigation regions of China were chosen for measuring the geometric parameters of the flow path by means of combining high-precision microscope and AutoCAD technology. On this basis, the discharge-pressure relationship, manufacturing variation coefficient of emitters, water flow velocity distribution within the flow path and the critical Reynolds number for the flow regime transformation are analyzed in detail for the purpose of laying the preliminary foundation for promoting the research and development of emitters.

2. BASIC EQUATIONS AND CONCEPTS

2.1 *Discharge-pressure relationship*

A general empirical formula, valid over a narrow range of operating pressure and characterizing the discharge-pressure relationship of various types of emitters, is

$$q = kH^x \tag{1}$$

where q is the discharge from individual emitter, H is the hydraulic head at the inlet of emitter (at the outlet, H =0), k is the discharge coefficient of emitter, x is the discharge exponent, which characterizes the flow regime and q vs. H relationship.

The sensitivity of an emitter discharge to H depend mainly on the values of x . The value of x is typically between 0.1 and 1.0, mainly depending on the design of the emitter. For microtubes with laminar flow, the discharge exponent x =1.0, for spiral long-path emitters x =0.7, for orifice emitters with fully turbulent flow x =0.5, for pressure-compensated emitters x =0-0.1, for vortex emitters x =0.4. The values of the discharge exponent x and discharge coefficient k or the pressure-discharge relationships are usually supplied by the manufaturer. Both American Society of Agricultural Engineers (ASAE) and International Standard Organization (ISO) use the flow regime index as one of the indices to evaluate performances of the emitters [1]. Searching for the appropriate method for reducing the discharge exponent x is a primary target for emitters developers.

2.2 *Flow regime transition*

The average velocity on the cross-section of the flow path $\overline{v}$ was studied, which can be expressed as

$$\overline{v} = \frac{q}{A} \tag{2}$$

$$A = W_{\min} \text{ or } W_{\max} \times D \tag{3}$$