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# 滴灌滴水器迷宮流道流場之模擬與分析

# Simulation and Analysis of Emitter Labyrinth Channel Flow Field in Drip Irrigation

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## 摘　要

滴灌是當前水分利用效率最高的灌溉方式，滴灌最重要的元件不外乎是滴水器。為深入瞭解滴水器的水力特性，本文利用 SolidWorks Flow Simulation 對常用的滴灌滴水器進行流場分析，並利用粒子研究模擬不同密度之雜質進入滴水器流道對流動之影響。結果顯示，滴水器利用齒狀流道結構使流經的流體逐漸耗散其壓力能量，而在出口處產生穩定緩慢的出水。較重的雜質容易堆積在滴水器流道的底部；反之較輕的雜質則隨著水流流動較少發生堆積的現象。因此滴灌水源必須盡可能濾除較重的雜質，加壓幫浦之入水口應避免插至儲水桶底部。

**關鍵詞**：滴灌，滴水器，迷宮，流場，模擬。

## ABSTRACT

Currently, the most efficient form of irrigation is drip irrigation, of which the key component is the emitter. For a comprehensive understanding of the hydraulic properties of the emitter, in this study, SolidWorks Flow Simulation was used to analyze the flow field of a commonly used emitter. The effects of various densities of impurities in the flow channel of the emitter were simulated by conducting a particle study. The results show that the dentate flow channel structure of the emitter causes the pressure energy of the flow of the fluid to gradually dissipate toward the outlet with a slow and stable outflow. Heavier impurities tend to accumulate at the channel bottom of the emitter, whereas lighter impurities flow with the water. Therefore, heavy impurities in drip irri-

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gation water must be filtered out to the greatest extent possible. Furthermore, the inlet of the pressurized pump should not be inserted into the bottom of the tank.

**Keywords:** Drip irrigation, Emitter, Labyrinth, Flow field, Simulation.

# I. Introduction

In recent years, because of the increasing population, rapid development of industry and commerce, and impact of climate change, the water shortage problem has worsened. Agricultural irrigation accounts for 70% of total water use; however, because water is prioritized for industry use and use in people's daily lives, agricultural practices such as fallow farming often have to be adopted to reduce water consumption. Developed in Israel, drip irrigation technology is currently the most popular method of agricultural water conservation; it is an agricultural water-saving technology that ensures water usage at maximum efficiency; this advanced irrigation technology can enable agriculture even on land in which more than 60% of the area is dry or semiarid. Drip irrigation (Figure 1) is currently the most efficient method of irrigation; its efficiency can reach 90%–95%, which is considerably higher the efficiency of furrow irrigation (35%–50% and sprinkler irrigation (60%–80%) [2]. The general drip irrigation pipe has an emitter inlaid into its inner wall (Figure 2). The most crucial features of drip irrigation include the uniform use of water, anti-clogging capability, and long service life [5]. In the present study, a drip irrigation pipe manufactured by Netafim was used to analyze the flow field of the emitter channel, and through a particle study, the flow of impurities in the water was simulated to investigate the deposition of impurities inside the flow channel.

Li *et al.* (2005) studied the six typical labyrinth flow channels of drip pipes. The researchers used the hydraulic performance test platform to measure outflow from the six emitters under various pressure conditions, and they analyzed the flow characteristics of the emitter flow path. Their results showed that the average flow velocity of water in the flow channel was 0.08–0.90 m/s, and that the Reynolds number in the labyrinth flow channel was between 105 and 930; the critical Reynolds number of laminar and turbulent flow transitions is smaller than that of conventional scale flow paths.

Regarding the prevention of suspended solids in irrigation water, which cause emitter clogging, Hsieh and Hsu (2013) recommended the use of

Fig. 1 Drip irrigation.

Fig. 2 Drip emitter.

filters of size greater than 10%–20% of the diameter of the outflow hole to filter out impurities, thereby preventing the presence of impurities in the pipeline. To ensure that a drip irrigation system can operate for a long period, the following precautions must be taken: (1) The working pressure of the drip irrigation system must be accurately controlled to prevent it from affecting the irrigation quality. (2) The filter in the irrigation system must be inspected regularly and be promptly replaced if damaged. (3) In nonirrigation seasons, the water in the piping should be discharged to prevent the emitter from being damaged by microbes in the pipeline.

Nakayama and Bucks (1991) analyzed that the current work of improving the drip irrigation system is divided into two research directions. One group concentrated on improving the hydraulic operation of emitters and the other focused on the clogging process and developing procedures to alleviate clogging.

Sachin *et al.* (2013) designed five dentate-shaped flow channels; moreover, using computational flow dynamics (CFD), they calculated the flow rate of an emitter under various pressure levels to analyze its water pressure characteristics. The flow field of the flow channel was simulated using SolidWorks FloXpress. The results showed that the concave channel structure was related to the energy dissipation of the fluid, and the concave portion of the flow channel was the main area of energy dissipation. Selecting an appropriate flow channel structure can create more vortices to increase energy dissipation and increase the flushing effect of the channel boundary, thereby enhancing the anti-clogging characteristics of the emitter.

Uys (2000) indicated that size and flow rate are the main factors affecting the clogging of the emitter. The size of the flow channel is closely related to the size of the filter mesh, which must be able to filter out particles larger than the size of the flow path, with a minimum size of 1/5 to 1/10.

# 2. Materials and Methods

In the present study, the emitter in the drip irrigation tube was analyzed because the labyrinth channel was extremely small. A camera with a high magnification lens was used to photograph the dripper channel, and the image was imported into AutoCAD for structural geometry measurement. Subsequently, SolidWorks was used to establish a solid model of the emitter channel, and the flow field simulation was analyzed using SolidWorks Flow Simulation. In addition to the flow field analysis of the flow channel, a particle study was conducted to simulate the flow state of water containing impurities, thereby enabling the analysis of impurity accumulation in the flow channel.

### 2.1 Experimental material

The most crucial component of the drip irrigation system is the emitter embedded in the pipe wall, which affects the drip irrigation performance. In this study, because of low water consumption common in greenhouses and agricultural fields, a Netafim emitter was set in the inner wall of the drip pipe with the model of Streamline 16080, with a diameter of 16 mm, wall thickness of 0.2 mm, flow rate of 1.05 l/h, and operating pressure of 0.85 bar was investigated.

### 2.2 Analysis software

SolidWorks Flow Simulation is professional CFD software that can be used to analyze various types of fluid flow. It uses a finite volume method to solve the fluid dynamic governing equation.

### 2.3 Theoretical model

CFD is primarily used to solve the mathematical model of Navier–Stokes governing equations and the finite volume method is used to calculate the average of the physical quantities of each grid element to show the variation of the flow field and temperature distribution. The Navier–Stokes equations [6] of the *x*, *y*, and *z* axial components are expressed as Equations 1, 2, and 3, respectively:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right) = \frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x \quad \text{.............(1)}$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right) = \frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y \quad \text{.............(2)}$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right) = \frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g_z \quad \text{...........(3)}$$

where

$\rho$: density of the fluid;

$u$: velocity of the x direction;

$v$: velocity of the y direction;

$w$: velocity of the z direction;

$p$: pressure;

$\mu$: dynamic viscosity of the fluid; and

$g$: gravity acceleration.

In the particle motion model [6] of the particle study conducted using SolidWorks Flow Simulation, the particle trajectory is calculated from the postprocessing results. After the flow of the fluid has been calculated, the particle mass and volume flow are assumed to be considerably lower than the mainstream; thus, the effect of particle motion and temperature on the fluid flow parameters is negligible, and the particle motion satisfies the following equation:

$$m\frac{dv_p}{dt}=-\frac{\rho_f(v_f-v_p)\,|\,v_f-v_p\,|}{2}C_d A+F_g \quad \text{...(4)}$$

where

$m$: particle mass;

$t$: time;

$v_p$: particle velocity;

$v_f$: fluid velocity;

$\rho_f$: fluid density;

$C_d$: particle drag coefficient;

$A$: particle cross-sectional area; and

$F_g$: gravity.

The particles are assumed to be nonrotating spheres composed of specific material and with a constant mass. The corresponding drag coefficient can be calculated according to the semiempirical formula of Henderson [6]; if the particle velocity relative to the carrier fluid is slow, the drag coefficient can be expressed as follows:

$$C_d=\frac{24}{\mathrm{Re}}+\frac{4.12}{1+0.03\times\mathrm{Re}+0.48\sqrt{\mathrm{Re}}}+0.38 \quad \text{.. (5)}$$

where the Reynolds number is

$$\mathrm{Re}=-\frac{\rho_f\left|v_f-v_p\right|d}{\mu} \quad \text{.................................. (6)}$$

$d$: particle diameter.

### 2.4 Model description

The emitter in the drip pipe is composed of an inlet, outlet, and internal flow channel. The inlet is formed by a parallel arrangement of grids that block larger particles. The main flow channel is formed by the space of two groups of conjugate dentate structure, as shown in Figure 3. The flow channel, which is limited by the dentate structure, forms a

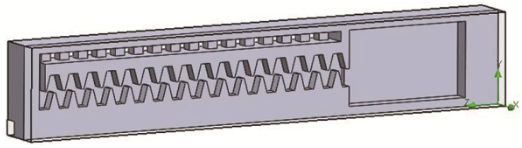

Fig. 3 Physical model of the emitter.

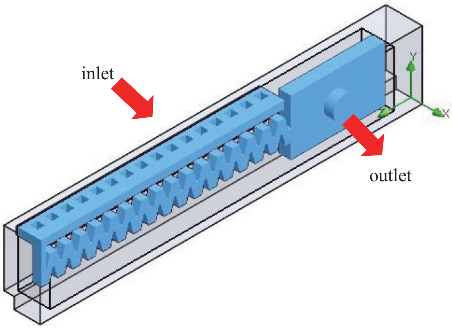


Fig. 4 Fluid subdomain of the emitter.

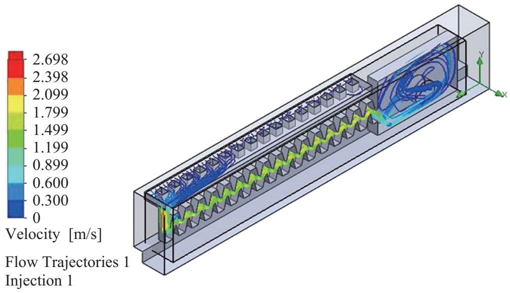


Fig. 5 Flow trajectories of the velocity.

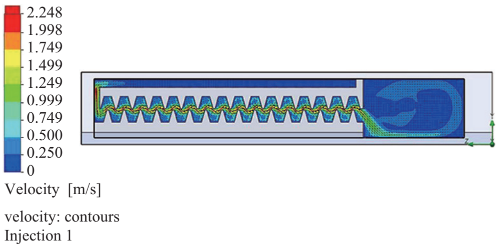


Fig. 6 Velocity contours of the emitter.

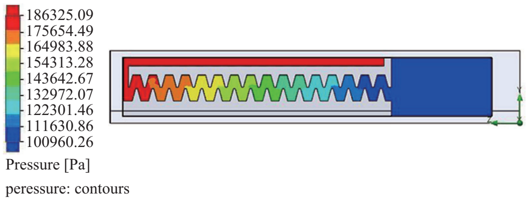


Fig. 7 Pressure contours.

zigzag channel. The end of the flow channel connects to a larger buffer pool, at the center of which a hole has been bored into the pipe wall to form a water outlet. The nonphysical space in the drip is filled with water during drip irrigation, as shown in Figure 4. The main calculations and analyses of this study are limited to this space.

## 3. Results and Discussion

### 3.1 Analysis and discussion of the flow field of the emitter

SolidWorks Flow Simulation yields a variety of graphics. Figure 5 shows a flow trajectory chart of the velocity of the emitter flow field. The results show that water flows slowly into the drip from the inlet, the flow velocity increases with the main flow path, and the flow path trajectory is commensurate with the shape of the flow channel. The cross-sectional view of the velocity field in the middle of the flow path is shown in Figure 6, where the flow vector field of the velocity illustrates that the main flow occurs in the middle of the flow channel. A vortex of slow flow is generated at the corners of the flow path, and a boundary layer is generated near the wall. Figure 7 shows the emitter pressure distributions of the flow field. The pressure in the flow path is highest at the inlet and decreases along the exit direction. To illustrate the velocity and pressure variations in the flow field in more detail, a streamline in the flow field can be selected, as shown in Figure 8, and its velocity and pressure can be displayed, as shown in Figures 9 and 10. The results show that in the zigzag flow channel, the flow velocity constantly fluctuates and drops rapidly after the flow reaches the buffer pool. The pressure exhibits an almost linear decreasing

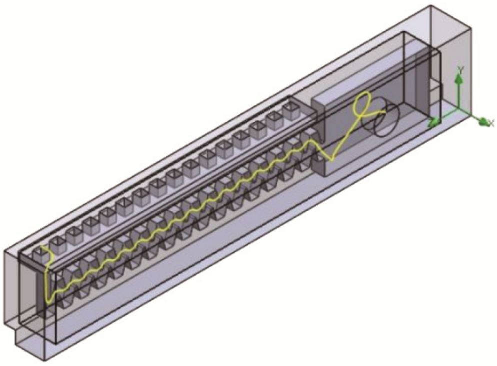

Fig. 8 Stream line in the emitter.

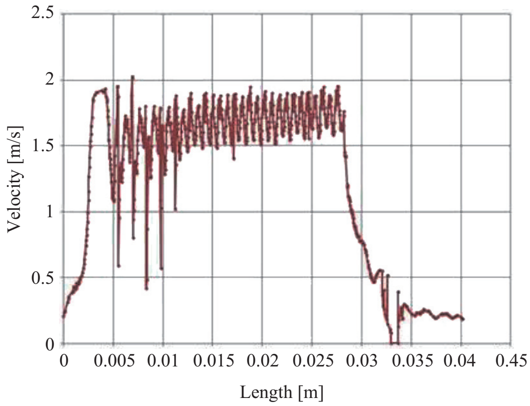


Fig. 9 Flow velocity on streamline trajectory.

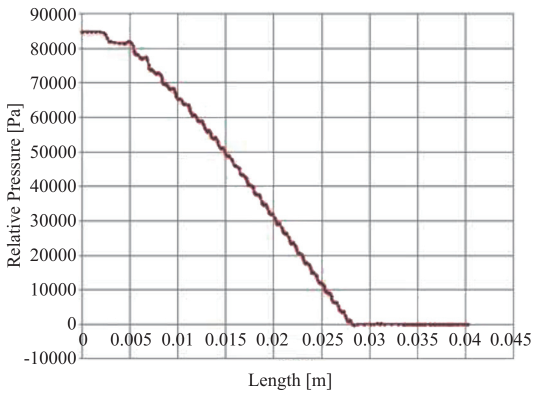


Fig. 10 Pressure on streamline trajectory.

trend. As inferred from the simulation results, the zigzag geometric structure of the emitter in the flow channel, resulting in the gradual dissipation of the fluid pressure energy. In addition, the flow velocity is reduced by a buffer pool with a large volume; thus, water flows through the flow channel with a steady and slow outflow at the outlet.

**3.2 Emitter particle study and discussion**

Anti-clogging is a crucial characteristic of the emitter that affects water outflow and service life. The emitter becomes clogged because impurities enter the flow channel or because particles in the flow channel form clumps that block the flow. To understand the flow of impurities in the flow channel, in this study, two specific particle densities with specific gravity (“sw” hereafter) values of 2.33 (equivalent to silica sand) and 0.93 (equivalent to general suspended solids) were simulated in the fluid at a flow rate of $5 \times 10^{-6}$ kg per second for analysis. The results are shown in Figure 11. As shown in Figure 13, the heavier particles flow more slowly in the flow field, and the lighter particles flow more rapidly with the water. An observation of the flow phenomena of the particles from the side direction of the gravitational direction reveals that the heavier particles tend to accumulate at the bottom of the flow path, as shown in Figure 12, whereas the lighter particles travel with the mainstream flow and thus do not accumulate, as shown in Figure 14. The results of the aforementioned analysis suggest that heavier particles are more likely to cause drip clogging; thus, heavy impurities in drip irrigation water must be filtered out to the greatest extent possible. Furthermore, to prevent the inhalation of silt, the inlet of the pressurized pump should not be inserted into the bottom of the storage tank.

## 4. Conclusions

The analysis results show that the main flow area of the emitter is in the middle of the flow

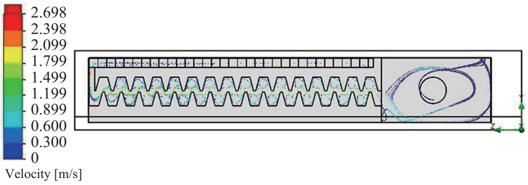


Fig. 11 Particle study top view of velocity trajectories (sw: 2.33).

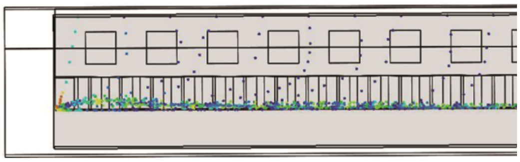

Fig. 12 Particle study side view of velocity trajectories (sw: 2.33).

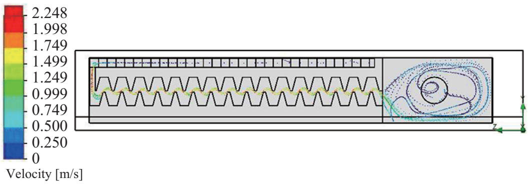


Fig. 13 Particle study top view of velocity trajectories (sw: 0.93).

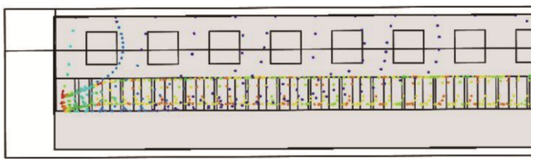

Fig. 14 Particle study side view of velocity trajectories (sw: 0.93).

channel, and a boundary layer is generated near the wall. The flow velocities reveal that the zigzag flow channel constantly fluctuates and drops rapidly after the flow reaches the buffer pool. In addition, the pressure of the flow exhibits an almost linear decreasing trend. The emitter utilizes the dentate geometric structure of the flow channel to gradually dissipate the pressure energy of the flow while using a large volumetric buffer pool to reduce the flow velocity, thereby yielding a slow and steady outflow. The labyrinth flow channel can generate velocity pulsation, which rapidly pushes the particles that may cause clogging toward the outlet. The results of the particle study show that heavier particles are more likely to cause emitter clogging; thus, heavy impurities must be filtered out of drip irrigation water to the greatest extent possible. Furthermore, to prevent the inhalation of silt, the inlet of the pressurized pump should not be inserted into the bottom of the storage tank.

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