PARAMETER OPTIMIZATION OF ANTI CRYSTALLIZATION FLOCKING DRAINAGE PIPE BASED ON FLOW FIELD DISTRIBUTION CHARACTERISTICS

by

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The crystal plugging of tunnel drainage pipe seriously affects the safe and normal use of the tunnel. In order to obtain the mechanism of flocking drainage pipe anti crystal plugging based on the characteristics of flow field distribution, numerical simulation was used to optimize the parameters of flocking drainage pipe. The results show that: with the existence of fluff, the velocity in the lower part of the drainage pipe decreases by about 50%, and the velocity in the upper part increases by about 25~50%. With the increase of the length of fluff, the velocity funnel between fluffs gradually increases, the velocity distribution at the bottom of the funnel is basically unchanged, and the velocity in the upper part gradually increases. The velocity in the upper part of the flocked drainage pipe fluctuates above the fluff to a certain extent. The flow velocity in the lower part of the drainage pipe forms a flow velocity ladder in the longitudinal direction of the villus, and the width of the ladder is about 2/3 of the longitudinal spacing of the villus. The optimized parameters of 3-D flow field of flocked drainage pipe are helpful to the further improvement of indoor test, and provide theoretical basis for the mechanism of preventing crystal blockage of flocked drainage pipe.

Keywords*: tunnel, flocked drainage pipe, 3-D flow field, anti crystal plugging pipe*

Introduction

With the rapid development of China's economic construction, infrastructure also ushered in the golden age of rapid development. By the end of 2019, there are 19067 highway tunnels in China, including 1175 extralong tunnels and 4784 long tunnels. With the operation of the tunnel, all kinds of diseases are gradually prominent, especially the lining cracking and leakage, fig. 1, caused by crystal plugging, fig. 2, of tunnel drainage system in karst area [1].

The problem of crystal plugging in tunnel drainage system has attracted the attention of experts at home and abroad. There are also some measures to prevent crystal plugging in

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tunnel drainage system [2-7], but the relevant technology is not mature. Laboratory tests have proved that flocking drainage pipe has the effect of preventing and controlling crystal blockage [8-11], and the flow rate is directly related to the amount of crystal in drainage pipe [12]. For the 3-D case, different fluids are compared for a fixed Reynolds number and blockage ratio, proving that pseudoplastic fluids increase mixing capacity [13]. The total drag and lift coefficients decrease from the parallel mode to oblique mode, owing to the intensified 3-D of wake flows and the phase difference in the spanwise vortex shedding [14]. In the region behind the cylinder, Taylor micro scale Reynolds number and turbulence standard deviation are the highest [15]. The bending stiffness and plate length have significant effects on the dynamic response of the plate, the fluid load of the cylindrical plate and the vortex pattern in the flow field [16]. The wake of two tandem cylinders is characterized by a region of local absolute instability of mean flow behind the second cylinder, followed by a long region of convective instability [17].

Figure1. Lining cracking and leakage

Figure 2. Crystal blockage of drainage pipe

Based on the groundwater flow field in the drainage pipe, this paper analyzes the influence of four factors, such as villus diameter, villus length and villus longitudinal spacing, on the groundwater flow field distribution characteristics in the flocked drainage pipe under the condition of low flow rate and high flow rate by using ANSYS Fluent finite element software, which provides theoretical support for the mechanism of preventing crystal blocking in the flocked drainage pipe.

Methods

The main parameters of 3-D flow field calculation model of flocked drainage pipe are shown in tab. 1. The fluid-flow (fluent) module of ANSYS Workbench is used for calculation, fig. 3. The inlet velocity of the drainage pipe is set to 0.02 m/s, the outlet velocity is set to non-pressure outlet, and the bottom velocity of the drainage pipe is set to non-slip smooth wall.

Table 1. Calculation parameters of numerical simulation

Parameter	Working condition	Parameter	Working condition
Current Speed [ms^{-1}]	0.02	Diameter of drainage pipe [mm]	100
Villus diameter [mm]	0.6, 1.0, 1.4, 1.8, 2.2	Longitudinal distance of villus [mm]	25, 35, 45
Villus length [mm]	5, 10, 15, 20	Circumferential distance of villus [°]	10,15,20

In order to analyze the influence of various factors on the flow field distribution characteristics of flocked drainage pipe, the velocity nephogram and velocity curve of different sections of flocked drainage pipe are selected for comparative analysis. The detailed section positions are shown in tab. 2 and fig. 4.

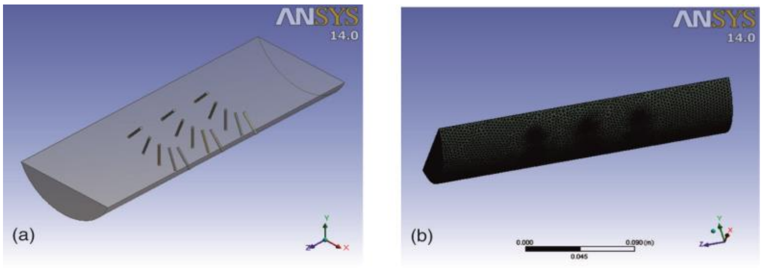

Figure 3. Calculation model; (a) geometric model and (b) grid model

Table2. Detailed location of analysis section

Section number	Section position	Section number	Section position
Section 1	30 mm from inlet	Section 6 (Velocity)	$x = 0$, $y = 3$ mm (line 11)
Section 2	80 mm from water inlet (1st row of villus)		$x = 0$, $y = 8$ mm (line 12)
Section 3	2nd row of villus		$x = 0$, $y = 13$ mm (line 13)
Section 4	3rd row of villus		$x = 0$, $y = 18$ mm (line 14)
Section 5	180 mm from inlet		$x = 0$, $y = 23$ mm (line 15)

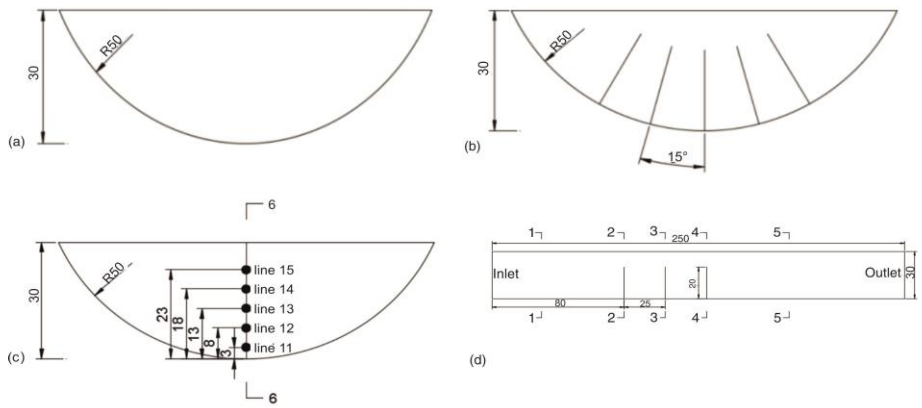

Figure 4. Flow field analysis position of flocked drainage pipe; (a) Section 1 and 5, (b) Section 2, 3, and 4, (c) Section 6-1, and (d) Section 6-2

Results and discussion

Influence of villus diameter on flow field distribution

The diameter of villus directly affects the amount of crystal adhesion, and also directly affects the force of villus in the process of water flow in the drainage pipe. The force of villus is closely related to the amount of crystal adhesion. Therefore, it is of great significance to study the influence of villus diameter on the flow field distribution characteristics of flocked drainage pipe, so as to obtain the mechanism of anti crystal plugging of flocked drainage pipe. Taking the villus diameter as variables (0.6 mm, 1.0 mm, 1.4 mm, 1.8 mm, and 2.2 mm), the flow field of flocking drainage pipe was compared and analyzed when the villus longitudinal spacing was 35 mm, the villus length was 10 mm, and the villus circumferential spacing was 10°.

Figure 5 shows the longitudinal velocity distribution curve of flocking drainage pipes with different villus diameters. It can be seen from the figure that:

- Under the condition of each villus diameter, the change rule of the five positions monitored is consistent, that is, the upper three monitoring points (y = 13 mm, 18 mm, and 23 mm) gradually increase along the water flow direction, and finally tend to be stable, and the lower two monitoring points (y = 3 mm and 8 mm) gradually increase along the water flow direction. There were abrupt changes in the front and back position and velocity.
- For the upper three monitoring points, the velocity at y = 18 mm is the largest, followed by y = 13 mm, and the velocity at y = 23 mm is the smallest. With the increase of villus diameter, the velocity fluctuation at y = 18 mm is gradually increased, but the fluctuation amplitude is very small. With the increase of villus diameter, the velocity at y = 13 mm gradually tends to the velocity at y = 23 mm, and finally is less than that at y = 23 mm.
- For the lower two monitoring points, with the increase of villus diameter, the velocity between villi at y = 8 mm gradually changes from more than 2 cm/s to less than 2 cm/s, and the velocity between villi at the first place is always greater than that at the second place. With the increase of villus diameter, the velocity between villi at y = 3 mm gradually decreases from close to 1.5 cm/s to close to 1.0 cm/s, and the velocity between villi at the first place is always greater than that at the second place flow velocity between villi.

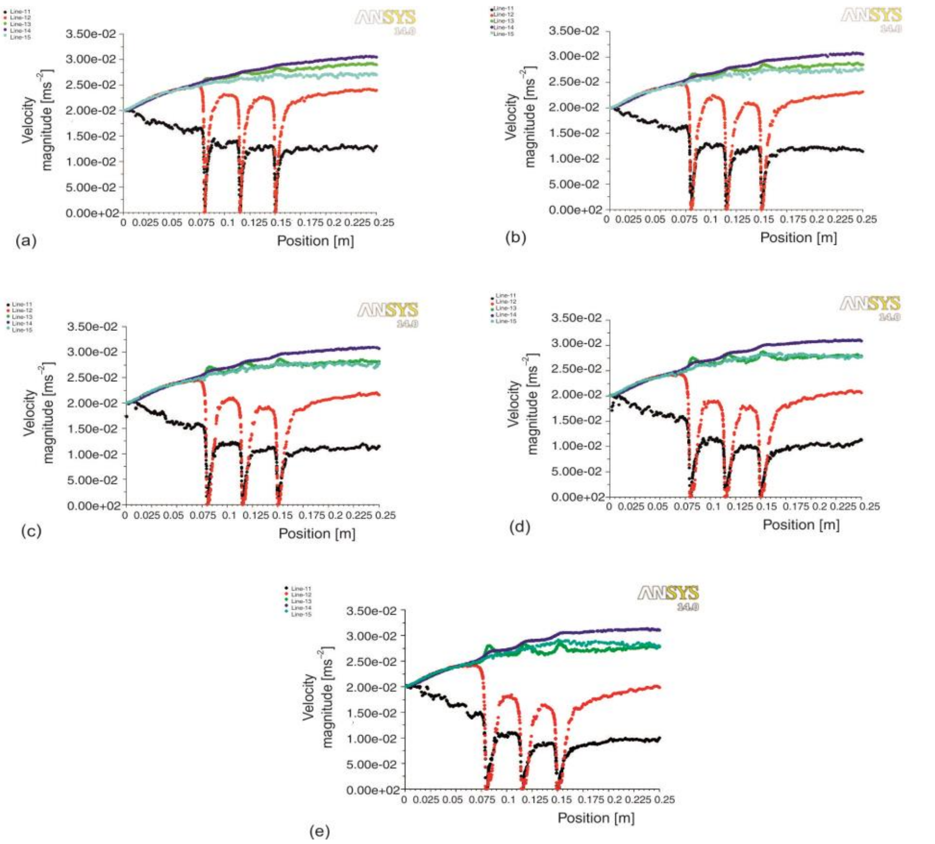

Figure 5. Longitudinal velocity distribution of flocked drainage pipes with different villus diameters; (a) 0.6 mm, (b) 1.0 mm, (c) 1.4 mm, (d) 1.8 mm, and (e) 2.2 mm

Influence of villus length on flow field distribution

The length of villus will also directly affect the amount of crystal adhesion. Different villus length will lead to different forces in the process of groundwater flow in the drainage pipe, especially when the water level in the drainage pipe changes. Therefore, it is of great significance to study the influence of villus length on the flow field distribution characteristics of flocked drainage pipe, so as to obtain the mechanism of anti crystal plugging of flocked drainage pipe. Taking the villus length as variable (5 mm, 10 mm, 15 mm, and 20 mm), the flow field of flocking drainage pipe was compared and analyzed when the longitudinal spacing of villus was 35 mm, the diameter of villus was 0.6 mm, and the circumferential spacing of villus was 10°.

Figure 6 shows the longitudinal velocity distribution curve of flocked drainage pipes with different villus lengths. It can be seen from the figure:

- As a whole, with the increase of villus length, the change of vertical local velocity of flocked drainage pipes gradually transits from $y = 3$ mm to $y = 18$ mm, and the fluctuation of velocity above the villus at the uppermost $y = 23$ mm also increases gradually. With the increase of villus length, the longitudinal velocity at $y = 3$ mm shows a gradual change. Two distinct steps were formed between the villi.
- With the increase of villus length, not only the velocity between villus increased by 25%, but also the velocity above villus increased significantly.

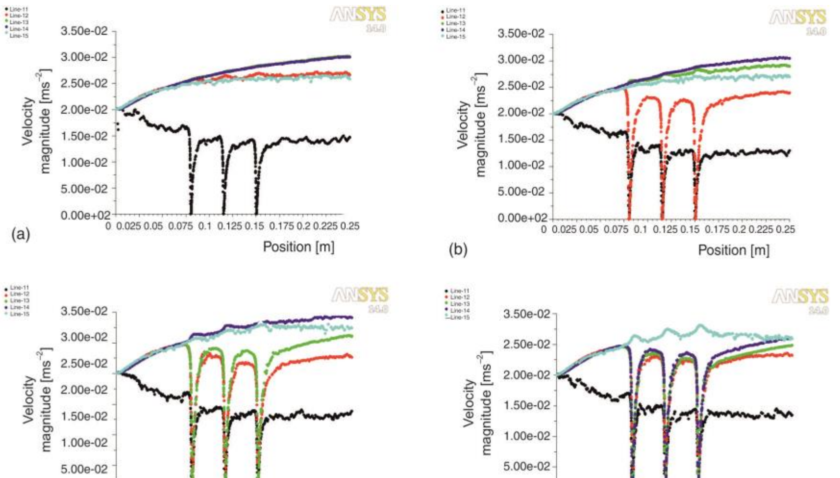

Figure 6. Longitudinal velocity distribution of flocked drainage pipes with different villus lengths; (a) 5 mm, (b) 10 mm, (c) 15 mm, and (d) 20 mm

Influence of longitudinal distance of villus on flow field distribution

The longitudinal spacing of villus directly affects the size and direction of the local velocity of groundwater in the flocked drainage pipe, and indirectly affects the amount of crystal adhesion on villus and the stress of villus in the process of groundwater flow in the drainage pipe. Therefore, the study on the influence of the longitudinal spacing of villus on the flow field distribution characteristics of flocked drainage pipe plays an important auxiliary role in obtaining the mechanism of anti crystal plugging of flocked drainage pipe. Taking the longitudinal distance of flocking as variables (25 mm, 35 mm, and 45 mm), the flow field of flocking drainage pipe was compared and analyzed when the diameter of villus was 0.6 mm, the length of villus was 10 mm, and the circumferential distance of villus was 10°.

Figure 7 shows the longitudinal velocity distribution curve of the drainage pipe with different flocking longitudinal spacing. It can be seen from the figure that:

– The upper y = 13 mm, 18 mm, and 23 mm have the same variation law along the longitudinal velocity, which gradually increases and finally tends to be stable. The velocity at y = 18 mm is the largest, followed by y = 13 mm, and the velocity at y = 23 mm is the smallest.
– The velocity at the bottom y = 3 mm decreases along the longitudinal direction. After passing the last row of villus, the velocity gradually tends to be stable. The velocity between villus changes in a step along the longitudinal direction. With the increase of the longitudinal distance of flocking, the step width increases gradually.
– When y = 8 mm, the velocity first increases along the longitudinal direction, and then forms a concave parabolic peak value when encountering the villus. When the distance between flocks is 25 mm, the velocity peak value between villus gradually decreases along the longitudinal direction, and when the distance between flocks is 45 mm, the velocity peak value between villus gradually decreases the peak velocity between the hairs did not decrease along the longitudinal direction.
– On the whole, the velocity of the upper part of the flocked drainage pipe fluctuates with the increase of the velocity above the villus.

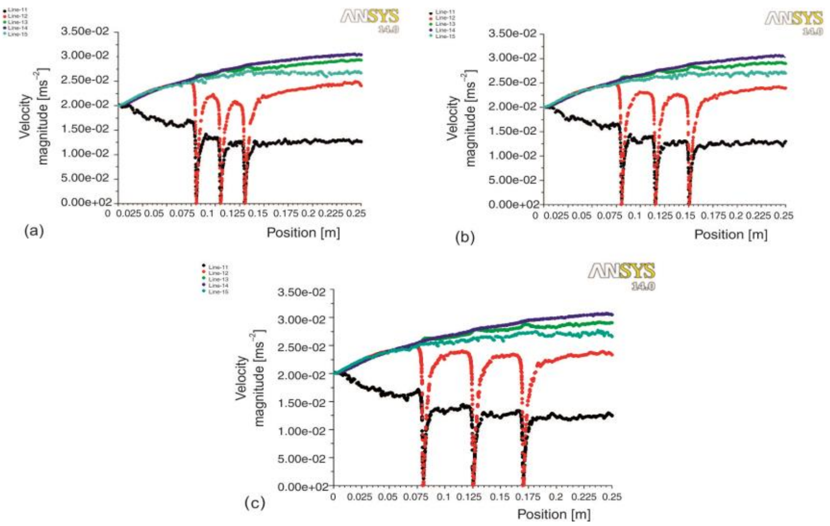

Figure 7. Longitudinal velocity distribution of flocking drainage pipe with different flocking longitudinal spacing; (a) 25 mm, (b) 35 mm, and (c) 45 mm

Conclusions

- With the increase of villus diameter, the maximum velocity inside the flocked drainage pipe increases gradually, and the area where the velocity tends to zero on the downstream side of villus increases gradually. The presence of fluff makes the flow velocity in the lower part of the drainage pipe decrease about 50%, and the flow velocity in the upper part of the drainage pipe increase about 25~50%.

- With the increase of the villus length, the length of the downstream side of the villus with the velocity approaching zero also increases, the local velocity between the villus increases by about 25%, and the velocity above the villus also increases significantly.
- With the increase of the longitudinal distance of flocking, the flow velocity in the flocking drainage pipe does not increase, but gradually becomes stable when it increases to a certain extent. The range of the flow velocity in the downstream side of the villus tends to zero also does not increase, which is about one time of the villus diameter along the longitudinal direction.
- Based on the comprehensive analysis of the 3-D flow field distribution characteristics, it can be seen that when the groundwater flow rate in the pipe is 0.02 cm/s, the optimal flocking parameters of flocking drainage pipe are: villus diameter is 0.6 mm, villus length is 10 mm, villus longitudinal spacing is 35 mm.

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References

[1] Duan, H., *et al*., The Phenomenon of Crystal Pipe Blocking in Karst Tunnel and its Induced Risk, *China Civil Engineering Journal,* 53 (2020), S1, pp. 332-335
[2] Zhou, Y., *et al*., Experimental Study on Prevention of Calcium Carbonate Crystallizing in Drainage Pipe of Tunnel Engineering, *Advances in Civil Engineering, 2018* (2018), ID9430517
[3] Jiang, Y., *et al*., Experimental Research on Maintainability of Drainage Facilities in Lining Construction Joints of Karst Tunnel, *Railway Standard Design, 63* (2019), 11, pp. 91-96
[4] Tian, C., *et al*., On Mechanism of Crystal Blockage of Tunnel Drainage System and Preventive Countermeasures, *Modern Tunneling Technology, 57* (2020), 05, pp. 66-76+83
[5] Guo, X. Crystallization Mechanism and Countermeasures of Drainage System for Railway Tunnel, *China Railway Science, 41* (2020), 01, pp. 71-77
[6] Zhao, P., *et al*., Research and Application of Dredge Equipment for Drainage Pipeline in Railway Tunnel, *Railway Engineering, 58* (2018), 01, pp. 30-32+66
[7] Hong, Y., *et al*., On Scavenging Performances of Cleaning Solvents for the Clogging in the Drainage System of Karst Tunnels. *Modern Tunneling Technology, 57* (2020), 06, pp. 160-170
[8] Liu, S., *et al*., The Effect of Flocking PVC Pipe on the Prevention and Crystallization of Tunnel Drains, *Science Technology and Engineering, 18* (2018), 21, pp. 313-319
[9] Liu, S., *et al*., The Effect of Anti-Crystallization of Tunnel Plumage Drainpipe Under Different Water Filling State, *Science Technology and Engineering, 18* (2018), 28, pp. 156-163
[10] Liu, S., *et al*., Effect of Fuzz Length on the Prevention of Crystallization of Tunnel Flocking Drainpipes, *Science Technology and Engineering, 19* (2019), 09, pp. 234-239
[11] Liu, S., *et al*., Experimental Study on Anti-Crystallization Law of Tunnel Transverse Flocking Drainpipe at Different Velocities, *Asia Pacific Journal of Chemical Engineering, 15* (2020), S1, e2470
[12] Liu, S., *et al*., Two-Dimensional Flow Field Distribution Characteristics of Flocking Drainage Pipes in Tunnel, *Open Physics, 18* (2020), 01, pp. 139-148
[13] Ruz, O., *et al*., Numerical Study of the Effect of Blockage Ratio on the Flow Past One and Two Cylinders in Tandem for Different Power-Law Fluids, *Applied Mathematical Modelling, 89* (2021), 2, pp. 1640-1662
[14] Ji, C., *et al*., Direct Numerical Simulations of Horizontally Oblique Flows Past Three-Dimensional Circular Cylinder Near a Plane Boundary, *Journal of Offshore Mechanics and Arctic Engineering, 142* (2020), 05, pp. 1-10
[15] Yanovych, V., *et al*., Structure Turbulent Flow Behind a Square Cylinder with an Angle of Incidence, *European Journal of Mechanics - B/Fluids, 85* (2021), Jan.-Feb., pp. 110-123

[16] Devaki, P., *et al*., Wall Properties and Slip Consequences on Peristaltic Transport of a Casson Liquid in a Flexible Channel with Heat Transfer, *Applied Mathematics and Nonlinear Sciences, 03* (2018), 1, pp. 277-290
[17] Selvi, C. K., Srinivas, A. N. S., Oscillatory Flow of a Casson Fluid in an Elastic Tube with Variable Cross Section, *Applied Mathematics and Nonlinear Sciences, 03* (2018), 2, pp. 571-582

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