The Influence of Geometrical Parameter of Dental Flow Passage of Labyrinth Drippers on Hydraulic and Anti-clogging Performance

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Abstract: The hydraulic performance and anti-clogging ability of emitters with dental flow passage were studied and results are presented in this paper. The orthogonal array was used for experimental design. Tests were conducted on dentation angle (104°, 108°, 112°, 117°), spacing between dentations (1.5, 1.8, 2.1, 2.5mm), dentation height (1, 1.3, 1.6, 1.9mm), and depth of flow passage (0.6, 0.9, 1.2, 1.5mm). Results showed that spacing between dentations had significant influence on the exponential value of flow state and the anti-clogging ability of emitters. The anti-clogging ability of emitters was not linearly correlated with flow rate as commonly believed and was improved nearly linearly with the increase in the width of flow passage. Results also indicated that the chance of emitters being plugged by sand particles was small if the openings of screen filter were selected according to the rule of $1/10^{th}$ of the size of the width of flow passage.

Key words: emitter; flow passage; hydraulic performance; anti-clogging performance

1. Introduction

Emitters are one of the key parts in trickle irrigation system, and their structure parameters affect corresponding hydraulic performance and anti-clogging ability. According to Gilaad et al. (1974) the hydraulic performance of emitters were determined by the forms, dimension, and the materials of the flow passage [1]. Ozekici and Sneed (1991) studied the hydraulic performance of dental form emitters. Their experimental results showed that most water pressure was lost at the dental structure parts [3]. Avner Adin and Mollie Sacks (1991) investigated the clogging problems in drip-irrigation systems using wastewaters, and the results revealed that the structure forms of flow passage had great influence on the clogging potential [4]. Wang et al. (2000) studied the flow state in labyrinth emitter using Finite Element Method and attained numerical simulation results, and investigated the influence of the Reynolds numbers on flow field [5]. However, the information on the relationship between structure parameters of flow passage and the hydraulic performance and anti-clogging ability of emitters were not specifically addressed and information on these are limited. The study was conducted to evaluate the hydraulic performance and anti-clogging ability of emitters with dental flow path with variation in dentation angle, spacing between dentations, dentation height, and the depth of flow passage. The term dental or dentation is used in this article to define the repeating zigzag or saw-toothed pattern of the emitter pathway.

2. Materials and Methods

2.1 Experimental Design

The structural factors of the emitters and the level of each factor are presented in Table 1. Each factor was evaluated at four different levels for dentation angles, spacing, height, and passage depth.

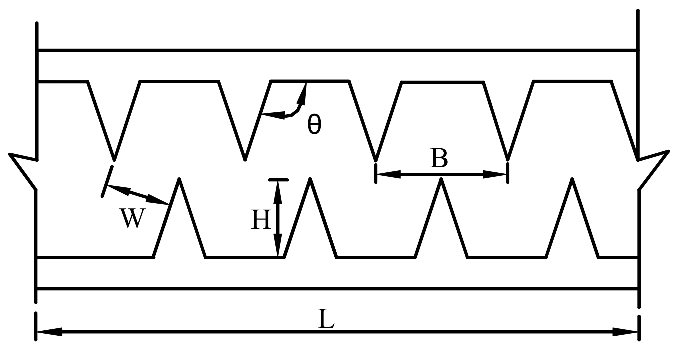
The value of each variable was selected on the basis of the dripper emitters available in the market.

Table 1: Independent variables or factors and values of four levels

Factors	level			
θ, dentation angle	104°	108°	112°	117°
B, dentation spacing	1.5mm	1.8mm	2.1mm	2.5mm
H, dentation height	1.0mm	1.3mm	1.6mm	1.9mm
D, depth	0.6mm	0.9mm	1.2mm	1.5mm

Note: The length of flow passage of all emitters was 19.4mm. Most manufacturers used this length.

A schematic representation of a dental labyrinth emitter is shown in Figure 1.



θ: dentation angle, B: dentation space, H: dentation height,

W: width of flow passage, L: length of flow passage

Figure.1: Dental structure parameters of a labyrinth emitter

The traditional factorial arrangement of all possible combination for four factors at four levels of variation coupled with 8 test phases for 8 mixes of particulate materials would raise the number of tests to an unmanageable level. The aim was to investigate the effects of the individual variables (or factors) and also how the variables interact. Considering the condition, the orthogonal array was adopted for the experimental design [2, 8].

2.2 Materials

The moulds for above 16 kinds of emitters were made and hundreds of emitters were manufactured for every type of emitter combination by extrusion and was installed in 16mm diameter drip tapes by Beijing Luyuan Company. The tests were conducted according to ISO 9261 and ISO/TC 23/SC 18/WG5 N4 [6, 7].

2.2.1 Methods

a) Hydraulic performance test

Hydraulic performance of emitters, that is, the relationship between working pressure and flow rate of emitter is given by the equation,

$$Q = kH^{x}$$

Where, Q = flow rate of emitters (L/h), H is working pressure (m), k is discharge coefficient, x is flow state exponent.

The Hydraulic performance of emitters was tested according to ISO9261 (Emitter-pipe systems—Specification and test methods)[6].

b) Anti-clogging performance test

Anti-clogging performance test methods for emitters were performed according to the "short term clogging test procedure" contained in first working draft of ISO/TC 23/SC 18/WG5 N4 (Clogging test methods for emitters). This method has been developed for testing the capability of emitters to either let pass or prevent entry of solid particles of a given size. The ISO test procedure suggests the use of aluminum oxide [7]. However, considering the fact that the sand acted differently from aluminum oxide in the water condition, we adopted river sand was adopted as a natural clogging material in the experiment.

The test condition and procedures are listed in Table 2, and the number of test phases for each kind of emitter was 8. Cumulated grain size distributions for sands used in different experimental phases are shown in Fig.2. The mix and the concentration of sands employed in the 8 test phases are shown in Table 3.

Table 2: Short term clogging test procedure for emitters

Test sample	25 emitters
Number of test lines	25, horizontal, with valves at both ends, water conserved in line when non pressurized
Test pressure	- nominal pressure of emitters, or - pressure mid-range of regulation range of emitters tolerance +/- 20%
Temperature of water	Ambient
Velocity of water at end of line	1 m/s tolerance +/- 20%
Phase duration	50 min (15 + 30 +5)
Duration 1 of line pressurization within cycles	15 min
Duration of line non-pressurization within cycles	30 min
Duration 2 of line pressurization within cycles	5 min
Number phases	8
Concentration of particles suspended in test water	As specified in Table 3
Grain size distribution	As specified in Figure 2
Measurement of emission rate	Individual (25 measurements taken between min 14 and min 15 of each phase) and the average of those
Detection of clogging	The emitter sample is declared clogged when the average of the 25 measurement of emission rate from test sample does not exceed any more 75% of the value of initial average emission rate of the sample
End of test	End of last phase (8) or whenever the average of the 25 measurement of emission rate from test sample does not exceed any more 20% of the value of initial average emission rate of the sample

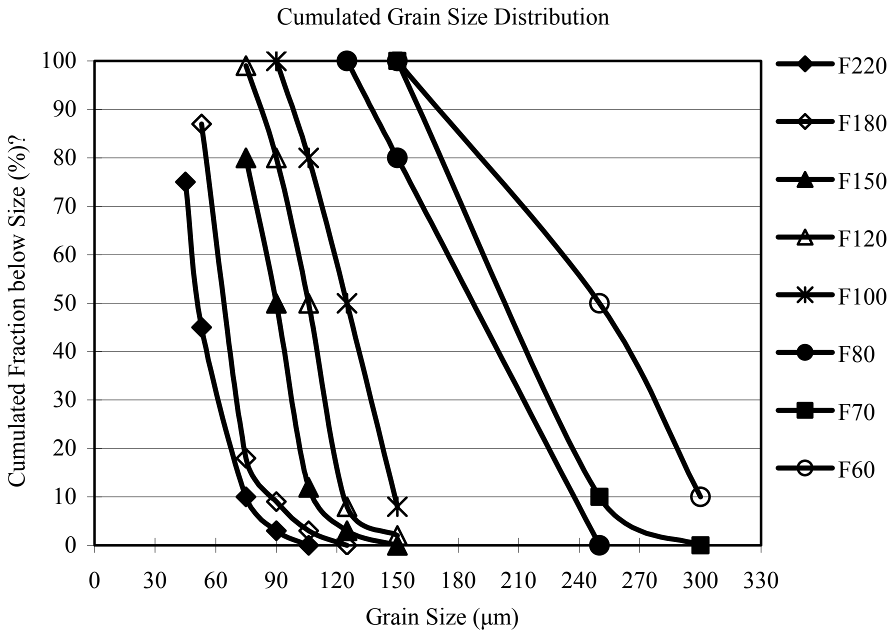


Fig 2: Cumulated grain size distributions curve of Clogging Experiment Stages for sands

Table 3: Specifications for concentration of sands to be employed in the 8 test phases

Sands grain size	F220	F180	F150	F120	F100	F80	F70	F60	Total load Per phase
Phase 1	250ppm								250ppm
Phase 2	250ppm	250ppm							500ppm
Phase 3	250ppm	250ppm	250ppm						750ppm
Phase 4	250ppm	250ppm	250ppm	250ppm					1000ppm
Phase 5	250ppm	250ppm	250ppm	250ppm	250ppm				1250ppm
Phase 6	250ppm	250ppm	250ppm	250ppm	250ppm	250ppm			1500ppm
Phase 7	250ppm	250ppm	250ppm	250ppm	250ppm	250ppm	250ppm		1750ppm
Phase 8	250ppm	250ppm	250ppm	250ppm	250ppm	250ppm	250ppm	250ppm	2000ppm

Data on emitting rates and percentage of clogged drippers for all of the 16 kinds of emitters with time or experimental phase were collected. The clogged drippers percentage at certain phase was calculated dividing the total number of experimental drippers by the clogged drippers. The grain size, which led to initial clogging for a certain kind of emitter, was taken as the index for evaluating the anti-clogging ability. The bigger the grain size, the better anti-clogging ability drippers held.

3 Results and Discussion

The flow passage structure parameters and the flow rate flow state exponent, and flow coefficient and the initial clogging sands size are listed in Table 4.

Table 4: Dripper structure, hydraulic performance, and grain size at initial clogging

Dripper type	θ Dentation angle	B Dentation spacing (mm)	H Dentation height (mm)	D Flow Passage depth (mm)	W Flow passage Width (mm)	A=W•D Cross section area (mm^2)	Q Flow rate at 10m (l/h)	k Discharge coefficient	x Flow state exponent	Grain Size for initial clogging (mm)
1	104°	1.5	1.0	0.6	0.73	0.438	1.49	0.37	0.59	0.09
2	104°	1.8	1.3	0.9	0.87	0.783	2.46	0.88	0.44	0.3
3	104°	2.1	1.6	1.2	1.02	1.224	4.45	1.37	0.51	0.23
4	104°	2.5	1.9	1.5	1.21	1.815	5.85	1.88	0.49	0.35
5	108°	1.5	1.6	1.5	0.71	1.065	3.80	1.09	0.54	0.125
6	108°	1.8	1.9	1.2	0.86	1.032	3.60	1.20	0.48	0.29
7	108°	2.1	1.0	0.9	1.00	0.900	3.57	1.07	0.52	0.28
8	108°	2.5	1.3	0.6	1.20	0.720	2.57	0.86	0.48	0.4
9	112°	1.5	1.9	0.9	0.70	0.630	2.62	0.81	0.51	0.1
10	112°	1.8	1.6	0.6	0.83	0.498	2.10	0.69	0.48	0.12
11	112°	2.1	1.3	1.5	0.97	1.455	6.61	1.96	0.53	0.15
12	112°	2.5	1.0	1.2	1.16	1.392	6.60	2.16	0.48	0.27
13	117°	1.5	1.3	1.2	0.67	0.804	3.54	1.11	0.50	0.095
14	117°	1.8	1.0	1.5	0.80	1.200	4.98	1.71	0.47	0.075
15	117°	2.1	1.9	0.6	0.94	0.564	2.46	0.81	0.49	0.2
16	117°	2.5	1.6	0.9	1.11	0.999	4.21	1.48	0.46	0.25

3.1 Variance Analysis of dental labyrinth drip emitter structure on the flow state exponent x

Statistical analysis for variance was done using SPSS statistical software. The results are shown in Table 5.

Table 5: Variance Analysis results of flow passage parameters on flow state exponent x

Dependent Variable: x

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	1.732E-02	12	1.444E-03	2.520	.242	.910
Intercept	3.970	1	3.970	6929.553	.000	1.000
Dentation angle	1.869E-03	3	6.229E-04	1.087	.473	.521
Dentation spacing	1.172E-02	3	3.906E-03	6.818	.075	.872
Dentation height	1.719E-03	3	5.729E-04	1.000	.500	.500
Flow passage Depth	2.019E-03	3	6.729E-04	1.175	.449	.540
Error	1.719E-03	3	5.729E-04			
Total	3.989	16				
Corrected Total	1.904E-02	15				

It is evident that dentation spacing had significant effect on the flow state exponent x at 0.1 levels, Table 5. The significance ranking of flow passage structure parameters on the flow state exponent x is: Dentation space >Depth of flow passage >Dentation angle>Dentation height. The x value at different dentation spacing is shown in Fig.3.

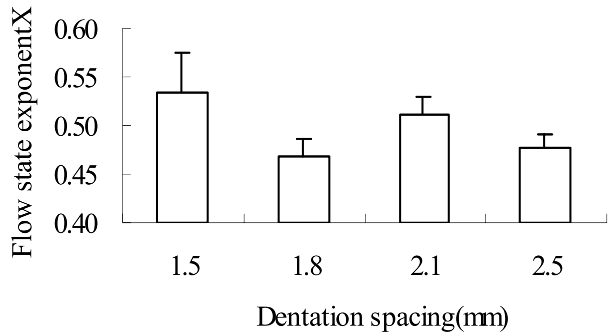


Fig.3 Relationship between dentation spacing and flow state exponent

3.2 Variance Analysis of dental labyrinth drip emitter structure on the flow rate of emitters

Variance analysis results are shown in Table 6.

Table 6: Variance Analysis of flow passage structural parameters on the flow rate of emitters

Dependent Variable: Flow rate Q

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected model	36.586	12	3.049	41.982	.005	.994
Intercept	231.877	1	231.877	3192.887	.000	.999
Dentation angle	2.777	3	.926	12.746	.033	.927
Dentation spacing	9.529	3	3.176	43.737	.006	.978
Dentation height	.732	3	.244	3.362	.173	.771
Depth of flow passage	23.548	3	7.849	108.082	.001	.991
Error	.218	3	7.262E-02			
Total	268.681	16				
Corrected Total	36.804	15				

The results obtained show that the depth of flow passage, dentation spacing, and dentation angle had significant effect on the flow rate of emitters at 0.1 levels. The ranking of significance was in the order of depth of flow passage >dentation spacing >dentation angle>dentation height.

3.3 Mathematical regression model

A linear regression model of SPSS software was used to develop relationship of structural parameters of emitters on flow rate. The results are shown in table 7.

Table 7 Linear regression model Summary and regression Coefficients

(a) Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.957	.915	.884	.5324	.915	29.710	4	11	.000

(b) Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-7.510	3.282		-2.288	.043	-14.734	-.286
	Dentation angle	2.250	1.624	.122	1.385	.193	-1.324	5.824
	Dentation interval	2.052	.360	.501	5.703	.000	1.260	2.844
	Dentation height	-.579	.397	-.128	-1.459	.172	-1.453	.294
	Depth of flow passage	3.599	.397	.796	9.070	.000	2.726	4.473

Dependent Variable: Q

The linear model describing the relationship between flow rate, Q, and structural parameters of flow passage under the present condition of flow passage length (19.4mm) and at 10m working pressure,

$$Q = -7.510 + 2.250\theta + 2.052B - 0.579H + 3.599D \qquad (1)$$

Where, Q is flow rate of emitters (L/h), θ is dentation angle (in radian unit), B is dentation spacing (mm), H is dentation height (mm), D is depth of flow passage (mm).

The R^2 value of 0.915 (Table 7, model summary) indicates that this model may be used in assisting the design of emitters.

3.4 The relationship between cross-section area and flow rate Q

The relationship of width of flow passage W with dentation height H, dentation spacing B, and dentation angle θ could be expressed by the following equation (see Fig.4):

$$W = [(\frac{B}{2} + \mathrm{Hctg}\theta)^2 + H^2]^{1/2} \mathrm{Sin}(\theta - arc\mathrm{ctg}\frac{B/2 + \mathrm{Hctg}\theta}{H}) \qquad (2)$$

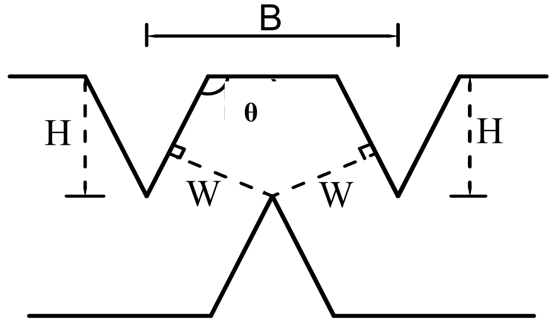


Figure 4: The relationship of flow passage width with dentation height, dentation spacing and dentation angle

Cross-section area of flow passage (A) = Depth of flow passage (D)× width of flow passage (W).

The cross section area of the emitter flow passage and flow rate Q at 10 m pressure are presented in Table 4. Using regression model the relationship between flow rate and cross-section area of flow passage was obtained as,

$$Q = 3.9A \qquad (3)$$

Where, A is cross-section area of flow passage (mm^2)
The plot of regression model is given in Fig. 5. The correlation coefficient R^2 of the equation is 0.91.

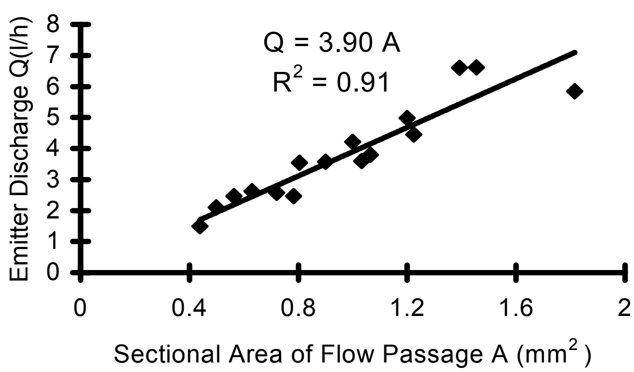


Figure 5: The relationship between cross-section area of passage and flow rate of emitters

3.5 The influence of flow passage structure parameters on the anti-clogging ability of emitters

3.5.1. Progression of emitting rate of drippers and clogged percentage with the increment of experimental phase

Four representative curves to show the progression of flow emitting rate with the increment of experimental phase for dripper 1, 8, 13 and 14 are presented in Fig.6.

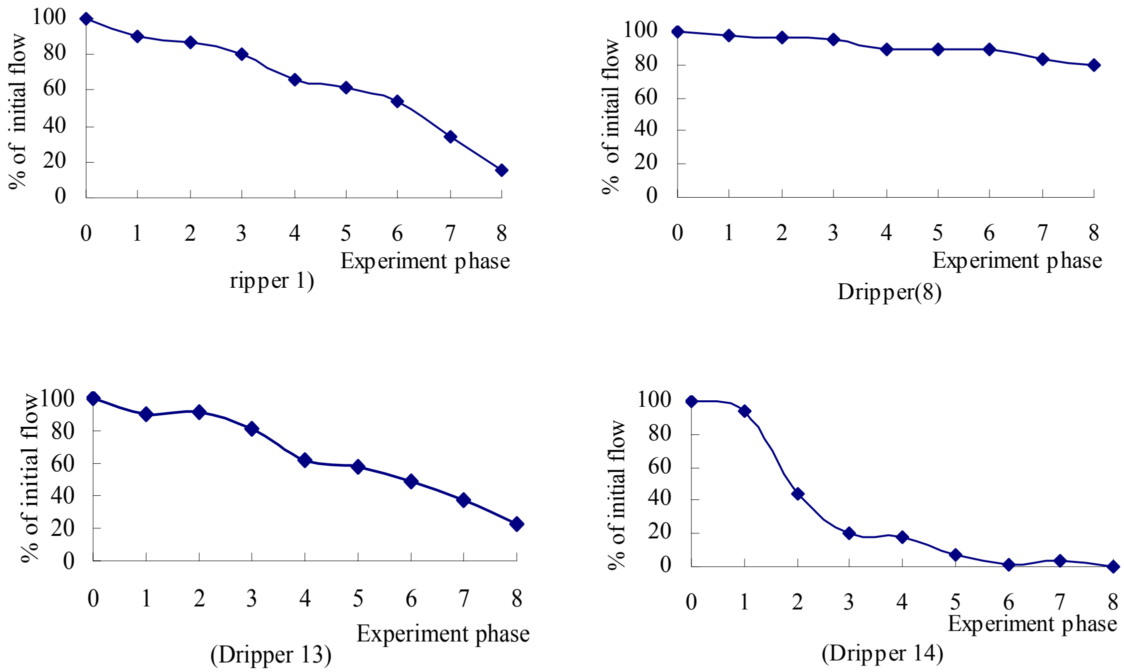


Figure 6: The progression of emitting rate with incremental experiment phase

Representative four curves to show progressive percentage of clogging with the increment of experiment phase are presented in Fig. 7. The emitter sample is declared clogged when the average of the 25 measurements of emission rate from test sample does not exceed any more 75% of the value of initial average emission rate of the sample.

The percentage of clogged drippers at any experimental phase may be calculated by dividing the number of clogged drippers by the total number of each dripper type in the test. Results shown in Fig. 7 indicate that dripper #1 and dripper #13 were gradually getting clogged whereas the dripper #14 was clogged to 60 percent at experiment phase 2. Dripper #8 remained unclogged till the end of experiment and displayed a good ability of anti-clogging.

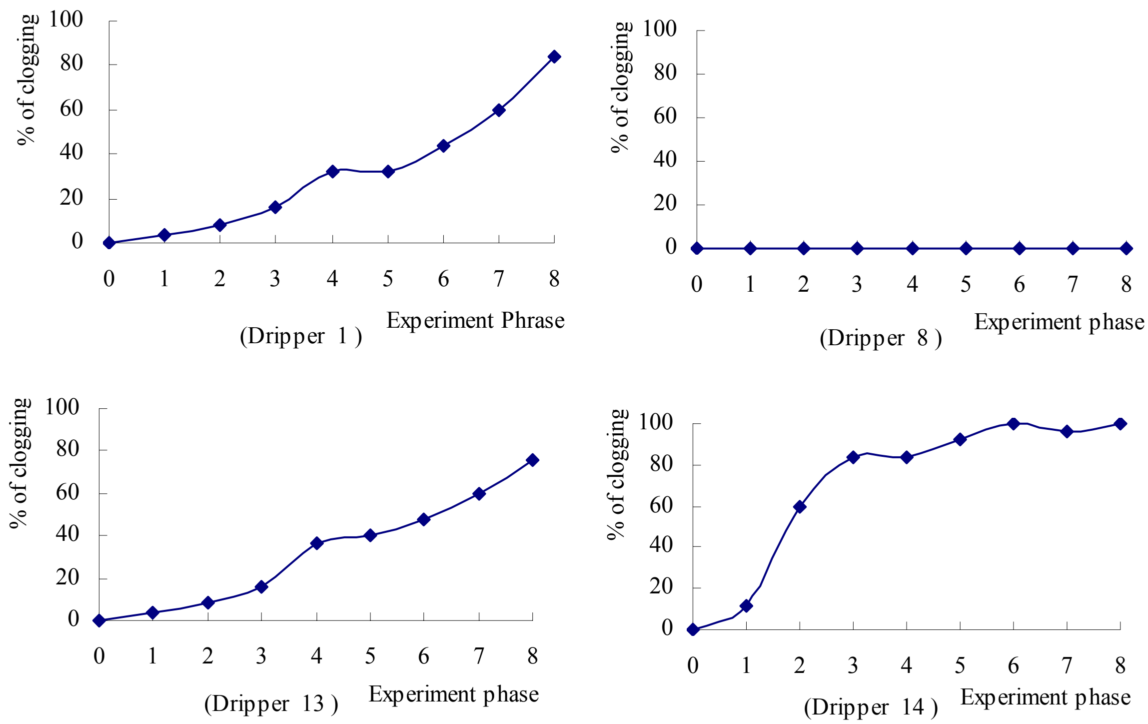


Figure 7: The progression of clogged drippers with experimental phase.

3.5.2 Variance Analysis for particle size interaction with emitter structure parameters

Variance Analysis results for particle size interaction as an indicator for ant-clogging ability of drip emitter is presented in Table 8.

Table 8: Variance Analysis of flow passage structure parameters on sand size for initial clogging

Dependent Variable: sand size for initial clogging

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	.156	12	1.298E-02	20.572	.015	.988
Intercept	.691	1	.691	1095.520	.000	.997
Dentation angle	4.250E-02	3	1.417E-02	22.463	.015	.957
Dentation spacing	9.323E-02	3	3.108E-02	49.271	.005	.980
Dentation height	1.239E-02	3	4.131E-03	6.549	.079	.868
Flow passage depth	7.580E-03	3	2.527E-03	4.006	.142	.800
Error	1.892E-03	3	6.307E-04			
Total	.849	16				
Corrected Total	.158	15				

Results from variance analysis (Table 8) indicate that dentation spacing, dentation angle, and dentation height had significant effect on the anti-clogging ability of drippers at levels of 0.1. The significance ranking of flow passage structure parameters on the anti-clogging ability of drippers is: Dentation spacing > Dentation angle > Dentation height > Depth of flow passage.

3.5.3. Relationship between flow rate and anti-clogging ability of drippers

Common perception may be that drippers with higher flow rate have good ability of delivering sands and thus should hold better anti-clogging performance. However, the present experiment results did not fully support the viewpoint. Plotting of the data in Fig. 8 show that the anti-clogging ability of drippers was not fully enhanced with the increase of flow rate. Similarly, results of this study failed to show a linear relationship between cross-section area of flow passage and anti-clogging ability of dental labyrinth turbulent drippers, Fig. 9. This may indicate that the tortuous path geometry is more important than the cross-section area.

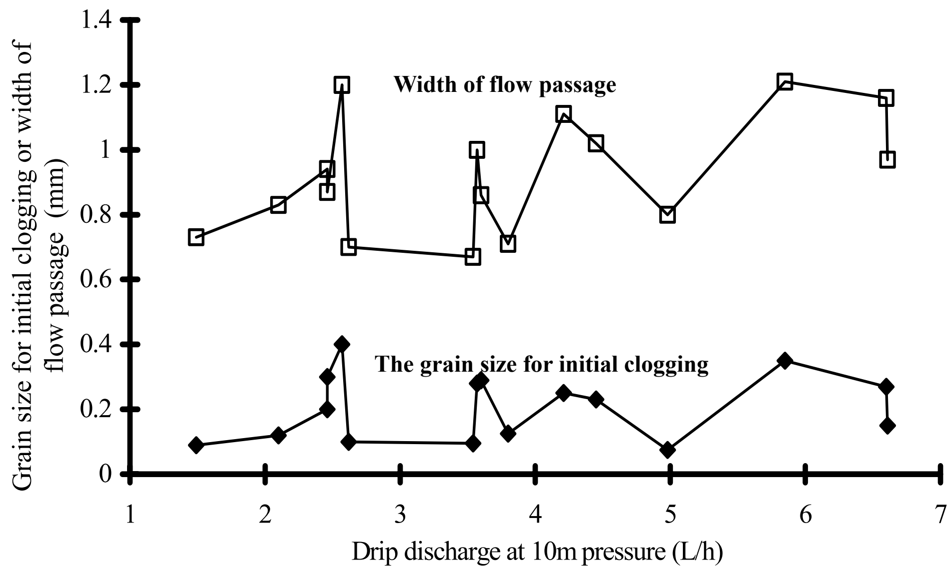


Fig. 8: Relationship of drip flow rate to width of flow passage or grain size for initial clogging

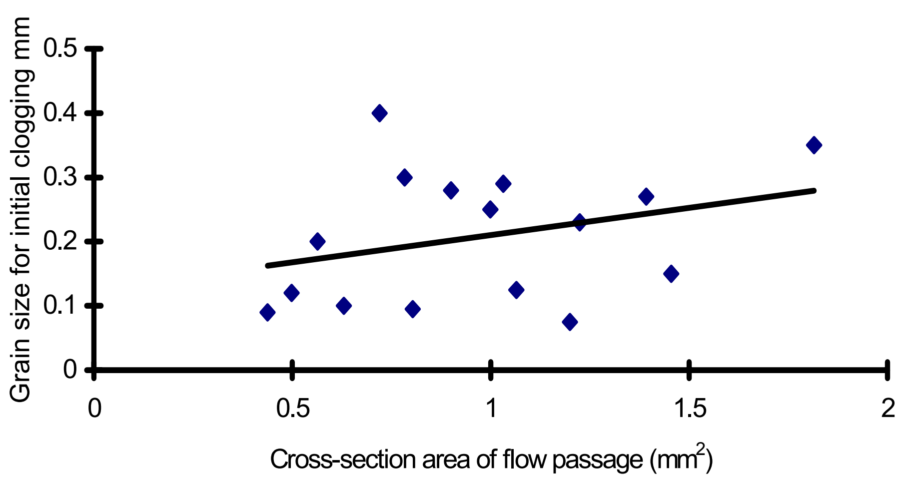


Fig 9: Relationship between cross-section area of flow passage and grain size at initial clogging

3.5.4 Relationship between depth of flow passage and anti-clogging ability of drippers

The experiment results failed to show any clear relationship between the depth of the emitter to grain size for initial clogging, Fig. 10. As mentioned above the labyrinth pathway geometry predominantly determined by dental spacing, angle, width, and dental height may contribute to how the particles move.

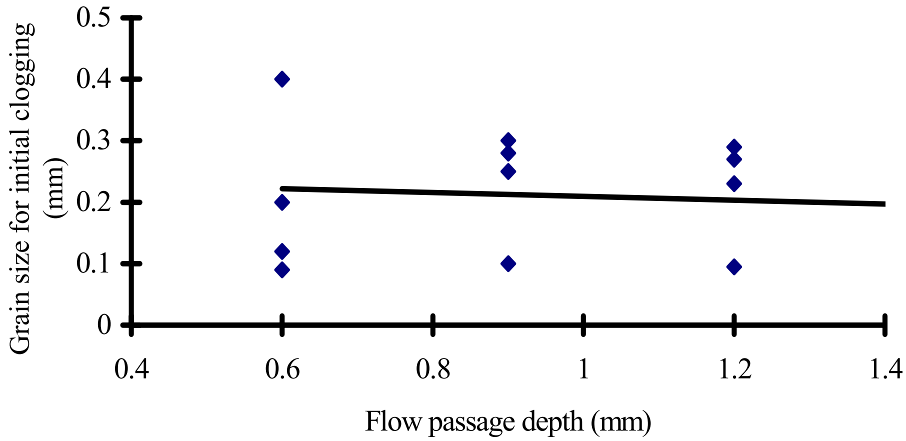


Fig 10: Relationship between flow passage depth to grain size for initial clogging

We observed that the width of all 16 kinds of drippers when plotted against the size of sand grain for initial clogging they produce a mirror image, Fig. 8, indicating a relationship of emitter width to initial grain size for clogging. This relationship is clearer when grain size of initial clogging is plotted against width of flow passage of emitter, Fig. 11. The dashed line in Figure 11 indicates that when the width of flow passage is between 0.6 - 0.8mm, there appears to be very little difference in anti-clogging ability for drippers. However, it changes to a more or less linear relationship as the width of flow passage goes above 0.8 mm.

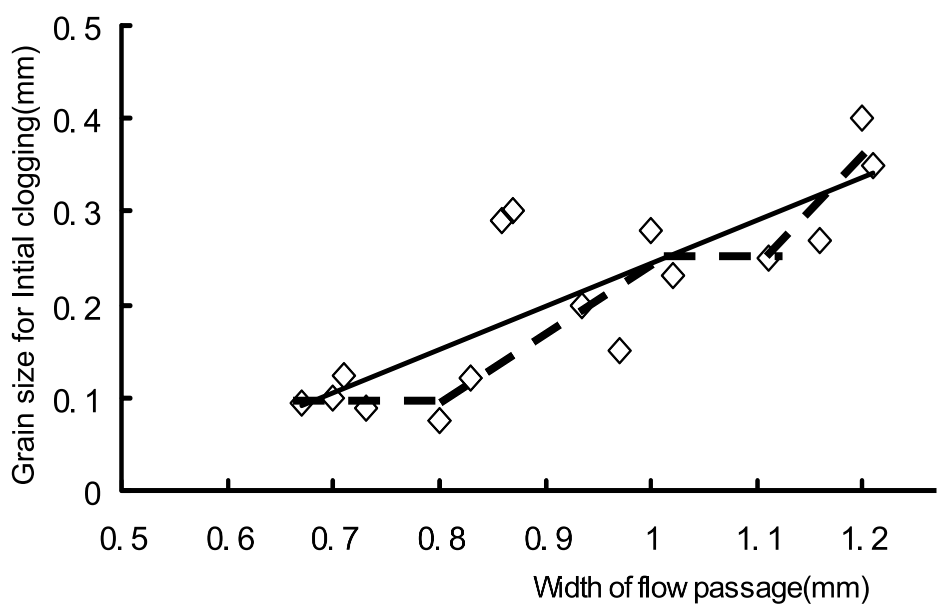


Fig 11 Width of flow passage and grain size for initial clogging

3.5.5 Relationship between the size of flow passage width and the filtering size

Figure 12 shows a graphical plotting of 1/7th and 1/10th of the width of flow passage opening of filter screen and the grain size that caused initial clogging. Most of the grains that caused initial clogging would be removed before it reaches the emitter.

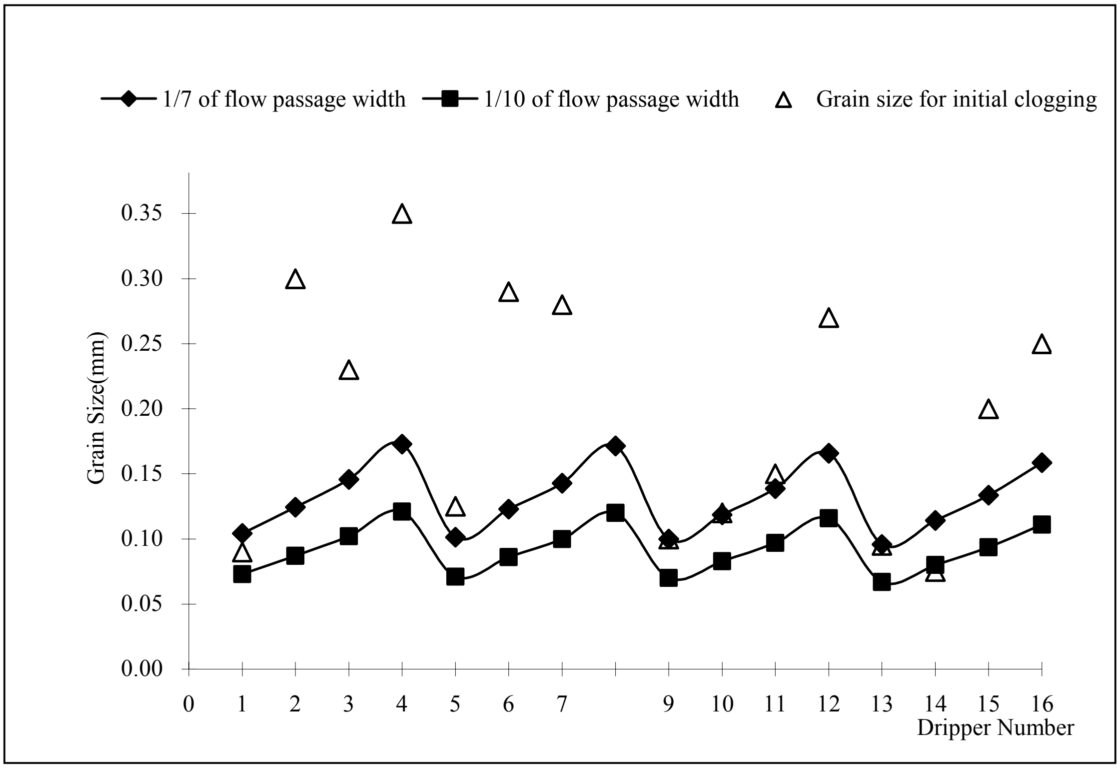


Figure 12 shows a plotting of filter screen opening sizes at 1/7th and 1/10th of the emitter flow path width and the sizes of the grains that caused for initial clogging

4. Conclusions

1. Dentation spacing of labyrinth pathway of emitter was significant for flow state exponent x. The ranking of significance for the flow state exponent x according to this study is: Dentation spacing >depth of flow passage >dentation angle>dentation height.
2. Depth of flow passage, dentation spacing, and dentation angle had significant effect on the flow rate of emitters.
3. The flow rate of 19.4 mm dental labyrinth drip emitter may be obtained from the linear prediction line, $Q = 3.9\ A$, where, Q is in L/H and A is cross sectional area. For the same emitter length the emitter design may be assisted by the equation $Q = -7.51 + 2.25\theta + 2.052B - 0.579H + 3.59D$, where θ = dentation angle, B = dentation space, H = dentation height, and D = flow passage depth.
4. Dentation spacing, dentation angle, dentation height had significant effect on the anti-clogging ability of drippers.
5. The chance of drippers plugged by sand particles was small if the openings of screen filters were selected according to the rule of 1/10th of the size of the width of flow passage.
6. More study is needed to evaluate the effect of flow passage depth on anti-clogging property of the emitter.

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