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Analysis of Flow through a Drip Irrigation Emitter

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ABSTRACT:- *Two-dimensional simulation of flow through drip irrigation emitter has been carried out to investigate the effect of dentate angle and dentate pitch on discharge using ANSYS Fluent 14 software. This work also aims on estimating the flow exponent that specifies the effectiveness of an emitter. Ansys Icem CFD Software has been used for the creation of models as well for meshing. Cases with various configurations of dentate angle and dentate pitch have been considered to simulate flow through the emitter for different pressure drops. K-ε realizable turbulence model with power law has been used for the simulation. Numerical approach adopted has been validated with experimental results and similar trend in dependency of discharge on pressure at inlet was observed. Discharge through the emitter with different dentate angles for same range of pressure drops has been observed in this work. From the results it can be understood that dentate pitch has a greater effect on flow rate than dentate angle for a given inlet pressure. Narrowly spaced dentate resulted in flatter variations in discharge with pressure. Flow exponent has been calculated for each of the cases considered and dentate angle of* 28^0 *was found best in dissipation of hydraulic energy.*

Keywords:- *Dentate pitch, Dentate angle, Discharge, Emitter, Flow exponent.*

I. INTRODUCTION

Water is becoming more and more a scarce and valuable resource as population and consumption rise. Evaluation of these factors, as well as technology and action to support healthy water supplies, is necessary to gain control of the situation. Agricultural use of water accounts for nearly 70% of the water used throughout the world, and the majority of this water is used for irrigation. Micro irrigation can be defined as the frequent application of small quantities of water on or below the soil surface as drops, tiny streams or miniature sprays through emitters or applicators placed along a water delivery lateral line. Many different emitters have been devised and manufactured within the last decade. The two main classifications of emitters are non-pressure compensating and pressure compensating emitters Non-pressure compensating emitters use a turbulent flow action which provides greater durability and longevity along with clogging resistance and low maintenance. Non-pressure compensating drippers will have varying output flow at varying inlet pressures. Therefore the flow will vary along uneven terrain, and each dripper will emit a different amount of water depending on its location on the supply line.

Research on emitters is growing year after year with the use of CFD and it has proven to be the best and only option to analyze flow through such minimum dimensions (of the range of millimeters). According to previous reports pertaining to drip emitters and in particular flat in-line drip emitters have each analyzed parameters of an emitter, which influence its performance such as dentate angle, path width, number of dentate etc. Emitter clogging has been considered as a major problem in emitters since the dimensions are very small and particles could easily clog and disrupt fluid flow. Extensive study on emitter clogging, factors influencing it and geometric designs that reduce it are being made using CFD and particle image velocimetry. Pressure drop across the emitter being paramount, we can conclude that, more tortuous the path more will be the pressure drop due to formation of eddies and the effect of dentate tips which effectively thwart pressure. In this work, literature on experimental and numerical investigation done by various researchers has been reviewed.

W. Niu in his study, "Influence of angle of Labyrinth channels on anti-clogging performance of emitter" realized that internal flow visualization inside the drip irrigation emitter is the basis of optimizing the labyrinth path structure and promoting its anti-clogging capability [4]. Qingsong Wei in, showed pressure loss in three emitters are in the order of triangular > trapezoidal > rectangular computationally and he also proved that rectangular emitters have the highest discharge per unit pressure [1].Li Yongxin in, computationally proved that the velocity in the flow path is maximum near the peak of the teeth (dentate tip) and down streams was highly affected by the vortices but these vortices contribute greatly towards anti-clogging characteristics of emitter through rinsing effect [2]. Xia Liu conducted analysis on clogging mechanism based on particle wall adhesion and they strongly argued that the inlet pressure of the emitter has a great effect on the particle-wall adhesion. Smaller inlet pressures lad to more adhesion whereas larger values of pressure increases the hydraulic performance [3]. Yan Dazhuang's numerical study concluded that rear of dentations and dentate tips were primary regions for energy dissipation, larger dentate angle enhances the hydraulic property with poor anti-clogging performance [5].

II. COMPUTATIONAL DOMAIN, MESHING, BOUNDARY CONDITIONS AND VALIDATION

DOMAIN: Emitter with triangular hydraulic energy dissipaters has been considered to study the effect of geometry on discharge for a given range of pressure drops. Replicating the emitter studied in experimental works, a 2D geometry with 11 dentate along with flow development spans of equal lengths at up and down streams is considered as the flow domain. The domain description and geometric parameters considered are as mentioned in figure1 and table1 respectively.

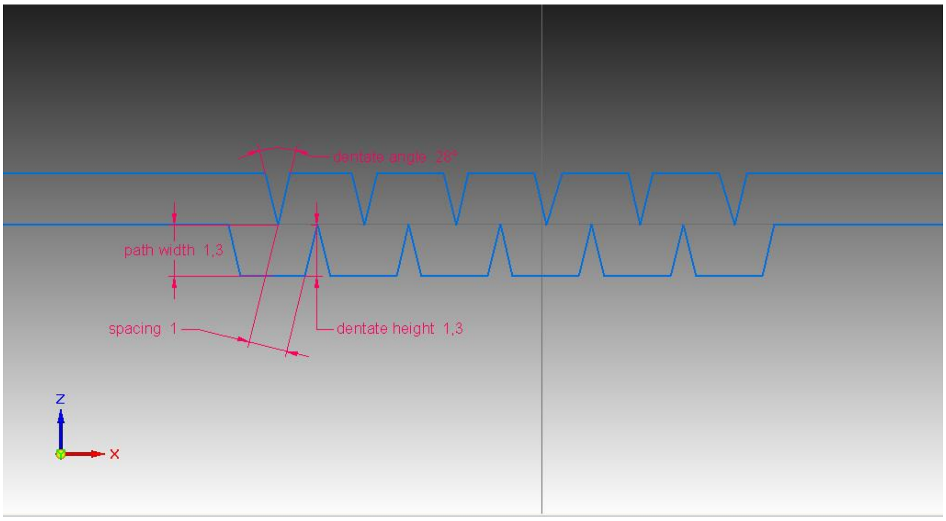


Figure 1: Geometric specifications of emitter

Geometric Parameters	Symbols	Dimensions
Path width	W	1.3mm
Dentate angle	X	28^0, 32^0, 36^0
Dentate height	H	1.3mm
Spacing	S	0.8, 1.0, 1.2mm

TABLE 1: GEOMETRIC DETAILS OF EMITTER

MESHING: The spatial discretisation of flow domain has been done with structured quadrilateral mesh throughout and it is meshed densely near wall surfaces where steep velocity gradients are anticipated. Grid independence test has been conducted for the 10m of water pressure with various geometric configurations and results are observed to be invariant with grid size around 105062 elements. Discretisation of flow domain has been done using Ansys and one of the models is as shown in figure2.

BOUNDARY CONDITIONS: The fluid is assumed to be incompressible with constant properties and the flow is turbulent and in steady state. All numerical simulations are carried out using a finite-volume method. The boundaries of the computational domain consist of inlet, outlet and wall. No-slip boundary condition is used at the walls with a wall roughness of 0.01mm. Boundary conditions for the domain are applied as tabulated in table 2.

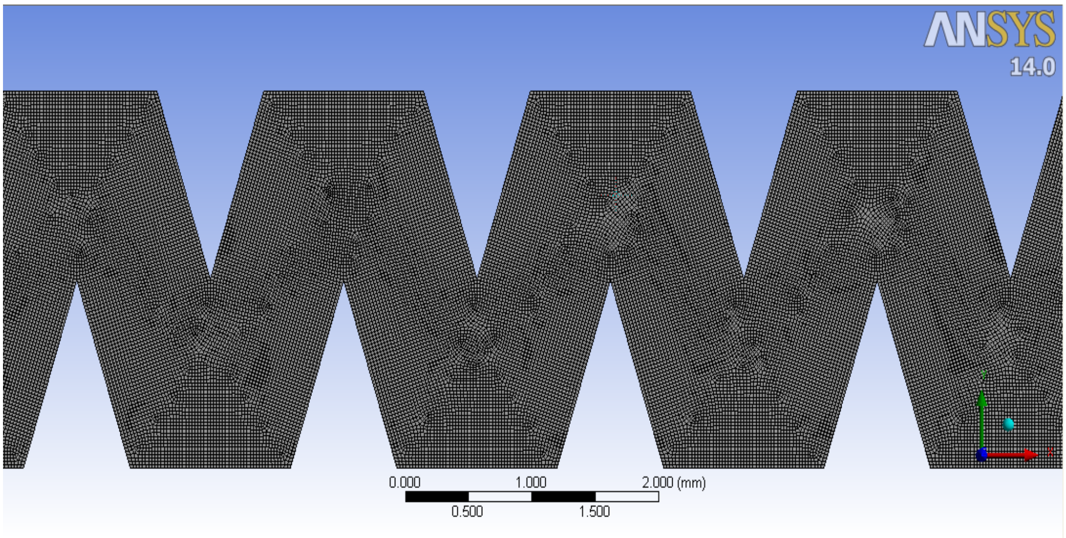
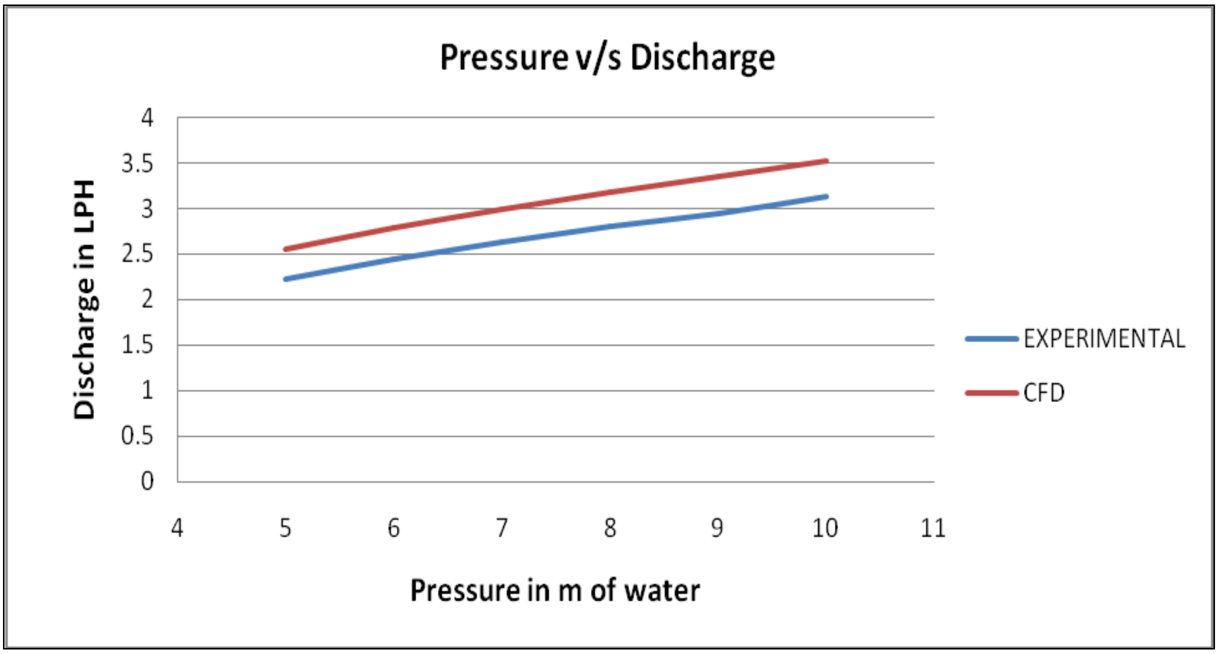


Figure 2: Discritized Model

Parameters	Boundary Conditions	Constraints
INLET	Dirichlet Boundary Condition: Uniform pressure, 'P'	P ranging from 5m to 10m of water
OUTLET	Dirichlet Boundary Condition	P = 0 (Gauge)
WALL	Dirichlet Boundary Condition: Fluid velocity = u = v = 0	Wall roughness = 0.01mm

TABLE 2: BOUNDARY CONDITIONS

VALIDATION: Among the turbulence models available with the software, k- ε realizable turbulence model resulted with closer estimations and same has been used to simulate the flow with all the geometrical configurations. Numerical approach adopted in this work is validated against experimental results [5]. Validation for the CFD methodology is as shown in the graph 1, similar trends in variation of discharge with pressure drops were observed as that of with experimental results. From graph it is evident that the discharge values computed using k-ε realizable model has proximate results to the experimental work. Further, same validated numerical approach and model selected are adopted to simulate rest of the cases in the work.



Graph 1: Validation with Available Experimental Data

III. RESULTS AND DISCUSSIONS

PRESSURE CONTOURS: In the present work effects of emitter's dentate angle and dentate space on the discharge, velocity and pressure drop has been analyzed computationally. Fig 3, 4 and 5 shows the contours of pressure for 1mm dentate space and 28°, 32°and 36° dentate angles at pressure 10 m of water respectively. From the above diagrams it is clear that pressure gradients occurred mainly at the dentate tips. There were low-pressure regions at the rear of dentations and this is the place where the maximum pressure drop was produced.

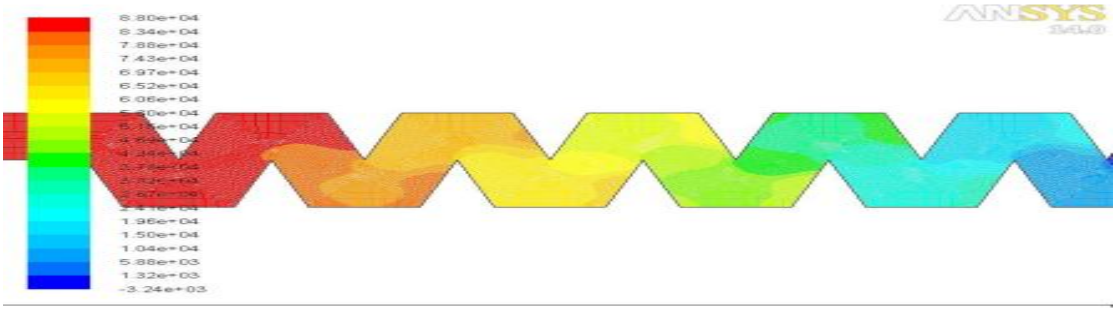


FIG 3: PRESSURE CONTOUR FOR 28°, 1MM SPACING

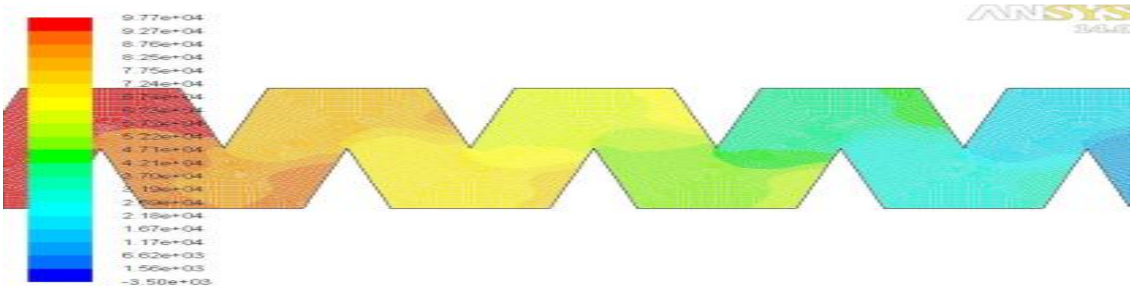


FIG 4: PRESSURE CONTOUR FOR 32°, 1MM SPACING

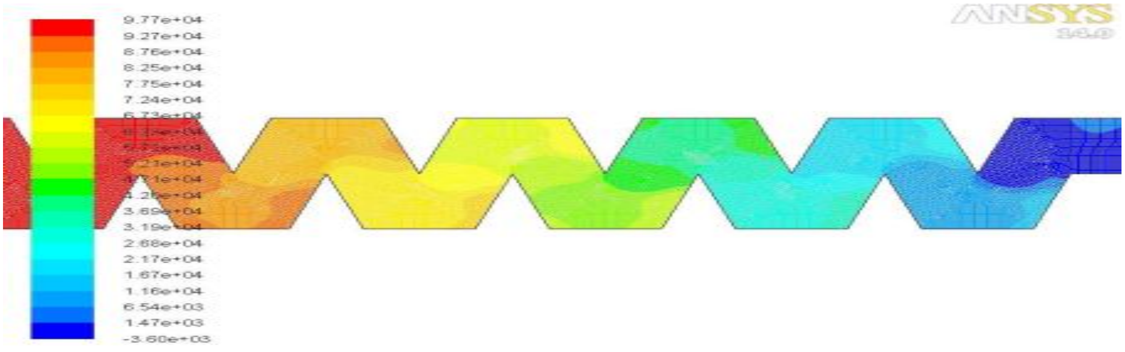


FIG. 5: PRESSURE CONTOUR FOR 36°, 1MM SPACING

VELOCITY CONTOURS AND VECTORS: To analyze the flow field within the flow path of the emitter by velocity vectors and contours have extracted from the post processing of CFD software. Velocity vectors with vortex and contours for pressure 10 m of water are shown in fig 6 and fig 7 respectively. The flow velocity at dentate tips is highest as these places experience minimum flow area. A vortex is formed at the downstream of dentate and flow velocity in the swirl area of the vortex is low as flow area gradually increases. The vortex inside the flow path improves the anti-clogging performance by rinsing effect.

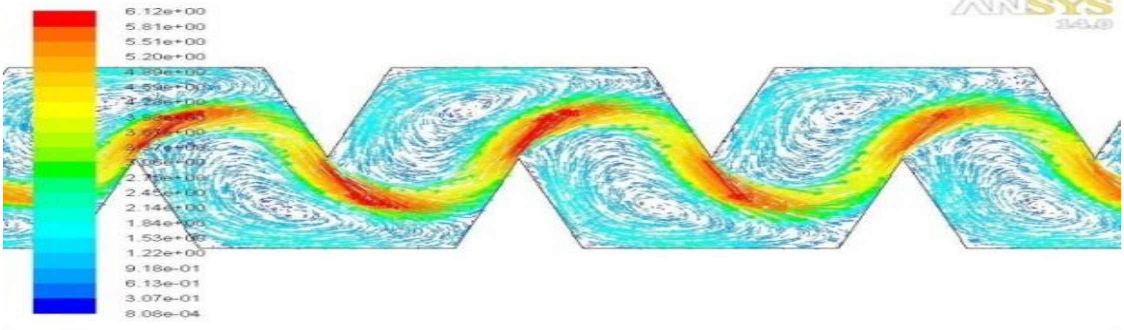


FIG 6: VELOCITY VECTORS IN FLOW DOMAIN.

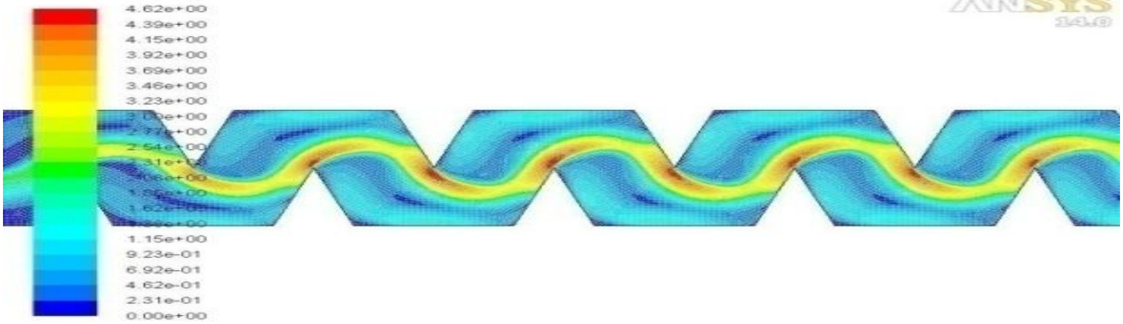


FIG 7: VELOCITY CONTOUR IN FLOW DOMAIN

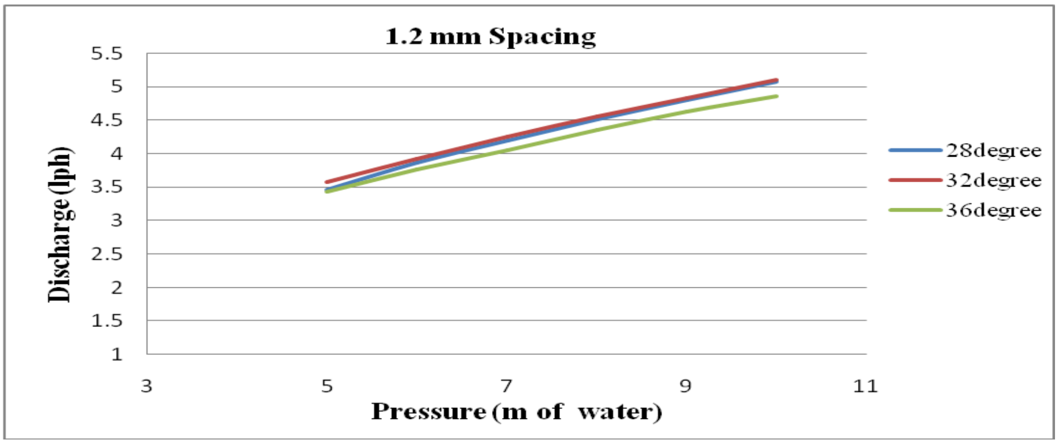
FLOW EXPONENT: Flow exponent is a parameter, which indicates sensitivity of flow rate to inlet pressure. A good NPC emitter has flow exponent value close to 0.5 indicating a fixed range of flow rate values for any inlet pressure. Flow exponent for different dentate angles of emitter is tabulated in a table 3. The flow exponent for 28^o was near to 0.5, which indicated the best hydraulic performance and effective hydraulic energy dissipation. With the increase of dentate angle, the flow exponent of emitters decreased initially and then increased with the further increase in the dentate angle.

Dentate Angle	Flow Exponent (x)
28°	**0.475**
32°	**0.452**
36°	**0.455**

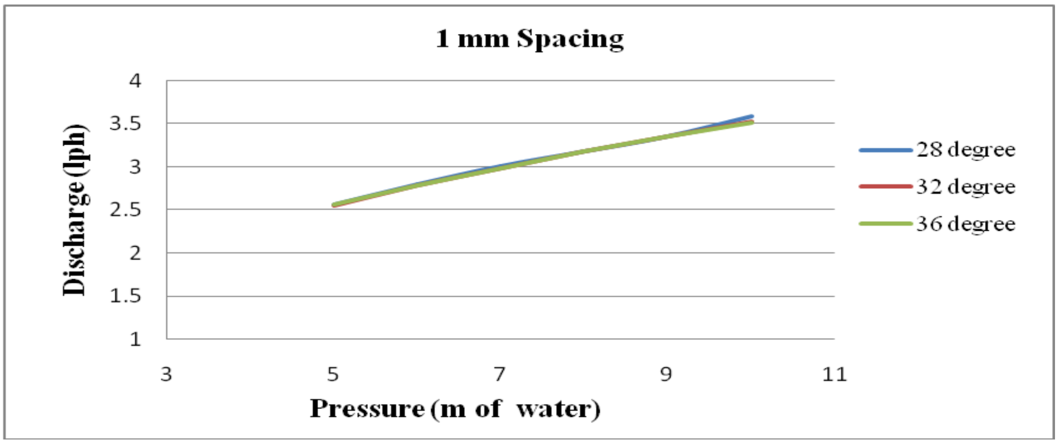
TABLE 3: FLOW EXPONENTS

EFFECTS OF VARIOUS PARAMETERS ON DISCHARGE

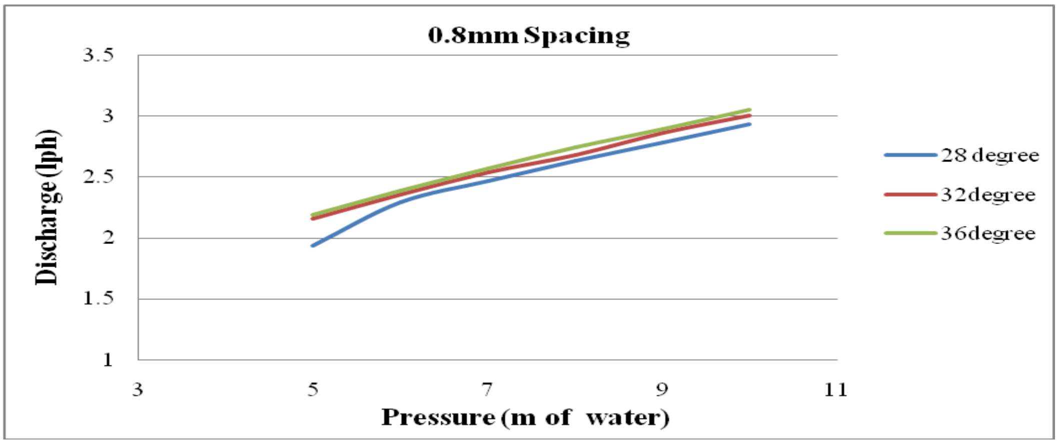
Even though the parameters to be observed are many in these types of emitters, the dentate angle, spacing and pressure are varied for different inlet pressures in terms of m of water. Graphs 2, 3 and 4 are plotted to depict the variation in discharge for different inlet pressures for various dentate spacing and angle and their details are listed in the table 4.



GRAPH 2: VARIATION OF DISCHARGE WITH PRESSURE FOR 1.2MM DENTATE SPACING



GRAPH 3: VARIATION OF DISCHARGE WITH PRESSURE FOR 1MM DENTATE SPACING



GRAPH 4: VARIATION OF DISCHARGE WITH PRESSURE FOR 0.8MM DENTATE SPACING

The discarge for dentate angle 32° and 1.2mm spacing is maximum and it is seen that for 0.8mm spacing and 28°dentate angle the discharge is minimum. As the spacing increases from 0.8mm to 1.2mm the discharge also increases with increase in dentate angle due to greater flow path and less resistance from walls. It can be obserevd from the graphs that 0.8mm spacing has resulted in flatter variation of discharge with pressure which is a desirable characteristic of any emitter. From the above graphs, we can observe that as the values of spacing increases, the discharge increases up to a value that is equal to that of path width. Further increase will cause a decline in flow rate due to change in cross sectional area of path.

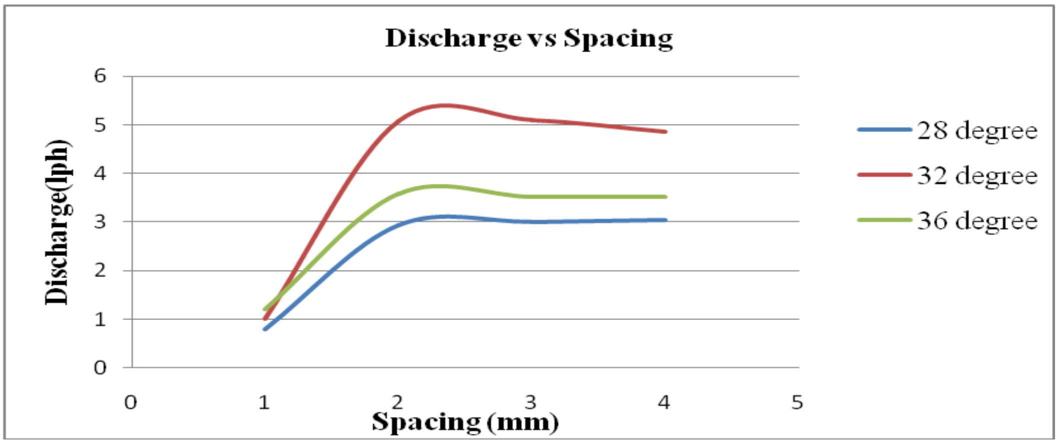
Pressure (m of water)	**Dentate Angle**								
	28 degrees			32 degrees			36 degrees		
	Spacing			Spacing			Spacing		
	0.8mm	1mm	1.2mm	0.8mm	1mm	1.2mm	0.8mm	1mm	1.2mm
	Discharge(lph)								
5	1.937	2.566	3.464	2.158	2.555	3.583	2.186	2.56	3.436
6	2.291	2.798	3.8	2.356	2.78	3.93	2.384	2.783	3.758
7	2.467	3.012	4.196	2.534	2.986	4.255	2.568	2.986	4.046
8	2.63	3.175	4.507	2.68	3.178	4.557	2.74	3.175	4.35
9	2.78	3.35	4.798	2.858	3.358	4.83	2.89	3.352	4.63
10	2.9338	3.586	5.079	3.006	3.528	5.108	3.05	3.518	4.86

TABLE 4: DISCHARGE VALUES FOR DIFFERENT DENTATE ANGLES AND SPACING

The above graphs 2, 3 and 4, and the table 4 clearly indicate that the variation in discharge for minor angle changes of about 4 degrees is negligible, where as the minute variation in the dentate pitch has greater effects on discharge.

EFFECT OF SPACING ON DISCHARGE

To study the effect of dentate spacing on discharge at given pressure graph 5 is plotted.



GRAPH 5: EFFECTS OF DENTATE SPACING ON DISCHARGE FOR VARIOUS DENTATE ANGLES

The above graph shows divergence for 3 different angles (28°, 32° and 36°) at a constant pressure 10m of water. It can be observed that the effect of dentate angle is negligible when dentate are narrowly spaced. As the spacing between dentate tips increases, the individual effect of dentate angle on flow rate also increases and it was found that for dentate angle of 32° discharge of is maximum for the given inlet pressure. Further increment in the dentate angle leads to decrease in the discharge because of domination in vortex flow and rinsing effect. Steep increase in discharge is observed between the dentate spacing of 1mm and 2mm, and further increase in the spacing showed negligible effect on discharge.

IV. CONCLUSION

- Dentate pitch has a greater effect on flow rate than dentate angle for a given inlet pressure.
- Small variations in dentate angle of about 4°, has negligible effect on discharge.
- Narrowly spaced dentate results in flatter variations in discharge with pressure.
- Effect of dentate angle increases with increase in the dentate spacing.
- Emitter with dentate angle 28° showed best hydraulic performance with flow exponent of 0.475 where as maximum discharge is observed for dentate angle of 32° with maximum dentate pitch.

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