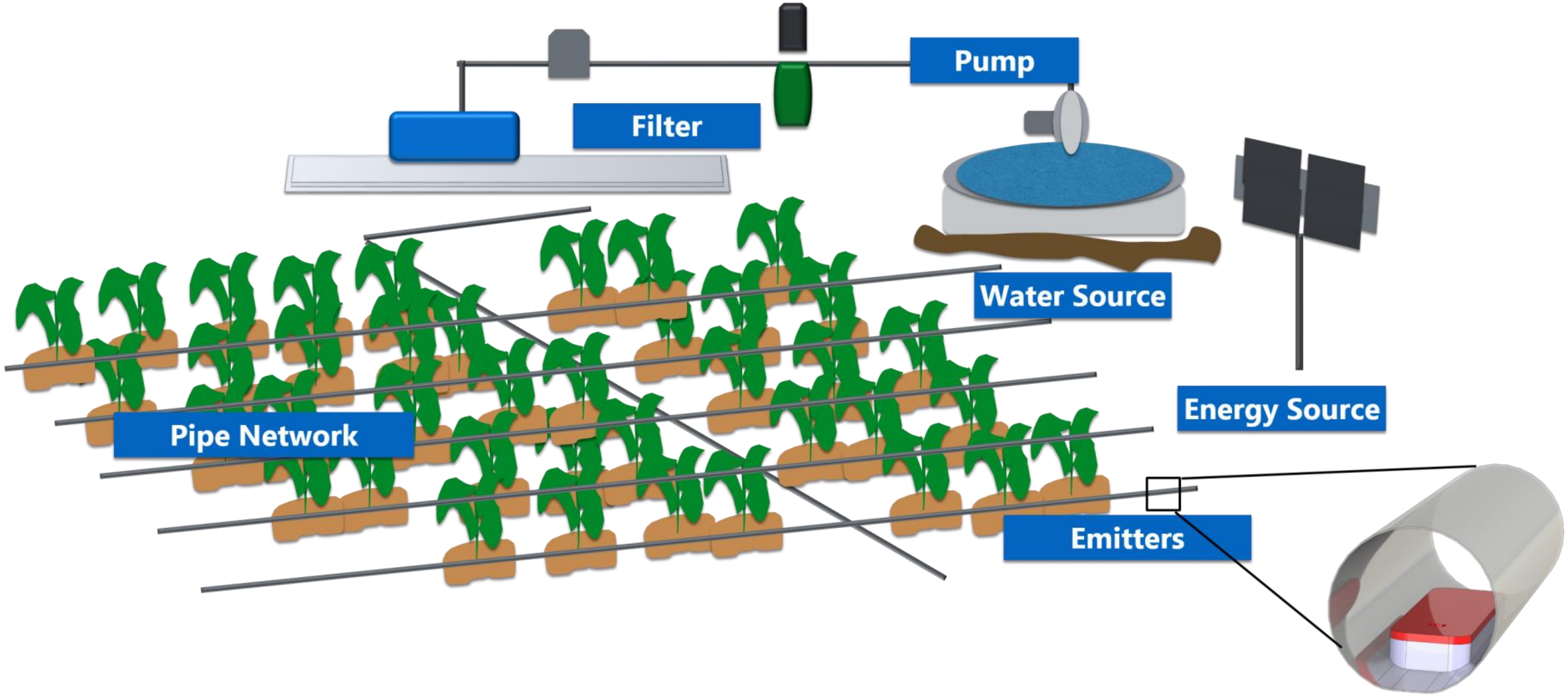
DEM Model of Clogging in Millimeter Scale Channels in Drip Irrigation Emitters

Jaya Narain

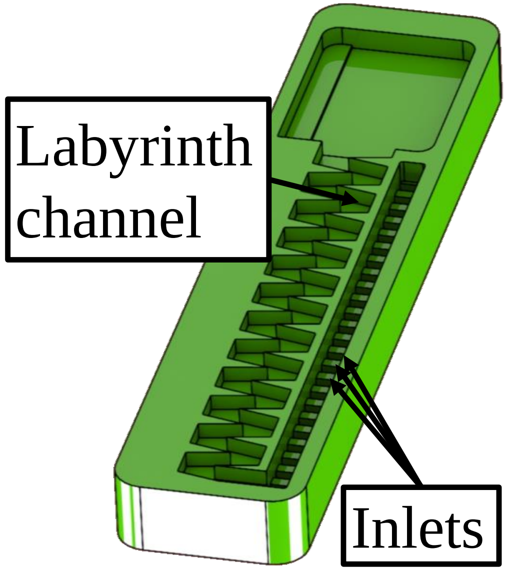
GEAR LAB
MIT GLOBAL ENGINEERING AND RESEARCH (GEAR) LABORATORY
GEAR.MIT.EDU

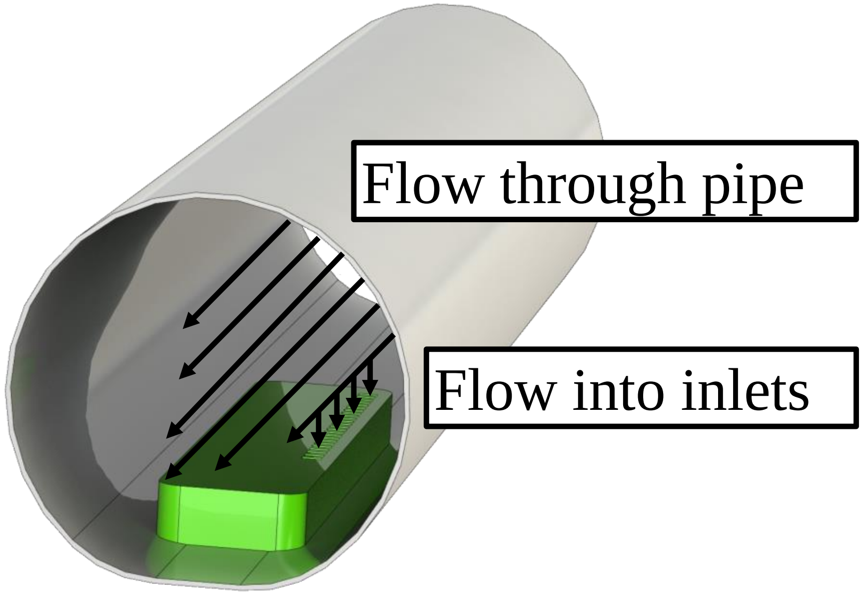
Massachusetts Institute of Technology

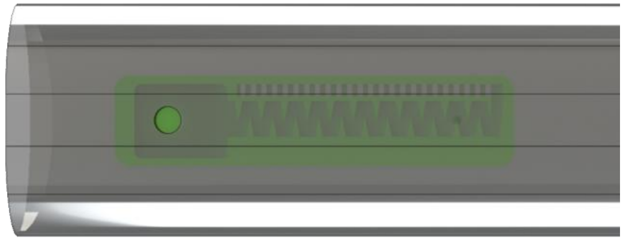
Drip Irrigation System



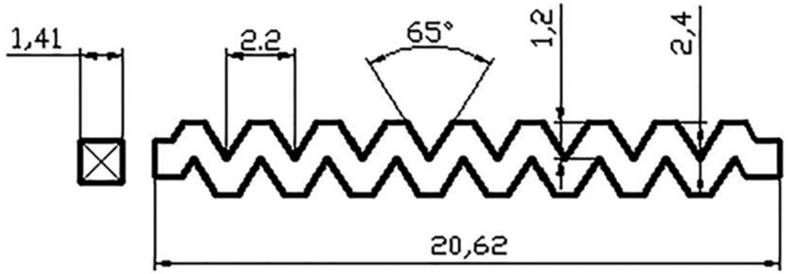
Commercial NPC Inline Emitter







DEM Model Validation: Bulk Flow



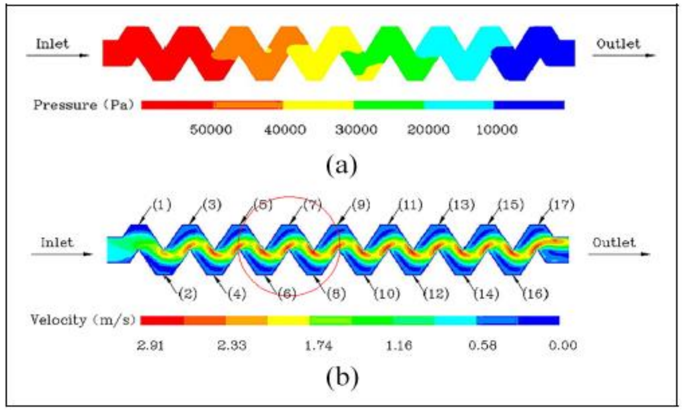
(b)

Study Parameters

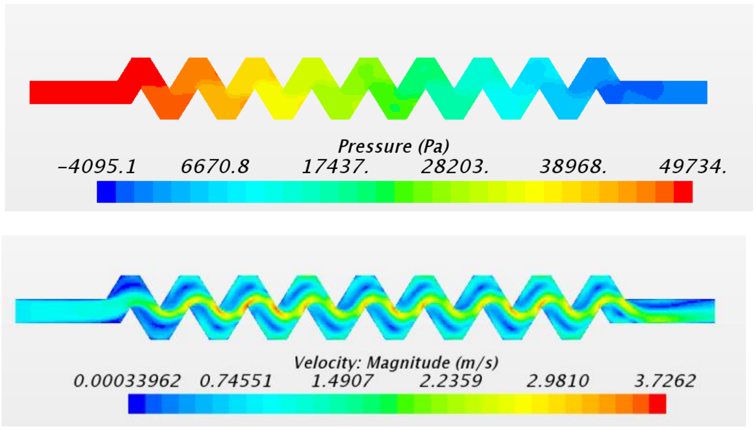
Total Inlet Pressure: 50,000

Outlet Pressure: 0 Pa

Standard k-ε turbulence



[1]



[2]

Realizable k- ε two layer

[1] Liming Yu, Na Li, Jun Long, Xiaogang Liu, and Qilang Yang. “The mechanism of emitter clogging analyzed by CFD-DEM simulation and PTV experiment.” *Advances in Mechanical Engineering.* 2018. Vol 10.

DEM Model Overview

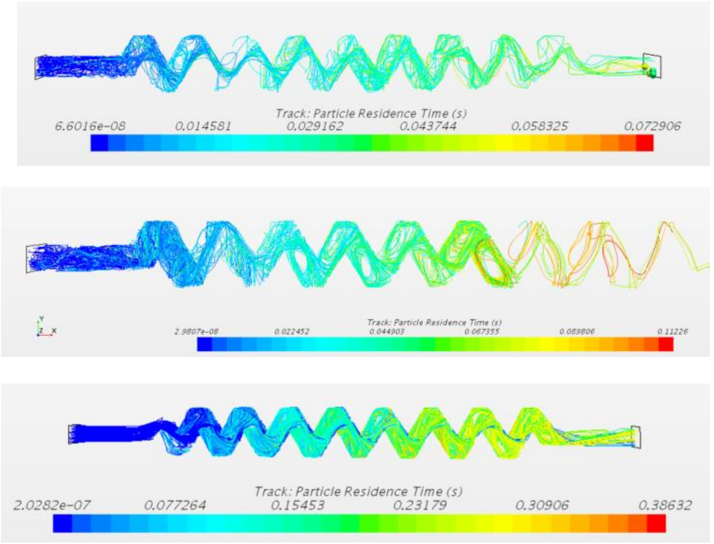
- Bulk Flow: 2nd order implicit unsteady solver; 2nd order convection, segregated (SIMPLE) P-V coupling
- Turbulence: Realizable k-ε turbulence with two-layer all y+ wall treatment
- Particles: Lagrangian multiphase DEM spherical particles; pressure gradient and drag forces; two-way coupling
- Hertz Mindlin no-slip contact model with frictional coefficients as defined in [1]

Solid and water properties as defined in [1]

Phase	Parameter	Symbol	Units	Value
Solid	Density distribution	ρ	kg/m^3	2500
	Particle diameter	d_i	μm	65 μm, 100 μm, 150 μm
	Rolling friction coefficient	μ_r		0.005
	Sliding friction coefficient	μ_s	–	0.3
	Poisson's ratio	V	–	0.4
	Young's modulus	E	N/m^2	2×10^7
	Coefficient of restitution	C	–	0.545
	Particle velocity at inlet	–	m/s	1.02
Water	Density	ρ	kg/m^3	998.2
	Viscosity	μ	kg/m/s	0.001
	Velocity at inlet	–	m/s	1.02

DEM Model Validation: Particle Tracks

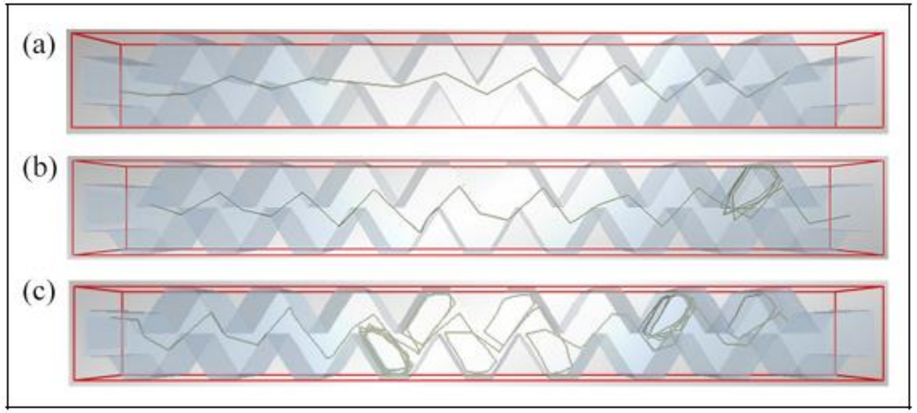
- Study ran simulation for a time of 1s with a time step of 0.001s [1]; due to computational limitations, a time step of 0.02s was used
- Particle flow rate selected as 100 particles/sec



50 µm

100 µm

150 µm



Particle trajectories [1]

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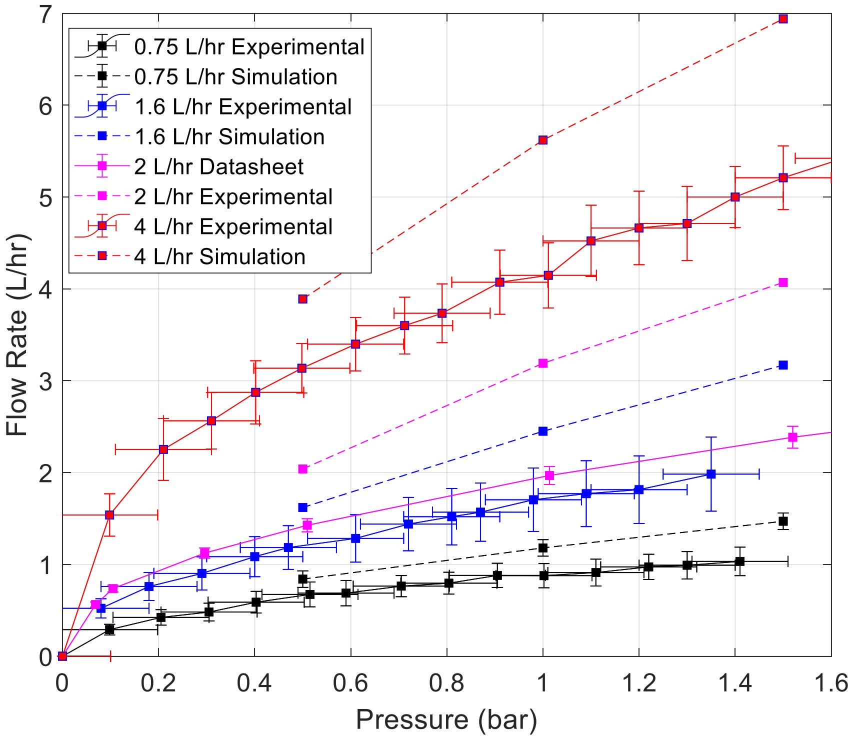
DEM Model Validation: Particle Tracks

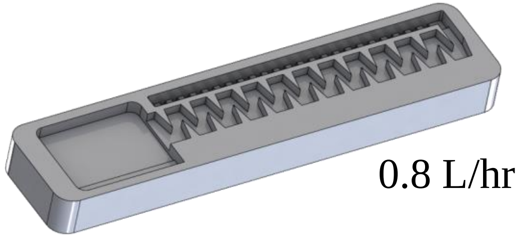
Particle Diameter (µm)	Average Residence Time (s)	Average Residence Time of Particles not in Recirculation (s) [1]
65	0.0173	0.019
100	0.0322	0.024
150	0.115	0.044

- Simulated trend matches trend from study [1] and other publications [2]
  - Would expect a longer residence time because recirculating particle tracks were not removed from average
  - Relatively small number of simulated particles may skew absolute values

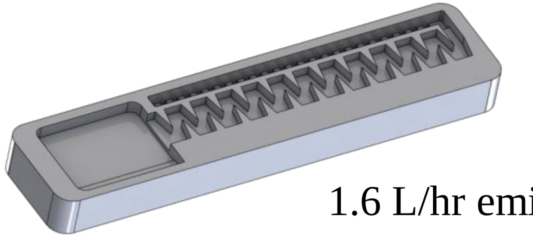
Model Validation: Steady State Results (One Phase) for Tested Emitters



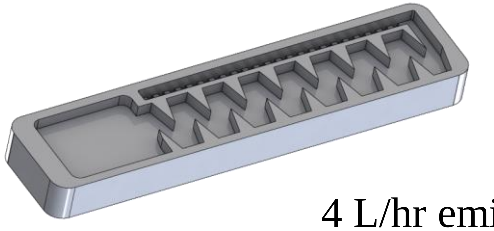
Modeled fluid domain



0.8 L/hr emitter



1.6 L/hr emitter



4 L/hr emitter

*Flow is modeled as turbulent in published literature ([1], [2], [3]); Realizable k-ε selected for robustness after extensive comparison

Model Validation: Steady State Results (One Phase) for Tested Emitters

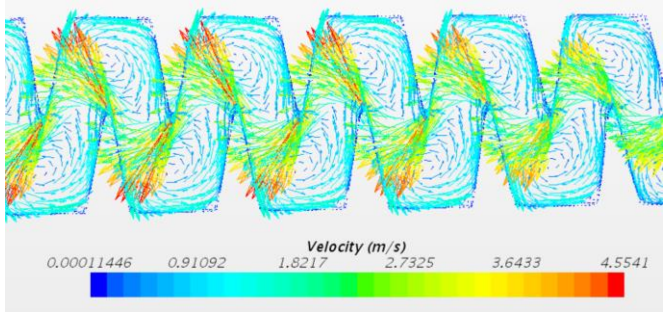
- For computational efficiency, simulated domain did not include filter or pipe flow (added resistance)
  - Simulation trends match expectations
- Mesh used curvature refinement and volume transition limiters and could not be refined evenly to calculate order of convergence
- Relative error between grids: ~0.01 m/s

3D Segregated flow (SIMPLE) solver with 2nd order convection, RANS realizable k-ε* two layer with all y+ treatment and wall y+ <1

*Flow is modeled as turbulent in published literature ([1], [2], [3]); Realizable k-ε selected for robustness

DEM Model Results

Particle tracks in 1.6 L/hr emitter

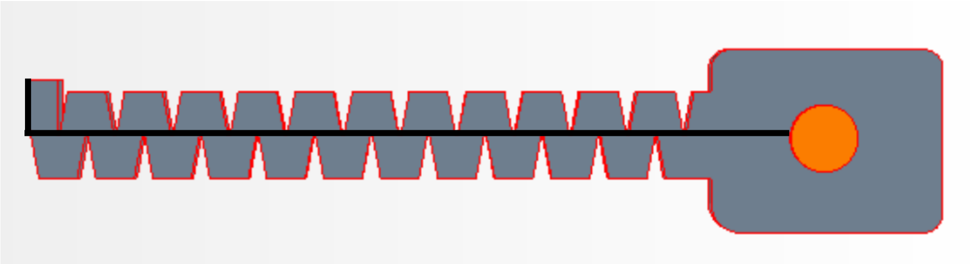


Velocity field in 1.6 L/hr emitter

Comparing Clogging in Emitters with Different Flow Rates

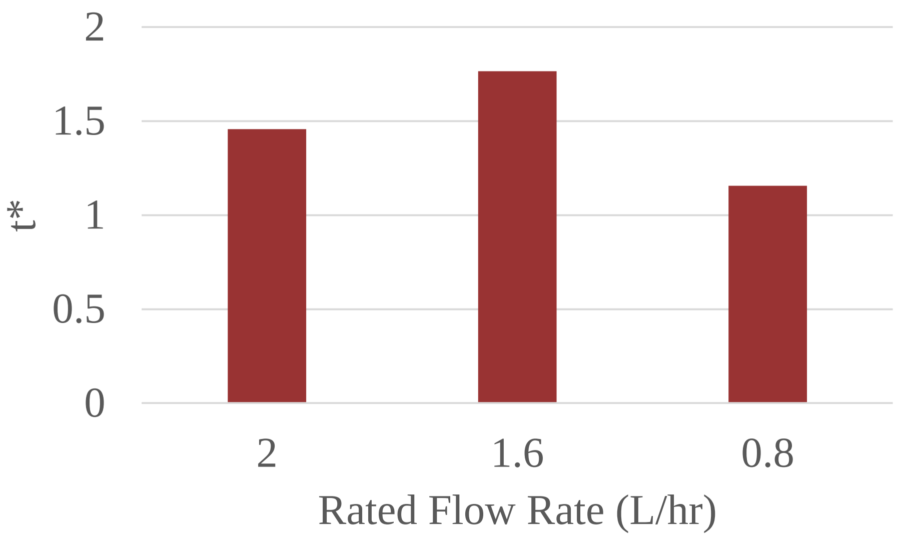
- Defined dimensionless time to compare data between emitters of different flow rates

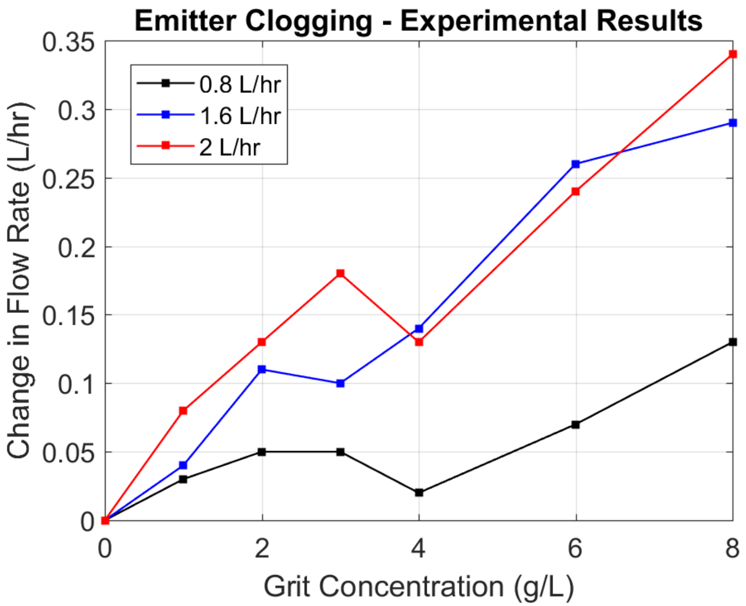
- $t_{char} = \left(\frac{L_{characcteristic}}{v_{outlet}}\right)$
- $t^* = \left(\frac{t_{avg\ sand\ residence\ time}}{t_{char}}\right)$



Characteristic length

Comparing Clogging in Emitters with Different Flow Rates





Experiments used 180 µm aluminum grit

- Trends appears correlated to flow rate; pressure variations in experiment may have skewed data
  - Additional simulation and experimental data necessary to evaluate numerical confidence and draw conclusive trends
  - Future work: How does the simulated particle concentration affect results?

Experimental data: Trang Luu

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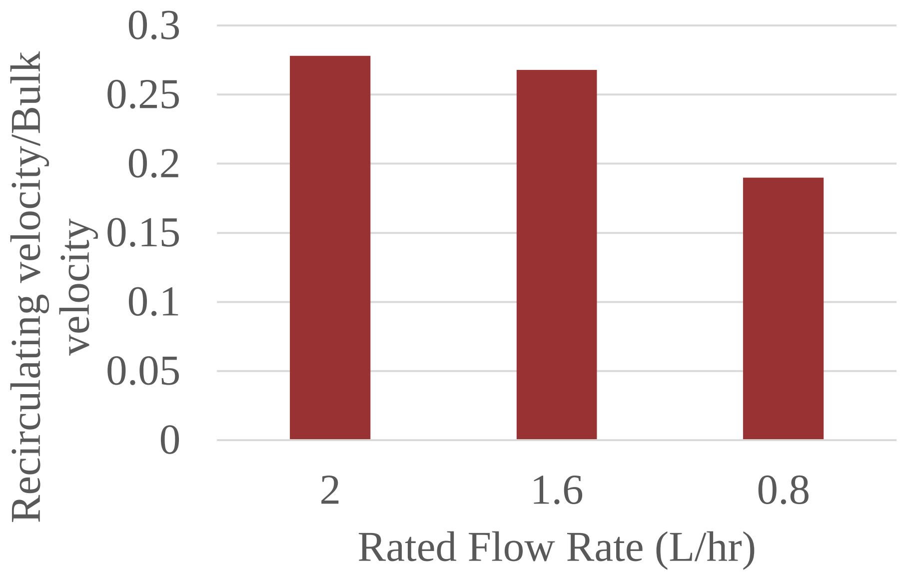
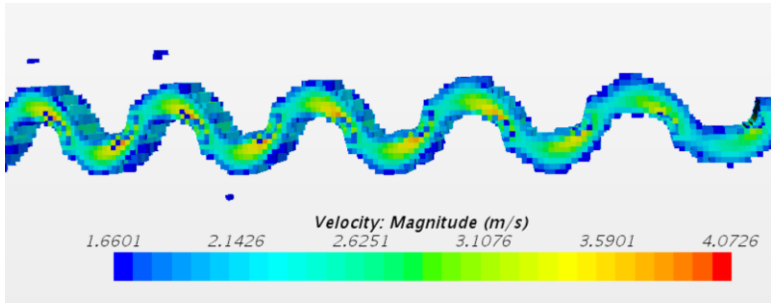
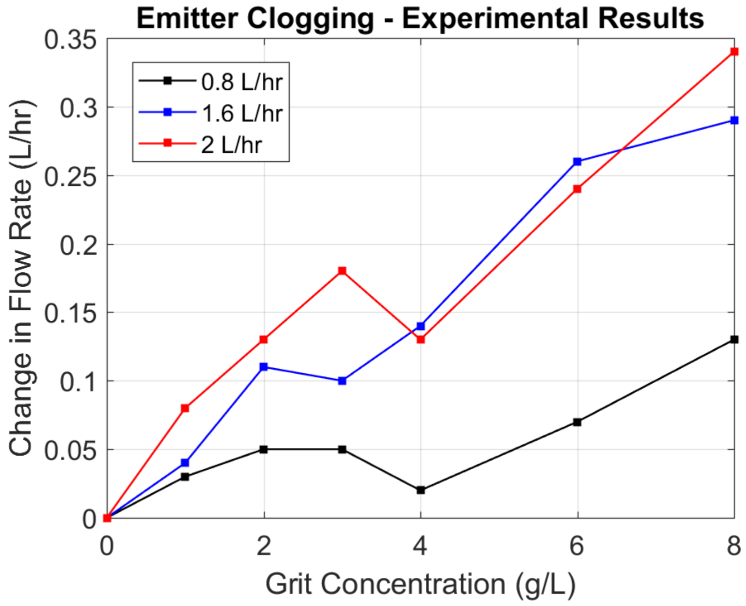
Flow Field and Clogging Behavior





Velocity filtered into bulk velocity and velocity in recirculation areas



Lower flow rates in the recirculation region may correspond to improved clogging resistance

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Design Applications

(1) Path design of traditional labyrinth channels using S_r as a design factor to minimize

– Simulation requires 10 minutes, while DEM simulation requires 6 hours

– Published studies in literature on optimizing design focus on DEM and experimental studies, [7]

(2) Novel path designs that avoid low flow velocity regions

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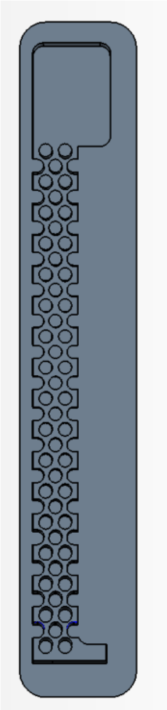
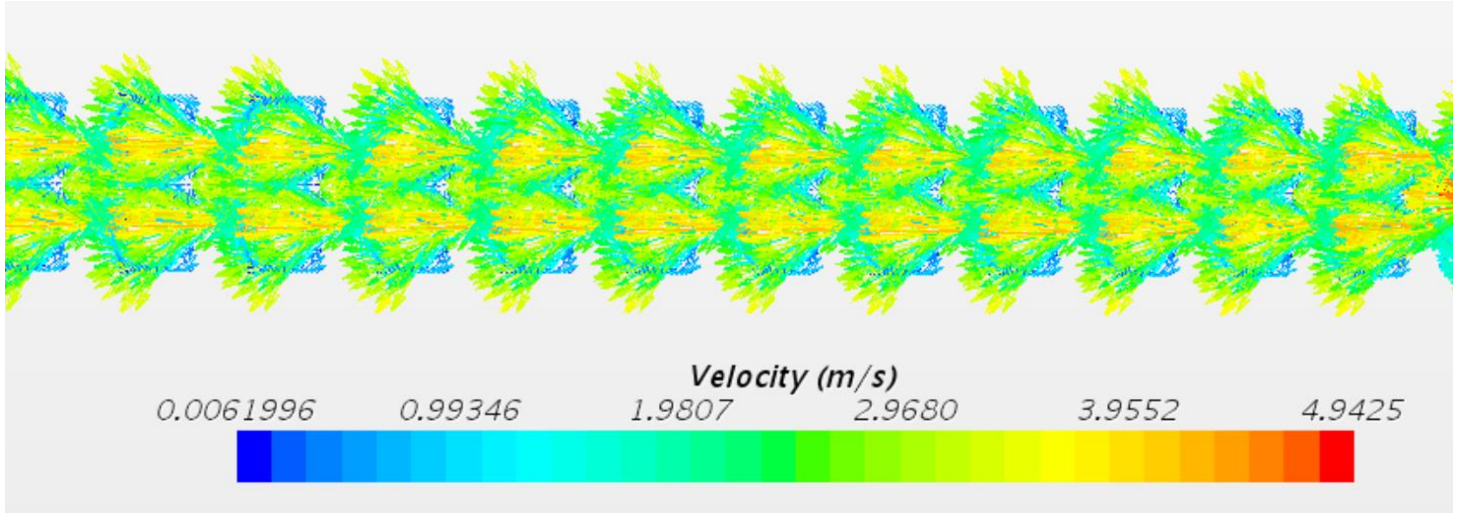
[7] Jun Zhang, Wanhua Zhao, and Yiping Tang. "Structural optimization of labyrinth-channel emitters based on hydraulic and anti-clogging performances" *Irrigation Science.* 2011.

Design: Flow Path Around Cylinders





No large zones with low flow velocity

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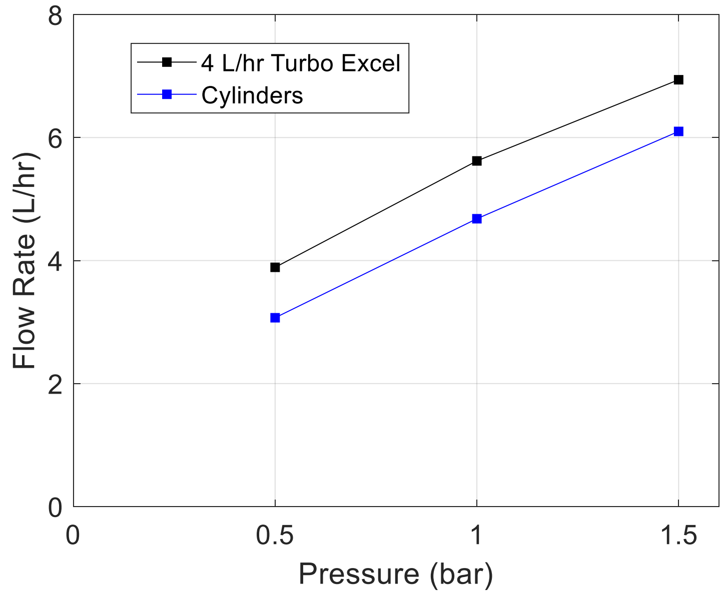
Design: Flow Path Around Cylinders

- The cylinder flow path has a significantly lower average residence time for particles than the traditional design, even at a lower flow rate

Emitter	Outlet Velocity (m/s)	Average Residence Time (s)	Length Scale (m)	Characteristic Time (s)	t*
Turbo Excel	0.649	0.0836	0.023	0.035	2.402
Cylinders	0.54	0.02139	0.021	0.039	0.545



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References

[1] Liming Yu, Na Li, Jun Long, Xiaogang Liu, and Qilang Yang. “The mechanism of emitter clogging analyzed by CFD-DEM simulation and PTV experiment.” *Advances in Mechanical Engineering*. 2018. Vol 10.

[2] Zhang un, Zhao Wanhua, Tang Yiping, Wei Zhengying, and Lu Bingheg. “Numerical investigation of the clogging mechanism in the labyrinth channel of the emitter.” International Journal for Numerical Methods in Engineering. 20017. **70**:1598-1612.

[3] “μ-PIV characterization of the flow in a milli-labyrinth channel used in micro-irrigation”. Al-Muhammad, Jufar; Tomas, Severine; Ait-Mouheb, Nassim; Amielh, Muriel; Anselmet, Fabien. 17th International Symposium on Applications of Laser Techniques to Fluid Mechanics. Lisbon, Portugal. July 2014.

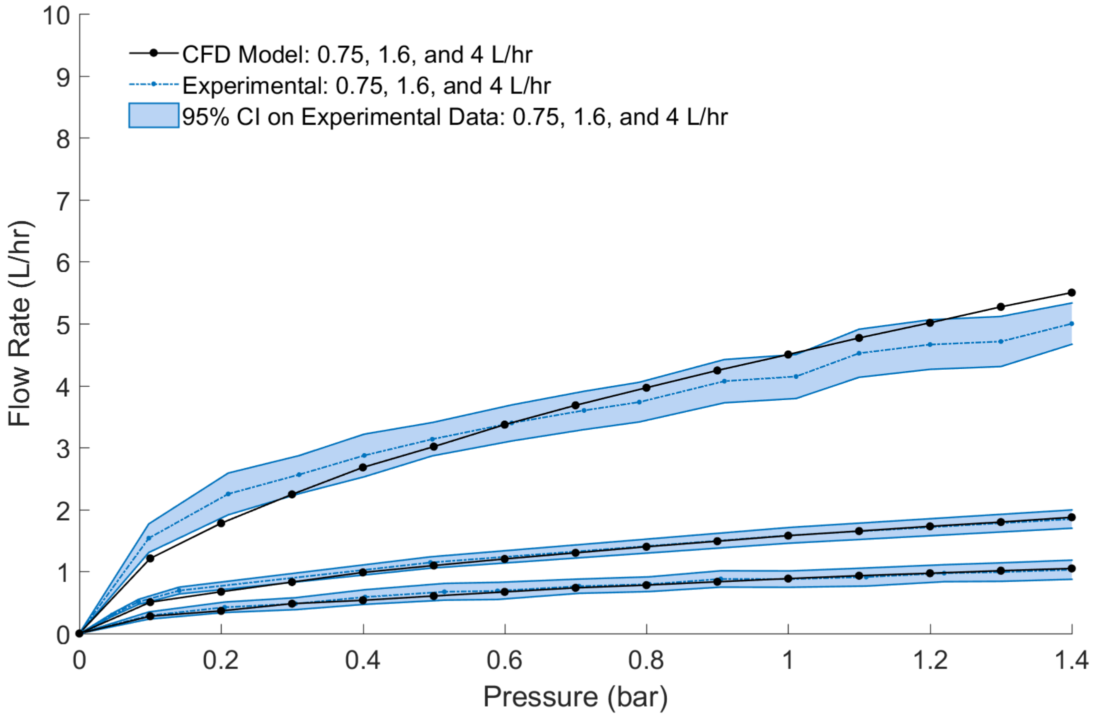
[4] Polyethylene material information. Goodellow. http://www.goodfellow.com/E/Polyethylene-High-density.html

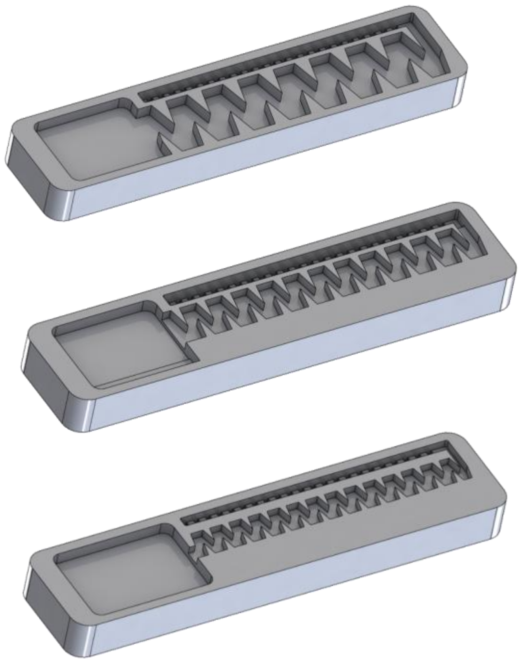
[5] Wenquan Niu, Lu Liu, and Xu Chen. “Influence of fine particle size and concentration on the clogging of labyrinth emitters” Irrigation Science. February 2012.

[6] Cemagref. Office of Science and Technology in France. “Testing Procedure”.

[7] Jun Zhang, Wanhua Zhao, and Yiping Tang. “Structural optimization of labyrinth-channel emitters based on hydraulic and anti clogging performances” *Irrigation Science*. 2011.

NPC Emitter Model with Filter and Pipe [3]





[3] Narain, Jaya and Amos G. Winter, V. “A Hybrid Computational and Analytical Model of Inline Drip Emitters.” ASME International Design and Engineering Technical Conference. August 2018.

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Clogging Experimental Set-Up Overview

Clogging Experimental Design & Data Collection: Trang Luu

- Clogging tests use different recommended times for operation and data collection and intermission (particle settling)
  - Cemagref: 8 hours operation, 16 hours intermission [5]
  - Niu, et. al.: 30 minutes operation, 6 hours intermission [6]
- Selected time for experiments: 30 minute operation, 30 minutes intermission
- During intermission, the concentration of 180 μm was increased

[5] Wenquan Niu, Lu Liu, and Xu Chen. "Influence of fine particle size and concentration on the clogging of labyrinth emitters" *Irrigation Science*. February 2012.
[6] Cemagref. Office of Science and Technology in France. "Testing Procedure".

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