Design, Fabrication and Performance Analysis of Anti-splashing Surface

Presented by:
MD. Hedayetul Islam Chy.
ID: 17702013
Dept. of EEE, CU

Supervised by:
Dr. Mohammed Arif Iftakher Mahmood
Associate Professor
Dept. of EEE, CU

EEE
University of Chittagong

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- Natural surface structure
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Introduction

- Hospital surgery ward basin, kitchen sink, urinals etc. surfaces contains germs and microbes.
  - Microorganisms will spread due to the droplet splashing.
  - Increase disease
- In juice industry, microbes may enter during product filling and packaging.
  - Reduce shelf-life of the produce

Bacterial transmission, spread disease

Reduce shelf life of a product containing liquids

Introduction

- Splashing of a droplet occurs due to
  - Drops kinetic energy, size
  - Surface tension
  - Viscosity
  - Surface roughness
  - Impacted phase
- Mainly two types of splashing occurs on four types of surfaces
  - Corona splashing
  - Prompt splashing

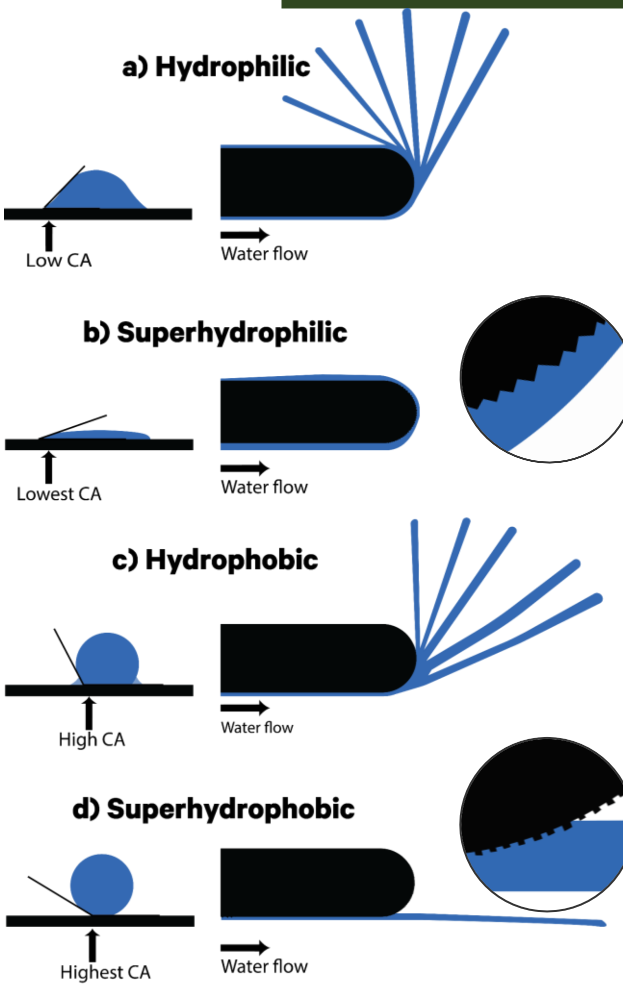


Fig1: Surface type

Introduction

- Corona splash
  - Drop spreads and lamella lifts up and forms a corona
  - Smooth, liquid films/pools
- Prompt splash
  - Drops spreads and recedes and immediately splashes.
  - Rough, dry solids

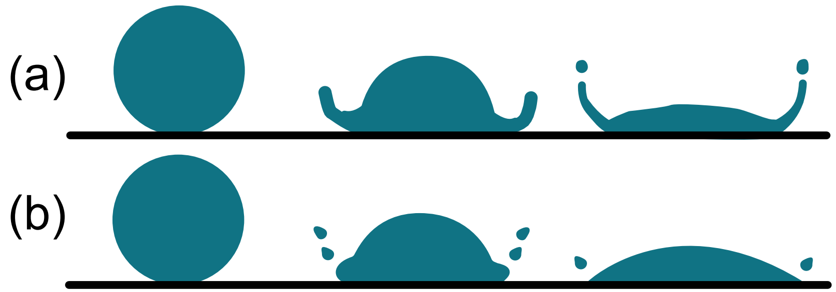


Fig1: (a) Corona splash (b) Prompt splash

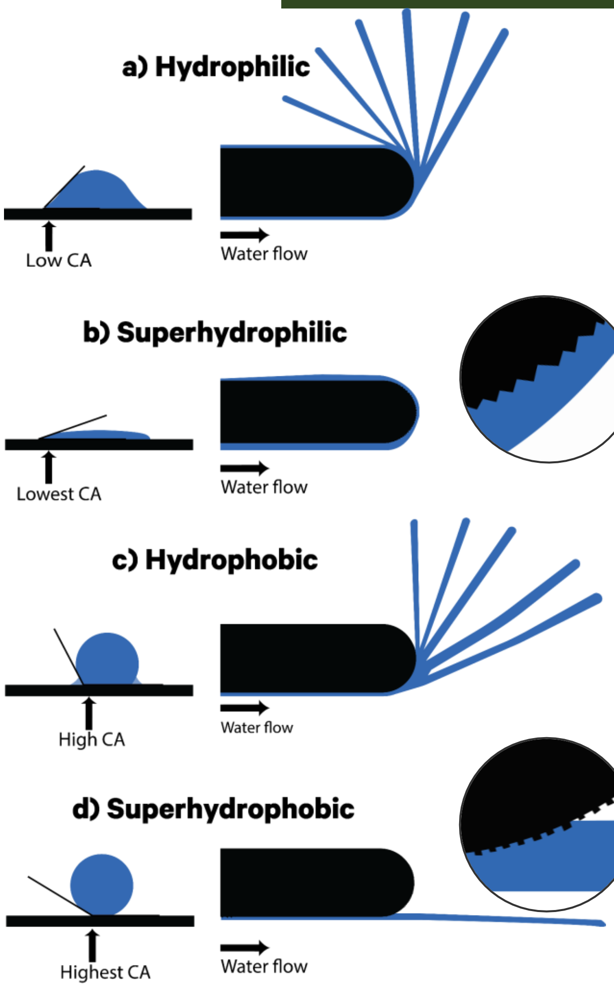


Fig2: Surface type

Natural surfaces

- Nature exhibits different types of surface structure.

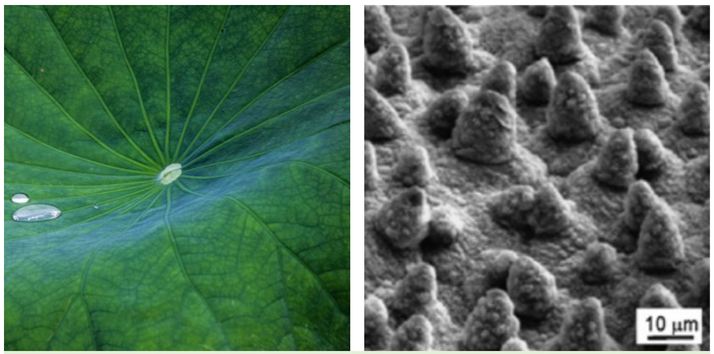


Fig 1: Lotus (Nelumbo Nucifera) leaf [1]

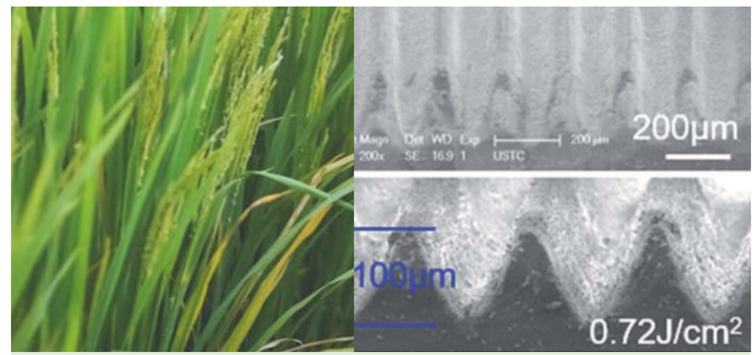


Fig 3: Rice (Oryza sativa) leaf[3]

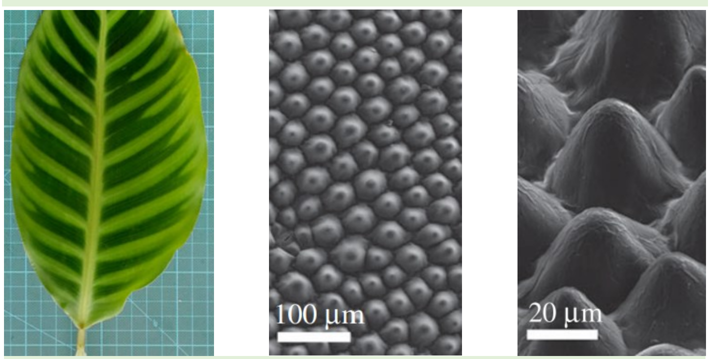


Fig 2: Calathea zebrina leaf [2]

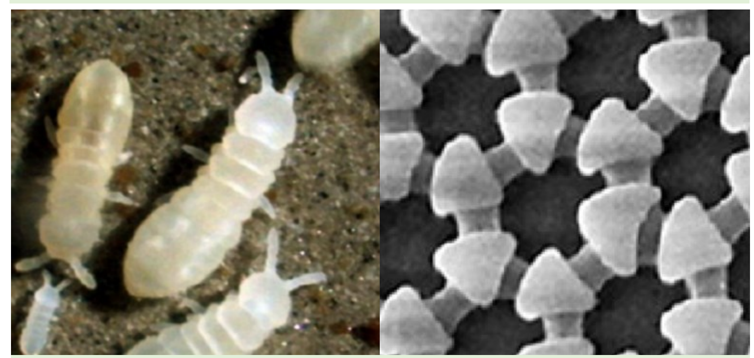


Fig4: Springtails(Orthonychirous statchinous)[4]

1. K. Koch et al., "Fabrication of artificial lotus leaves and significance of hierarchical structure for superhydrophobicity and low adhesion,"
2. Koch, K., & Grichnik, R. Influence of surface structure and chemistry on water droplet splashing.
3. Y. Lu et al. "Biomimetic surfaces with anisotropic sliding wetting by energy-modulation fem tosecond laser irradiation for enhanced water collection,"
4. R. Hensel et al., "Wetting resistance at its topographical limit: the benefit of mushroom and serif t structures,"

Objective

- To mimic the natural anti-splashing structure
- Study the formation and splash effect of water droplet on a pillar.
- Design different geometric pattern and compare their splashing
- To check the flexibility of the anti-splash surface for different droplets physical properties(density, velocity, viscosity, surface tension and falling direction).

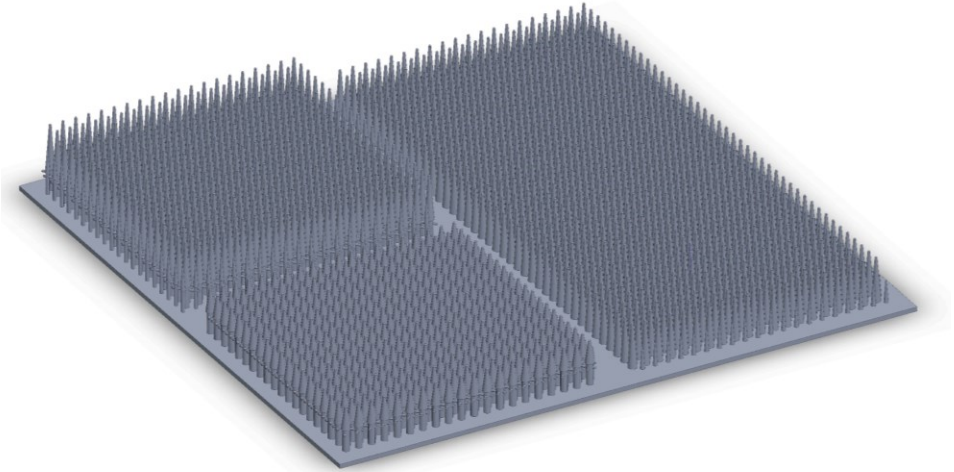


Fig 1: CAD model

Design Procedure

Mainly two types:

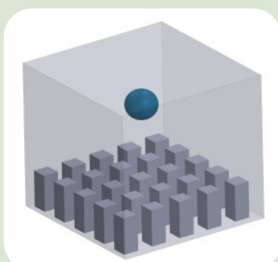
(a) Pillar based

1. Pillar width optimization
2. Morphology of the pillar cross-section
3. Topography of the tip
4. Uniform array structure
5. Non-uniform structured model

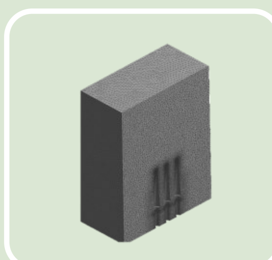
(b) Droplet based

1. Analysis with different fluids
2. Droplets with different falling velocity

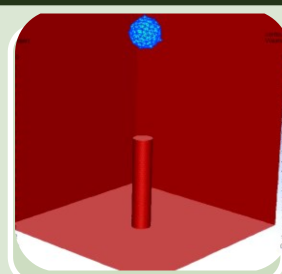
CFD Simulation procedure



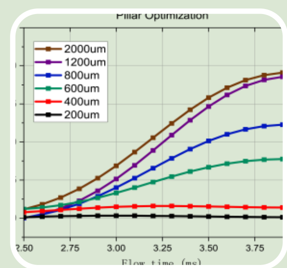
Geometrical Model



Mesh Generation



Optimization



Post processing

Geometrical model

- Droplet diameter is fixed as 1mm. [20droplets = 1ml or 1000uL]
- Pillar width to height ratio 1:5
- Droplet adapted inside the model.
- More than 35 models are designed using Solidworks3D.

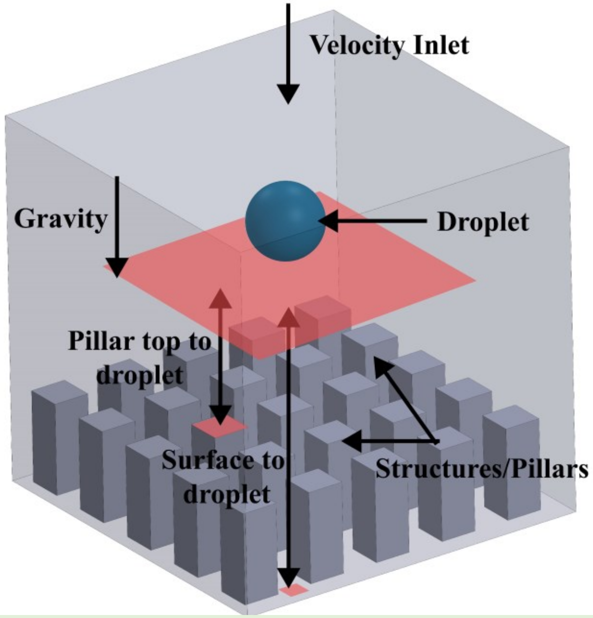


Fig1: Graphic depiction of an example geometrical model

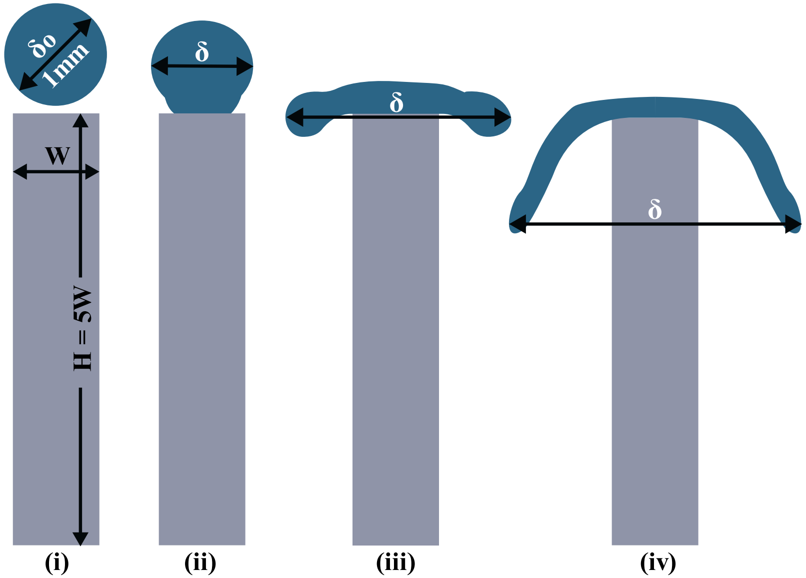
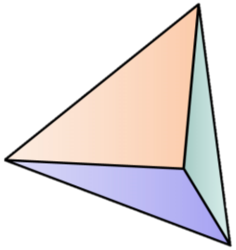


Fig2: Impact of droplets on a small pillar

Mesh refinement study

- Tetrahedron mesh utilized for every model.
- Velocity changes remains constant for 1.4M to 3.1M cells.



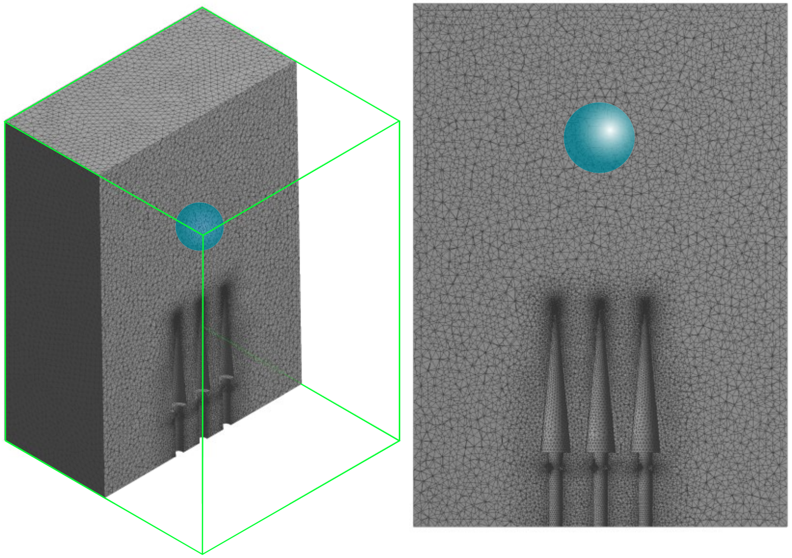


Fig1: 3D mesh and x-plane

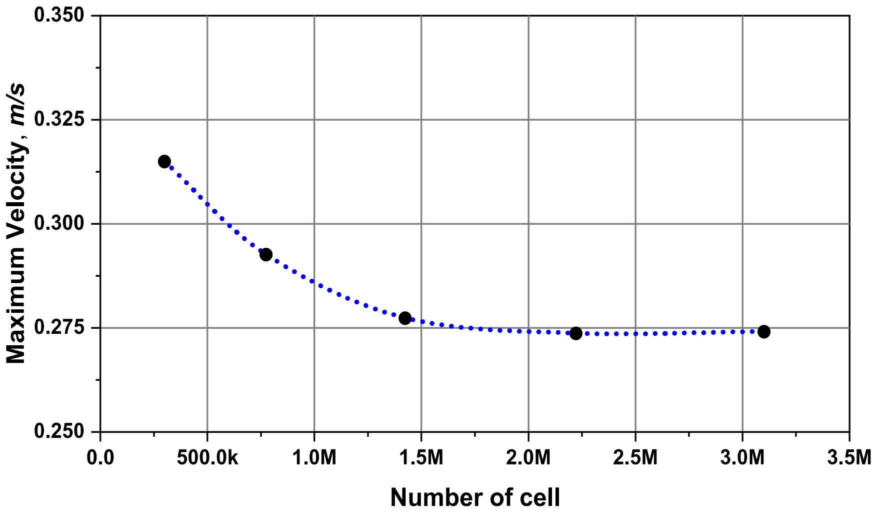


Fig2: Cell independence study

CFD physics

- We use Multiphase flow Volume of Fluid method.
- It is a numerical technique for tracking and locating the free surface.
- Consider, the volume is sub-divided into many cells that is ***C,***
- If, cell is occupied by Fluid A, ***C = 1***
- If, cell is occupied by Fluid B, ***C = 0***
- If, cell is occupied by both,***0<C<1***

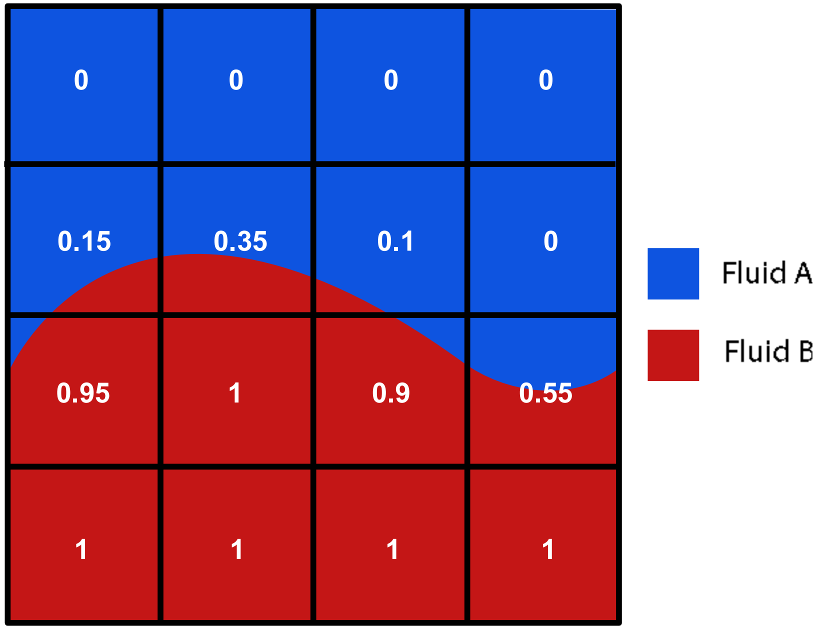
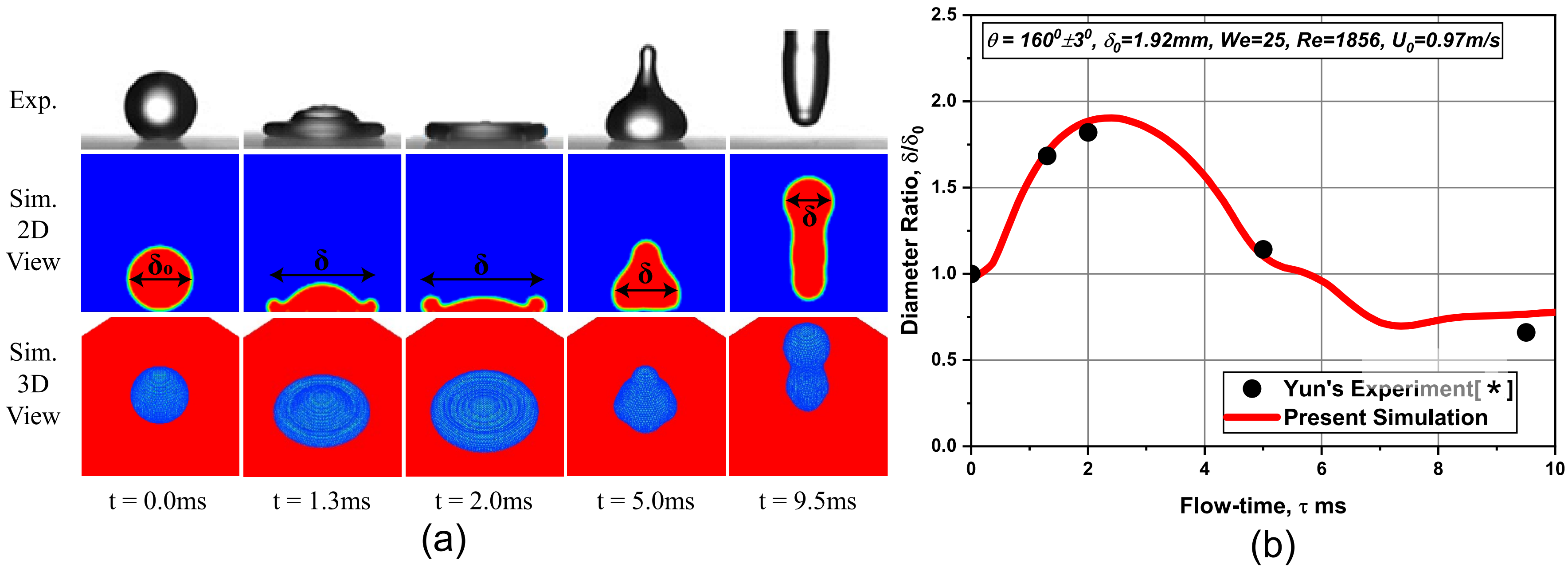


Fig: A VoF approach

Validation

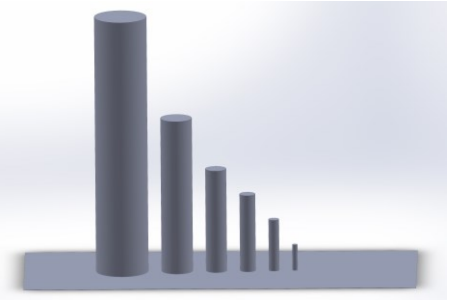


Comparison of (a) 2D plane and 3D view and (b) diameter ratio between the simulation and experimental data

* S. Yun and I. Kim, “Spreading dynamics and the residence time of ellipsoidal drops on a solid surface

Results (Pillar width optimization)

- Pillar widths ranging from 200µm to 2000µm were investigated
- Reduction in pillar width correlates with decreased liquid spreading.
- 200um and 400um pillar shows minimal spreading effects.



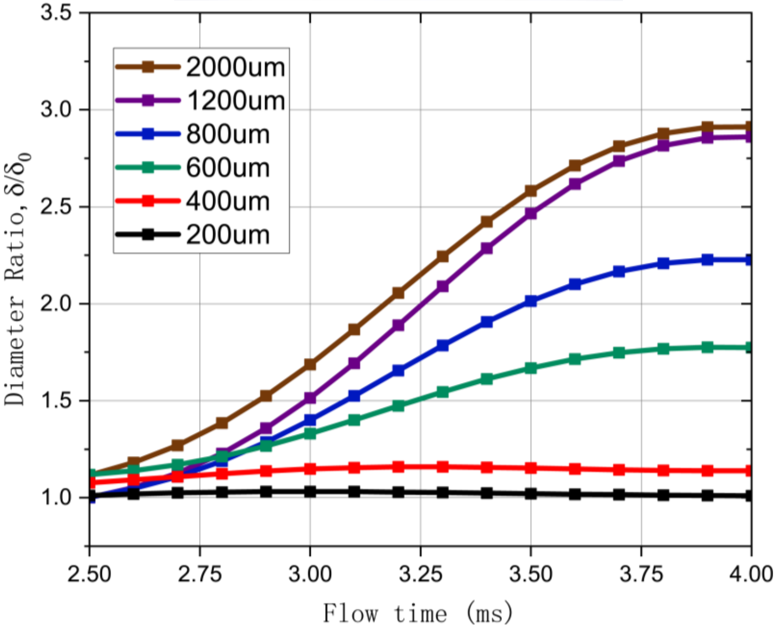


Fig: Lamella expansion

Morphology of the pillars cross-section

- We observe increased spreading on a flat top surface.
- Tetrahedron and conical-shaped pillars demonstrate nearly identical expansion of lamella.

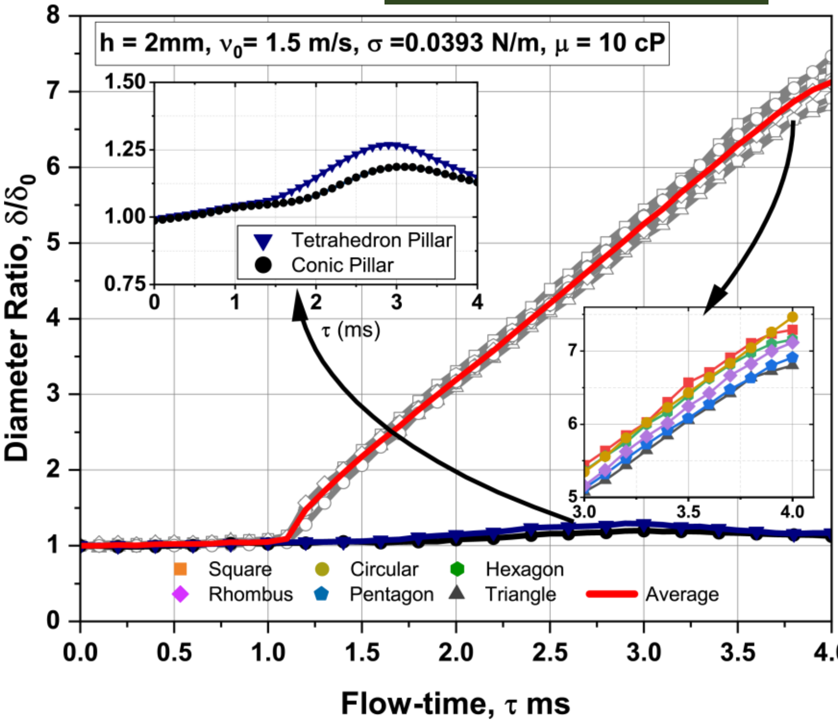
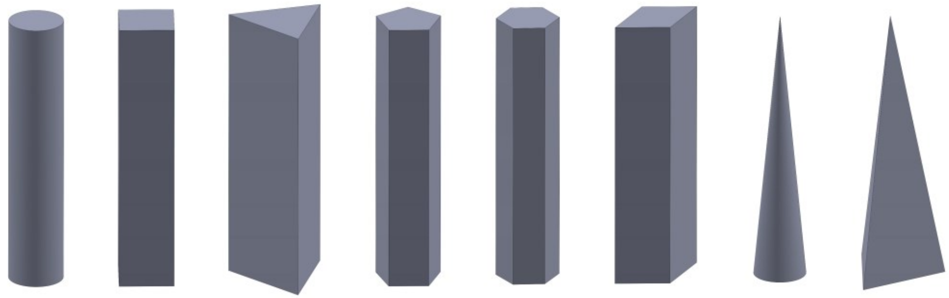
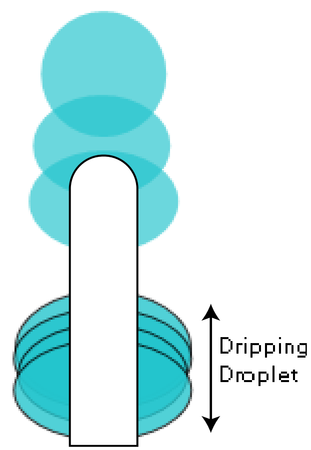


Fig: Lamella expansion



Topography of the tip

- Adding a tip on top will reduce droplet spreading.
  - Conic tip
  - Hemispheric tip (dome shape)
- Maximum height tip will reduce velocity more due to the dripping process.



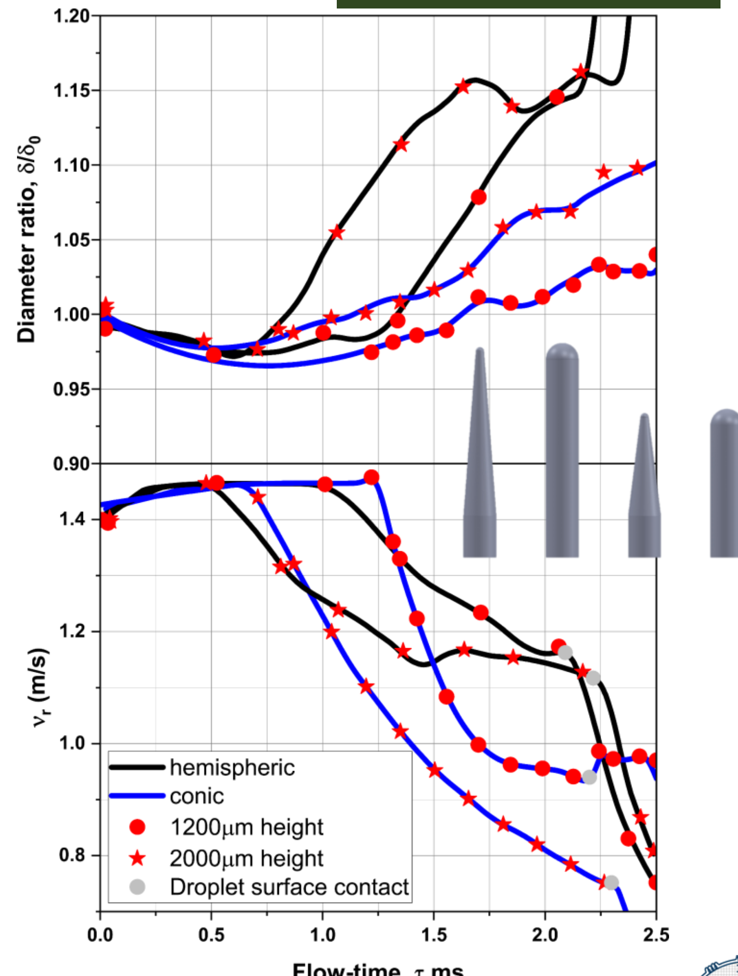


Fig: Velocity reduction (Top) & Lamella expansion (Bottom) graph

Uniform array structure

- Hemispheric array and conical array.
- Droplet will fall in the middle of the pillar array.
- Minimum inter-pillar distance shows greater velocity reduction.

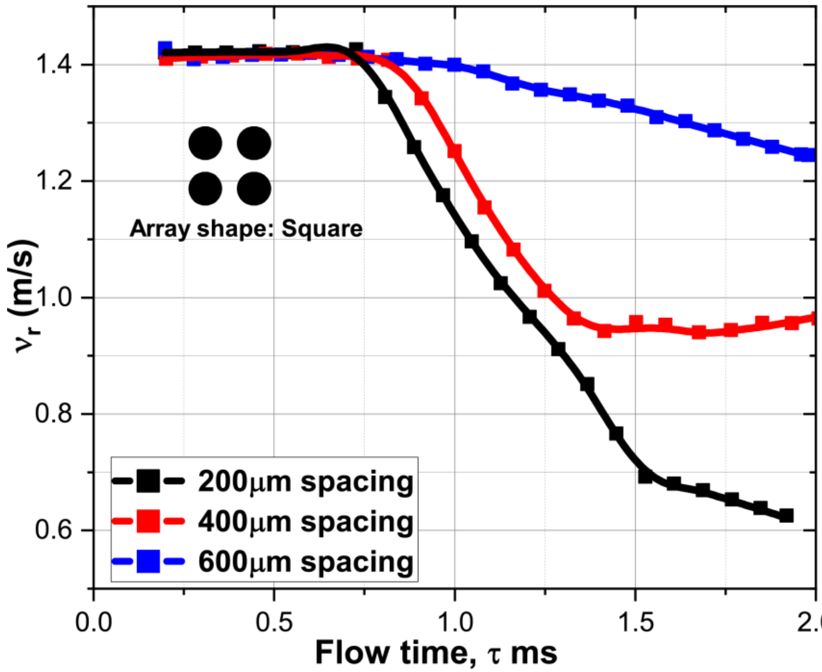


Fig1: Hemispheric pillar array

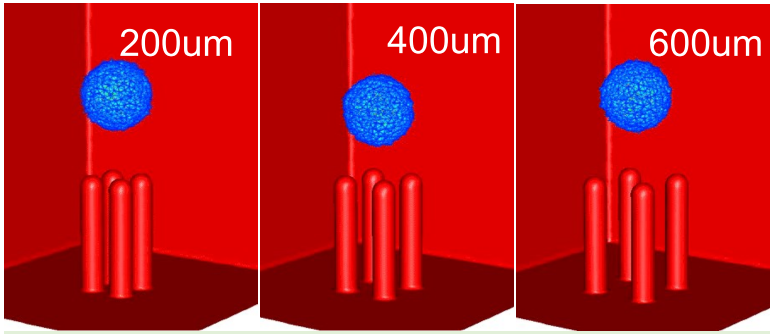


Fig2: Hemispheric pillar square array

Uniform array structure

- Two types of conical array optimization:
  - Triangular/Circular array
  - Square array
- A smaller inter-pillar distance, demonstrated a more significant reduction in velocity.

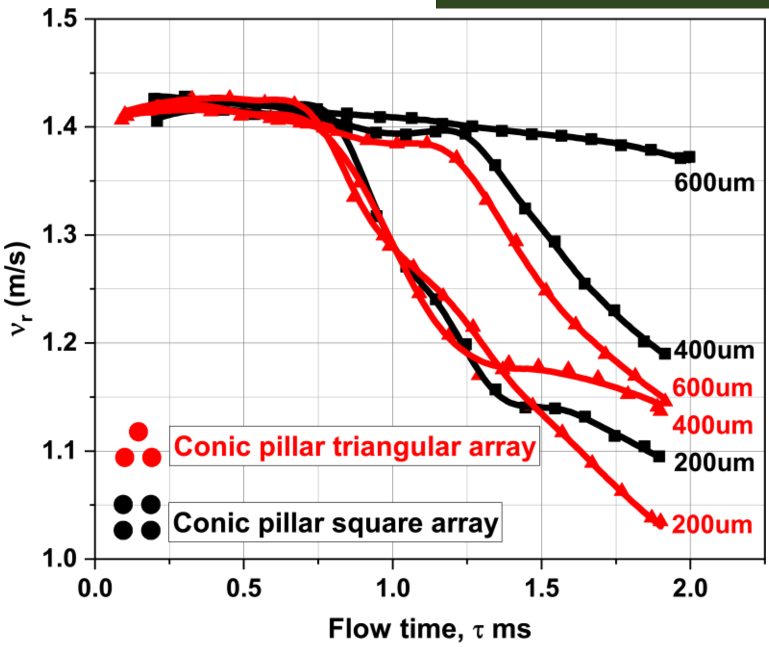


Fig1: Conic pillar array

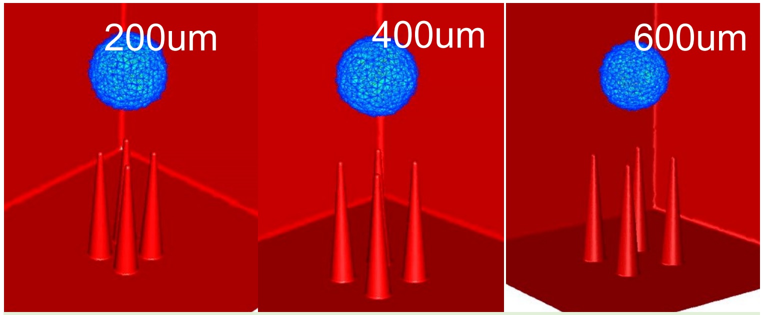


Fig2: Conic pillar square array

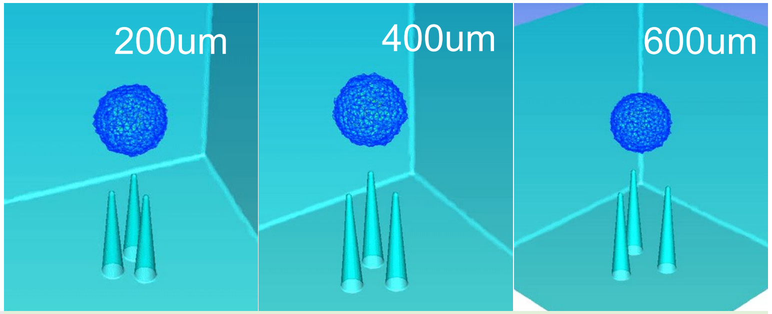
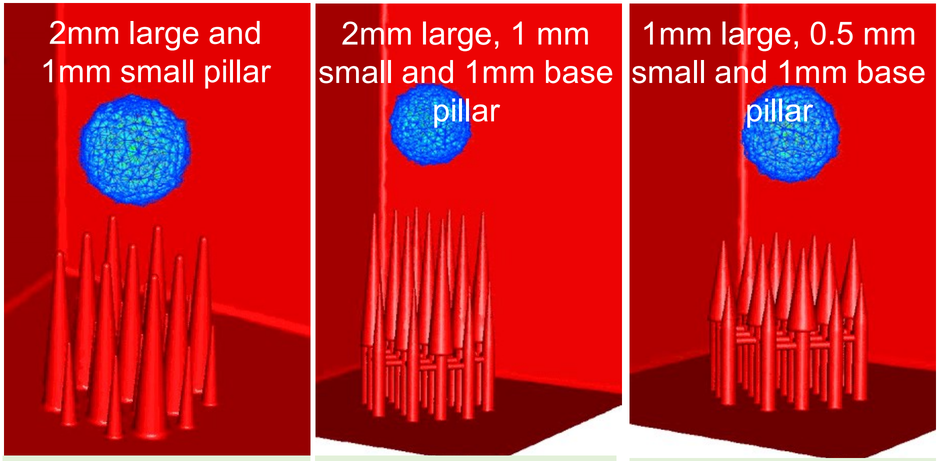


Fig3: Conic pillar circular array

Non-uniform array structure

- Adding an extra pillar inside inter-pillar distance will reduce the velocity more. [200um diameter pillar added inside]
- Elevate the structure and connect those with a bridge create a porous structure.
- Also increase the strength of the structure.



Case 1 | Case 2 | Case 3

Non-uniform array structure

	Max splashing ratio	Velocity reduction, %
Case 1	1.22690	35.0
Case 2	1.25117	63.5
Case 3	1.45442	69.0

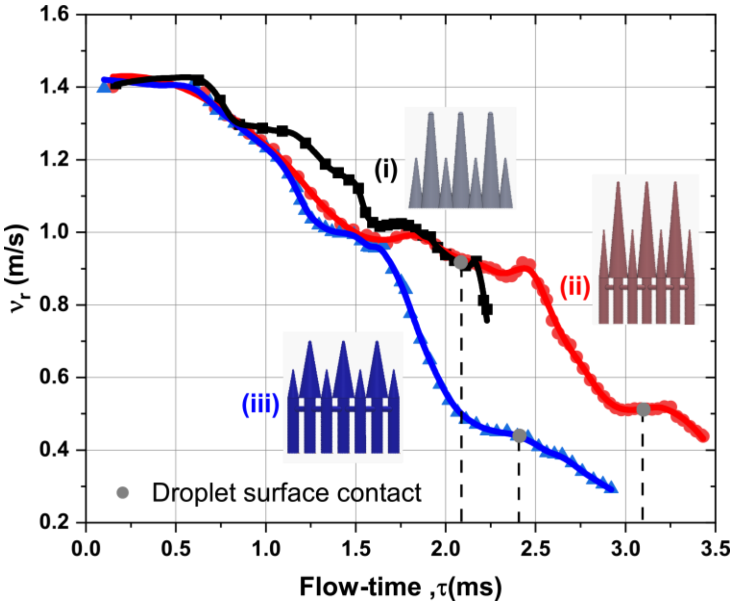


Fig 1: Velocity reduction graph

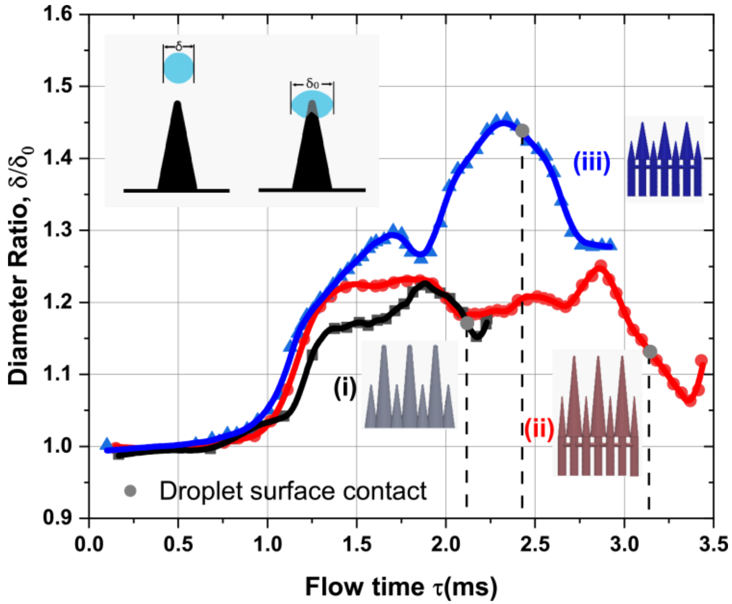


Fig 2: Lamella expansion

Printed model

- SLA printer has higher precision range of (0.1mm to 0.2mm)
- A 4cm by 4cm printed model.

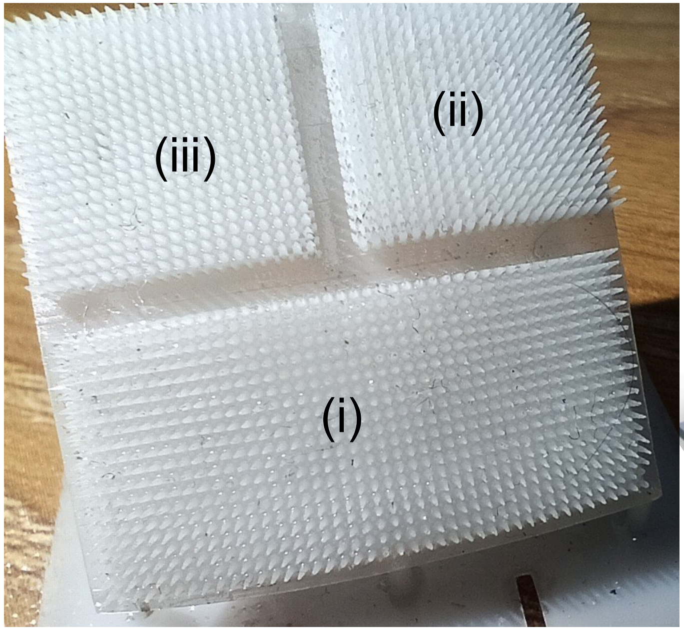


Fig 1: SLA printed model

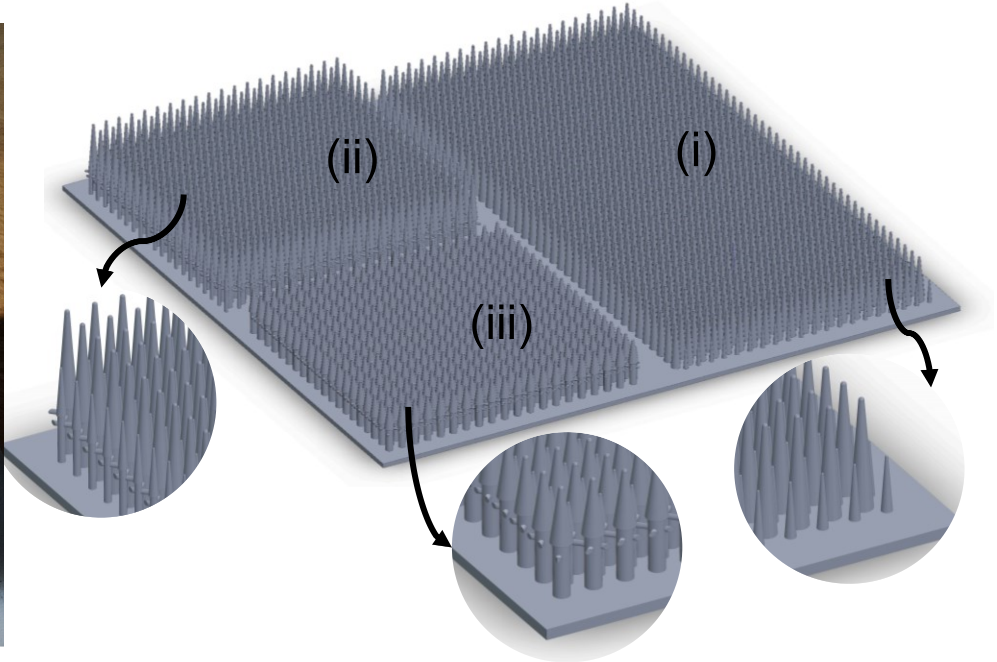


Fig 1: CAD model

Analyzes with different fluid

- Due to low surface tension of blood and juice(orange) the lamella expansion is maximum.
- For highest viscous value of fluid, the velocity reduction is faster.

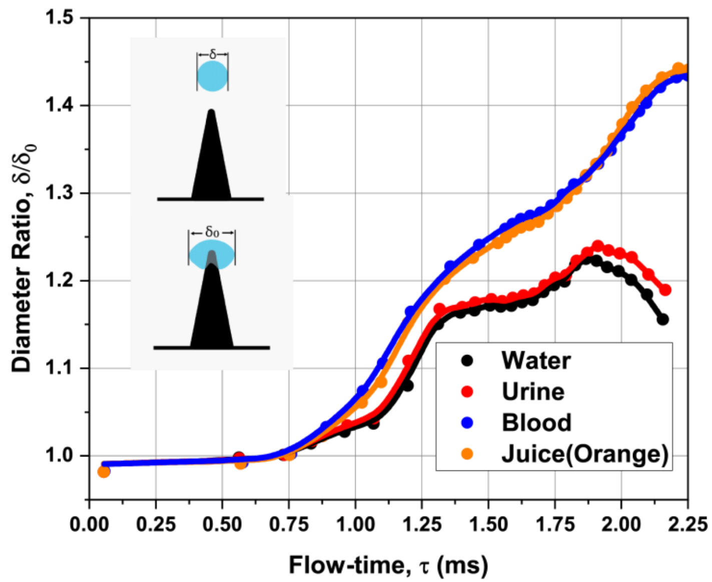


Fig 1: Droplet spreading for different fluids

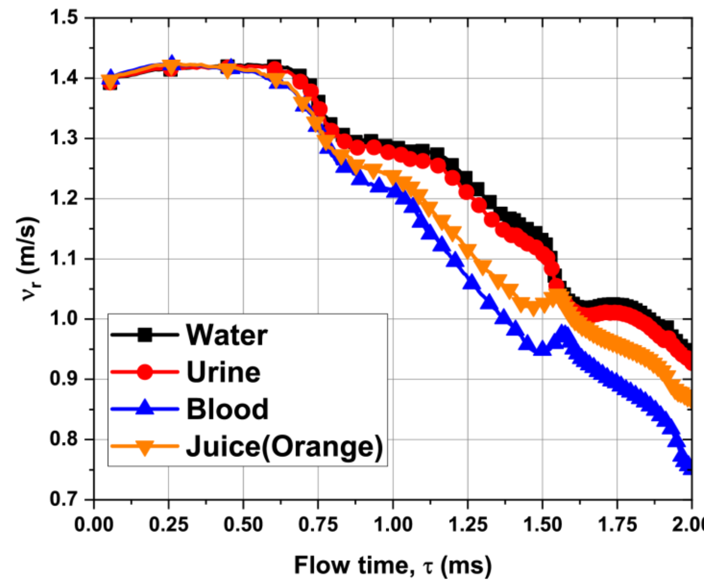


Fig 2: Velocity reduction due to different fluids viscosity level

Falling in different velocity

- Investigate the Case 1 (2mm large and 1mm small pillar) for 10m/s, 20m/s and 30m/s falling droplets.

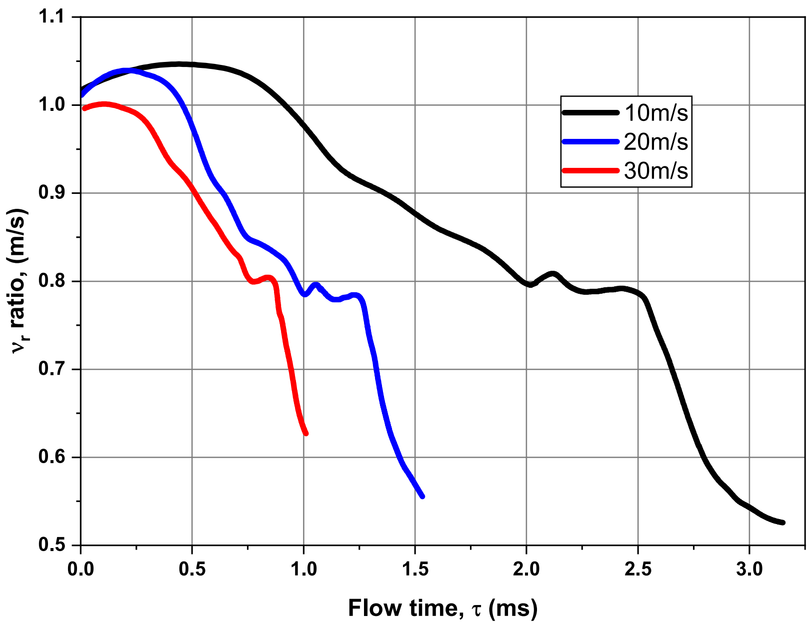


Fig 1: Velocity reduction graph

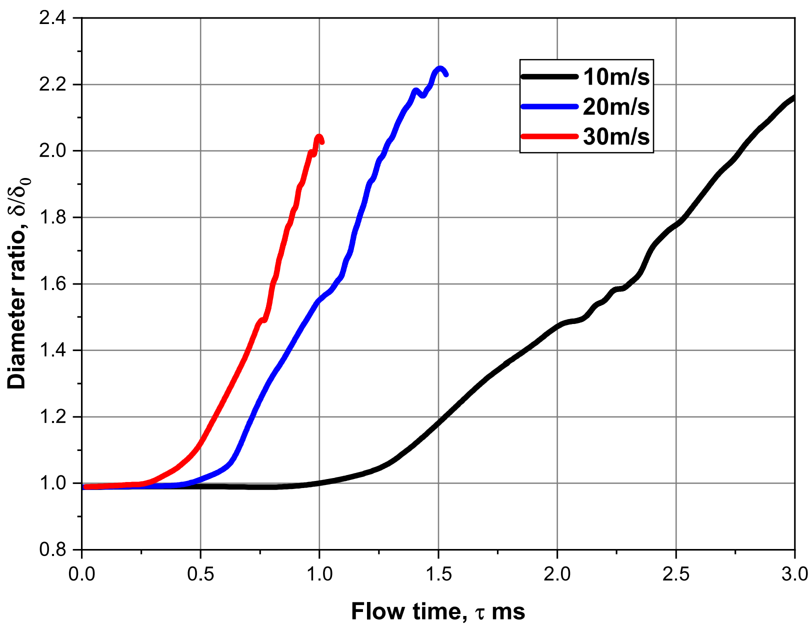


Fig 2: Lamella expansion

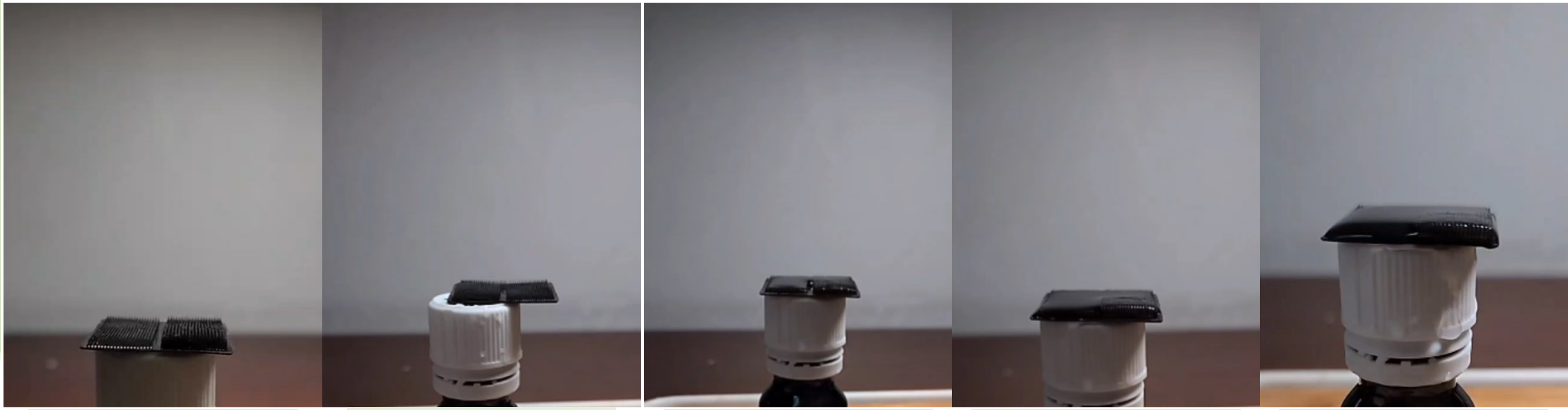
Conclusion

- Droplets spreading factor depends on pillar height, shape and tip.
- Array of pillars participate in reducing the velocity.
- An extra-pillar between inter-pillar distance has an impact of reducing velocity more.
- Not only concentric impact but also eccentric impact are studied
- Analyzed the spreading behavior of different droplet-based criteria for final non-uniform structured model.

Future scopes

- The model can be checked for hemispheric and tetrahedron models.
- The final model has an issue with water retention.
- Investigation is required for material and inter-pillar gap study beneath the bottom structure.

Printed model



(a) (b) (c) (d) (e)

Publication state

- An article on these topics has been accepted for publication in the journal "**Physics of Fluids**."

RESEARCH ARTICLE | JANUARY 22 2024

Design optimization of anti-splashing targets and simulation of droplet impact on it FREE

Md. Hedayetul Islam Chy (মোঃ হেদায়েতুল ইসলাম চৌং) ; Riya Biswas (রিয়া বিশ্বাস) ;
Md. Fazlul Kader (মোঃ ফজলুল কাদের) ; Yuan Wan (万源) ;
Mohammed Arif Iftakher Mahmood (মোহাম্মদ আরিফ ইফতেখার মাহমুদ)

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Physics of Fluids 36, 013323 (2024)

https://doi.org/10.1063/5.0175724 Article history

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