Optimized Impingement with Reduced Splatter

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Presentation Outline

→ Purpose of Study

→ Past Literature

→ Set-up (Experimental & Numerical)

→ Results

→ Conclusions and Future Direction

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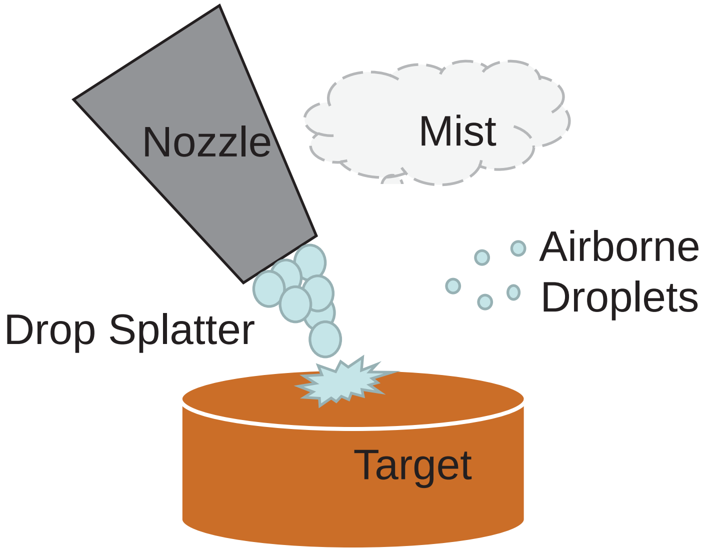
Purpose of study



Spray applications: Cooling, lubricating, spreading, coatings industries

Consequences: small airborne droplets and mists that present occupational risk factors for workers. (inhaled & ingested by workers)

Hazard Evidence: asthma, hypersensitive pneumonitis, lung cancer, cancer of esophagus, pancreas, larynx, colon and rectum due to prolonged exposure to aerosols.

Purpose of study contd.

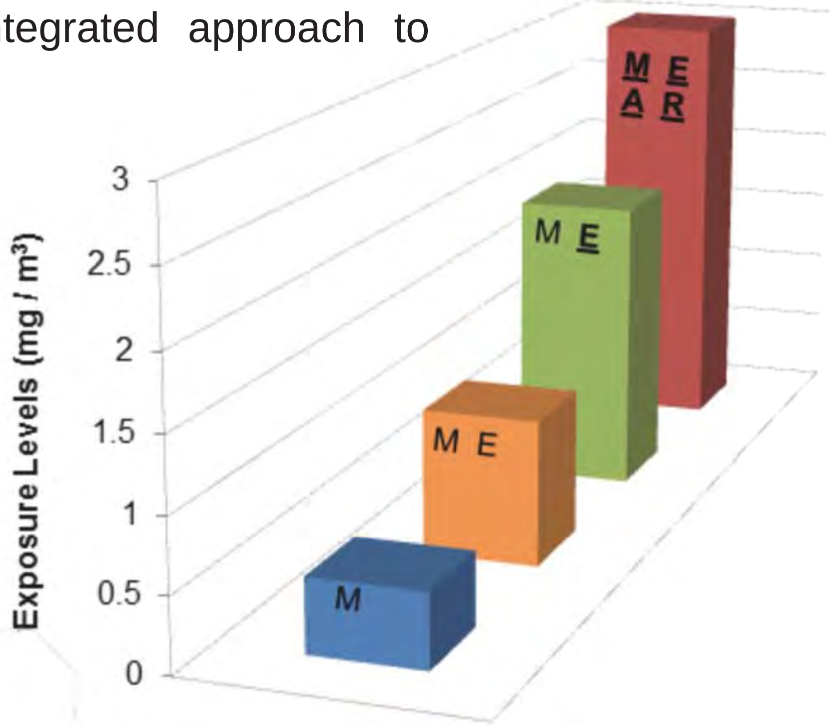
Permissible Exposure Limits

OSHA : 5 mg/m^3 for oil-mists.
NIOSH : 0.5 mg/m^3 for total suspended particulates.

Study by Coehn et al.[1] proposed an integrated approach to minimize exposure by incorporating:

A: administrative controls (e.g. job rotation)
E: engineering control and
R: provision respiratory protection.

Recommend (M) medical surveillance for all levels of exposure.



Thus, it is crucial to minimize splash from impinging drops and thus reduce human contact.

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Past Literature

- Studies on reducing splash look at eliminating or reducing impingement:
  - Cryogenic studies [1]:
    - requires increased safety measures
    - can cause physical burn on contact
  - Others studies are application specific
    - minimizing fluid usage[3]
    - optimizing heat transfer while minimizing drop size [4]

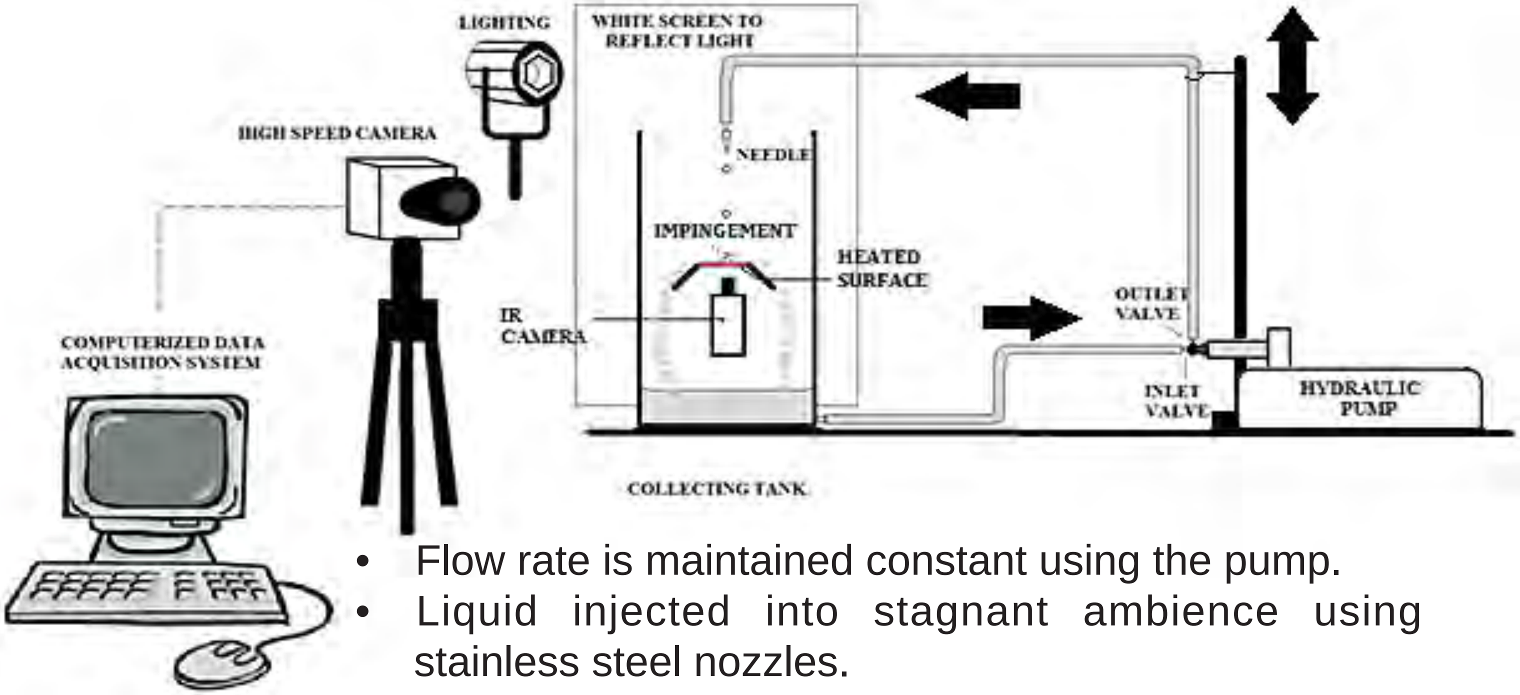
- Need to look at minimizing splash due to impact.
  - Most drop impact studies: impact on dry surface or on deep pools
  - More studies required on impact on thin film surface

Variation in the few studies that look at drop impact on thin films:

- Mundo [5], Cossoli [2] and Riobbo [7] : viscosity inhibits splash
- Rang and Feuillebois [6] : viscosity has no impact
- Vander Wal [8] and Xu [9]: viscosity promotes splashing

Requires a physical understanding of splash and means to predict it

Experimental Setup

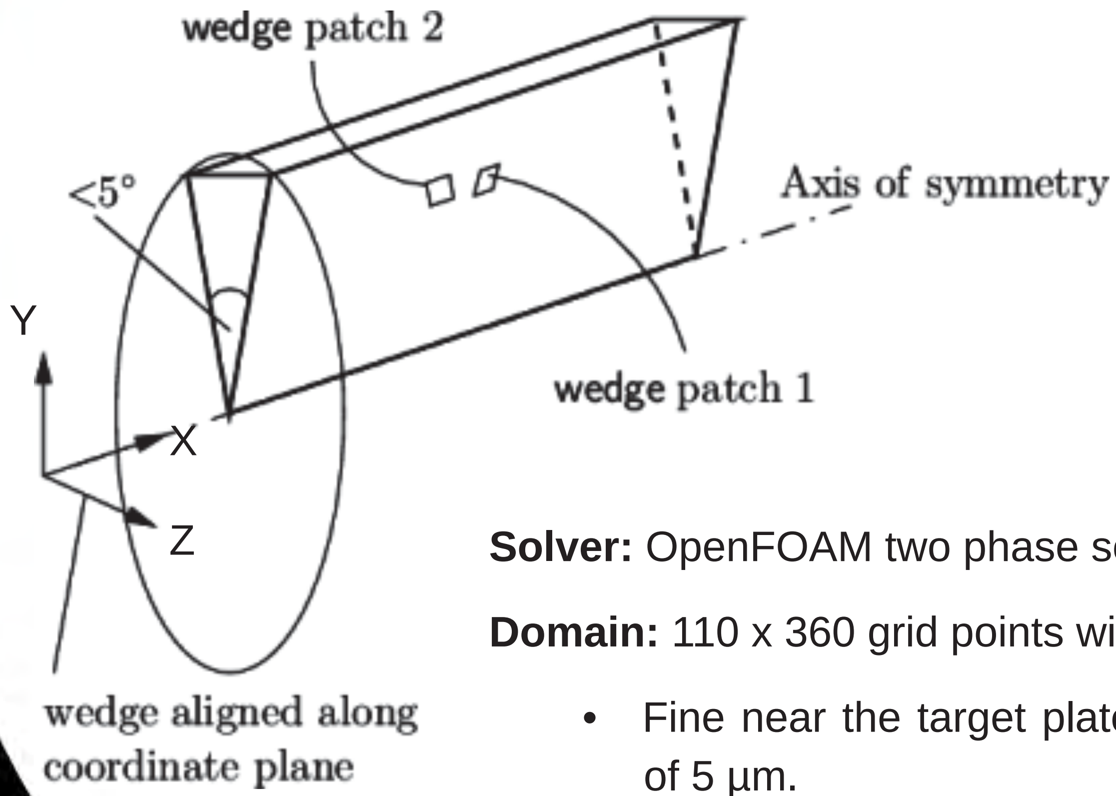


- Flow rate is maintained constant using the pump.
- Liquid injected into stagnant ambience using stainless steel nozzles.
- Liquid is impinged on a copper plate that has heaters at the bottom. The IR Camera (FLIR E60) is placed under the copper plate.

<u>IMAGE CAPTURE:</u>

- A high speed camera (NAC Image technology) at 2000 fps is used.
- Image processing – Image-Pro Plus 4.0
- Calibration: a standard SS needle.

Numerical Setup

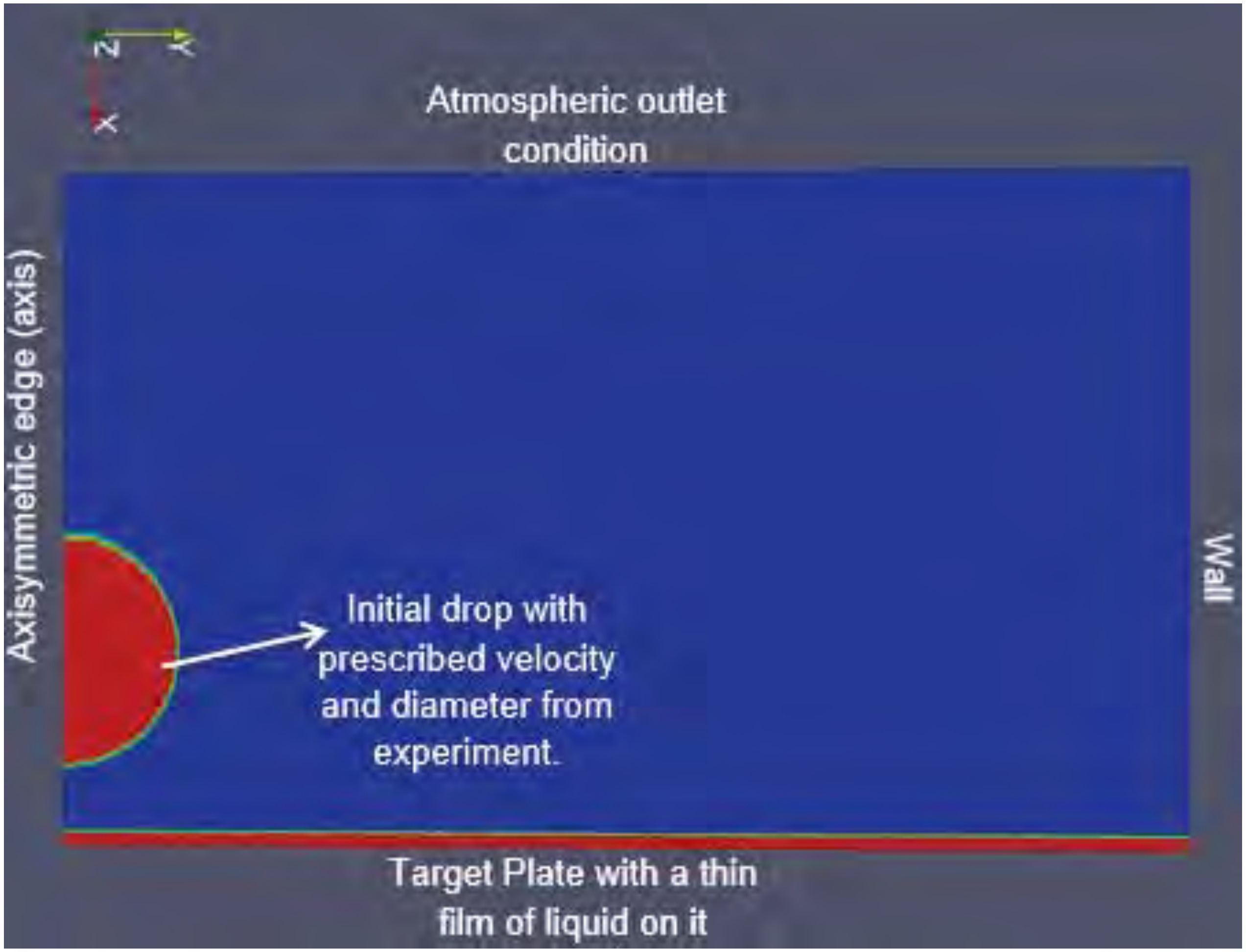


Solver: OpenFOAM two phase solver using VOF technique

Domain: 110 x 360 grid points with a total of 39,600 cells.

- Fine near the target plate with a minimum grid size of 5 µm.
- The aspect ratio of the mesh is maintained close to one near the target plate.

Initial Case Configuration



Results

The most common forms of correlations developed in the past are:

$$We_c = C = constant$$ [8, 5] (equation 1)

$$We \cdot Oh^{-0.4} = K = constant$$ [2, 7] (equation 2)

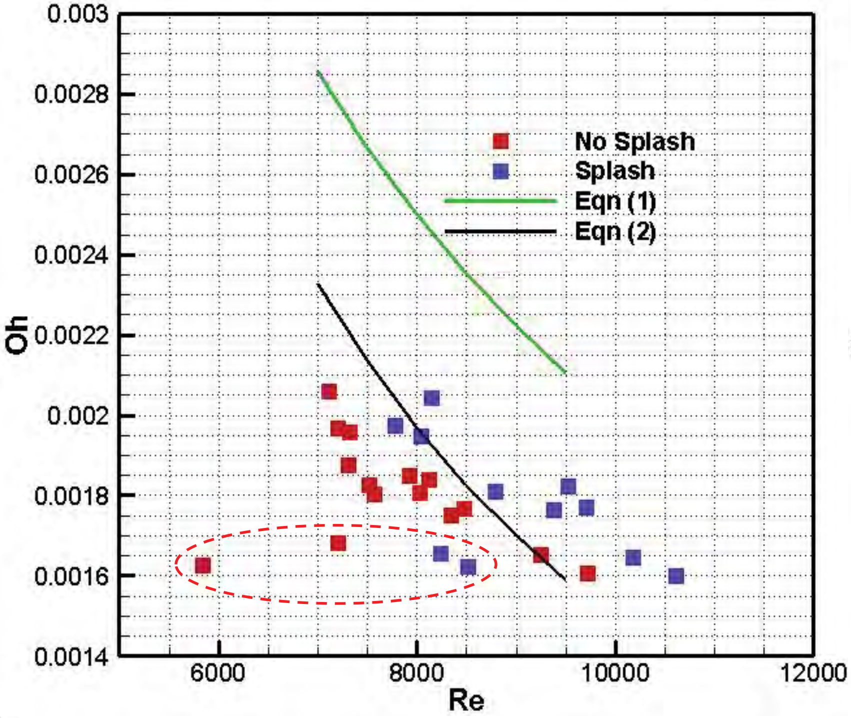
Reason for variation in correlation:

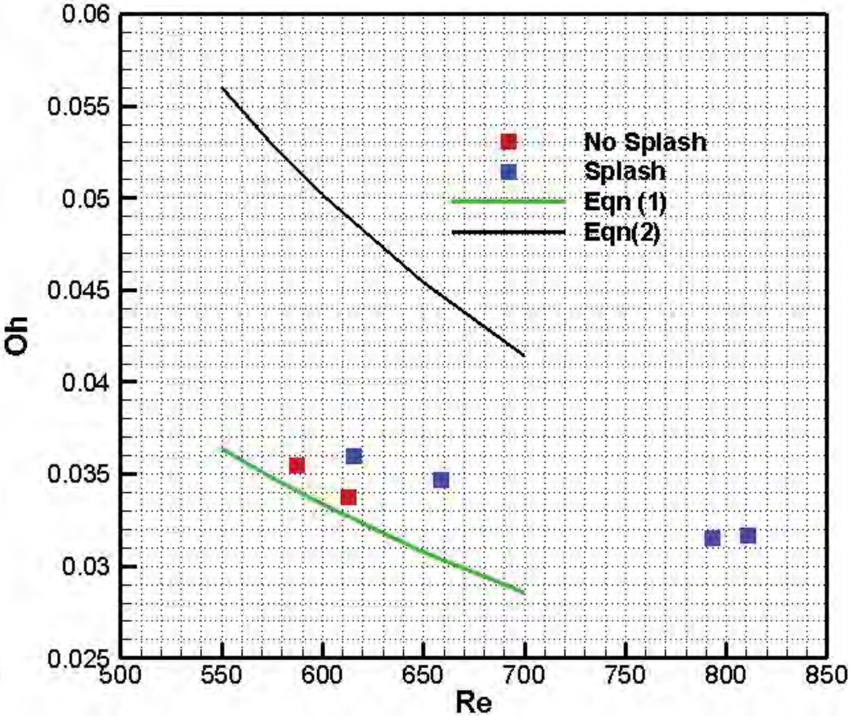
- Liquid properties
  - Viscosity Effect
  - Surface Tension
- Film thickness

<u>Current Experimental parameters</u>:

- Film thickness: 0.02 – 0.15 times drop diameter
- Needle diameters: 0.8284 mm to 1.5 mm
- Working liquids: Water and Ethylene glycol
  - Viscosity : 1 and 16.1cP
  - Surface tension : 72.8 and 48.4 dynes/cm
  - Density: 1000 and 1113.2 kg/m^3

Results contd.


Water

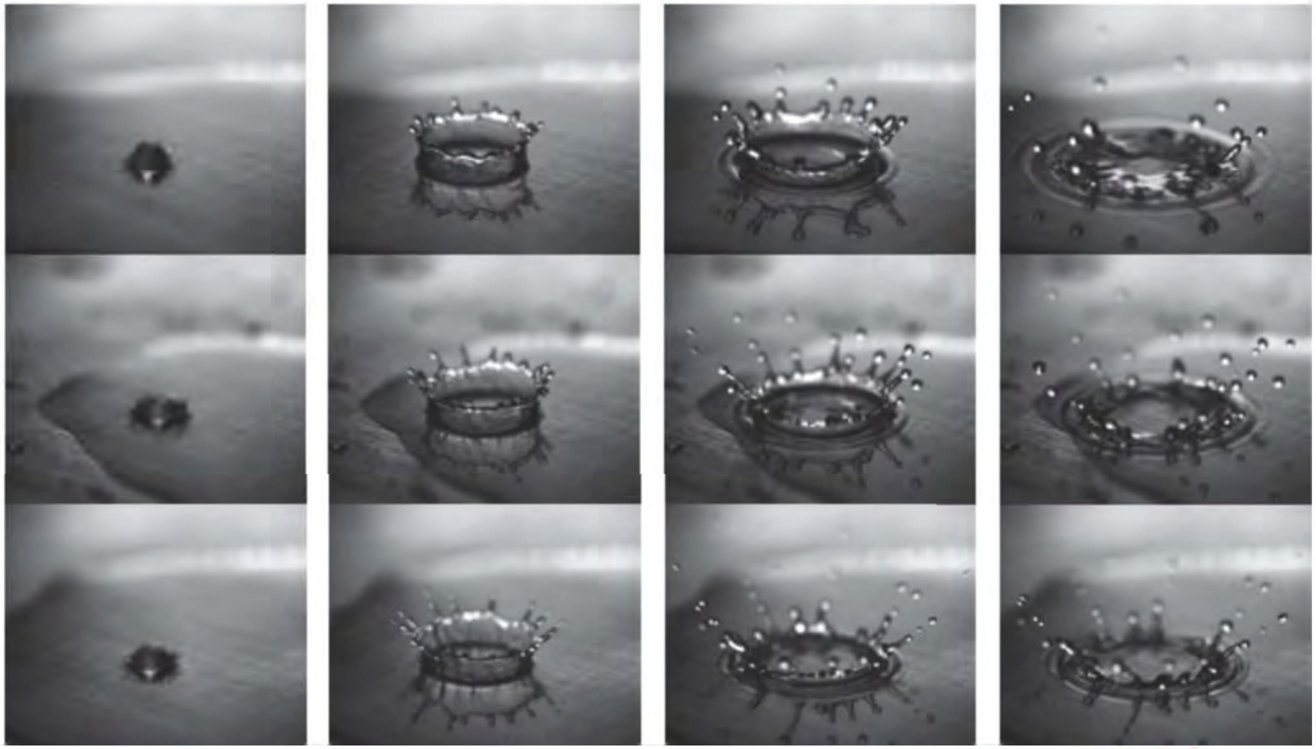

Ethylene Glycol

- ➢ Suggested correlations are not consistent.
- ➢ Large diameter drops behavior differently.

  when Drop diameter > capillary length the pattern is different : suggests significance of gravitational force

Results contd.

Influence of surface temperature on splash pattern



Results contd.

Instantaneous Surface Temperature Profile during splash

Impact location initial temperature = 30 °C

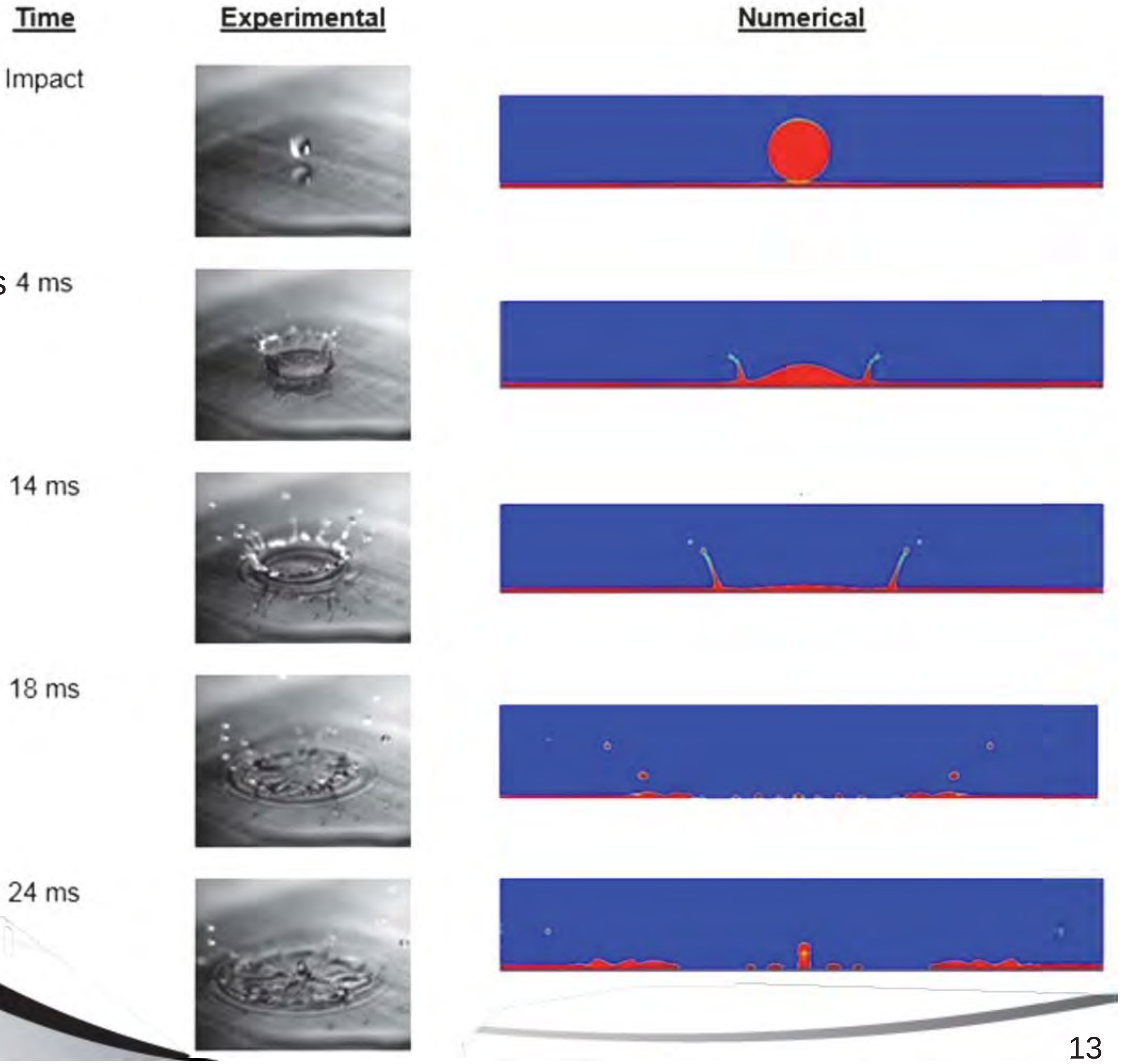
Impact location initial temperature = 40 °C

Nusselt number (a measurement of convective heat transfer to conductive heat transfer) is higher for impact temperature of 30 °C.

A steady state thermal analysis is required: continuous drop impact on the constant heat flux surface will help determine the thermal behavior at steady state.

Numerical model validated

Drop diameter:4.146 mm
Impact Velocity:2.303 m/s
Re:9530



Conclusions and Future Direction

- Past scaling analyses are unable to predict onset of splash.
  - Effect of gravitational force has been identified.
  - Effect of target surface temperature has been noted.
- Computational modeling and validation for existing model has been performed.
- Current numerical two phase models for viscous liquid are not good. A better way to model this using better numerical interface tracking has been developed. Experimental validation is being conducted. (results not presented)

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Conclusions and Future Direction

- More liquids (wider range of properties) needs to be tested to understand physical phenomena.
- Predictive correlation from experimental observation with numerical understanding to be developed
- Steady state drop impingement heat transfer: experimental and numerical study.
- Array of droplets splashing: optimal distance between droplets impacting.

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THANK YOU

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