NTNU
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TGTC 2011

One step further from detailed experiments to design of heat exchangers for natural-gas liquefaction plants

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Outline

Overview

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Review

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Experimental methods

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Experimental observations

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n-pentane flow regime characterization

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Conclusion and further work

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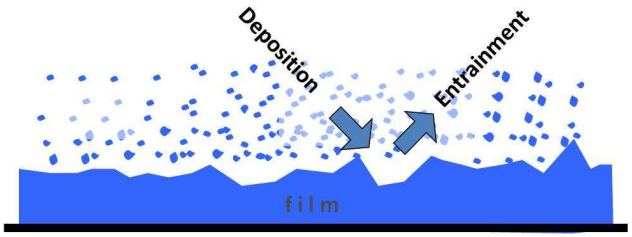
Motivation and approach

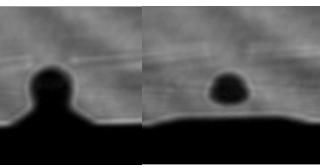
What's the project focus? And why important?

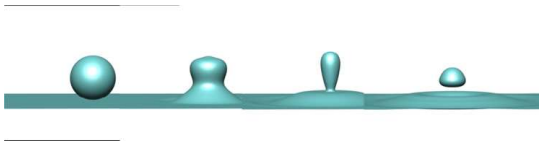
- Focus: droplet pheonema in LNG processes.
- Importance: heat transfer, robust model.



How do we do it?

- Two-way coupling: experimental and numerical.





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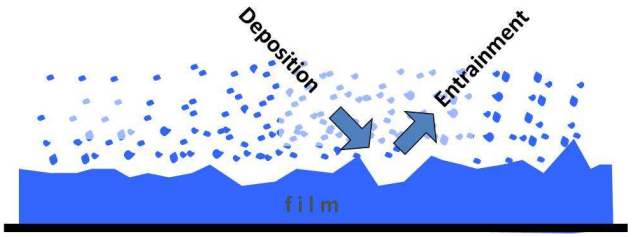

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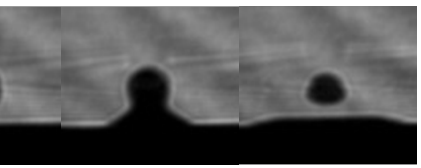

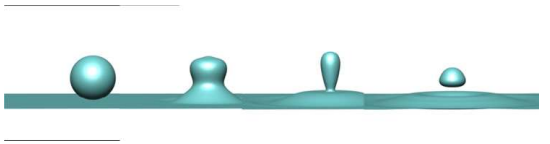

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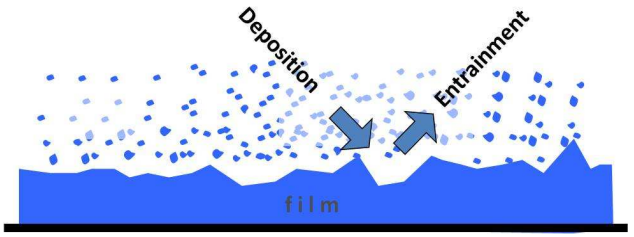

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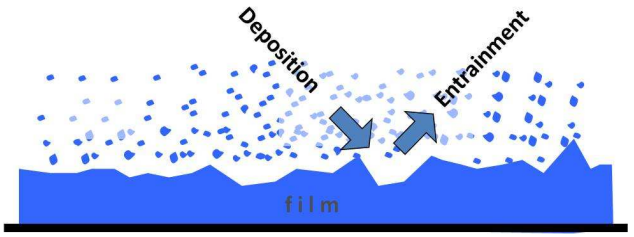

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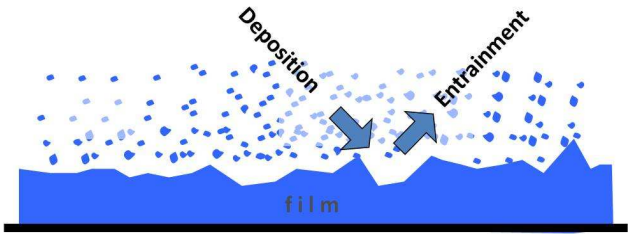

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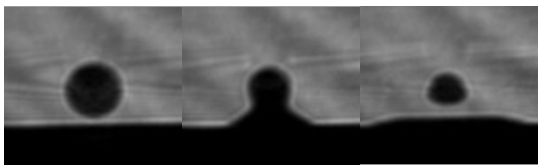
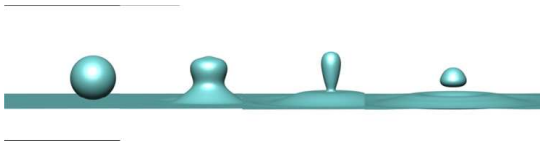
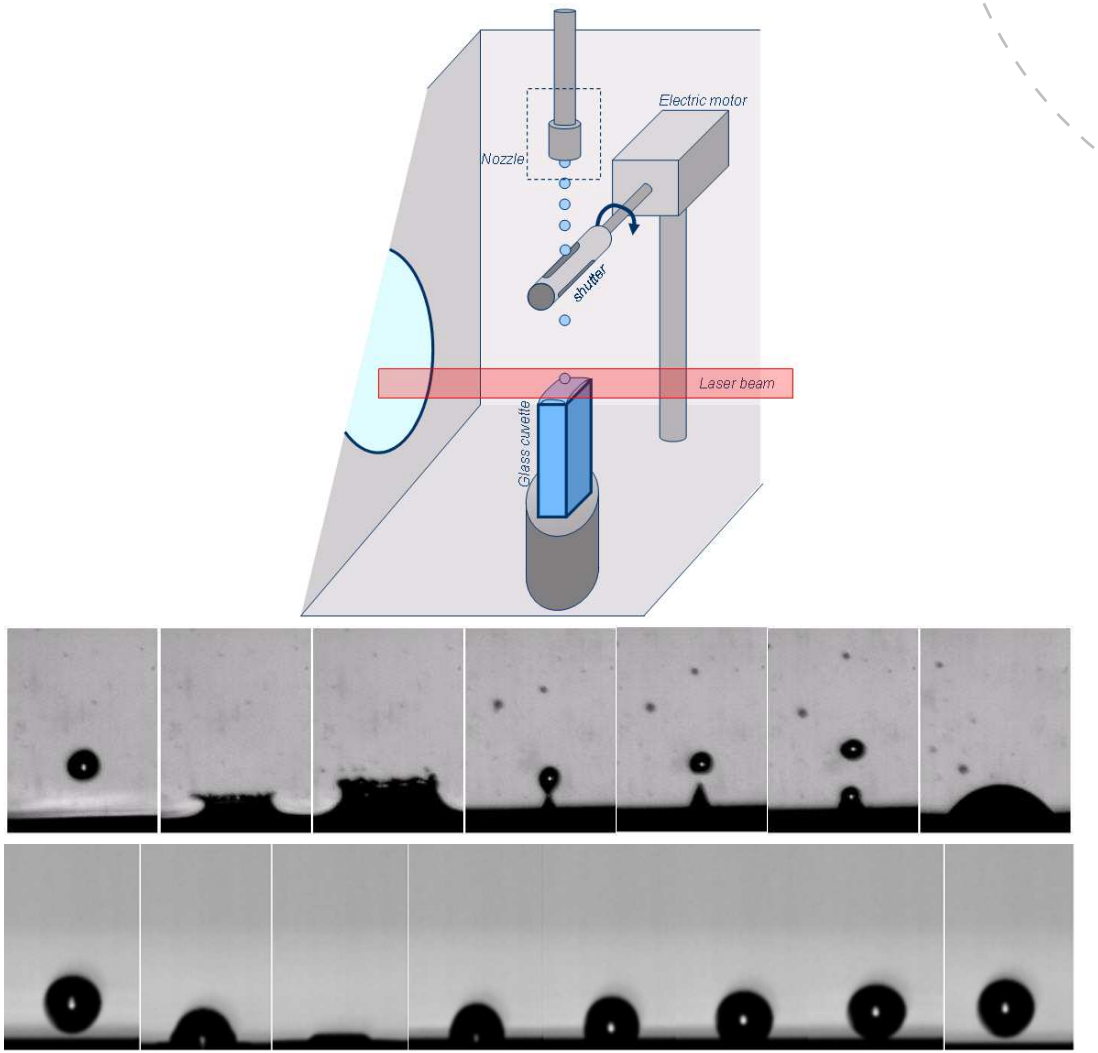




Outline

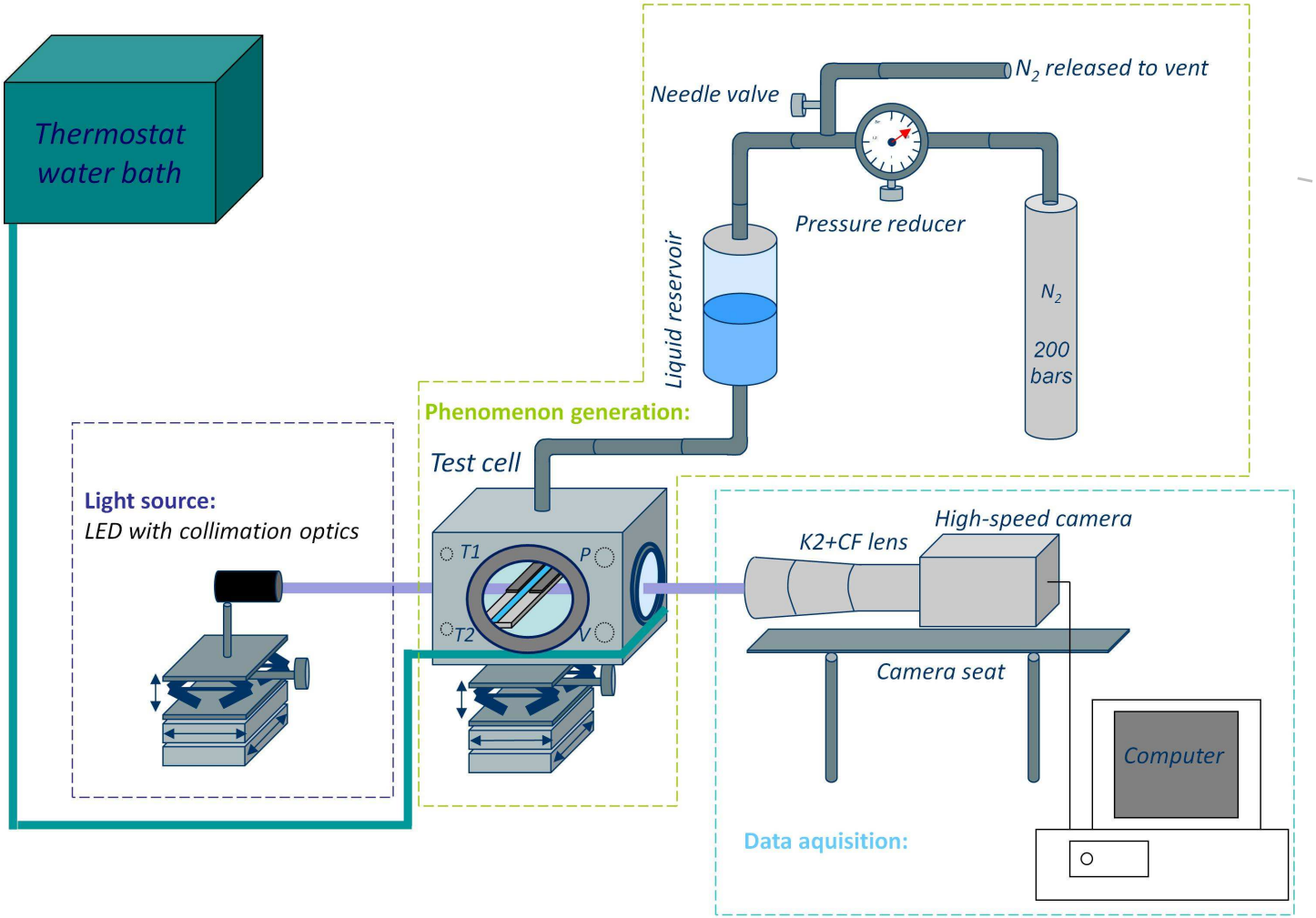
What were presented in TGTC 2009?



Droplet impact with a deep pool.

Outline

Experimental setup



Material

Physical properties of the fluids

Fluids	$\rho\ (\mathrm{kg/m^3})$	$\mu\ (\mathrm{mPa \cdot s})$	$\sigma\ (\mathrm{mN/m})$
Distilled water[a]	996.93	0.890	71.99
n-pentane[b]	605.69	0.1969	13.66

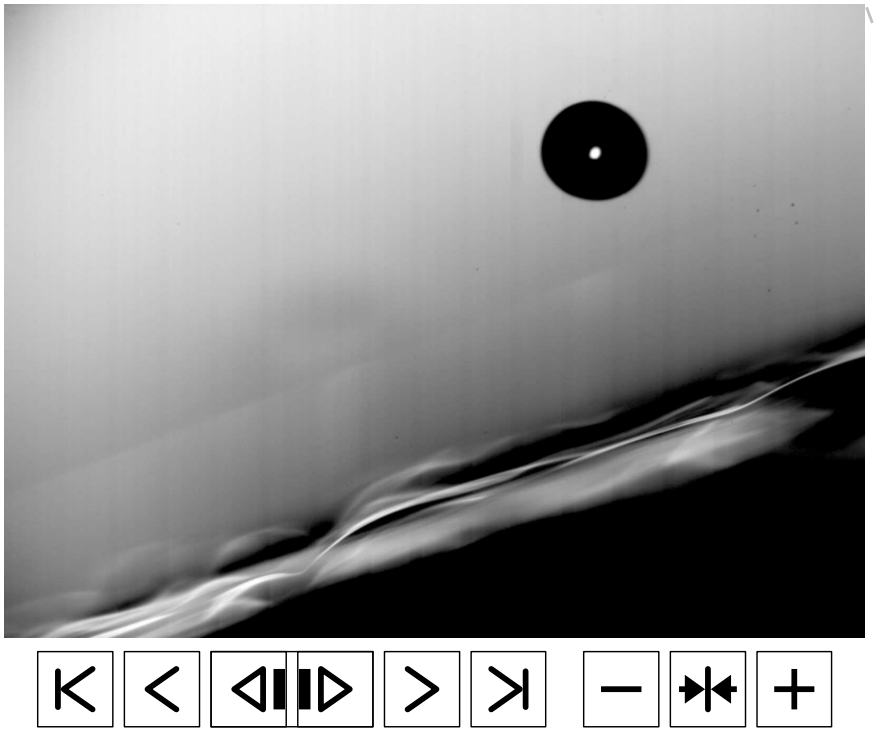
[a] Reference fluid.
[b] Model fluid for MR.

Outline

Film impact – water splashing 20°

Water droplet ($D = 1.99\,\mathrm{mm}$, $V = 3.87\,\mathrm{m/s}$) falling on a 20° tilted film with a thickness of $0.55\,\mathrm{mm}$ and mean velocity of $\approx 0.20\,\mathrm{m/s}$.

Film impact – n-pentane splashing 20°



n-pentane: $D = 1.46(\,\mathrm{mm})$ $V = 2.0(\,\mathrm{m/s})$. The following image-sequence: water drop splashing.

$t = 0\,\mathrm{ms}$ $t = 0.9843$ $t = 1.9685$ $t = 2.9528$ $t = 3.9370$

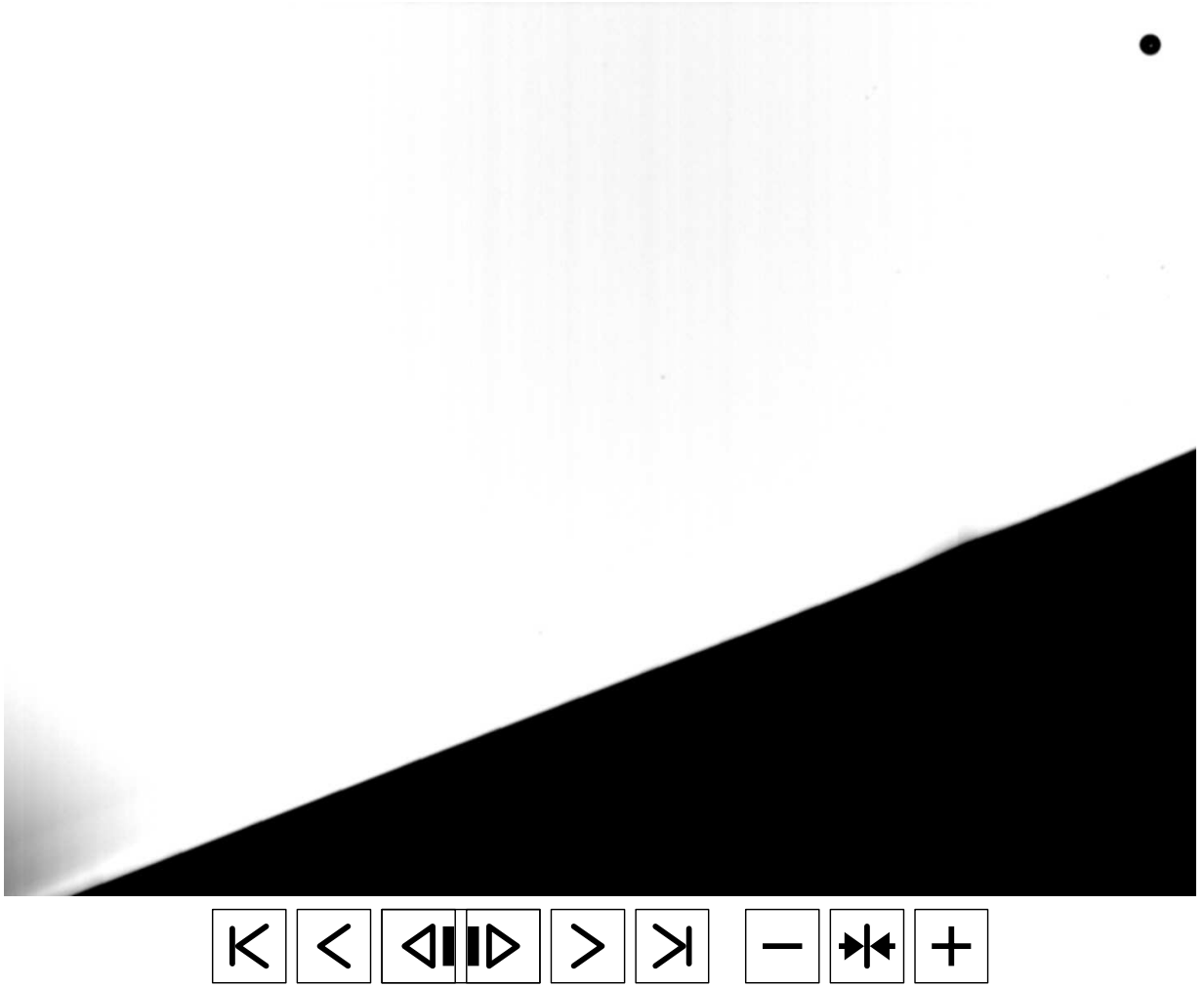
Film-impact: jetting

Water droplet ($D = 2.13\,\mathrm{mm}$, $V = 2.32\,\mathrm{m/s}$).

Film impact: Coalescence

Water droplet ($D = 0.53\,\mathrm{mm}$, $V = 1.71\,\mathrm{m/s}$).

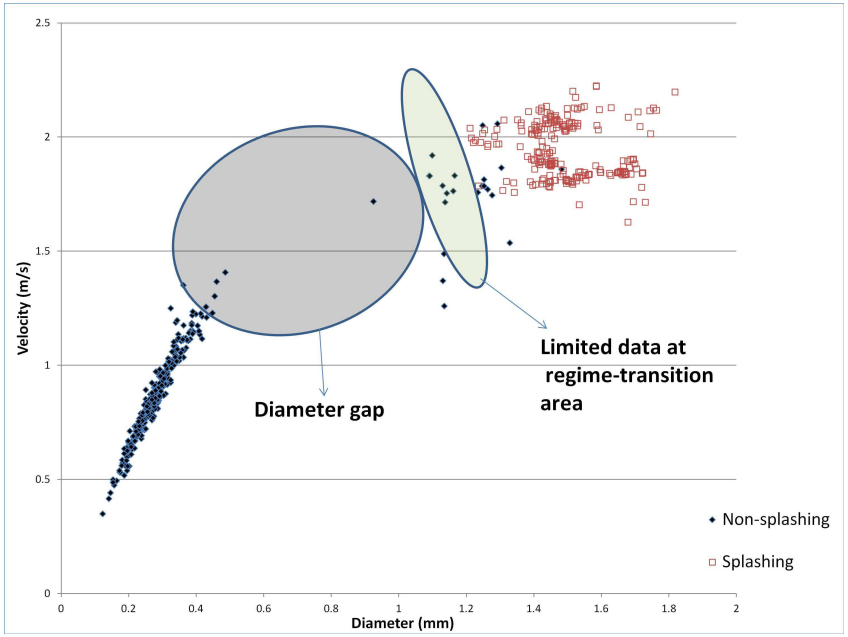
Bouncing



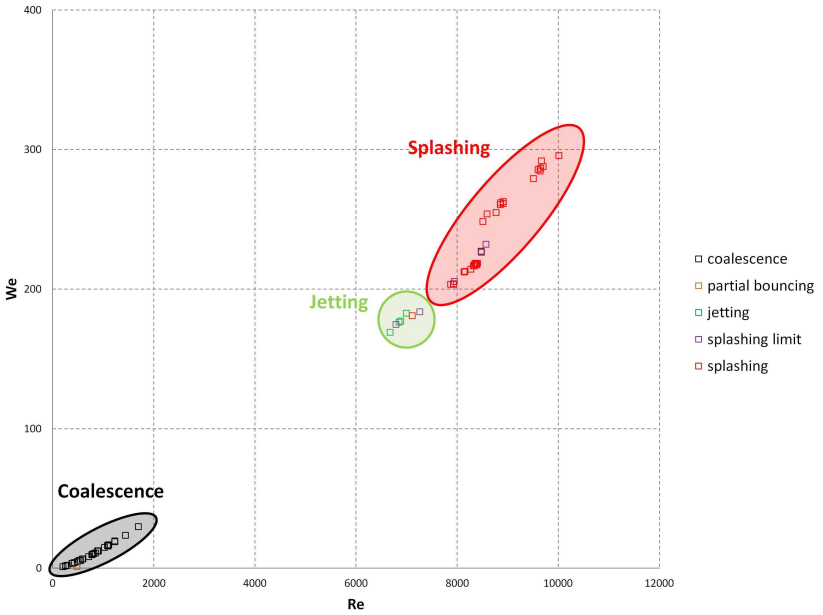
Water droplet ($D = 0.28\,\mathrm{mm}$, $V = 1.03\,\mathrm{m/s}$), bouncing droplet ($D = 0.28\,\mathrm{mm}$, $V_y = -0.13\,\mathrm{m/s}$, $V = -0.51\,\mathrm{m/s}$).

Outline

Flow regime characterization



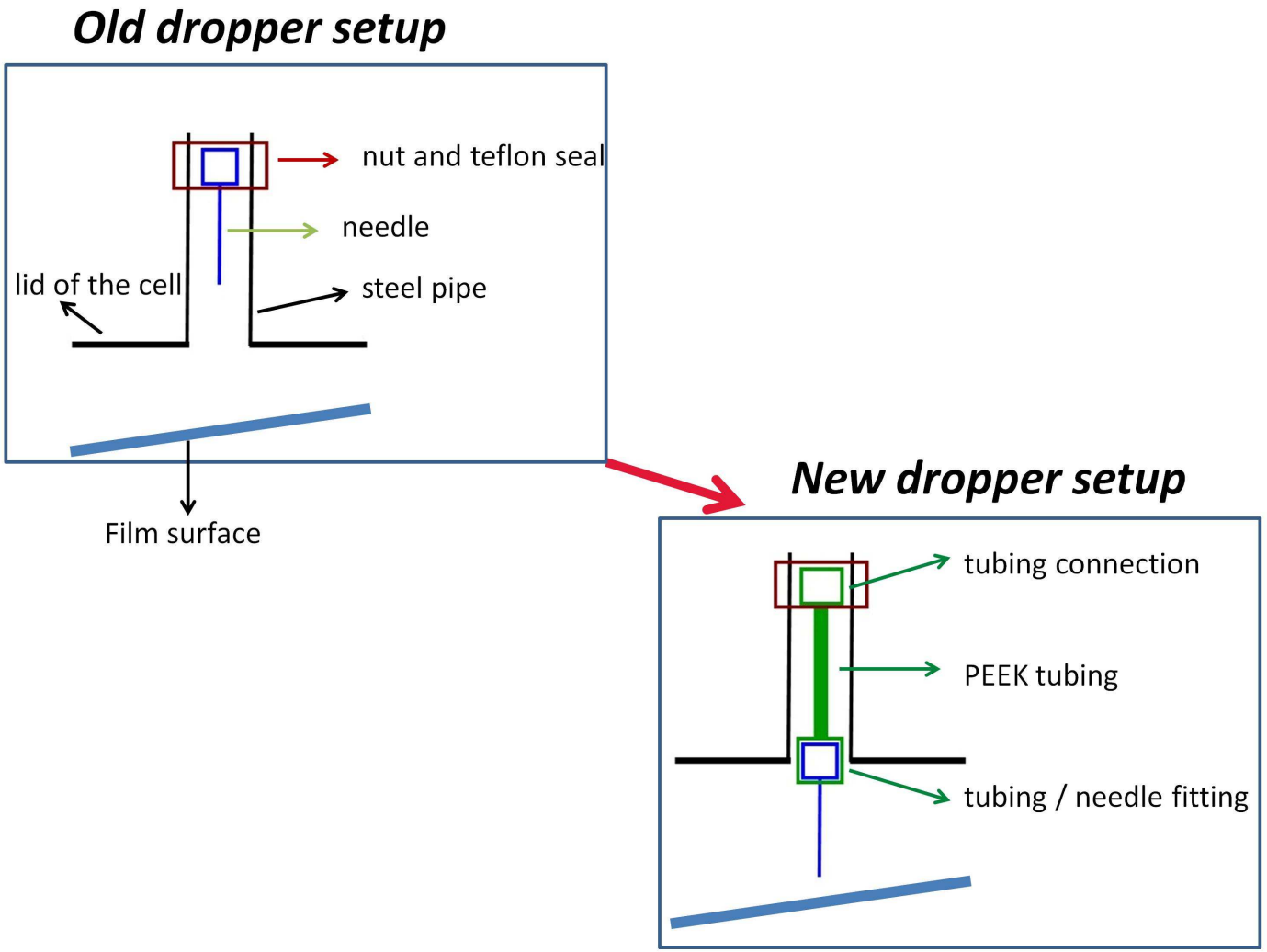
V-D for all flow rates and angles.



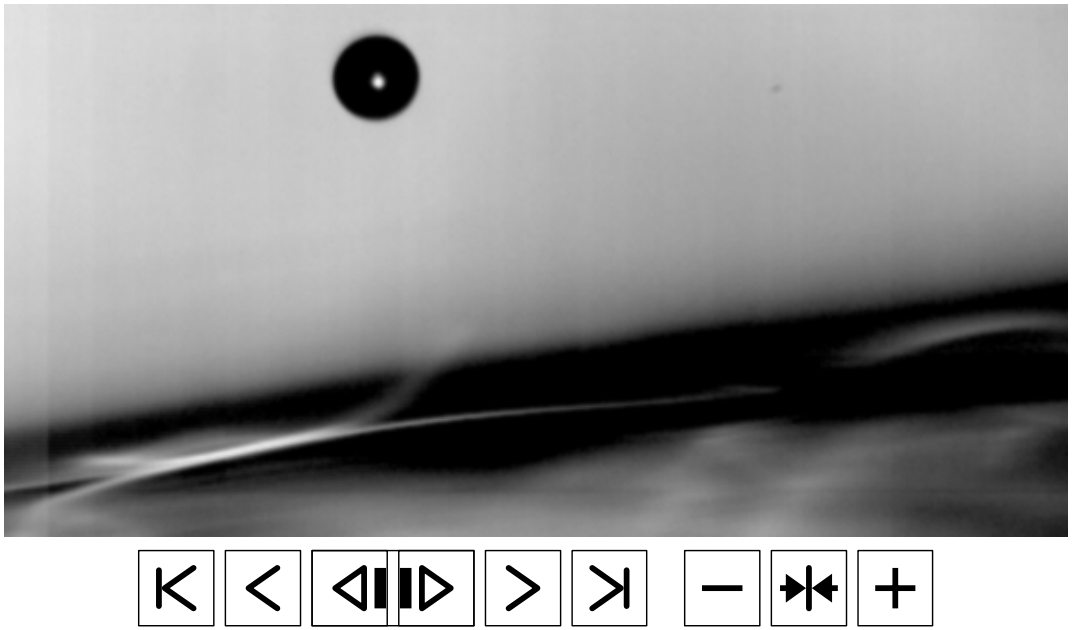
We-Re for film at $2.4\,\mathrm{ml/s}$ and $7°$.

▸ *Bouncing of n-pentane*

Dropper setup modification



Film impact – bouncing 7°

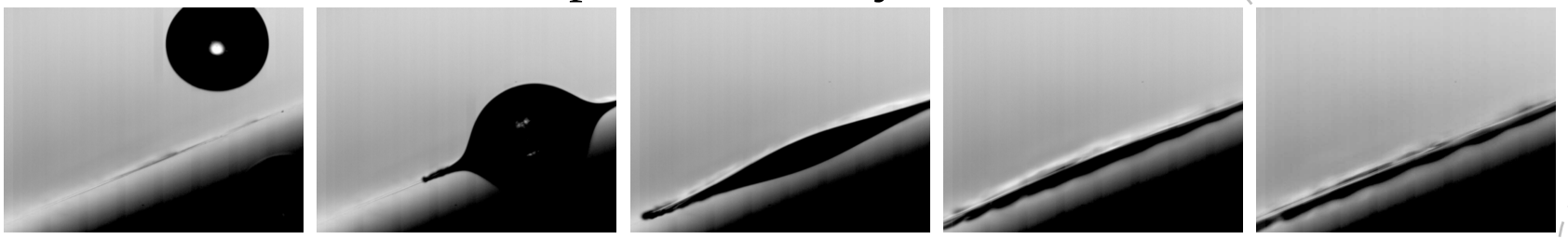


n-pentane: $D = 0.34(\,\mathrm{mm})\ V = 0.75(\,\mathrm{m/s})\ V_b = 0.28(\,\mathrm{m/s})\ V_{by} = 0.20(\,\mathrm{m/s}).$

▸ *V–D with the old dropper*

Board impact – deposition dominant

[n-pentane on dry board]



$t = 0\,\mathrm{ms}$ $t = 0.7748\,\mathrm{ms}$ $t = 1.5496\,\mathrm{ms}$ $t = 2.3244\,\mathrm{ms}$ $t = 3.0992\,\mathrm{ms}$

[water on dry board]

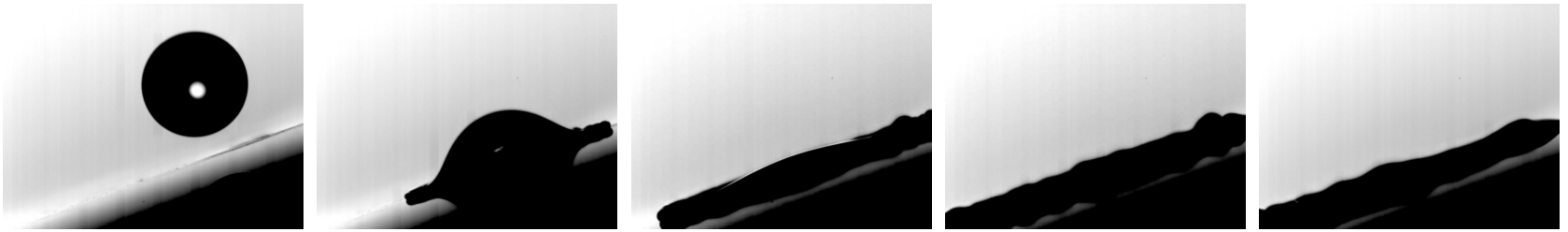


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Figure: Similar droplet parameters: $D = 1.7$–$2.0\,\mathrm{mm}$, $V = 2.0\,\mathrm{m/s}$ impinging on a dry board at $20°$.

Outline

Conclusion and further work

Conclusion

- A well-functioning setup.
- Different flow regimes identified.
- Low-inertia impact possible for n-pentane.

Future work

- Finishing low-inertia impact for n-pentane.
- Flow regime diagram and threshold model.

Acknowledgement

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Thank you for your attention!