Acoustic cavitation bubble structures in viscous liquids

Georg-August-Universität Göttingen & TU Clausthal Universität

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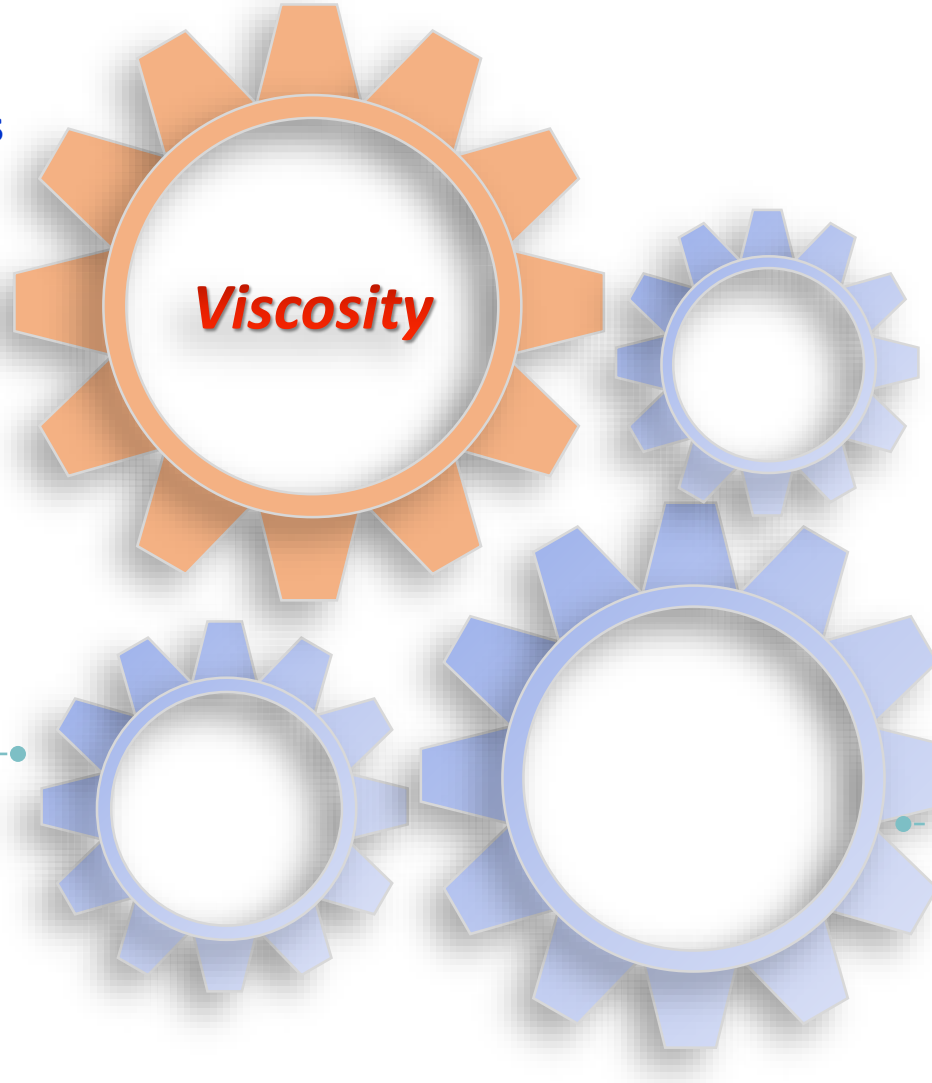
General Motivation

Viscosity causes rather large changes at least in Bubble structures!



Bubble Dynamics

Sound Pressure Field

Bubble Structures

History and Applications

Viscosity of Sulfuric acid μ= 25 cP

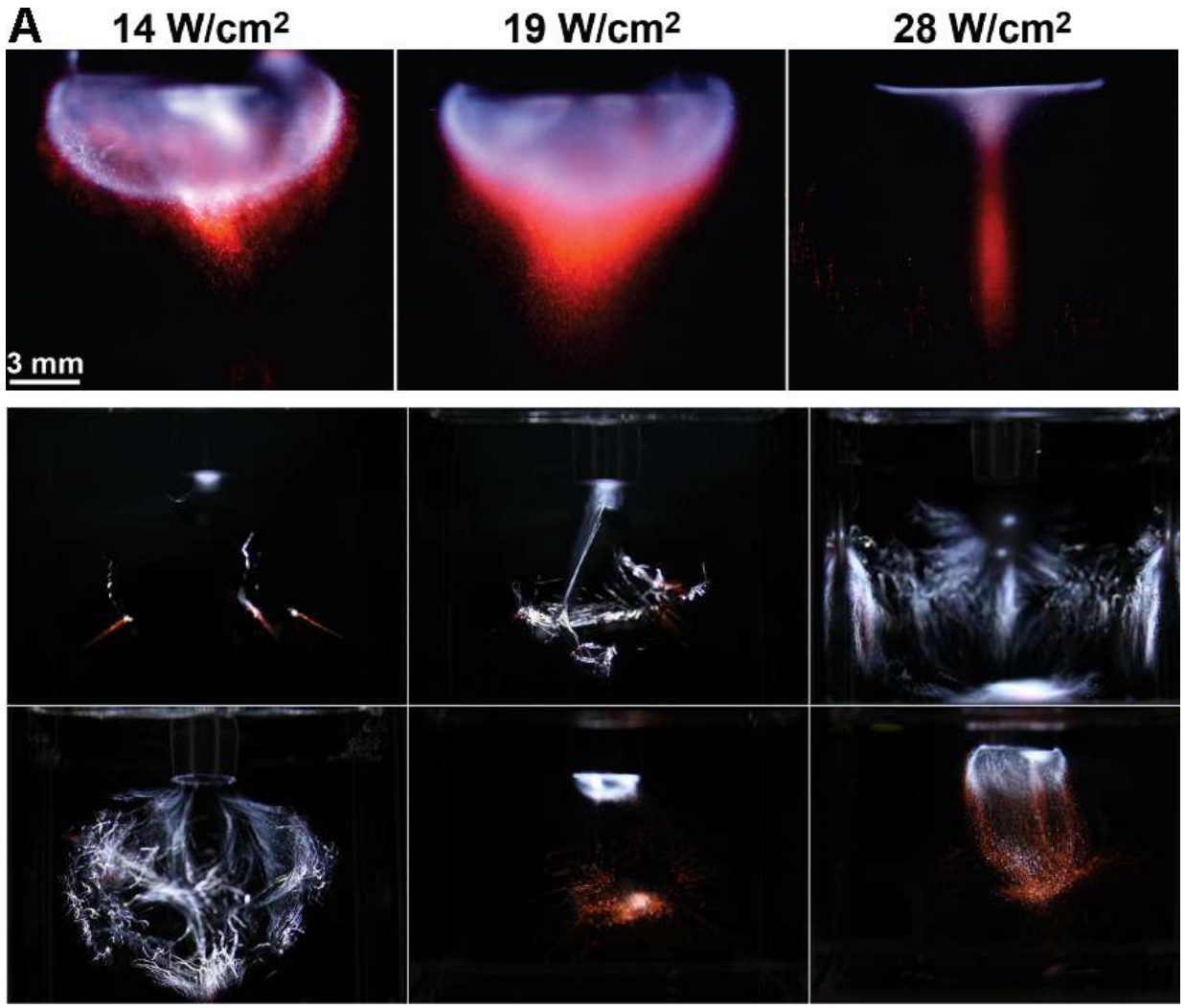
Photographs (3 s exposures) of MBSL from a 0.1 M Na2SO4 solution in 95 wt % H2SO4 saturated with Ar at 298 K at different acoustic intensities.[1]

Sonoluminescence

Digital color photographs of various distinct sonoluminescence structures below the sonotrode (95–98% sulfuric acid with 0.1M sodium sulfate, xenon saturated; exposure time 1 s; acoustic frequency approx. 23 kHz). [2]

Applications:

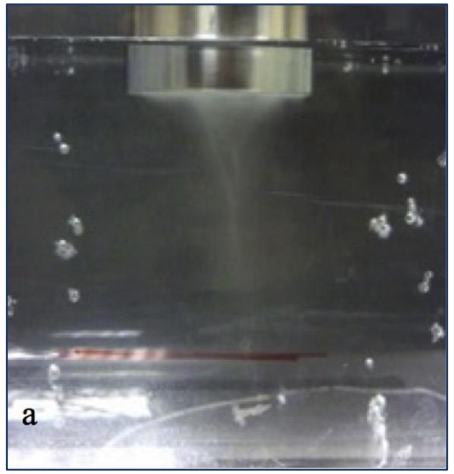
- *Metal recycling*
- *Food Industries*

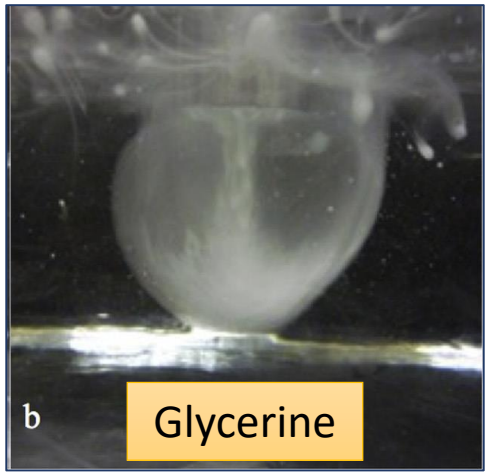


[1] Xu, H., Eddingsaas, N.C. and Suslick, K.S., 2009. Spatial separation of cavitating bubble populations: the nanodroplet injection model. *Journal of the American Chemical Society*, *131*(17), pp.6060-6061.
[2] Thiemann, A., Holsteyns, F., Cairós, C. and Mettin, R., 2017. Sonoluminescence and dynamics of cavitation bubble populations in sulfuric acid. *Ultrasonics sonochemistry*, *34*, pp.663-676.

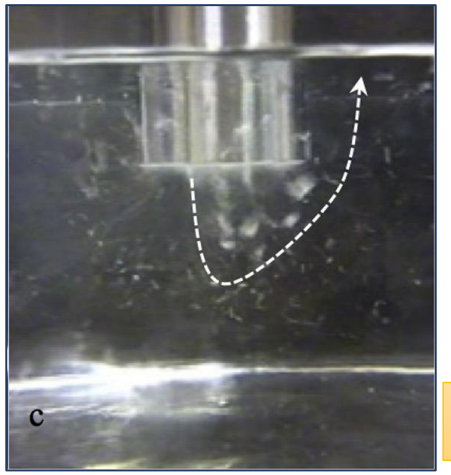
Experiments

Water





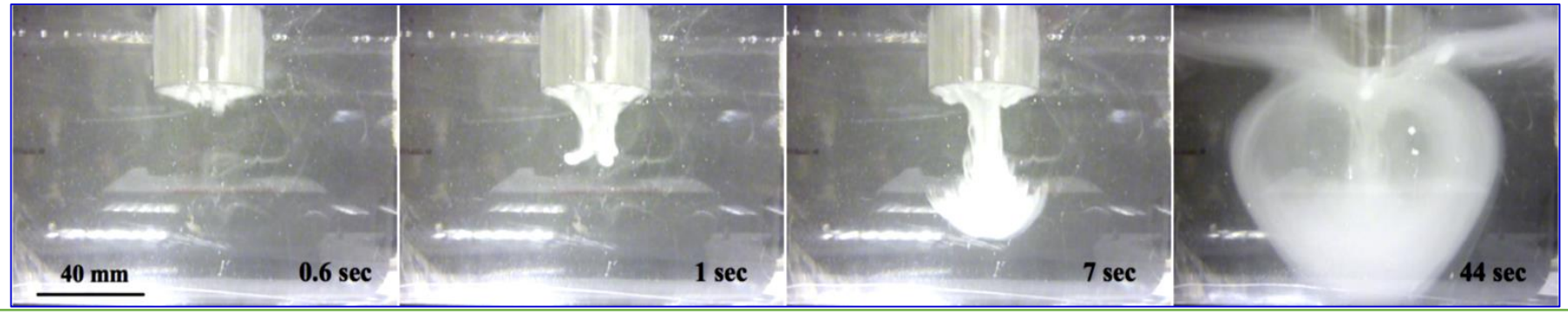
Glycerine



Ethanol

Different cavitation bubble structures underneath the sonotrode tip forming a) a conical shape (water) and b) a circulating pattern with symmetrical vortexes (glycerine). In the case of the ethanol (c) bubbles are generated and dispersed outside the cavitation zone and towards the free surface as indicated by the white dashed arrow [4].

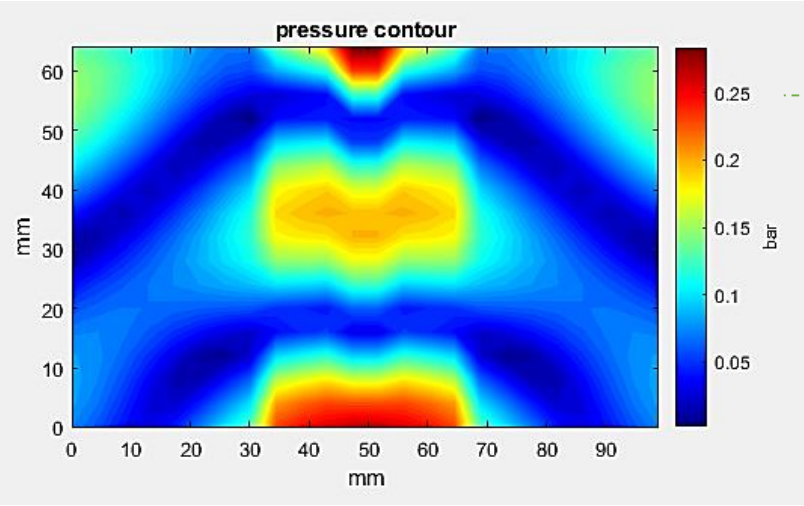
Glycerine



Evolution of acoustic cavitation in glycerine solution. Amplitude of the sonotrode tip (diameter 40 mm) was adjusted to 100% [4].

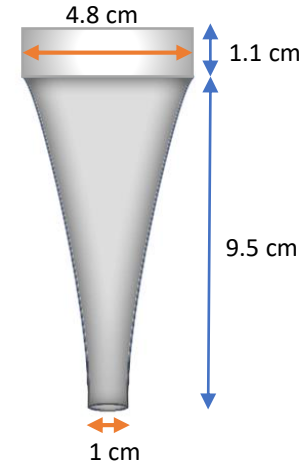
[4] Tzanakis, I., Lebon, G.S.B., Eskin, D.G. and Pericleous, K.A., 2017. Characterizing the cavitation development and acoustic spectrum in various liquids. *Ultrasonics sonochemistry*, *34*, pp.651-662.

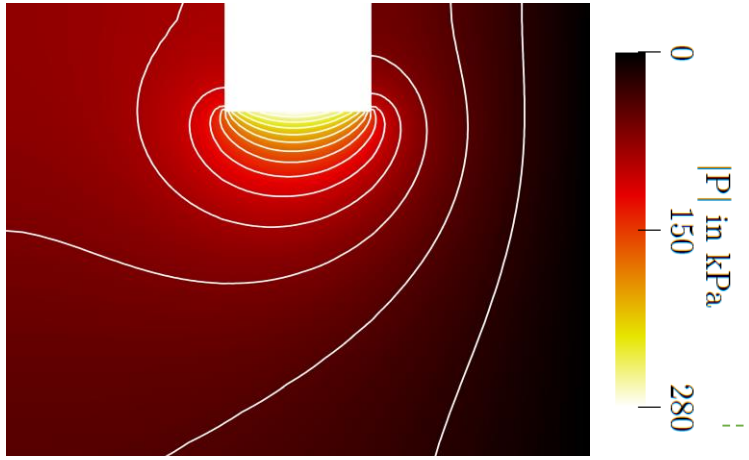
Setup



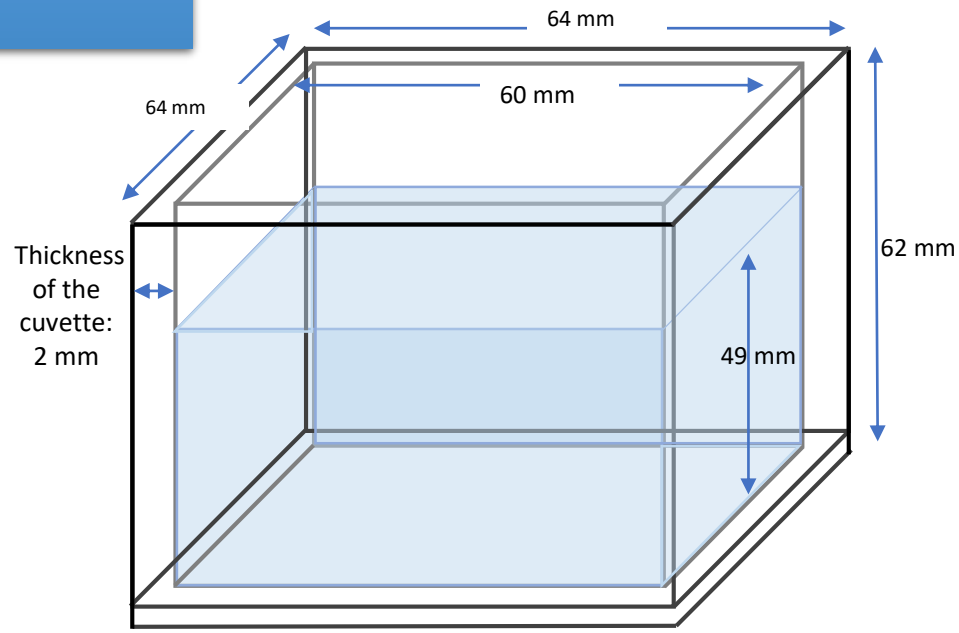
Measured pressure field

- Cuvette & Sonotrode
- Resonance Frequency @ 21.25 kHz
- PMMA walls





Simulated pressure field



Acoustic pressure amplitude distribution |P| in the middle cross-section of the 1 cm-horn case. White lines represent contours of |P|. [3]

[3]Sergey Lesnik PhD Thesis, 2021.

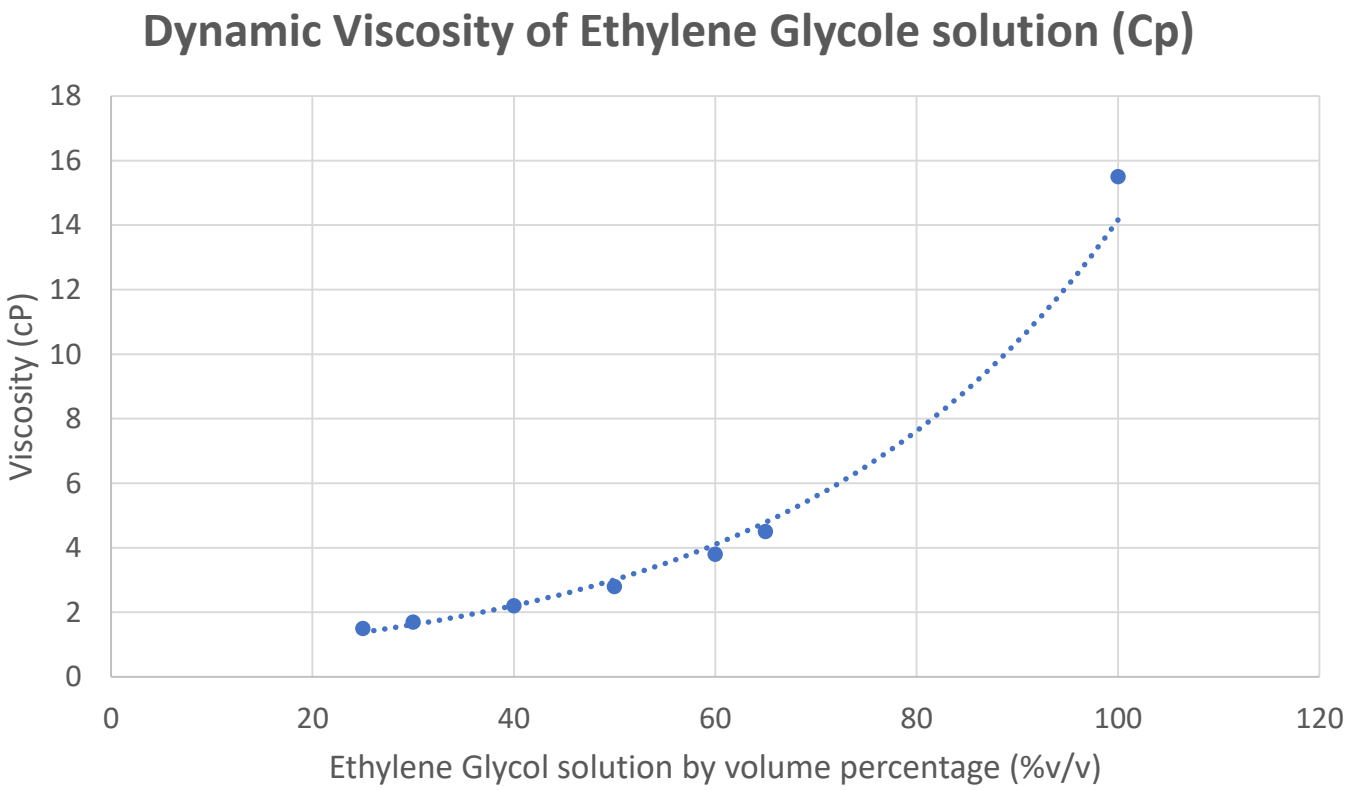
Setup

Liquids

- DI water
- DI + 50% v/v Ethylene Glycol
- DI + 80% v/v Ethylene Glycol
- 100% Ethylene Glycol

Viscosity at room temperature (centiPoise)

- DI water: 1
- DI + 50% Ethylene Glycol: 2.8
- DI + 80% Ethylene Glycol: 8
- 100% Ethylene Glycol: 15.5

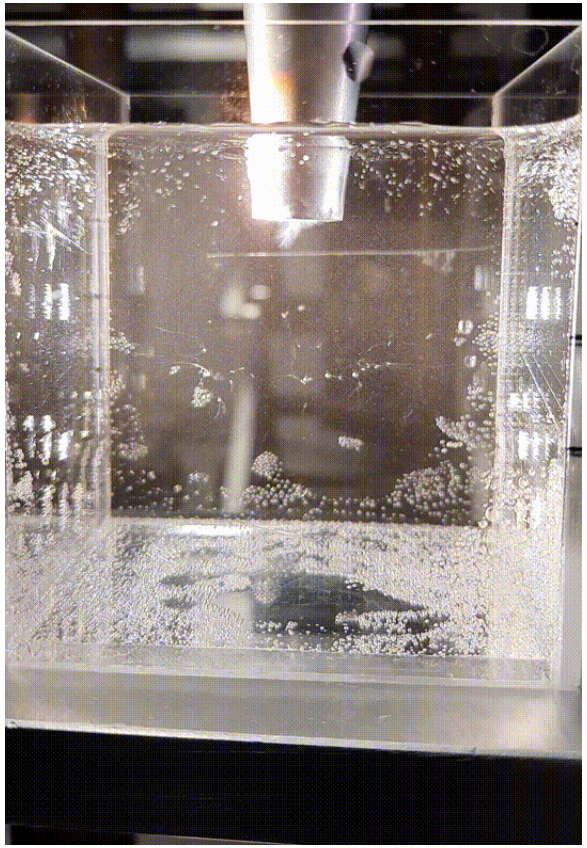


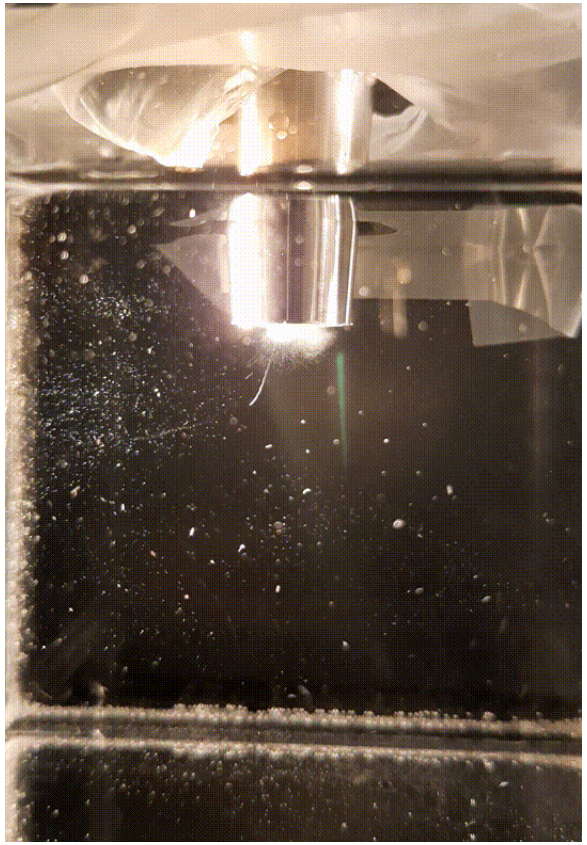
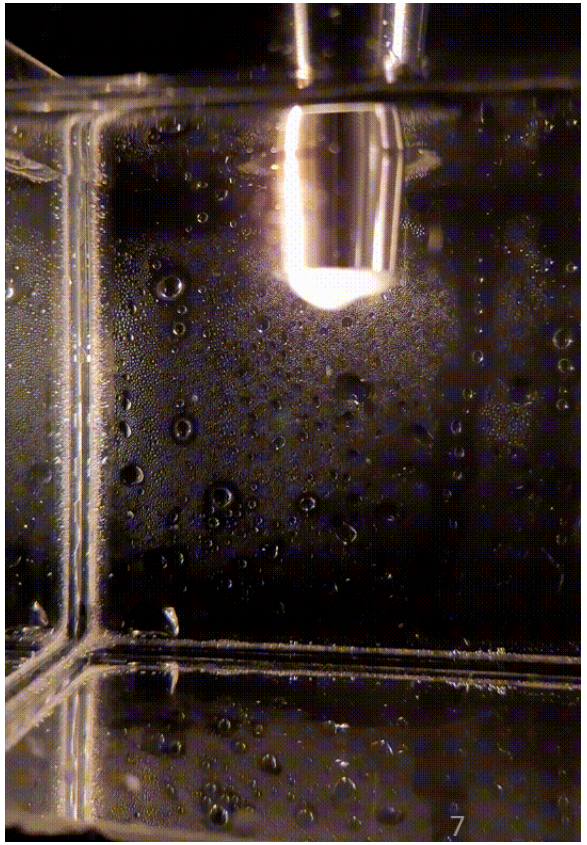
Viscosity values are taken from https://www.engineeringtoolbox.com/ethylene-glycol-d_146.html

Experiments- Overview

Low amplitude Sonotrode displacement ~ 2.5-5 µm

Deionized Water (DI)	*DI + 50% Ethylene Glycol*	*DI + 80% Ethylene Glycol*	*100% Ethylene Glycol*
µ= 1 cP	µ= 2.8 cP	µ= 8 cP	µ= 15.5 cP



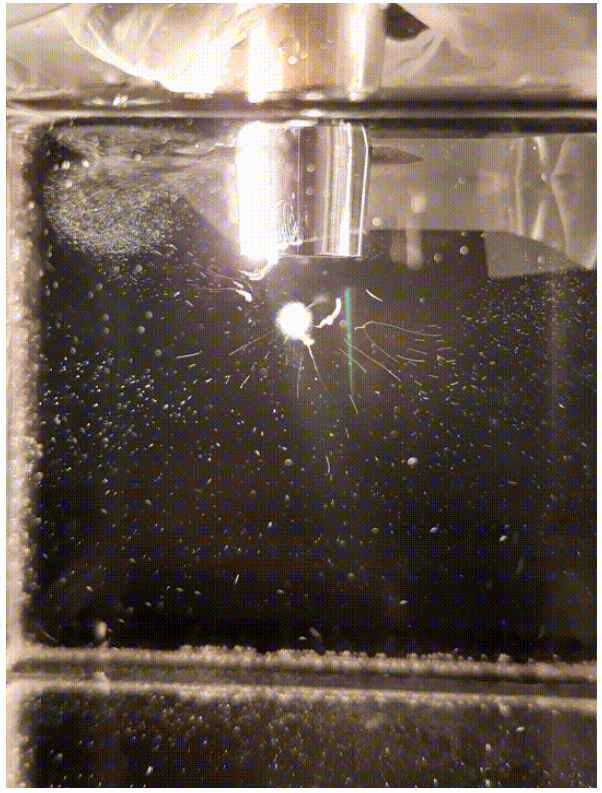
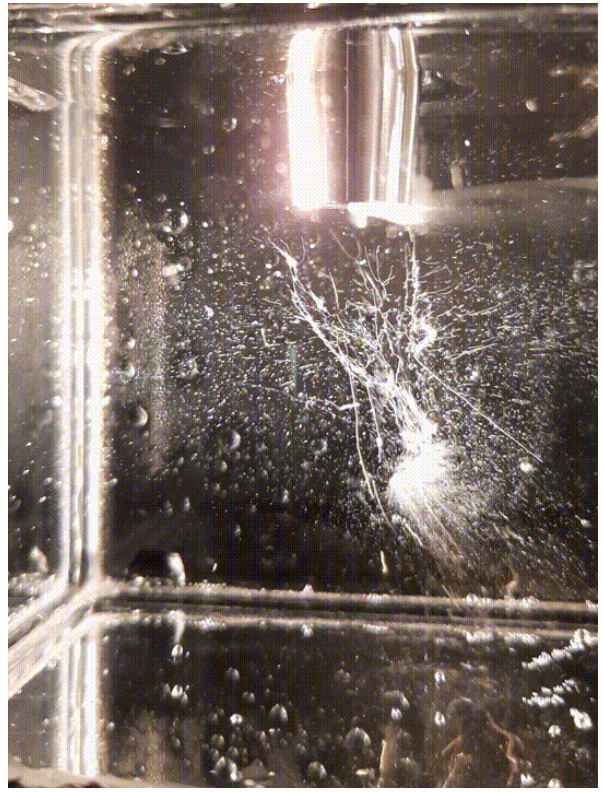



Experiments- Overview

***Moderate** amplitude Sonotrode displacement ~ 5-10 µm*

Deionized Water (DI)	*DI + 50% Ethylene Glycol*	*DI + 80% Ethylene Glycol*	*100% Ethylene Glycol*
µ= 1 cP	µ= 2.8 cP	µ= 8 cP	µ= 15.5 cP

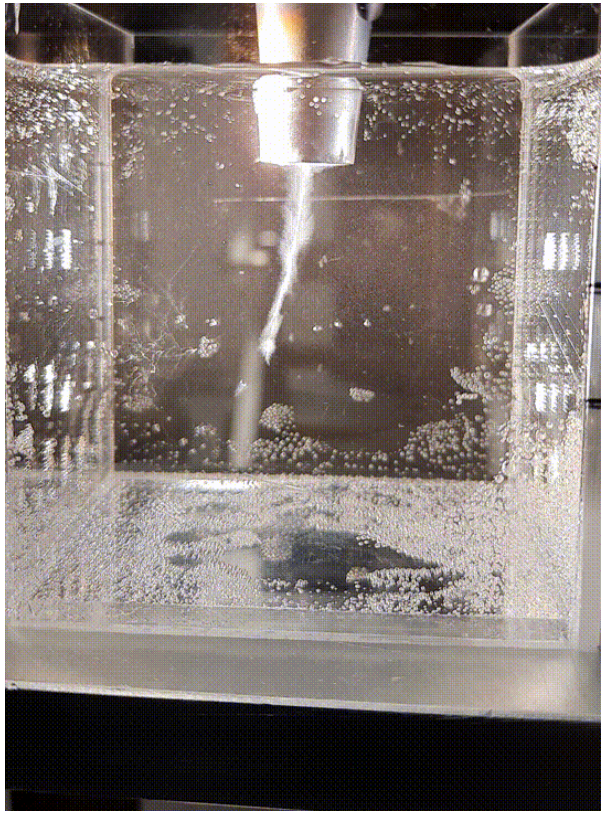


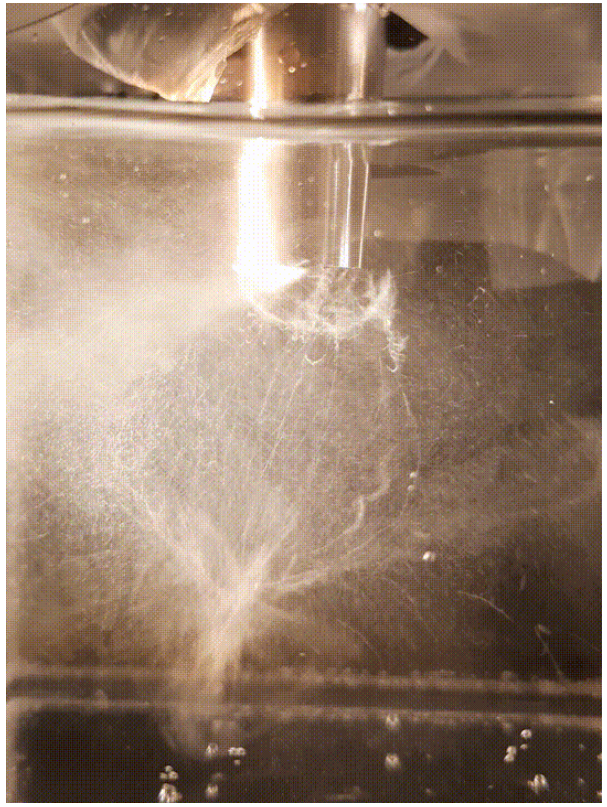



Experiments- Overview

***High** amplitude Sonotrode displacement ~ 10-15 µm*

Deionized Water (DI)	*DI + 50% Ethylene Glycol*	*DI + 80% Ethylene Glycol*	*100% Ethylene Glycol*
µ= 1 cP	µ= 2.8 cP	µ= 8 cP	µ= 15.5 cP

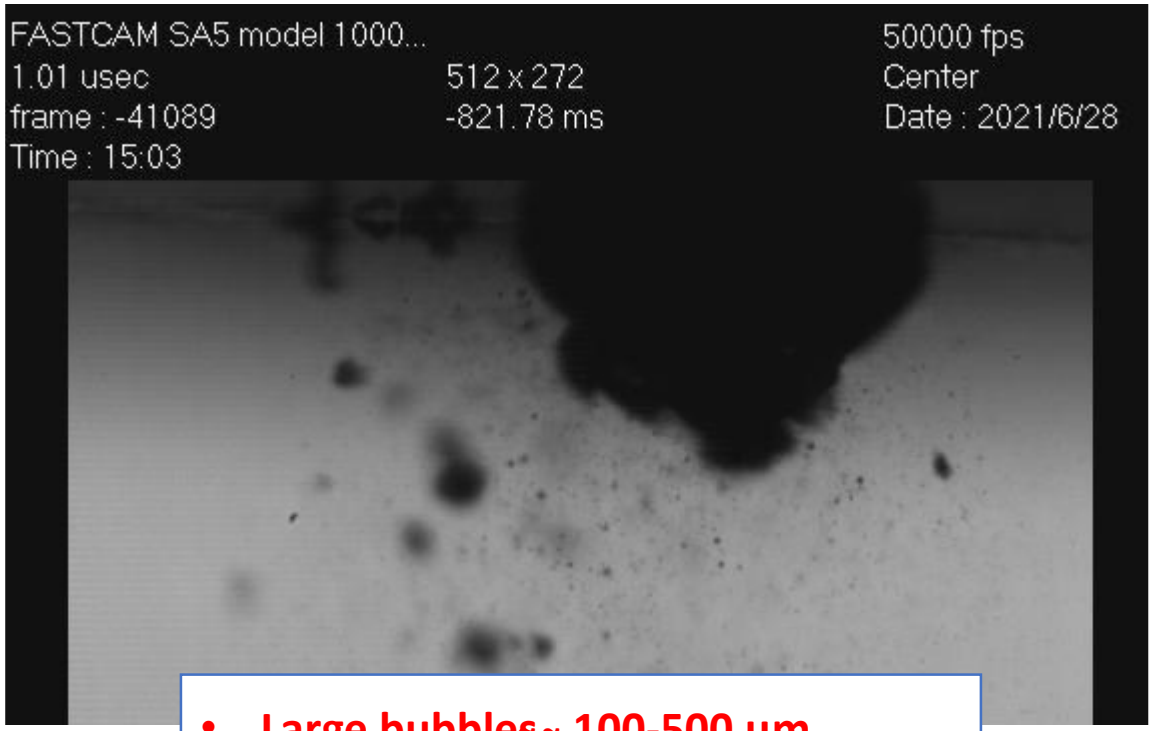





Experiments

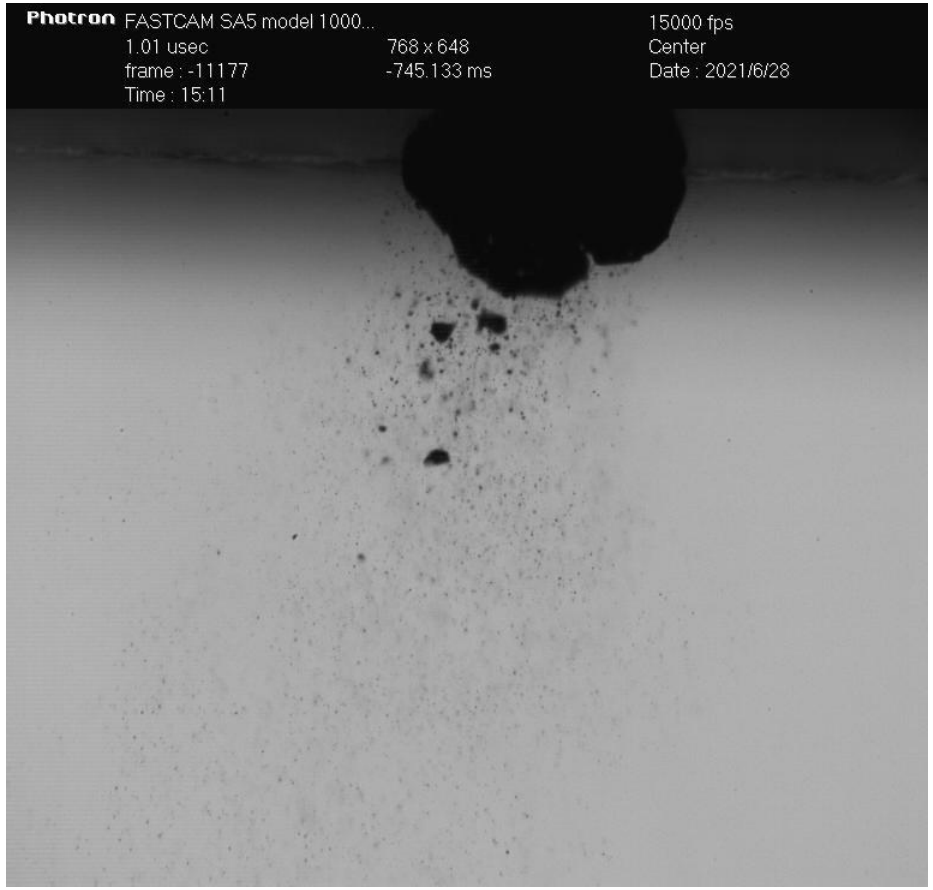
Low Amplitude & Deionized Water

Recording Speed: 50kfps
Showing Speed: 10 fps
Shutter Time: 1.01 µs
Width of frame: 0.606 mm



- **Large bubbles~ 100-500 µm**
- **Medium bubbles~ 5-50 µm**
- **Small (micro) bubbles~ 1-sub-µm**

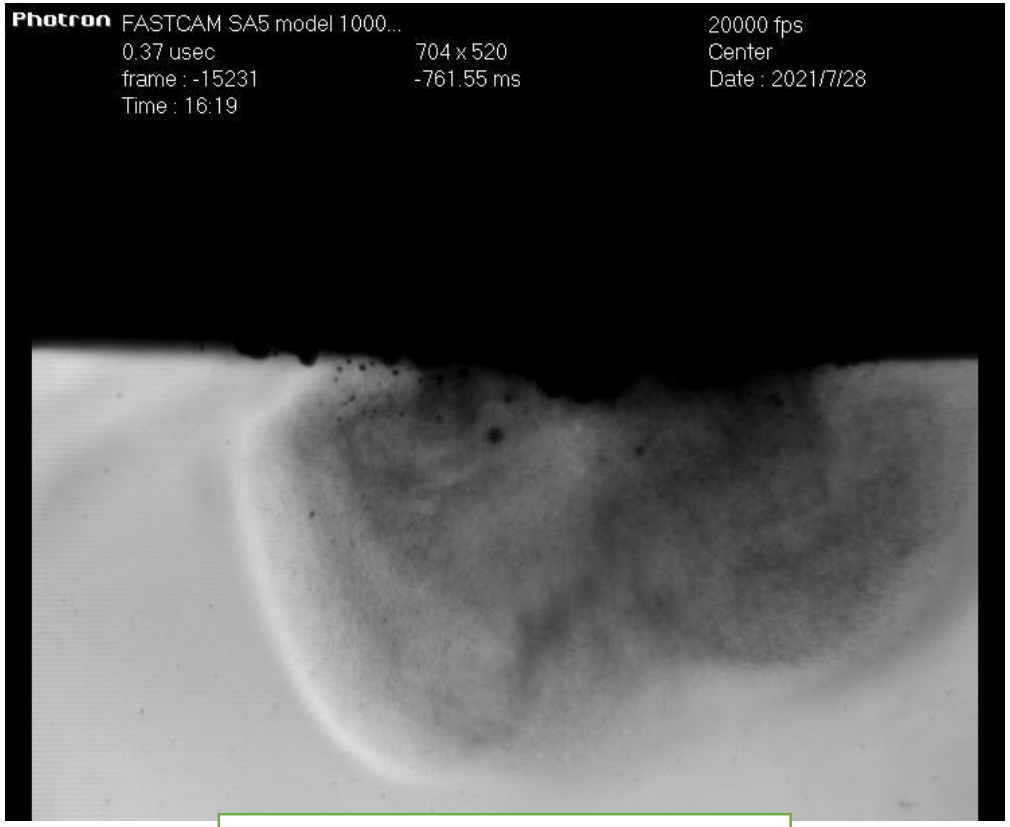
Recording Speed: 15kfps
Showing Speed: 10 fps
Shutter Time: 1.01 µs
Width of frame: 1.79 mm



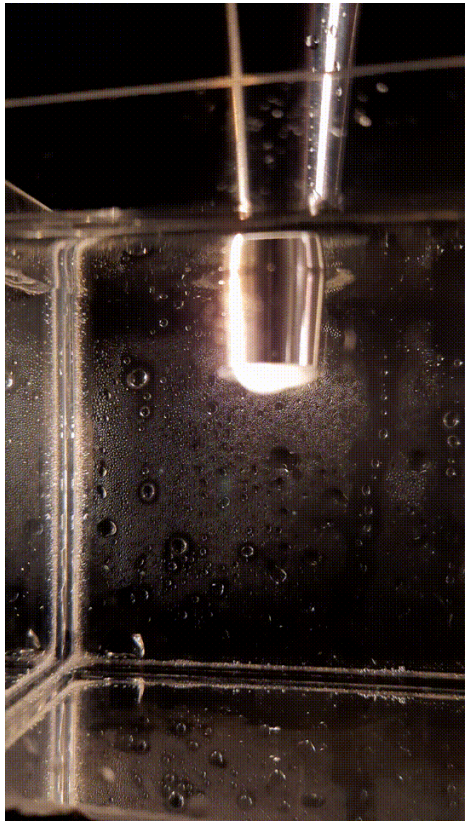
Experiments

Low Amplitude & 100% Ethylene Glycol

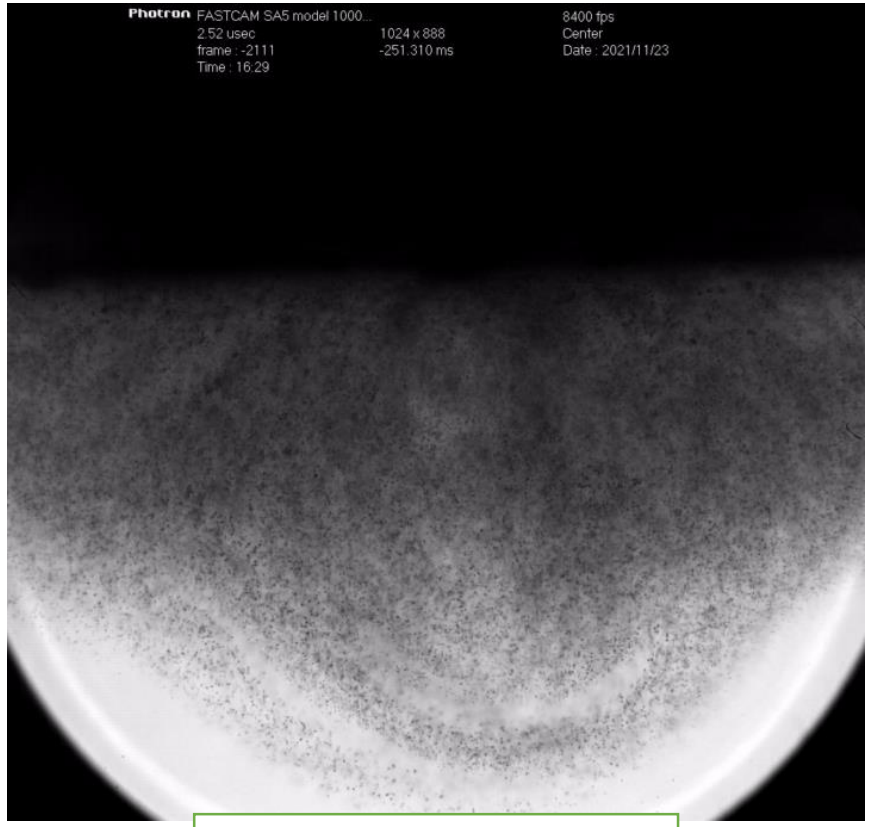
μ= 15.5 cP



Recording Speed: 20kfps
Showing Speed: 80 fps
Shutter Time: 0.37µs
Width of frame: 12.875 mm



Mobile phone camera
Speed: 30 fps
Width of frame: 7 cm



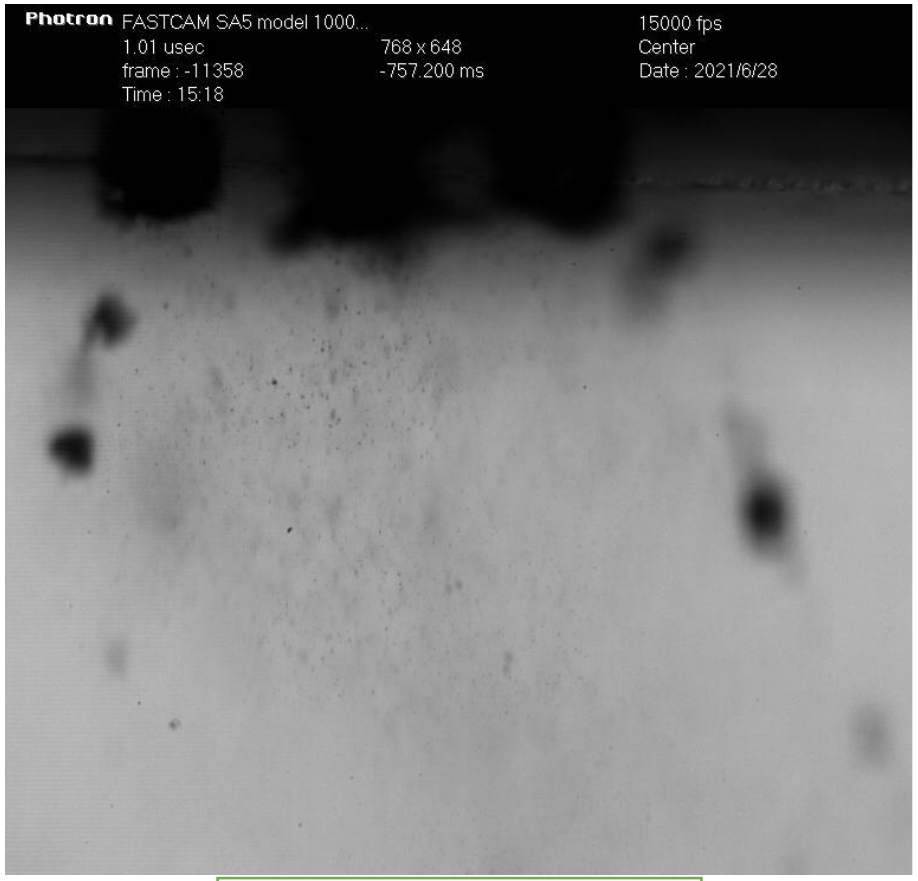
Recording Speed: 8.4kfps
Showing Speed: 10 fps
Shutter Time: 2.52 µs
Width of frame: 2 mm

Experiments

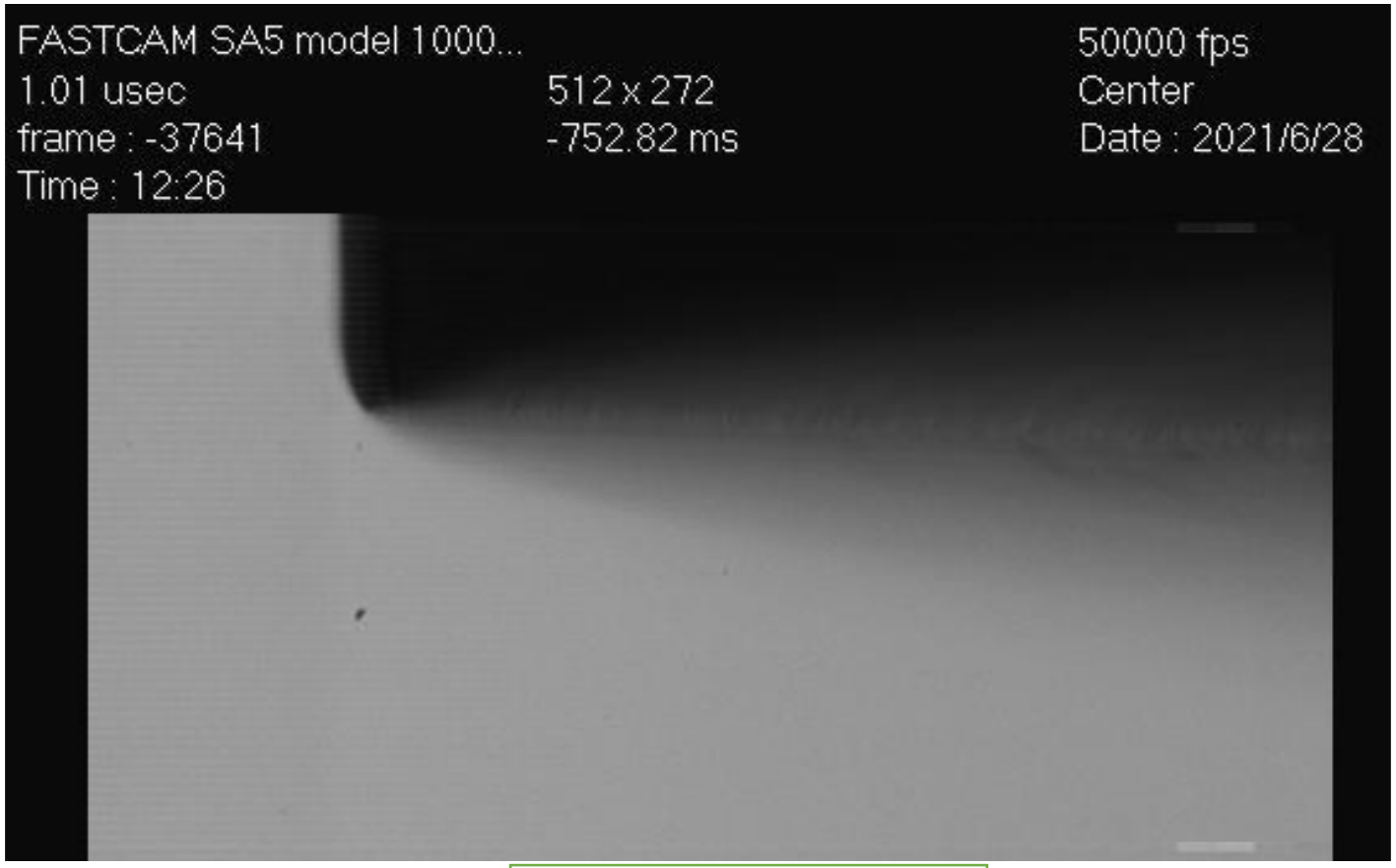
Deionized Water & Moderate Amplitude

μ= 1 cP

Deionized Water & High Amplitude



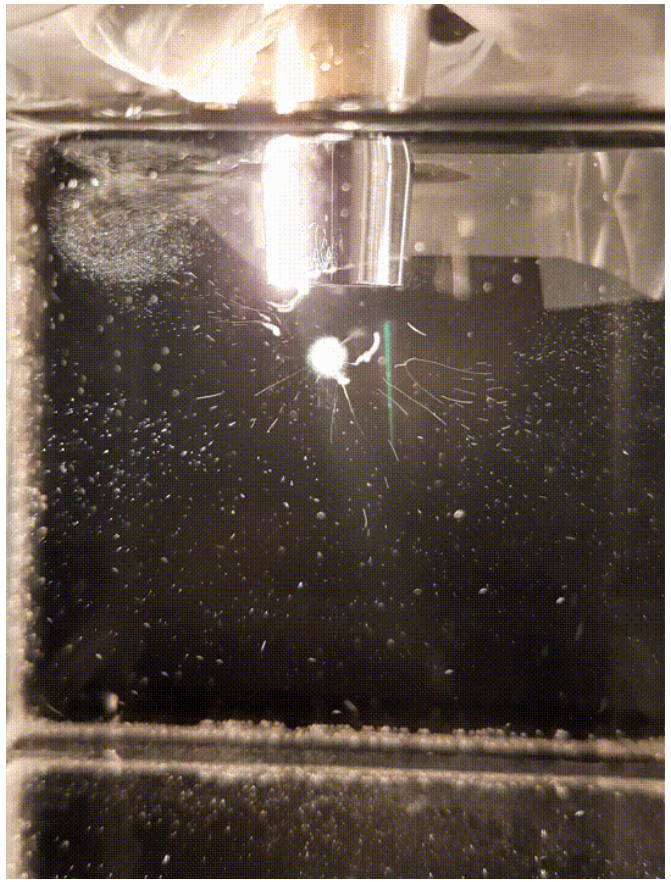
Recording Speed: 15kfps
Showing Speed: 10 fps
Shutter Time: 1.01 µs
Width of frame: 1.79 mm

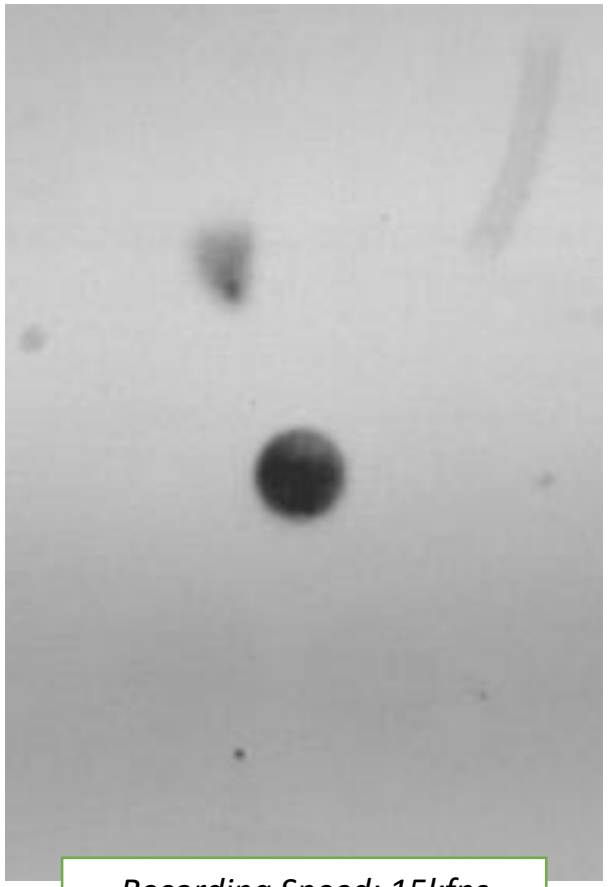


Recording Speed: 50kfps
Showing Speed: 30 fps
Shutter Time: 1.01 µs
Width of frame: 1.79 mm

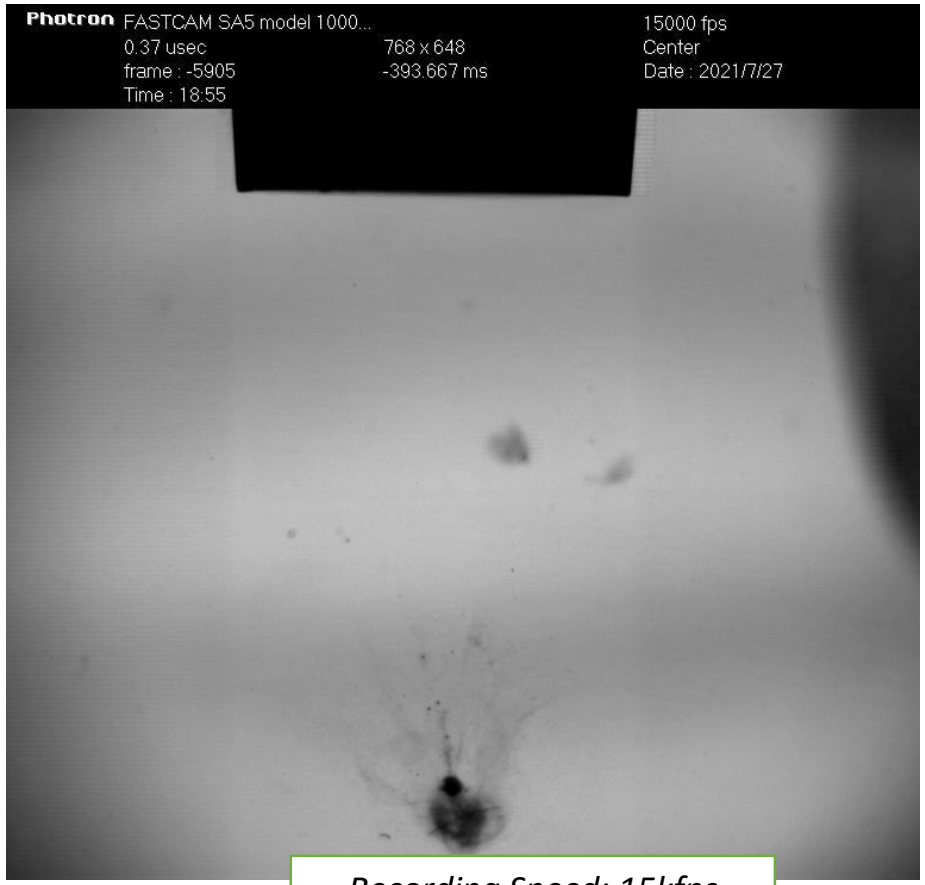
Experiments

Moderate Amplitude & 80% Ethylene Glycol





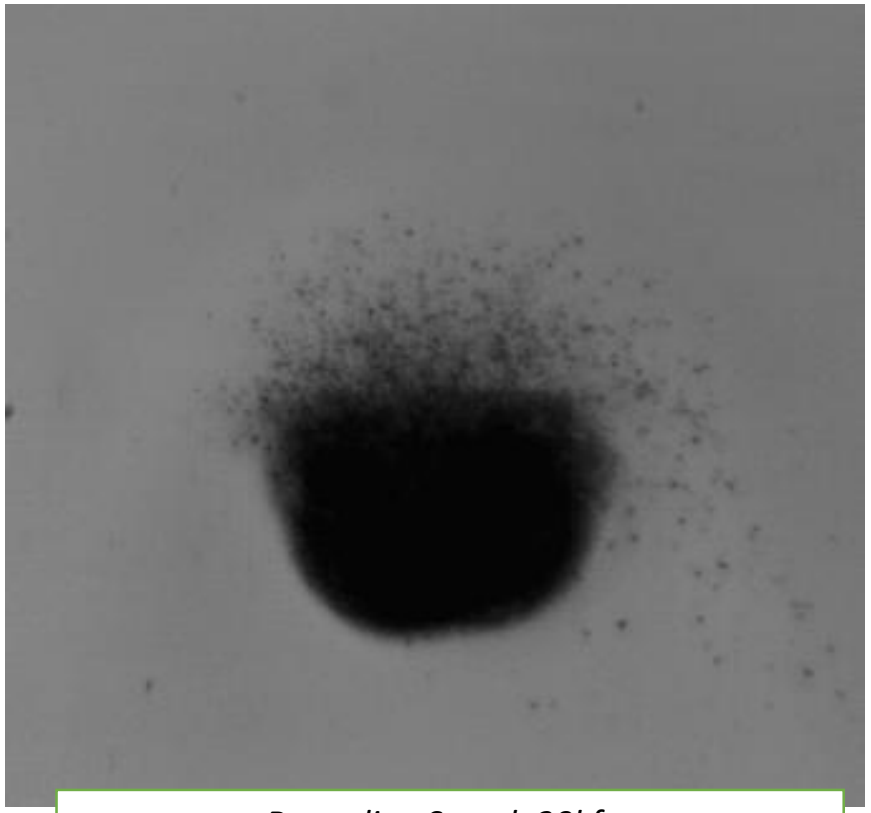
Recording Speed: 15kfps
Showing Speed: 3 fps
Shutter Time: 0.037 µs
Width of frame: 4.89 mm



Recording Speed: 15kfps
Showing Speed: 3 fps
Shutter Time: 0.037 µs
Width of frame: 23.0 mm

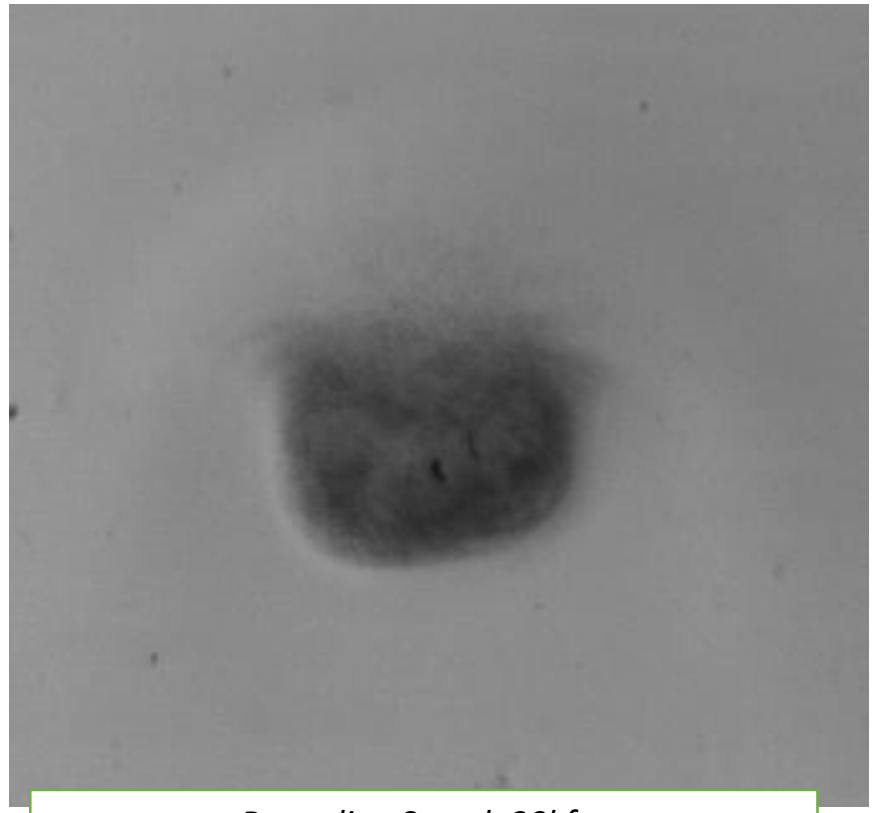
Experiments

Moderate Amplitude & 100% Ethylene Glycol



Recording Speed: 30kfps
Showing Speed: 80 fps
Shutter Time: 0.37µs
Width of frame: 6.86 mm

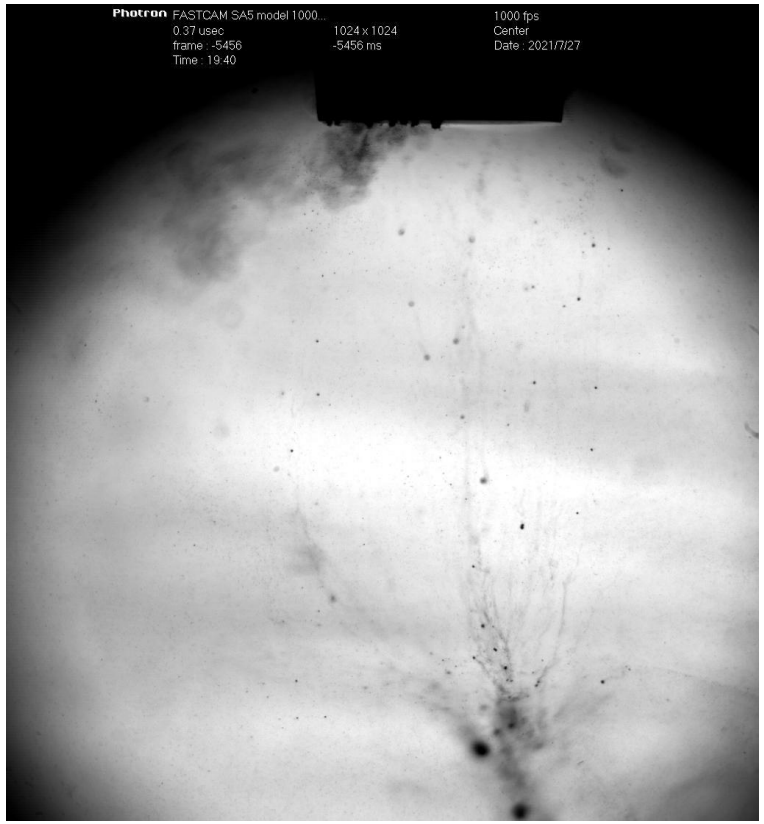
Mobile phone camera
Speed: 30 fps
Width of frame: 2 cm



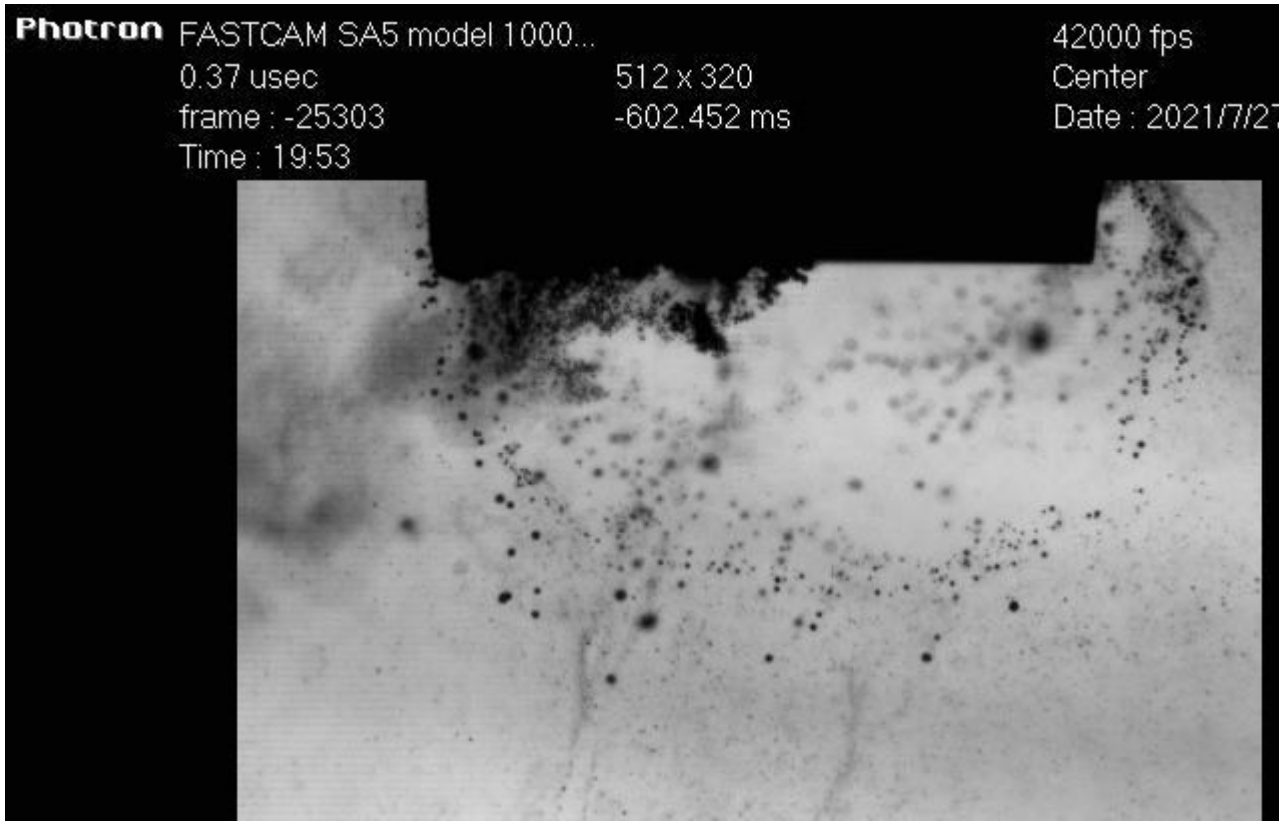
Recording Speed: 30kfps
Showing Speed: 2 fps
Shutter Time: 0.37µs
Width of frame: 6.86 mm

Experiments

High Amplitude & 80% Ethylene Glycol



Recording Speed: 15kfps
Showing Speed: 3 fps
Shutter Time: 0.037 µs
Width of frame: 21.10 mm



Recording Speed: 42kfps
Showing Speed: 3 fps
Shutter Time: 0.037 µs
Width of frame: 15.42 mm

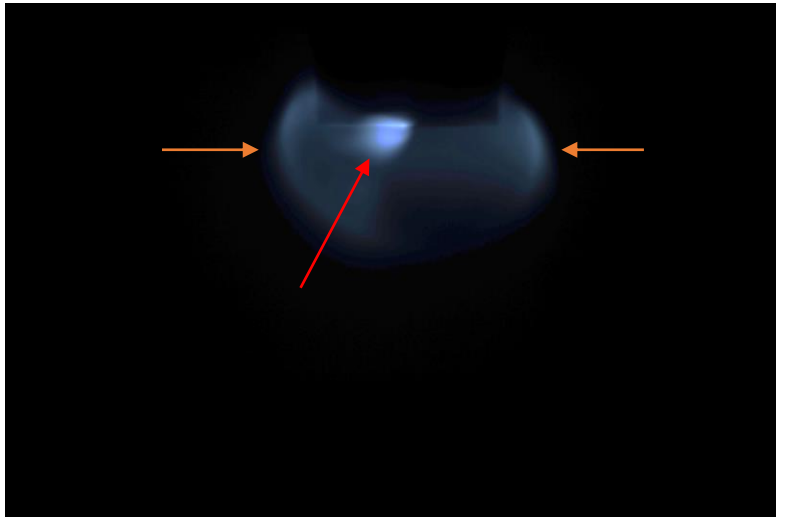
Experiments

Sonoluminescence light

100% Ethylene Glycol, Exposure time: 4 minutes

Degassing: none
Regassing Ar: none

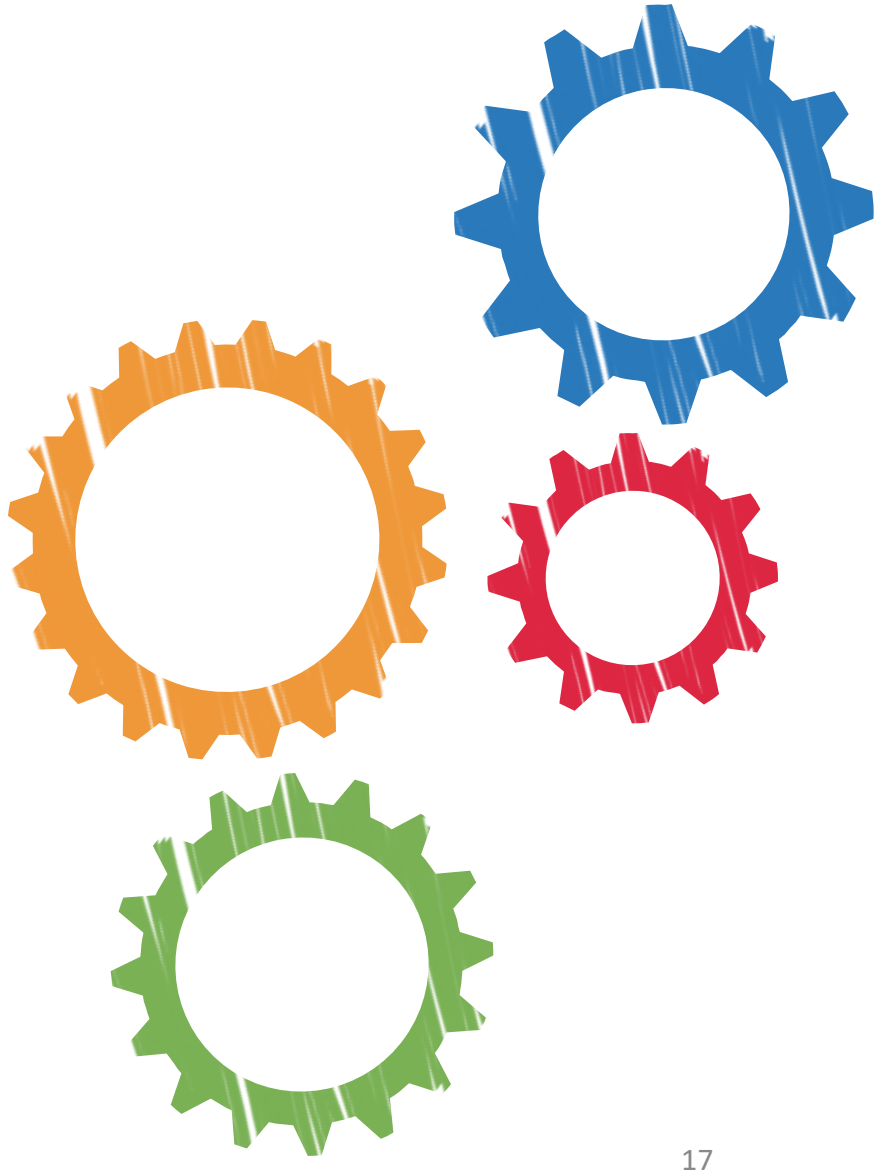
Degassing: 25 min
Regassing Ar: 15 min



Degassing: none
Regassing Ar: 30 min

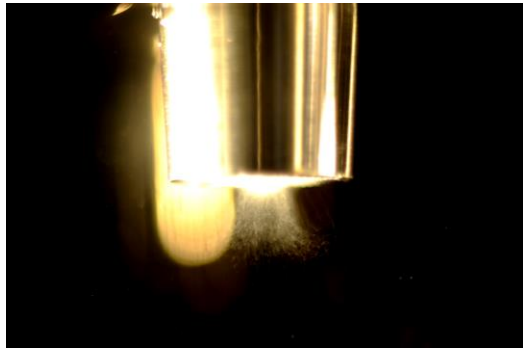
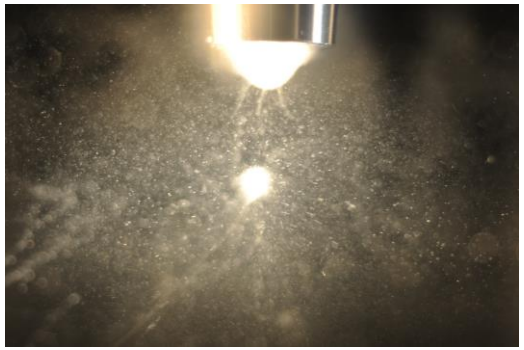
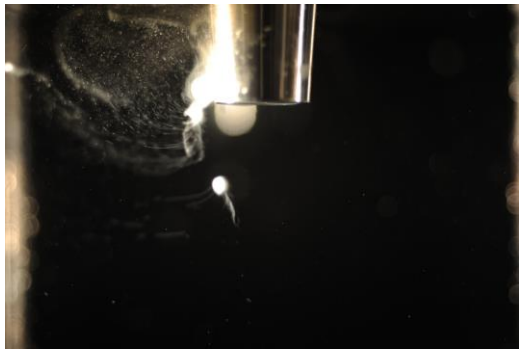
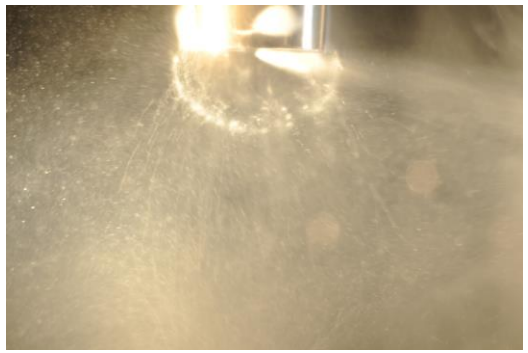
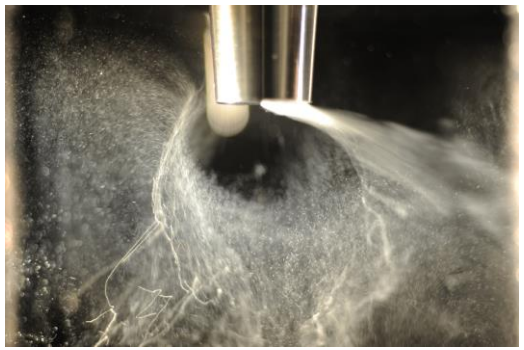
Mechanisms

- Nucleation
- Sound Field & Sound propagation
- Primary Bjerknes Force
- Secondary Bjerknes Force
- Drag Force
- Bubble Stability
- Collection of ingredients (Bubble Structures)
- Further aspects: Gas diffusion, Coalescence,…



Conclusion

- Viscosity does matter!
- Similar Patterns with acids
- Mechanisms are not fully understood yet.

Liquid / Sonotrode displacement	*Deionized Water (DI)*	80% Ethylene Glycol +DI	100% Ethylene Glycol
***Low* Amplitude**			
***Medium* Amplitude**			
***High* Amplitude**			

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