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Investigations on Technical Aspects of the Thermal Disposal of Dumped Ammunition at Sea in the Form of Suspension in Water

V. Weiser, E. Roth, P. Pietrek, A. Raab, A. Kessler

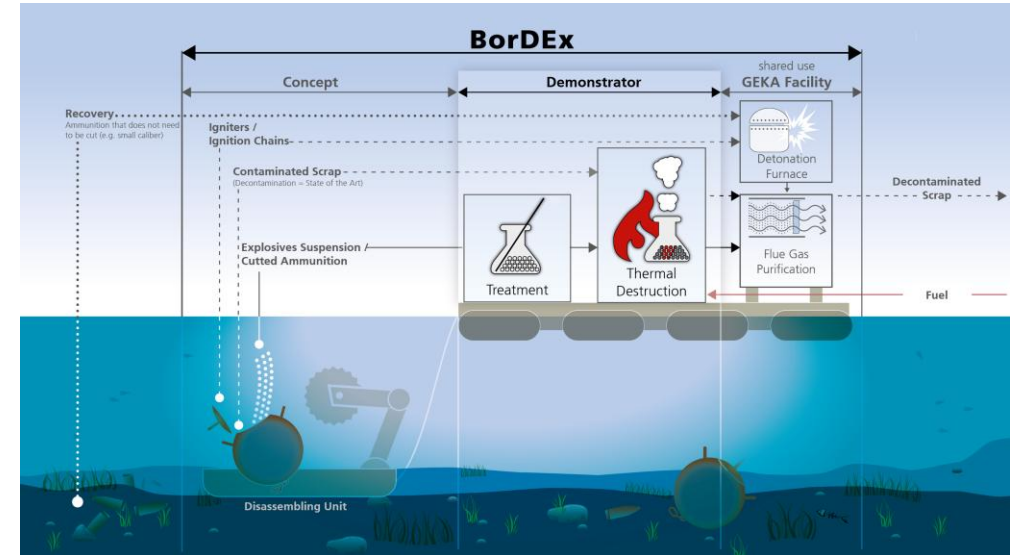
Motivation



- Task: build-up a demonstrator for thermal disposal of recovered unexploded ordnance (UXO) → **B14 & B15**
 - Focus on moored mines
 - For safety reasons, aged ammunition is handled as finely ground particle suspension in water (particles size: ≤ 2.5 mm)
 - burned at high temperatures in a combustion chamber at ≥ 800 °C assisted by a fuel-fired burner
- ❖ No experience exist on processing technologies and combustion of an explosive-water slurry with a high excess of water

Aim of this presented study:

- ✓ **Primary and fundamental studies on a laboratory-scale on process engineering and the combustion of an explosive-water slurry**



Content

Motivation

Test Samples and Preparation

Processing Tests

- Sedimentation
- Stirring Tests Suspension Stability
- Foam Formation & Inhibition

Combustion Tests

- Assisted pool fire
- hovering droplets at combustion chamber conditions

Conclusion

**Additional focus
on diagnostic methods
using
video image analysis**

Test Samples

Dumped Moored Mines: Typical Explosive Composition

Schießwolle 18:

60% Trinitrotoluene (TNT)
24% Hexanitrodiphenylamine (HND)
16% Aluminium powder (Al),

Schießwolle 36:

67% TNT, 8% HND, 25% Al

Schießwolle 39:

45% TNT, 5% HND, 30% AN, 20% Al

Amatole:

AN/TNT: 40/60; 50/50, 80/20%

Minol:

TNT/AN/Al 40/40/20%

+ Non-explosive Additives:

sand, sawdust, rock salt, gypsum
iron sawdust from the dismantling the mine



**Explosive charge:
100 to 300 kg**



<https://www.jpi-oceans.fraunhofer.de/>

Test Samples and Preparation

For lab tests

- Synthetic suspension, produced using clean freshwater
- Sedimentation and stirring:
 - 50% TNT 30% AN + (200%) 300% water
- Combustion
 - 50% TNT 30% AN + 300% water
 - 50% TNT 30% AN 20% Al + 300% water



Question on crushing/grinding

Does grinding work in an aqueous suspension?

- The brittle texture of TNT makes it possible to carefully crush the material in a mortar using light manual pressure, both in its dry form and when mixed with water
- Particle size (microscopy): $<1\mu\text{m} < x \leq 2\text{ mm}$
- AN dissolves completely in water



Processing

Sedimentation and Suspension Stability

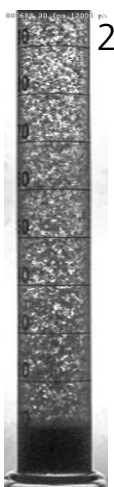
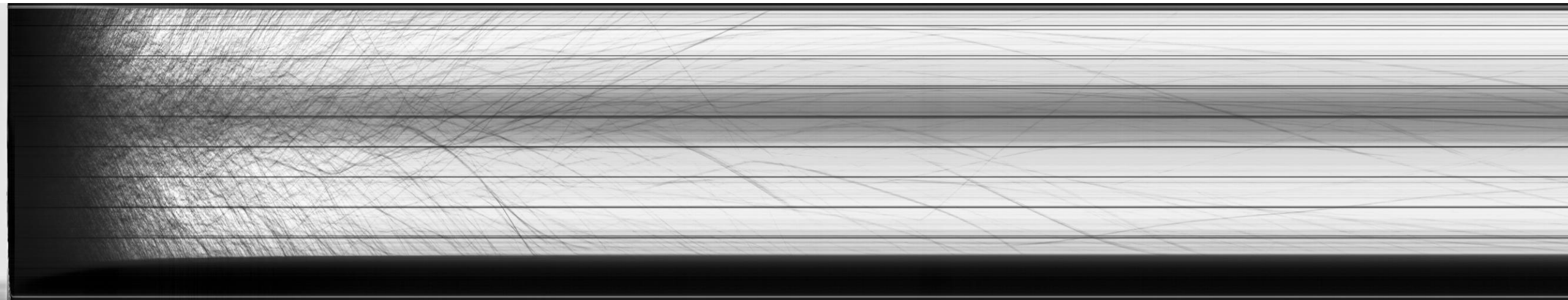
Question on Sedimentation and Suspension Stability

- *What happens when mixed with water?*
- *How quickly does the suspension settle?*
- *How can the settled material be resuspended?*
- *Does caking occur by aging?*



Sedimentation

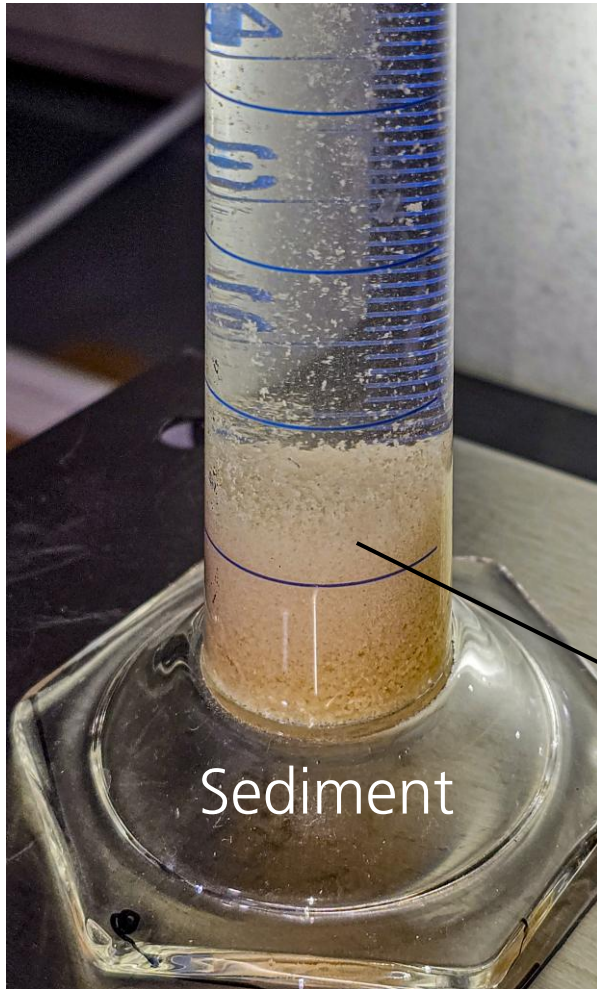
Video analysis of sedimentation process



- Separation starts immediately
- 5 s Sedimentation half-life
- 25 s 90% Separation
- A certain amount of the particles rise!

Sedimentation

3 distinct phases within a few seconds



Formation of stable, thick and firm foam cap

Sample Aged for 7 month

- After 7 months, the sample shows no apparent change from its original condition
- 6 months after the last resuspension, the foam is still intact
- No caking after 7 month
- Settled sample can be resuspended in a manner similar to the fresh material



Sample aged 7 month

Suspension

Resedimented

Stirring Tests

Questions and Set-up

Questions Regarding Stirring Tests:

How quickly does the suspension form?

What is the critical stirring speed?

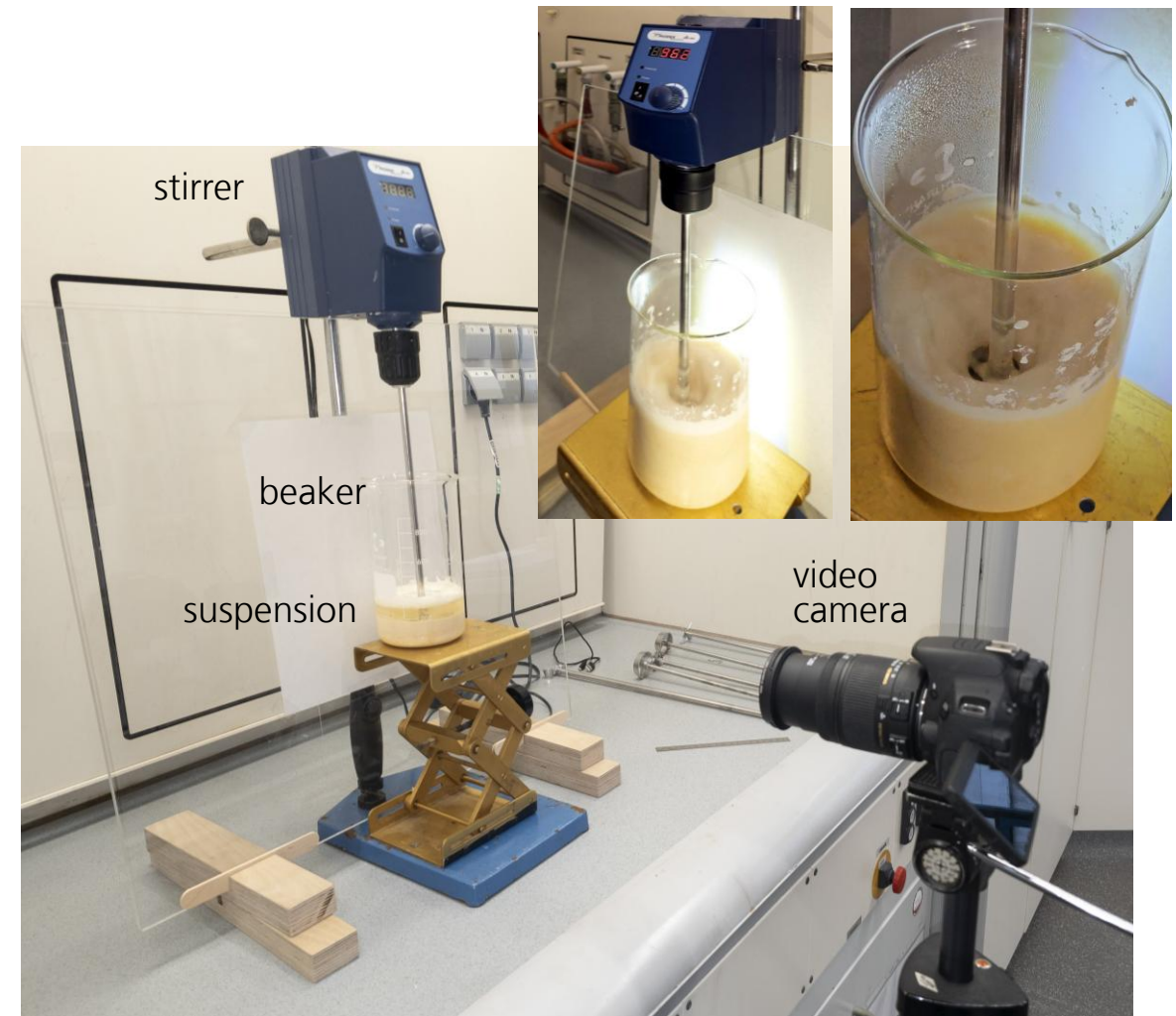
How does sedimentation depend on the stirring?

How to estimate the critical stirring speed for larger mixing vessels?

How do we understand the observed foam formation?

Can the foam be stirred back down by increasing the stirring speed?

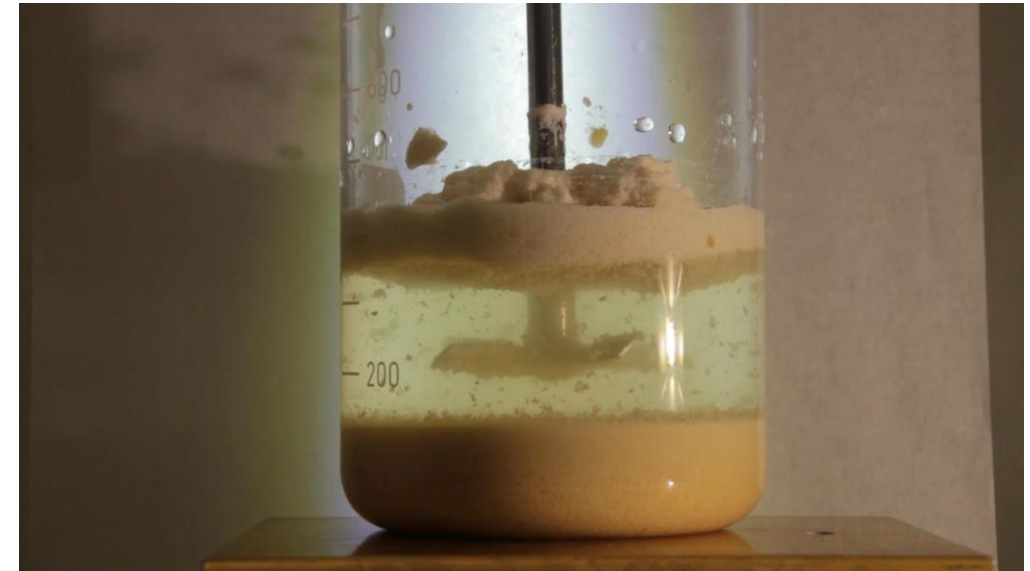
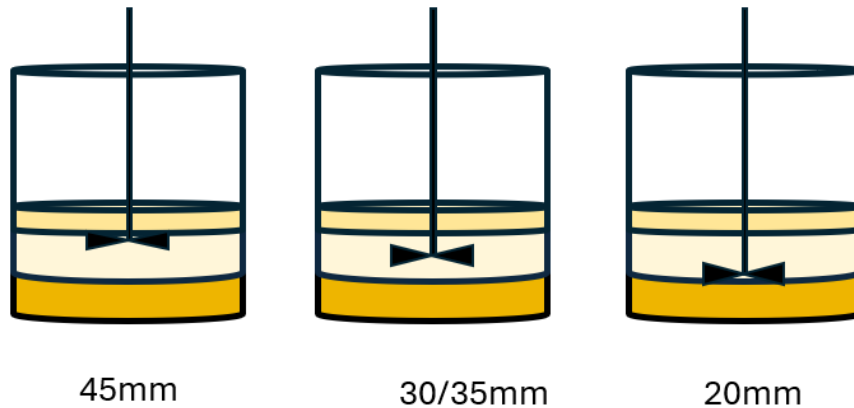
Can foam be prevented?



Stirring Tests

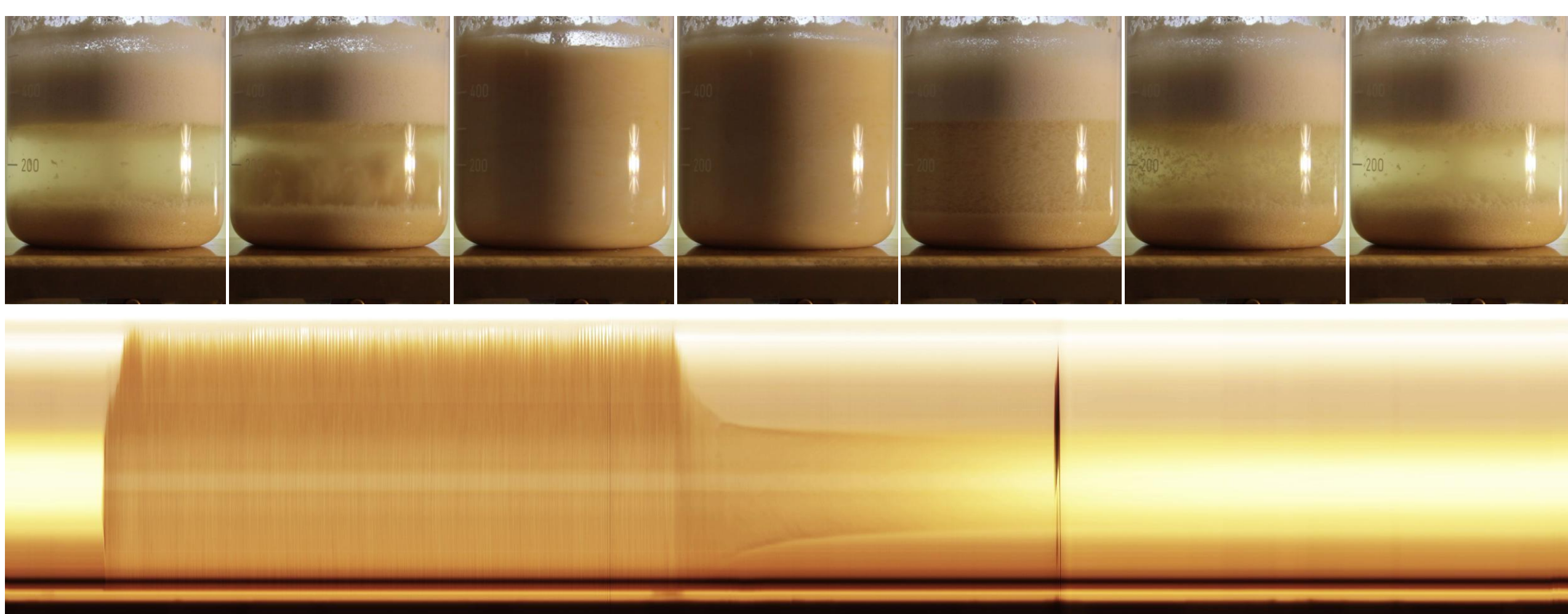
Experimental Parameter

- explosive/water: (1 : 2 and) 1 : 3
- Various types of stirrer
- Ratio of the stirrer diameter to the inner diameter of vessel: 1 : 2
- Various positions of stirrer above the vessel bottom:
 - 20 mm (top of sediment)
 - 30/35 mm (center between sediment and foam)
 - 45 mm (below foam, only 200 ml water)
- Variation of stirrer speed
 - 60, 120, 340, 300, 360, 420, 480, 600, 720, 840, 1000 rpm



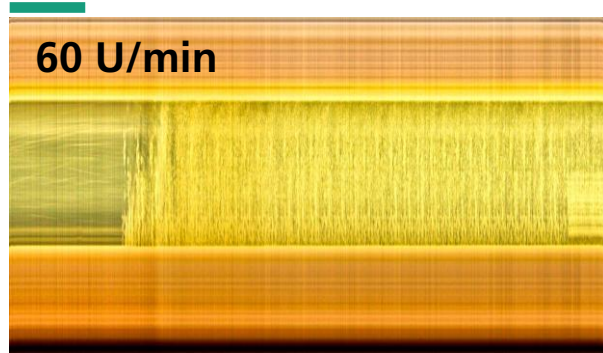
Stirring Experiments: Suspension of TNT Particles in Water

Example: M6 angled-blade stirrer, 960 rpm, 20 mm



Stirring Experiments: Suspension of TNT Particles in Water

Example: M6 angled-blade stirrer, 60, 120, 240, 360, 960 rpm, Position : 20 mm



Stirring Experiments: Suspension of TNT Particles in Water

Some results

Foam observed in all experiments

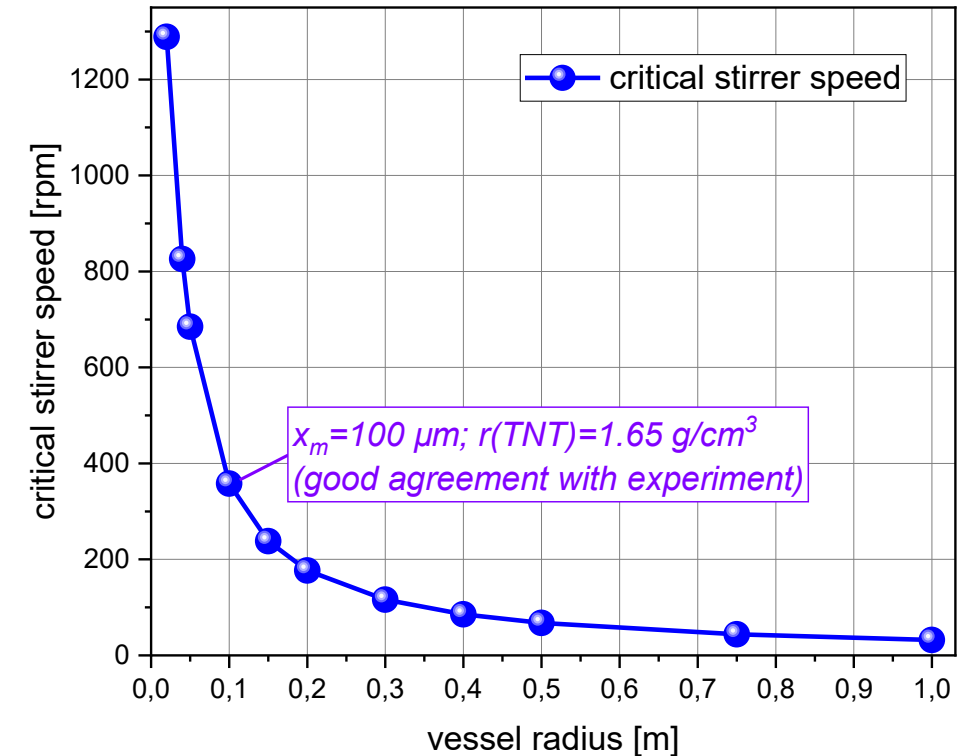
Critical stirrer speed: $300 < 360 < 400$ rpm

- Best results with angled-blade stirrer
- Optimum position close to sediment surface



Depending on the stirring speed, sedimentation and the foam layer returned between 0.5 to 3 seconds after the stirrer was turned off.

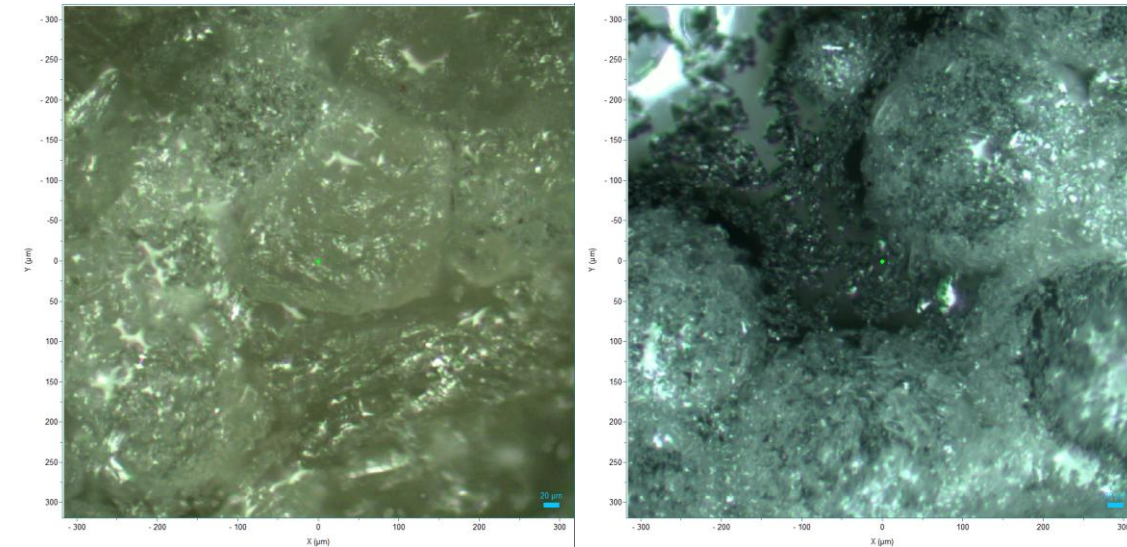
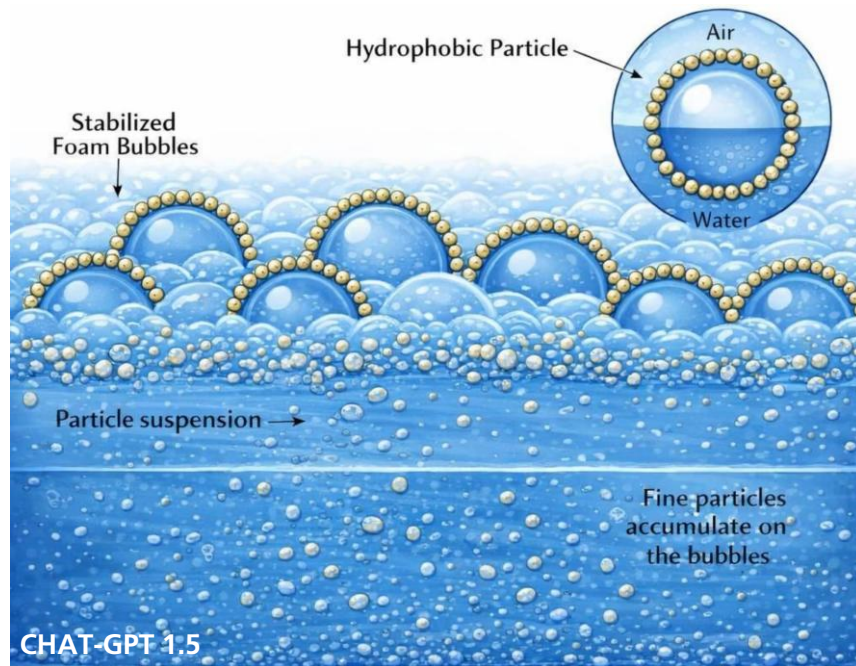
Up-Scaling: using approaches of Einenkel/Mersmann and Voit/Mersmann



Foam Formation & Inhibition

Foam Formation due to Pickering-Effect

- TNT-particles are extremely hydrophobic
- The particle size distribution of the ground TNT particles includes a fraction of very fine particles smaller than $1\text{ }\mu\text{m}$
- Stirring introduces air bubbles into the suspension
- Foaming occurs due to the **Pickering effect**



New Question: *How to avoid foaming?*

Foam Formation & Inhibition

Inhibition tests with various anti-foaming agent

Reference: 10% TNT-particles in water

Test Series 1: +3% AN, Al (<100 µm)

Test Series 2: Ultrasound

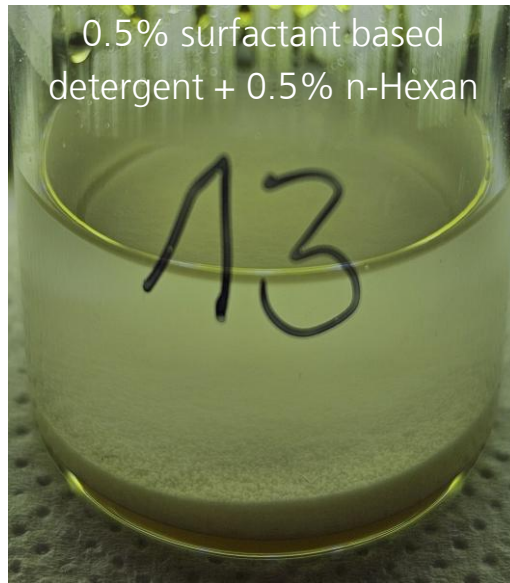
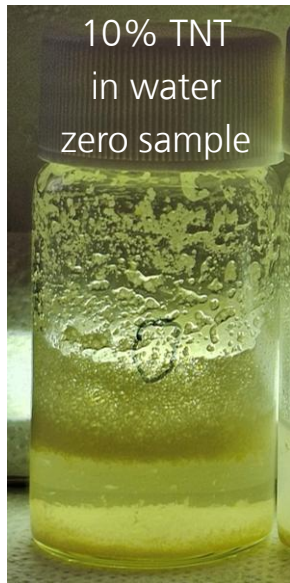
Test Series 2: +3% surfactant-based detergents, Glycerin, Silicon oil, Alkanes, Alkane-Alcohols, ...

Test Series 3: +3% selected mixtures of test series 2

Test Series 4: reduction of concentration until 0.5 %

→ no influence of foam formation

→ no inhibition



→ Additional benefit:
Reduced critical stirrer
speed: 240 rpm



Combustion Tests

Pool Fire Tests

Questions on Combustion:

- *How do the explosive/water suspensions burn?*
- *What temperatures are reached?*



The sample (containing TNT/AN/ $\pm$ Al) is placed at a defined distance in a shallow crucible above a Bunsen burner.

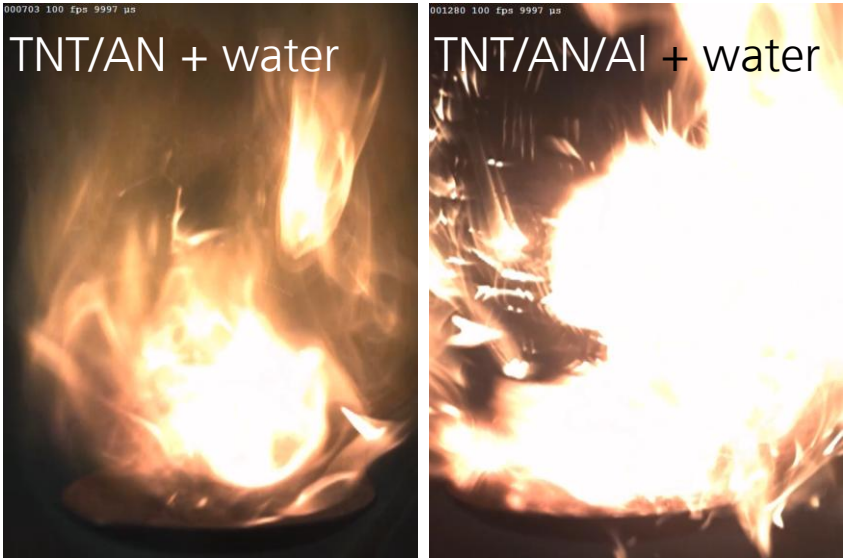
After lighting the Bunsen burner, the behavior of the sample and the combustion process are observed.

Measurement techniques:

- Camera (100 fps)
- NIR emission spectrometer (temperature measurement)

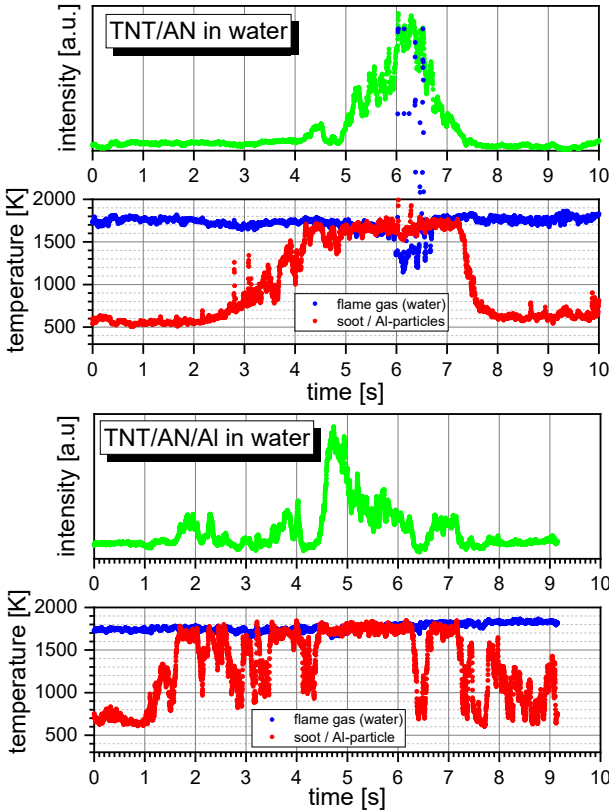
Combustion Tests

Results: Pool Fire Tests



flame temperature
(from burner, blue):
approx. 1750 K

temperature of the
explosive flame (red):
1700–1750 K



Burner ignition First water heats up to boiling small TNT-particles erupted from bubbling water burn immediately With further evaporation, TNT- and Al-particles rise to the surface and burn intense combustion when water has largely evaporated afterburning

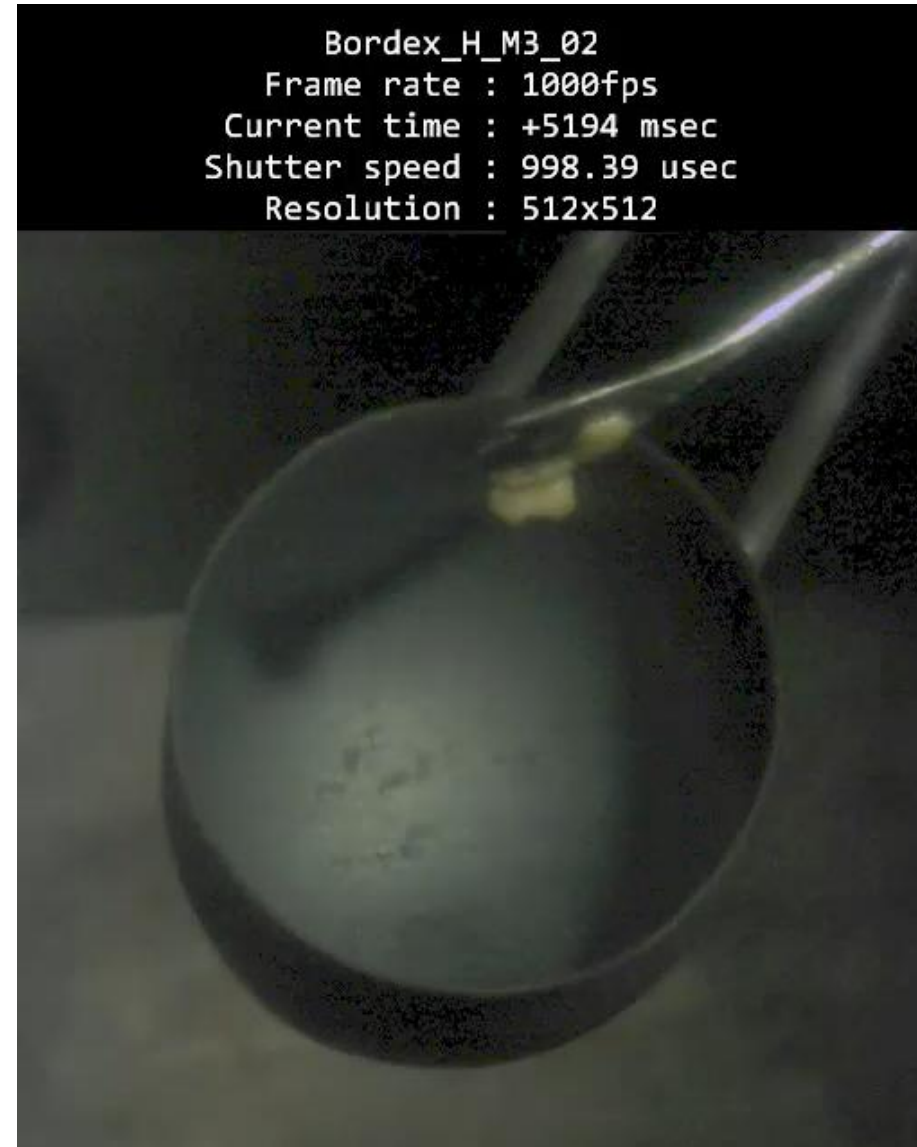


Combustion Tests

Tests using Leidenfrost phenomena

Questions on Combustion:

- *How does the droplet burn occur?*
- *How long does single particles burn?*



Conclusions

Limited prior experience with thermal disposal of explosive/water slurries. Small-scale experiments provide valuable insights into processing and combustion behavior.

Key Findings - Processing:

- Extremely fast sedimentation (within seconds), largely independent of processing parameters
- Critical stirrer speed is estimable and can be influenced by additives
- Unexpected foam formation caused by small hydrophobic TNT particles
- Foaming controllable through appropriate additive

Key Findings – Combustion:

- Combustion process initially governed by water evaporation (predictable)
- Subsequent rapid combustion of explosive particles (TNT, Al) on millisecond timescales
- AN decomposition occurs after complete evaporation at approx. 300–400 °C and has little effect on combustion in air.
- Combustion temperatures of 1700–1750 K for explosive particles in a combustion chamber at 800 °C

Contact

Volker Weiser

Energetic Systems (ES)

Tel. +49 721 4640-156

volker.weiser@ict.fraunhofer.de

Fraunhofer ICT

Joseph-von-Fraunhofer Str. 7

76327 Pfinztal

www.ict.fraunhofer.de

