

INVESTIGATIONS ON TECHNICAL ASPECTS OF THE THERMAL DISPOSAL OF DUMPED AMMUNITION AT SEA IN THE FORM OF SUSPENSION IN WATER

Volker Weiser, Evelin Roth, Philip Pietrek, Angelika Raab, Armin Kessler*

Fraunhofer Institut für Chemische Technologie (ICT)

Joseph-von-Fraunhofer-Straße 7, 76327 Pfinztal, Germany

**volker.weiser@ict.fraunhofer.de*

Extended Abstract

After the world wars, large quantities of unused ammunition were dumped in the sea. The slow decomposition of the ammunition and the release of energetic chemicals pose a risk to humans and the environment. International efforts are currently underway to safely and environmentally soundly recover and dispose of unexploded ordnance.

As part of the BorDEx project funded by the German government, a demonstration plant is being developed for the safe thermal disposal of the energetic components contained in ammunition. The project focuses on moored mines as an example. The main components include TNT, ammonium nitrate, aluminium particles accompanied by a variety of different fillers (e.g. "Schießwolle 39" [1]). For safety reasons, the aged ammunition is fed into the demonstrator as a finely ground particle suspension in water and burned at high temperatures in a liquid gas-fired combustion chamber. The process should be designed so that ground explosive particles smaller than 2 mm are suspended in a multiple excess of water. The material shall be injected into a combustion chamber, vaporized and burned at a temperature of 800 °C or higher assisted by fuel-fired burner.

Prior to plant design, laboratory studies examined stirring and sedimentation of a representative TNT/AN suspension in water (62 % TNT and 38 % AN combined with twice and three times the mass of water, particle sizes from <1 µm up to 2 mm). Various stirrer types and positions were tested in a 1-liter beaker with an inner diameter of 100 mm and a stirrer diameter of approximately 50 mm. The formation of the suspension was investigated at stirrer rotational velocities ranging from 60 rpm to 1000 rpm. A novel cinematographic measurement technique was developed to characterize the stirring and re-sedimentation process and to determine the critical stirring velocity required to achieve complete suspension (Figure 1).

Critical impeller velocities required for complete suspension were found to range from 240 to 360 rpm. The lowest critical stirring velocity was obtained when a pitched-blade impeller was positioned close to the surface of the settled solids. Using various engineering methods, attempts were made to estimate the critical velocities at the actual scale [2]. Once the stirrer is turned off, the suspension re-sediments within a few seconds.



Figure 1 Visualisation of the timeline of suspension formation through stirring and its sedimentation after switching off the impeller.

An unexpected process engineering issue arose from the formation of a stable foam during suspension preparation due to Pickering stabilization [3] of the finest hydrophobic TNT particles at air-water interfaces (Figure 2a). Adding less than 1% of a harmless defoaming additive both controlled foaming and reduced the critical stirring speed required to maintain the suspension by about 20% (Figure 2b).

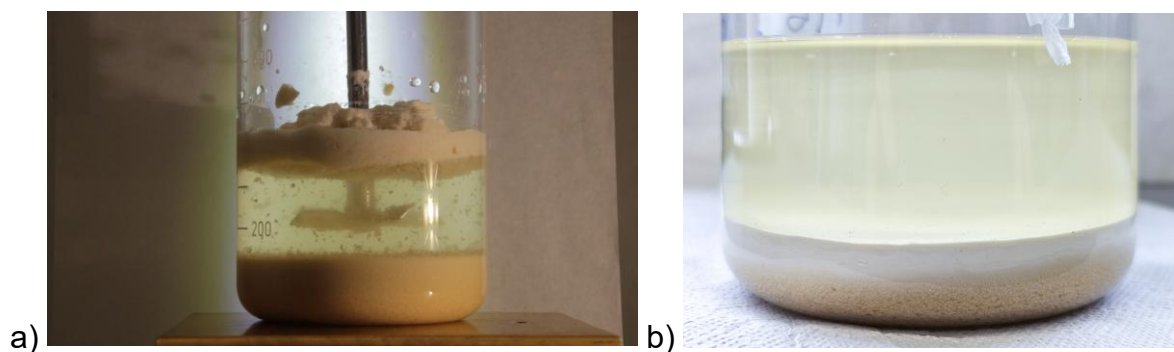


Figure 2 a) Foam formation by stirring the explosive suspension. b) sediment of finest TNT particles from Pickering foam using 1% organic defoaming additive.

In further studies, individual suspension droplets of TNT/AN in water with and without aluminium particles were burned at simulated combustion chamber temperatures of 600 to 800 °C to gain insights for the design of the combustion unit. Tiny amounts of the suspension were placed into a hemispherical, temperature-controlled container made of steel (diameter 35 mm) open to air heated with a Bunsen burner from below. Due to the Leidenfrost effect, hovering droplets are formed, which evaporate and burn. The time-resolved droplet formation and combustion were recorded with a high-speed camera. Parallel measurements with a fast emission spectrometer in the

wavelength range 300 to 2100 μm provided time-resolved temperatures of the container interior and the combustion gases [4].

The high-speed images show immediate droplet formation, followed by opacity due to the melting of TNT at 80 $^{\circ}\text{C}$ (Figure 3a). Black plumes of smoke form early near the droplets, presumably due to the pyrolysis of TNT in water vapor at the droplet surface. Continued heating causes bubbles to form, which burst and eject individual TNT particles that burn as bright flames within a few milliseconds with air (Figure 3b). In droplets with a high particle concentration, part of the TNT burns only after the water has completely evaporated, accompanied by intense soot formation and producing a bright yellow flame. Afterward, a white solid residue becomes visible, which melts rapidly and decomposes. This is presumably ammonium nitrate, which accumulates in the droplet and is heated to its melting point (169.9 $^{\circ}\text{C}$) and boiling with decomposition temperature (above 210 $^{\circ}\text{C}$) only after the water has evaporated [5].

These findings are contributing to the design and operation of the demonstration plant for the safe, controlled thermal disposal of obsolete ammunition in a water-based suspension.

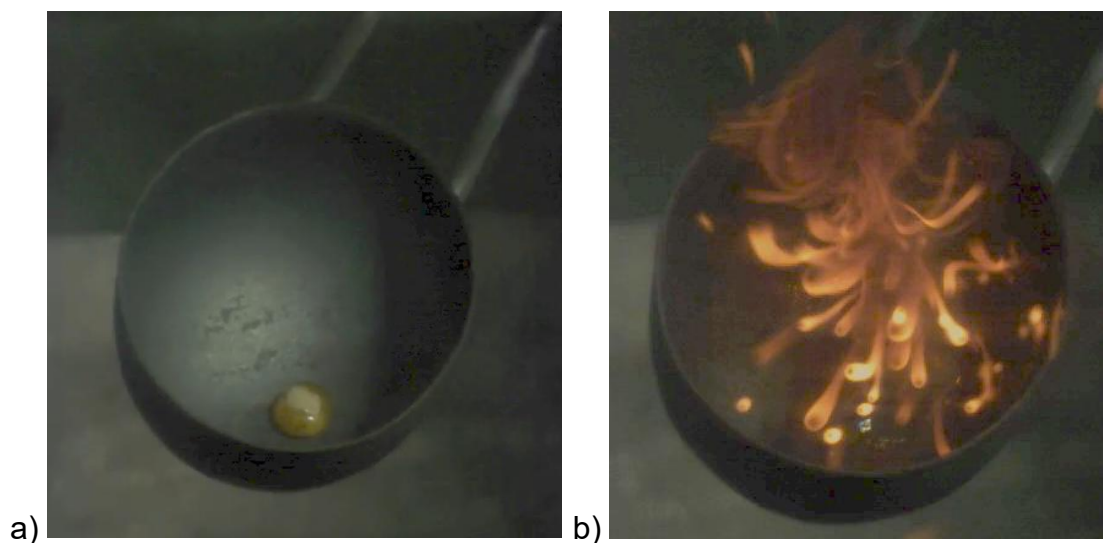


Figure 3 a) Hovering suspension droplet with partially molten TNT b) Burning TNT droplets ejected from a boiling drop of a suspension of ground ammunition particles in water.

References

- [1] Haas, R., Thieme, J.; Bestandsaufnahme von Rüstungsaltslast-verdachtsstandorten in der Bundesrepublik Deutschland, Band 2: Explosivstofflexikon. 2. erweiterte Auflage, 378 S. UBA-Texte 26/96; Umweltbundesamt, Berlin 1996

- [2] Stieß, M. Mechanische Verfahrenstechnik-Partikeltechnologie 1 (3. Aufl.), 2009
- [3] Binks, B. P., & Horozov, T. S. (Eds.). Colloidal Particles at Liquid Interfaces. Cambridge University Press, 2006
- [4] Weiser, V.; Eisenreich, N.; Fast emission spectroscopy for a better understanding of pyrotechnic combustion behaviour; Propellants, Explosives, Pyrotechnics 30, 67-78, 2005. DOI 10.1002/prep.200400087
- [5] Koch, E.-C.; High Explosives, Propellants, Pyrotechnics; Walter de Gruyter GmbH & Co KG; 2021