NUMERICAL STUDY ON SHOCKWAVE ATTENUATION BY WATER MIST IN CONFINED SPACES

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CONTENTS

Introduction

- Application scenarios of HFCVs can be anywhere of the existing conventional traffic infrastructure, such as underground carparks, traffic tunnels, underpasses, even maintenance shops
- In extreme accidental cases, hydrogen-air mixture may explode, producing pressure shockwaves in confined spaces like tunnels, and endangering safety of human life and properties
- Water intervention is a traditional safeguard for a fire emergency
- This study is to investigate the interaction between detonation shockwaves and injected water mist in a confined space

Shockwave attenuation mechanisms

- Momentum absorption

  molecule momentum → droplet motion onset (entrainment)

- Droplet breakup – kinetic energy absorption

  kinetic energy → surface energy of defragmented descendant droplets

- Heat absorption

  hot gases → cold liquid

- Wave reflection

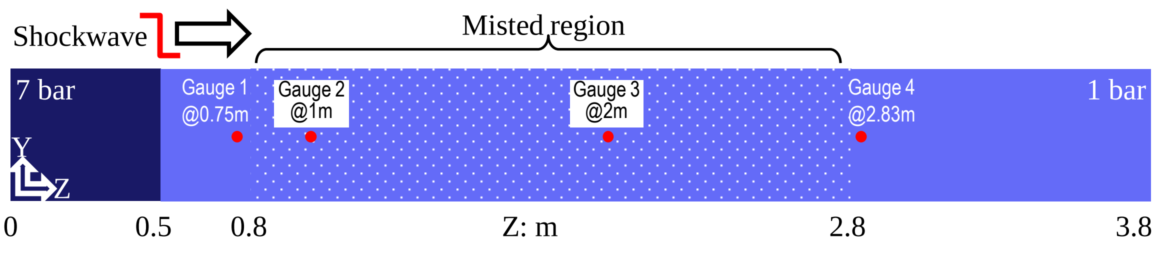
  shockwave hits on and is reflected partially on liquid droplet surfaces

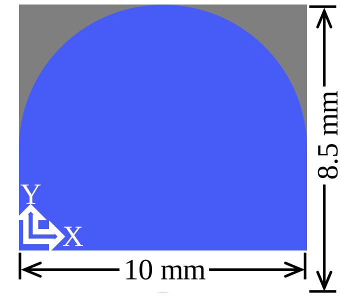
Model formulation and verification in code are presented in "ICHS2021 Paper ID 180" -

STUDY OF ATTENUATION EFFECT OF WATER DROPLETS ON SHOCKWAVES FROM HYDROGEN EXPLOSION, A. Kotchourko, et al.

Simulation of a mini-scaled tunnel

❑ Geometry and boundary conditions



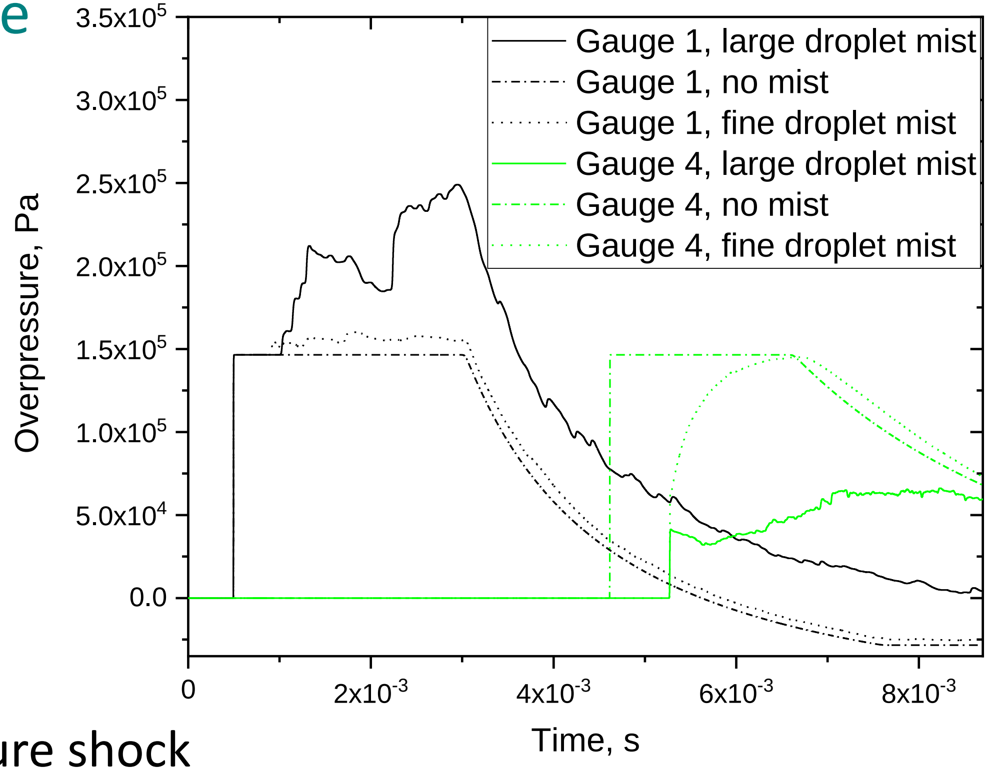


- 3.8 m long tube with a horse-shoe shape in 10 X 8.5 mm^2
- High pressure of 7 bar generates a shockwave in Ma ≈ 1.5
- Misted region: 0.8 – 2.8 m
- Pressure sensors @ 0.75 m (before mist), @2.83 m (after mist)
- Fine droplet: Φ120 µm, ρ 2 kg/m^3 and droplet number of 197,000
- Large droplet: Φ800 µm, ρ 40 kg/m^3 and droplet number of 13,280

- Total cell number: 2.6×10^6, with a uniformed ΔX = 0.5 mm

Simulation of a mini-scaled tunnel

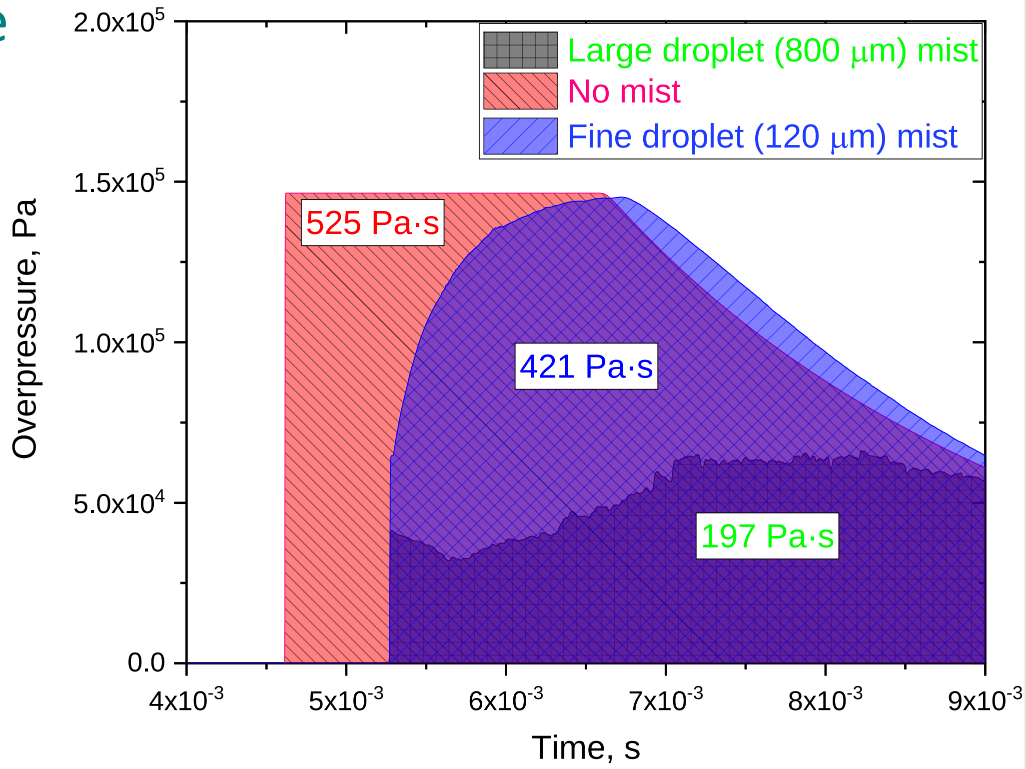
❑ Attenuation of peak overpressure



- ○ Shockwave 1.5 bar, 500 m/s
- ○ Shielding effect of mist against pressure shock
- ○ Shockwave reflection in case of large droplets
- ○ Shockwave attenuation: up to 50%
- ○ Shockwave deceleration: up to 12% (0.6 ms)

Simulation of a mini-scaled tunnel

❑ Attenuation of shockwave impulse

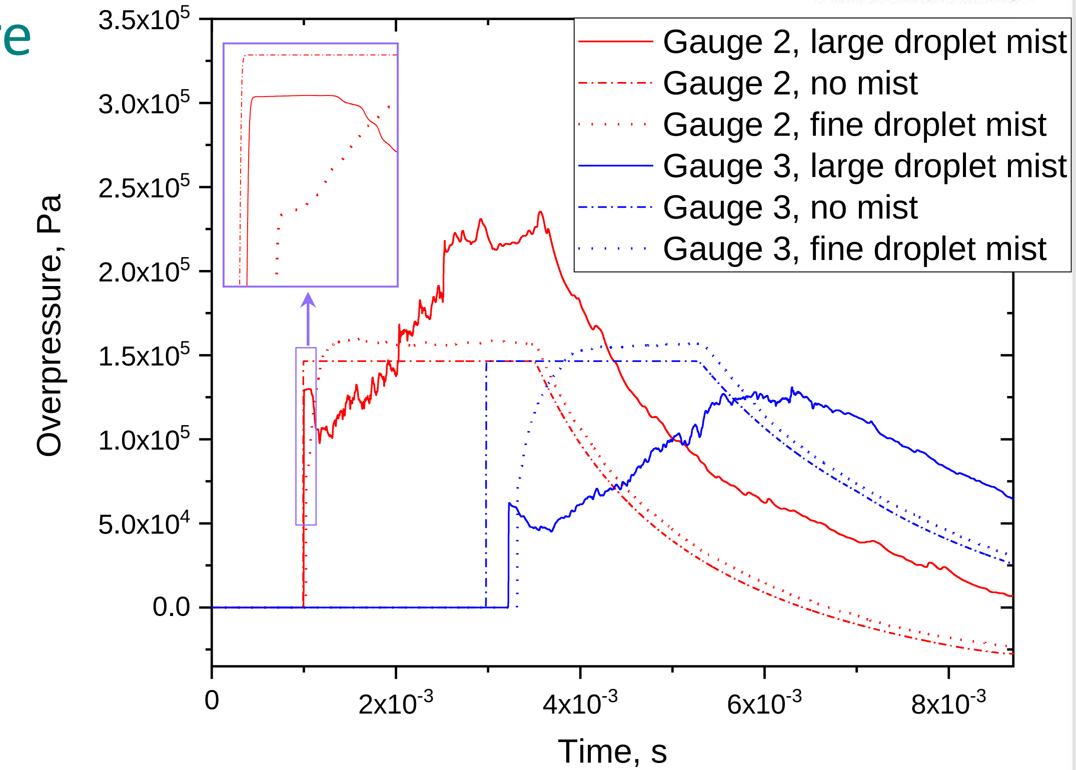


- Impulse – 2nd index of potential damage
- Original 525 Pas → 421 Pas by large droplets
- Original 525 Pas → 197 Pas by fine droplets

- Large droplet mist is better at SW attenuation than fine mist

Simulation of a mini-scaled tunnel

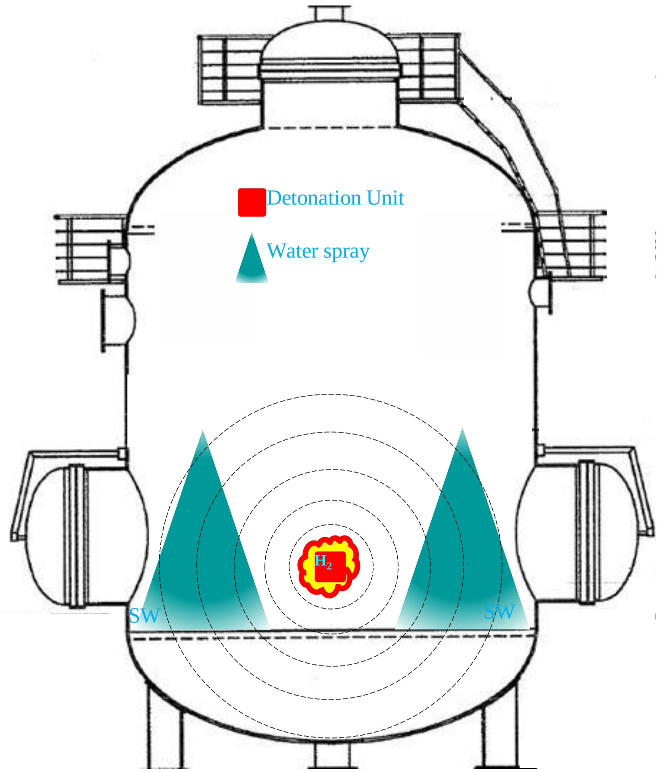
❑ Attenuation of peak overpressure

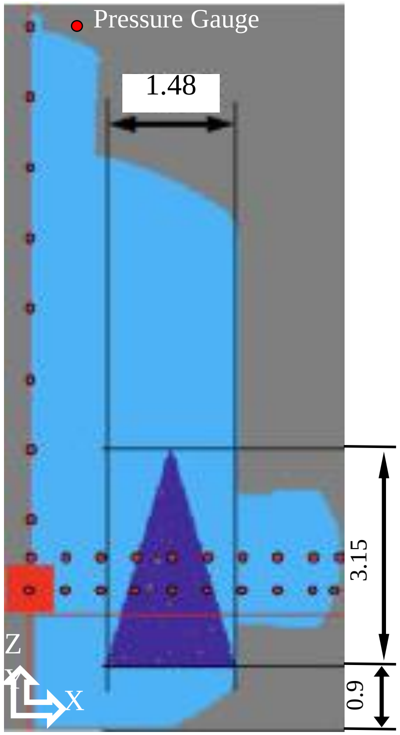


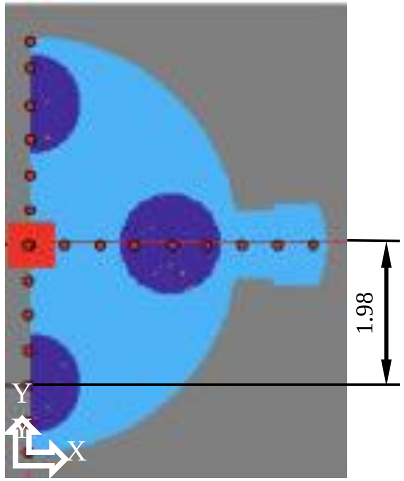
- Fine mist case: Front pressure decreases significantly, mostly due to momentum absorption at earlier stage; Front pressure stays at later stage, because droplet breakup barely occurs
- Coarse mist case: Pressure shock is attenuated mostly due to droplet breakup mechanism in the whole process

Simulation of a detonation facility with mist spray

❑ Detonation facility with spray







- A2 Vessel @ KIT: $V = 220\ m^3$
- Detonation of 4 g H_2
- Spray: H = 3.15 m; $R_{max} = 0.74$ m
- Droplet: Φ50 µm, ρ 1 kg/m^3 and droplet number of 2.76×10^7
- Total cell number: 1.82×10^6 (half domain), with a uniformed $\Delta X = 0.0435$ m

Simulation of a detonation facility with mist spray

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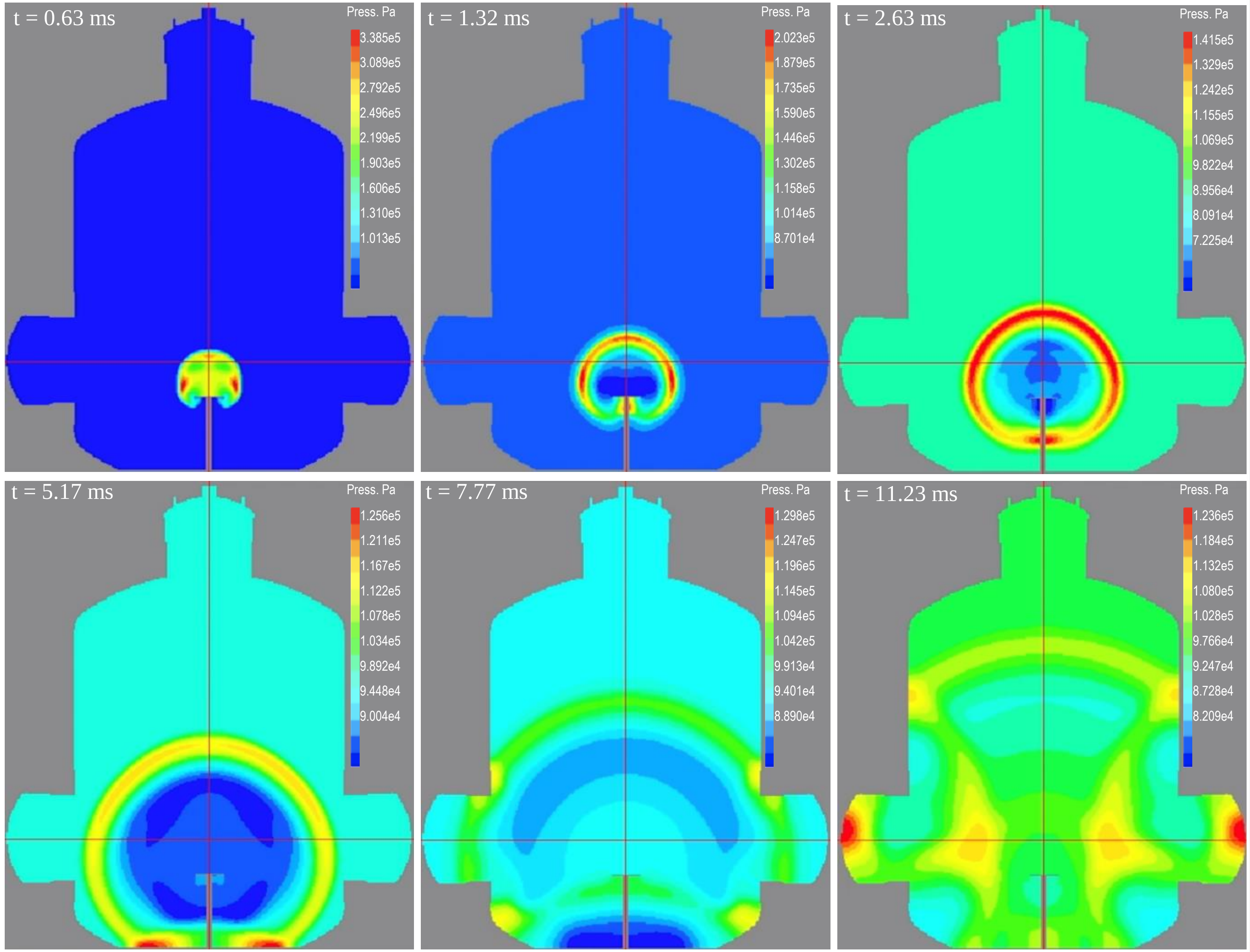
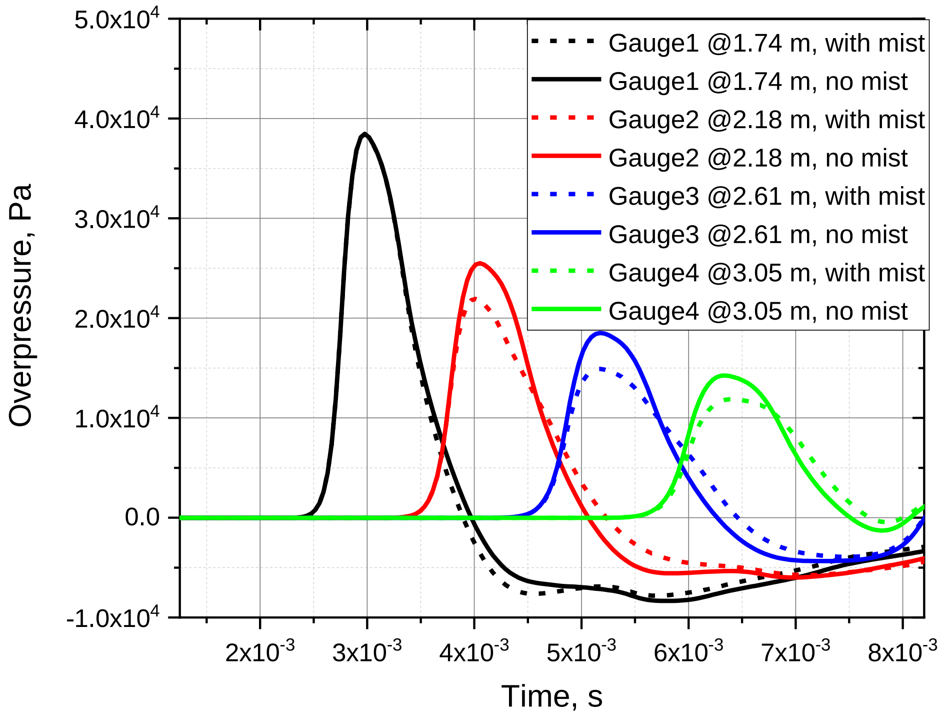
❑ Detonation without water intervention

- ○ P_{max} = 8 bar
- ○ T_{max} = 2000 K
- ○ Ma = 1.4



Simulation of a detonation facility with mist spray

❑ Detonation with spray



- Overpressure at Gauge 1 is not affected, which is outside of the water cloud
- Overpressures at Gauge 2,3,4 are deducted by 15 – 20 %, by the mist cloud
- Simulated shockwave speed is almost not affected by the cloud

- Shockwave attenuation effect is not as strong as the mini-channel case, perhaps due to the too coarse mesh for numerical calculations.

Conclusions

- *Shockwave attenuation mechanisms by liquid droplets are elaborated*
- *By using a turbulent combustion code with droplet models, the water mist attenuation phenomenon on shockwaves is studied by simulations in a conceptual mini-tunnel and an experimental facility in a large scale*
- *Attenuation effect of water mist on shock front pressures is observed in both cases*
- *The simulation results of the experimental facility supplies hints to design tests in laboratory. Further validation of the developed particle models is foreseen next step*

Acknowledgements

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