Pre-normative REsearch for Safe use of Liquid HYdrogen

Work Package 3 / Release & Mixing

GA meeting, 7-8 March 2019, Bergen
Alexandros Venetsanos (NCSRD)
WP3 / Modeling-Simulations

- CFD dispersion validation
  - SNL cryogenic tests (2018)
    - NCSRD, UU, AL
  - INERIS LHe releases (2001)
    - NCSRD, AL

- Two-phase choked flow modeling / validation
  - 0d
    - NCSRD (HEM, HNEM) against Simoneau and Hendricks (1979) data
  - 1d along discharge line
    - NCSRD (HEM, HRM, DEM) against Super Moby Dick data
  - 3d CFD
    - UWAR (HRMFoam) against Xu et al. (1995)
Deliverables

- D3.4 Summary of experiment series E3.1 (Discharge) results (PS, CO, m11) => delayed
- D3.1 Theory and Analysis of cryogenic hydrogen release and dispersion (NCSRD, PU, m18)
- D3.5 Summary of experiment series E3.4 (Pool) results (PS, CO, m19)
- D3.6 Summary of experiment series E3.5 (Rainout) results (HSL, CO, m22)
- D3.2 Computational investigation of cryogenic hydrogen release and dispersion (NCSRD, PU, m36)
- D3.3 Experimental investigation of cryogenic hydrogen release and dispersion (KIT, PU, m36)
D3.1 Theory and Analysis of cryogenic hydrogen release and dispersion

- Two-phase multicomponent flow and dispersion / mathematical closures
  - NCSRD, all

- Turbulence modeling in two phase flow multicomponent mixtures / droplet-particle effects
  - KIT, HSL

- Physical properties of H2 and two-phase multicomponent mixtures of H2 with air
  - NCSRD, UU

- Phase change / flashing / droplet-particle diameters
  - HSL, NCSRD, UWAR

- Cryogenic H2 release / source estimation / virtual nozzle approach
  - NCSRD, UU

- Cryogenic pool formation-evolution / mathematical closure
  - AL, KIT, NCSRD

- Ground heat transfer / mixed convection / boiling
  - HSL

- Effects of condensation / freezing of air components (O2, N2, H2O)
  - NCSRD

- Comparison between cryogenic H2 and other cryogenic substances (Helium, Natural gas)
  - NCSRD, HSL

- The similarity law for momentum dominated cryogenic jets for use in calculation of hazard distances for unignited releases of cryogenic hydrogen.
  - UU
CFD validation

- SANDIA cryogenic H2 releases (Hecht and Panda IJHE, 2018)
  - Tests shared within PRESLHY for benchmarking

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<th>$T_{\text{noz}}$ (K)</th>
<th>$p_{\text{noz}}$ (bar abs)</th>
<th>$d_{\text{noz}}$ (mm)</th>
<th>$n_{\text{heights}}$</th>
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- Preliminary CFD results NCSRD for test1: (58K, 2 bar, 1mm)
CFD validation

- SANDIA cryogenic h2 releases (Hecht and Panda IJHE, 2018)
  - NCSRD results
CFD validation

- INERIS large scale LHe releases on flat ground (Proust et. al 2001)
  - Tests 1 and 3 shared within PRESLHY for benchmarking.
  - Test 3 simulations by NCSRD on-going

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<th>duration (s)</th>
<th>Mass flow rate (kg/s)</th>
<th>Wind speed (m/s at 3 m height)</th>
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<th>Temp (°C)</th>
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<th>H2 (m)</th>
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$L$ the length of the cloud on the ground  
$H_1$ the height of the base of the cloud  
$H_2$ the height at the top of the cloud.
Two-phase choked flow

- 0d HNEM model (Venetsanos, IJHE 2018)
  - Validation against Simoneau and Hendricks (1979) tests

**NASA elliptical nozzle**

\[ \frac{G_e}{G_{cr}} / \frac{P_e - P_l}{P_{cr}} \]

\[ P_0 = 12.9 \text{ bar}, \ T_0 = 30.7 \text{ K} \]
Two-phase choked flow

- 1d simulation tool along discharge line
  - Solves 1d steady state pipe mass, momentum and energy equations using PIF algo
  - EoS based on free energy formulation.
  - Preliminary results against Super Moby Dick data (liquid water, 20bar, 212.3 C)
  - Models compared: HEM, HRM (Homogeneous Relaxation) and DEM (Delayed Equilibrium).