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Motivation

• Nuclear reactor accident
  – Hydrogen release in containment

• Simulation tasks:
  – Prediction of containment atmosphere mixing
  – Prediction of critical $H_2$ concentrations
  – Pressure build-up
MiniPanda Test Facility

H ≈ 2 [m]

D ≈ 1 [m]

Hot air

Ritterath, PSI (2011)
Geometry

- CAD geometry provided by Kelm et al. (2012)
Mesh Information

- ANSYS ICEM CFD
  - Structured hexahedral mesh

<table>
<thead>
<tr>
<th></th>
<th>Vessel1</th>
<th>Vessel2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>176,648</td>
<td>5,340,238</td>
</tr>
<tr>
<td>Nodes</td>
<td>184,603</td>
<td>4,039,603</td>
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<tr>
<td>Max. Aspect Ratio</td>
<td>59</td>
<td>834</td>
</tr>
<tr>
<td>Min. Grid Angle</td>
<td>37.3°</td>
<td>29.1°</td>
</tr>
<tr>
<td>Average $y^+$ ($t = 1500$ s)</td>
<td>-</td>
<td>0.767</td>
</tr>
</tbody>
</table>
Mesh Information
Mesh Information: Vessel2

Vessel 2

Injection Line Exit

Interconnecting Pipe
Mesh Information

Top view on plane $z = 0.8$ m

Vessel 1

Vessel 2

Injection Line
Initial Condition for He

\[ x_{He} = x_{He}(z) \]

\[ T = T(z) \]
Boundary Conditions

Outlet
P = 1 atm

Walls
No Slip
\( T_{wall}(t = 0, z) \)

Inlet
\( m_{air}(t), T_{air}(t) \)

Vessel 1

Vessel 2
Boundary Condition @Inlet

**MP1I_1**

\[ \dot{m}_{air} = 0.683 \, [g/s] \]

**MP1I_2**

\[ \dot{m}_{air} = 1.517 \, [g/s] \]

\[ \text{Re}_{inj} = 2350; \quad \text{Fr}_i = 0.7; \quad \text{Pe}_m = 530 \]

\[ \text{Re}_{inj} = 4400; \quad \text{Fr}_i = 1.3; \quad \text{Pe}_m = 990 \]

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MPII_2 has approximately the same inlet temperature curve
CFD Simulation Setup

- **URANS simulation**
  - 1800s real-time
  - Multicomponent fluid mixture
    → He as the constraint material
  - SST turbulence model
  - Buoyancy induced turbulence
    → production & dissipation
  - Kinematic diffusivity law for Air-He mixture

- **Time discretization:**
  2\textsuperscript{nd} order backward Euler

- **Advection scheme:**
  HiRes / 2\textsuperscript{nd} order upwind scheme
  1\textsuperscript{st} order for turbulence

- **Timestep:** \( \Delta t = 0.01s, \ldots, 0.05s \)
CFD Simulation Setup

• Main aim & difficulty of MiniPanda simulations:
  – Include all relevant physics
  – Ensure required accuracy of the CFD simulation (mesh & time resolution, convergence)
  – Reduce computational time as much as possible
  – Increase simulation time step as much as possible for a feasible advancement of the CFD simulation in real-time

• Due to this aim separate investigations had been carried out to determine:
  – Grid resolution
  – Residual targets (RMS vs. MAX)
  – Convergence criteria
  – Time step
Results MPII_1

The graph shows the comparison of experimental data and simulations using ANSYS CFX and ANSYS FLUENT. The x-axis represents time (t [s]) and the y-axis represents He volume fraction. The lines represent different simulations and experimental results for models KATH30, KATH26, KATH14, and KATH10.
Results MPII_1

$\text{t} = 0 \text{ [s]}$

$\text{t} = 250 \text{ [s]}$

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Results MPII_1

- t = 1000 [s]
- t = 1250 [s]

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Results MPII_1

ANSYS CFX

Experiment
Results MPII_2
Comparison MPII_1 / MPII_2

MPII_1

MPII_2

Temperature Experiment

Temperature Simulation

Vertical Velocity Simulation

Eddy Viscosity Ratio Simulation

t = 500 [s]
Conclusion

- CFD results in good agreement with He data
  - ANSYS CFD has the ability to predict the turbulent mixing and transport of He in density- and temperature-driven buoyant flows
  - Good agreement between ANSYS CFX and ANSYS Fluent
  - Physical modeling applicable to variation of MiniPanda test conditions, i.e. variation of Re, Fr and Pe numbers

- Agreement with temperature data less satisfactory
  - Uncertainties in experimental boundary conditions for injected air temperature
  - Uncertainties in thermal BC’s for vessel walls (heat capacity, heat flux)
  - better controlled experiment required
References


3. Ritterath, M. et.al.: MiniPanda – A small-scale-containment test facility with novel instrumentation is used for code validation for an air ingress scenario, NURETH-14, Toronto, Ontario, Canada, September 25-29, 2011
4. Studer, E. et.al.: Interaction of a light gas stratified layer with an air jet coming from below: Large scale experiments and scaling issues

