Development and Validation of CFD Methods for Nuclear Reactor Safety Assessment

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Development and Validation of CFD Methods for Nuclear Reactor Safety Assessment

- WP 1: CFD benchmarks on mixing and stratification
  - Participation in OECD/NEA benchmarks

- WP 2: CFD modeling of PPOOLEX experiments
  - Stratification of pressure suppression pool of BWR

- WP 3: OpenFOAM solver for nuclear reactor safety assessment
  - Development and validation of open-source CFD code
  - Co-operation of VTT, Aalto University, LUT, Fortum, KTH and other international partners

- WP 4: Coupled CFD-Apros simulations of NPP components
  - Two-way coupled calculation of steam generator
WP 1: CFD benchmarks on mixing and stratification:

OECD/NEA HYMERES
Panda HP1_6_2 benchmark

Risto Huhtanen
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OECD/NEA–PSI HYMERES Benchmark
Panda Test HP1_6_2

- **Motivation:** Stratification of hydrogen may be important in severe accidents.

- Erosion of density stratification in Panda-vessel
- Experimental arrangement by PSI in Switzerland
- International benchmark, blind simulation of the experiment
- Extensive post simulations in several steps
Computational grid and measuring points

Five cell levels:
Basic grid: 10 cm
Top of Vessel-1 and connection pipe sector of Vessel-2: 5 cm
Plume and connection pipe: 2.5 cm
Plume area: 1.25 cm
Injection pipe and plate: 0.625 cm

Number of cells: 2,872,435 (Blind)
Initial and boundary conditions

Helium [vol]
- Constant flow 58.4...61.2 g/s
- Steam 100%

Density [kg/m$^3$]
- Initial temperature 107 °C
- Steam injection temperature 107°C -> 151 °C
- Injected mixture is lighter than in the lower part, but heavier than in the top part of the vessel
- Constant pressure outlet about 1.3 bar
Used models and methods (Post simulation)

- The commercial code ANSYS Fluent version 16.2 was used.
- Turbulence was modelled with SST $k-\omega$ model, where turbulent buoyancy terms were added.
- Computational grid improvements, more cells (3.4 million).
- Radiation heat transfer was added.
- Injection pipe was included in the calculation.
Temperature
Conclusions

- k-ω SST turbulence model with added buoyancy terms seem to perform well in stratification modelling.
- The post-simulation shows essential improvement when radiation is taken into account.
- Increasing number of cells does not improve the results unless all relevant physical models are included (radiation in this case).
- Calculated temperature is too high already when the jet hits the plate (same result for all simulations).
- The velocity and temperature profiles in pipe exit was boundary condition in the blind simulation.
- In post simulation, the inflow pipe is included in the simulation domain.
WP 2: Simulation of PPOOLEX
sparger test SPA-T1

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PPOOLEX test facility at LUT

- Model of a BWR pressure suppression pool.
- Study of formation and breaking of thermal stratification.
- Experiment by Markku Puustinen, Jani Laine and Antti Räsänen (LUT).

Sparger submerged in the water pool.
Motivation: Thermal stratification reduces the capacity of the pressure suppression pool when it is acting as a heat sink.

In the experiment, steam is injected through a pipe into a pool with cold water (13°C)

Injection is done through 8 orifices (ø8 mm) around the pipe

In the stratification phase (13 650 s) steam flow is 30 g/s

In the mixing phase (1 240 s) steam flow is 123 g/s

In the calculation, it is assumed that steam is condensed when entering the pool, direct-contact condensation is not simulated

The mass, momentum and enthalpy of steam are added as a source term to the cells in front of the orifices
Temperature and velocity at the end of the stratification phase, $t = 13\,650\,s$

Temperature

Velocity
Development of temperature profile
Stratification 260 – 13 900 s, mixing 13 900 – 15 150 s
Temperature comparison, vertical Line 1

Stratification near the bottom is not strong enough

<table>
<thead>
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<th>Point</th>
<th>Height [m]</th>
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<tbody>
<tr>
<td>T4109</td>
<td>2.022</td>
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Conclusions

- Stratification of cold bottom part is mainly maintained in the first phase. However, there is too strong mixing in simulation during the stratification phase compared to experiments.
- This could be improved by refining the grid in the density gradient layer.
- The higher steam mass flow in mixing phase mixed the fluid in the simulation properly.
- Due to too effective mixing in the stratification phase, the thermal transient in mixing phase is mild.
- Heat loss to the environment has been taken into account. The influence is not large.
WP 3: OpenFOAM solver for nuclear reactor safety assessment

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WP3: OpenFOAM solver for NRS assessment

- Development and validation of open-source CFD solver in cooperation with national and international partners
- Modelling of Departure from Nucleate Boiling (VTT)
- Direct-contact condensation (LUT)
- Heat transfer in fuel rod bundles (Aalto, Fortum)

Available in the OpenFOAM Foundation development repository: https://github.com/OpenFOAM/OpenFOAM-dev
WP 4: Coupled CFD-Apros simulations of NPP components

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WP 4: CFD-Apros coupling

VVER-440 steam generator

Water level control

CFD

Pressure measurements

Heat transfer

Steam collector

Break Location

Steam

Feedwater

Feedwater

Emergency Feedwater

Hot Leg

Cold Leg