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Methodology Development for 3D Analysis of Spray Cooling in a NPP containment using OPENFOAM

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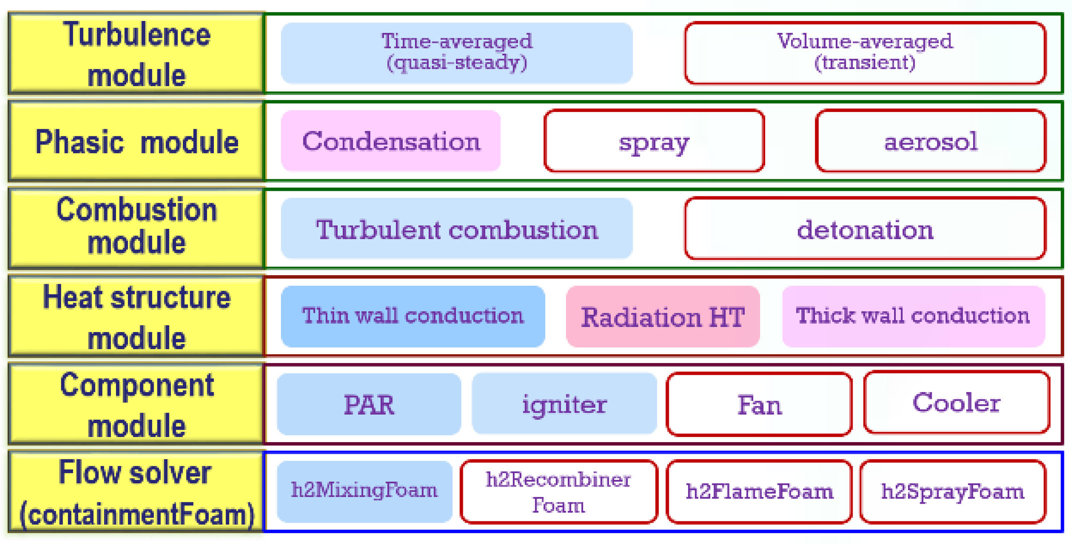
Introduction

Backgrounds & Objective

- Hydrogen behaviors during a severe accident in an NPP containment strongly depend on various phenomena. Implementation of all the models for each phenomena in a single code makes it complicated to run for long-term accident scenarios. Modularization of an analysis code is a commonly used technology to keep the code manageable. To resolve important phenomena by changing models and correlations, a conservative but best-estimate approach requires repeated simulations.



- A new analysis code is needed, which is cost-effective for heavy use and manageable for improvement and addition of numerical and physical models and correlations. Another important thing is a development of tools helping an analysis procedure to make a final conclusion of a hydrogen safety in a specific NPP.
- An analysis tool for hydrogen behavior in a containment is under development based on the OpenFOAM library.
- The present work concerns the interaction of an internal water spray used at the top of the containment in order to reduce the steam partial pressure, under air-steam mixtures conditions. The module for the simulation of spray cooling is under development based on the Euler-Euler approach using OpenFOAM. The module is validating by comparing the analysis results with TOSQAN experiment.

Development of numerical methods

Spray modeling

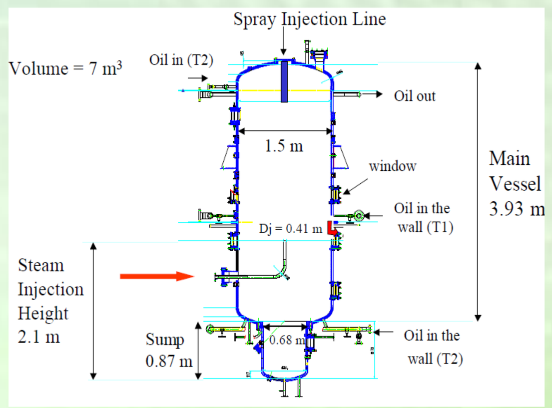
- , the gas and the liquid (droplet) phases are modelled with separate flow-field. The Euler equations of mass, momentum, energy can be employed for each phases. The gas and the dispersed droplet phases interact each other and exchange momentum, thermal energy and mass.
- We select **reactiongTwoPhaseEulerFoam** to evaluate the applicability to analysis of water spray system. The basic algorithm of the solvers is pressure-based semi-implicit method (SIMPLE and/or PISO) with non-staggered arrangement of variables on a computational mesh.
- The phase system is run time selectable and can optionally represent different types of momentum, heat and mass transfer. In this version, we select interfacecompositionPhaseChangeSystem in reacting TwoPhaseEulerFoam to consider interfacial heat and mass transfer between a number of phases according to an interface composition model. There are also several models for the interaction terms.

Benchmark problem

TOSQAN experiment & Initial information

- The TOSQAN experiment program have been created to simulate typical thermal hydraulic conditions representative of a severe accident in the reactor containment. The several spray tests were performed to analyze the heat and mass transfer between spray droplets and gas mixtures. **Test No. 101 is the reference test with air-steam mixture (A-S).**

	Initial gas mixture characteristics				Spray characteristics		
	Mixture	Tg (°C)	P (bar)	Xs	Qinj (g/s)	Tinj (°C)	D (µm)
Test 101	A-S	120	2.5	0.6	30	22~27	130
Input	A-s	120	2.5	0.6	30	25	150

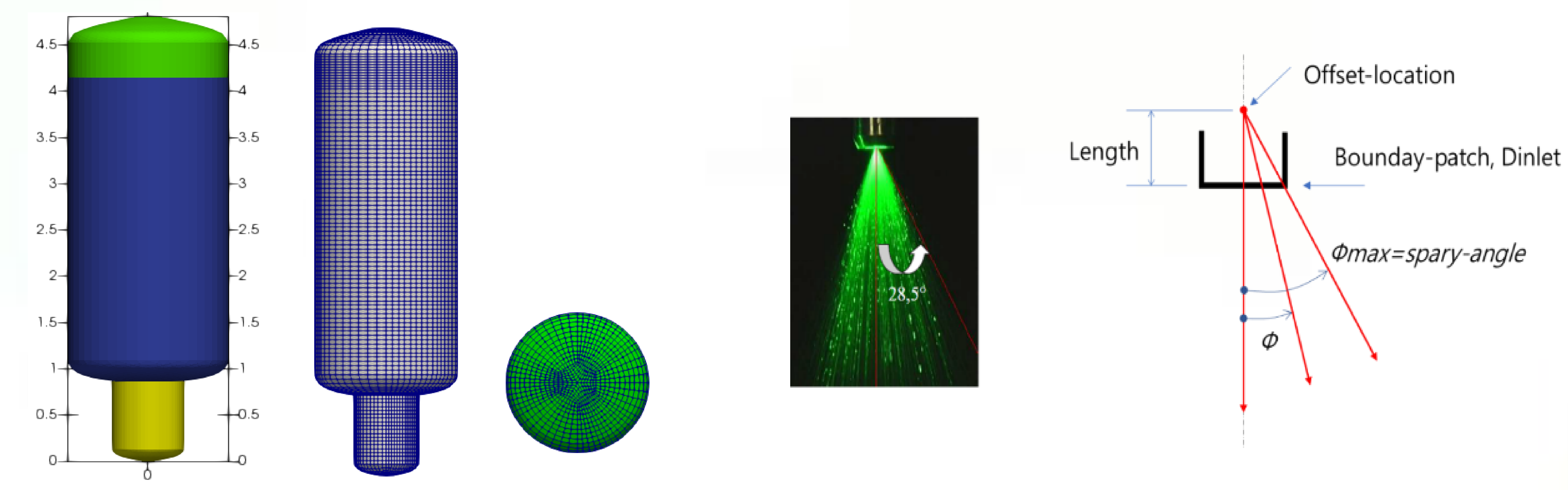


[4] E. Porcheron, et al., Nuclear Engineering and Design 237, 1862-1871 (2007)

Preliminary analysis

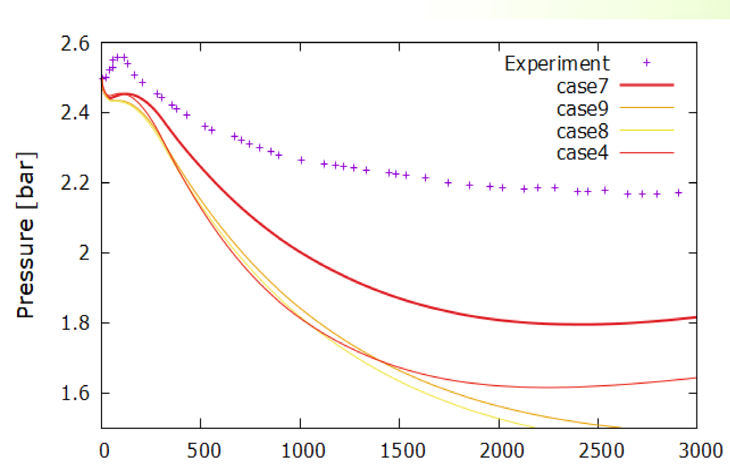
Preliminary analysis

- A 3D analysis computational model was developed.
- Based on the 3D CAD data of the TOSQAN, a 3D mesh was constructed using the SALOME
- In this Preliminary analysis, the number of cells are 58777 and the number of faces are 182257.



- The saturated model for the interface composition model, the spherical and frossling model for mass transfer model, and the alphatPhaseChangeJayatillekeWallFunction for the heat transfer at the wall were used..
- The preliminary analysis was performed to investigate the sensitivity of the major variables of the spray model and determine their values.
- The parameter conditions were summarized in table. 2. The droplet **velocity** is the spray droplet velocity at below 5 cm of the spray injection nozzle. **Cdt value** is a variable that controls the degree of spread of the sprays. As the Cdt value increase, the spreadability of the spray increases.

case	Droplet velocity	Cdt table	Spray angle
Unit	m/s	-	°
4	-5	1000	27.5
7	-0.5	100	27.5
8	-0.01	0	27.5
9	-0.01	100	27.5



- The thermo-dynamical global behavior concerns the pressure variation in the TOSQAN vessel.
- The figure is shown that as the increase in the droplet velocity and the spreadability of the spray, the pressure increases. The reason is that the contact between the droplet and the wall increases.
- The analysis results underestimate the experimental results. One of the reasons is the limitation of the water-droplet wall evaporation model. It is shown in the Ref.5 that considering the droplet-wall interaction predicts the experimental results better, and depending on whether the droplet-wall interaction effect is considered or not, the pressure differed by 20 to 46% on the analysis pressure.

Future work

- To take the droplet-wall interaction phenomena, a new grid near the wall will be constructed, and the wall heat transfer model at the wall is being modified. .

[5] J. Malet, P. Lemaitre, E. Porcheron, J. Vendel, A. Bentaib, W. Plumecocq, F. Dumay, Y.-C.Chin, M. Krause, L. Blumenfled, F. Dabbene, P. Royl, and J. Travis, Modelling of Sprays in Containment Applications: Results of the TOSQAN Spray Benchmark (Test 101), SARNET: FI6O-CT-2004-509065

Conclusions

- It is underway to develop a methodology for 3D analysis of spray cooling in NPP containment. The methodology is going to be developed by using OPENFOAM library.
- The preliminary analysis was performed to evaluate the applicability of reactingTwoPhaseEulerFoam in OpenFOAM to the spray cooling module based on the TOSQAN test No. 101.
- It was found that the wall-droplet interaction is one of the major parameter affecting on the prediction of the pressure in the spray cooling.
- In ongoing research, the mesh system and the wall heat transfer model will be modified to better simulate the wall-droplet heat transfer.

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