3-D Visualization of Data from Experiments and Lumped-Parameter Analyses about Containment Thermal Hydraulic Phenomena

Jongtae Kim [a*], Hyoung Tae Kim [a]
[a]*Thermal Hydraulics Severe Accident Research Division, KAERI, Daeduk-daero 989-111, Daejeon, Korea*
[*]*Corresponding author: ex-kjt@kaeri.re.kr*

1. Introduction

A containment of a nuclear power plant (NPP) plays an important role as a last physical barrier to prevent the release of the radioactive materials to the environment in an accident. During a severe accident in a NPP, many thermal hydraulic phenomena including hydrogen behaviors such as hydrogen distribution and combustion may occur in the containment. The containment thermal hydraulics is so important because understanding the thermal hydraulic phenomena during a severe accident is necessary to an accident management.

For years, methodology of post-processing and data visualization has been developed and used for analysis of thermal hydraulics in a nuclear reactor. In order to evaluate experiment data from discrete measurements of thermal hydraulic properties such as velocity, pressure, temperature, or species concentrations, x-y plotting is commonly used in the form of time or line variations of the data. This kind of local or point-wise evaluation is important to understand local characteristics and for quantitative comparisons. But it is still difficult to understand global characteristics and correlations of the thermal hydraulic phenomena by using the time-histories or point-wise distributions of the properties measured during experiments. Sometimes it is possible to measure and visualize velocity or temperature distributions in a specific surface or volume (field of view, FOV) in a test facility. But the test conditions and size of FOV are very limited.

Lumped-parameter (LP) codes such as MELCOR [1] and MAAP [2] are very useful to predict progression of a severe accident because they are fast-running on a PC and they include models and correlations for most of the severe accident phenomena. LP codes simulate evolution of accident phenomena on control volumes (CV) linked by flow paths. In most of analytical works, solutions of each CV are used in a form of CV-wise evolutions along time. So, it is believed that a methodology for a 3-dimensional visualization of data from measurement or LP analysis is useful for an inspection of a global characteristics of thermal hydraulic phenomena.

2. Modeling and Results

In this section a methodology to 3-dimensionally visualize the data from experiments or LP parameter analyses is described. And results from its application to visualize the data from a SPARC-PAR experiment [3] and a MELCOR analysis.

2.1 Methodology for 3-D visualization

In order to 3-dimensionally visualize the data from experiments or LP parameter analyses, a mapping method of solutions from a coarse mesh to a fine mesh is used, which is well applied in computational fluid dynamics (CFD). The data to be 3-dimensionally visualized are considered as solutions on a coarse mesh. Then the data can be easily mapped on a real mesh which is considered as a fine mesh. It is necessary to convert the experimental or LP data to a designed data format before mapping. The software tool for 3-D visualization is composed of a python program as pre-processor to convert data format and a C++ program to map the data to a real mesh and export solution to be visualized at user-specified time steps. Currently paraview [4] is used as a 3-D visualization software. Fig. 1 shows an example of a solution mapping from CVs for MELCOR analysis onto a real mesh.

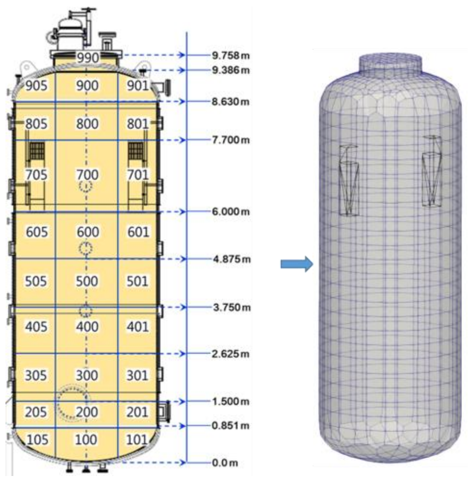

Fig. 1. Solution mapping for 3-D visualization

In the case of experimental data visualization, an excel data file made by a data acquisition system (DAS) is loaded by the python program and the program extracts user-specified data and exports them in the designed format. This procedure is called a pre-processing. A list of CVs to be used for the data conversion must be defined before the pre-processing.

The solution mapping program also needs a user input which is in the form as shown in Fig. 2.

```
wrinteInterval   20;
startTime        0;
endTime          5000;
fields (T H2);

H2
{
    dataFile        "constant/xH2.dat";
    probeLocations  14
    (
        (0    0        0.235)
        (0    0        2.27)
...
T
{
    dataFile        "constant/temp.dat";
    probeLocations  112
    (
        (0.0000 0.0000 1.2200 )
        (0.0000 0.0000 2.2700 )
```

Fig. 2. Input file for the mapping program

The mapping program is so generalized that it can accept different positions for different variables.

2.2 SPARC-PAR experiment

The SPARC-PAR experiment is a test to experimentally simulate a phenomenon of a hydrogen stratification induced by PAR activations. By the SPARC-PAR experiment, it was going to be verified that hydrogen might not move upward by hot exhaust gas of PARs accumulated in the upper part of a compartment.

Fig. 3 is a nominal plot of time-histories to show distribution of hydrogen concentration at measuring points along a vertical center line. In the test of SP5, hydrogen was released at a rate of 0.4 g/s during 1,100 s. It is possible to expect the occurrence of a hydrogen stratification by comparing the concentrations along the measuring points in Fig. 3. But it needs a great amount of effort to figure out a global structure of characteristic of a hydrogen stratification.

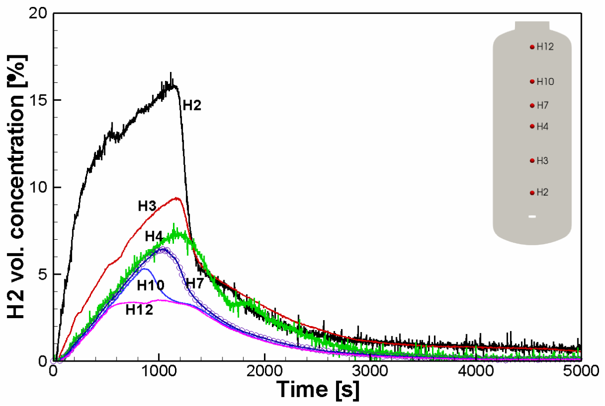

Fig. 3. Hydrogen concentrations along time at measuring points for SPARC-PAR SP5 test

On the contrary it is very intuitive to understand the global behaviors and a correlation between fields of temperature and hydrogen concentration varying along time as shown in Fig. 4.

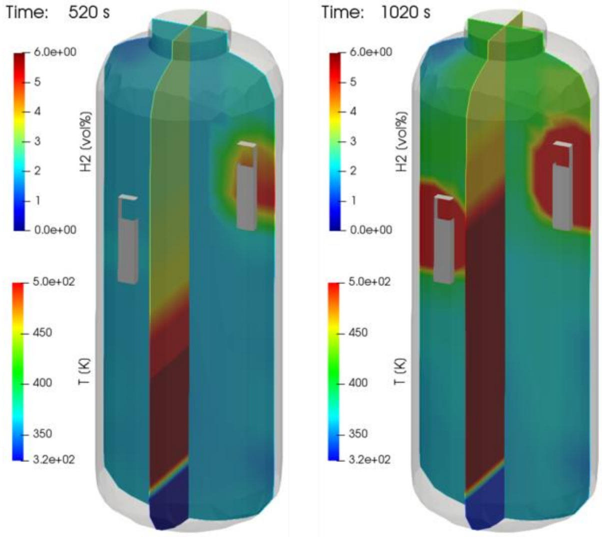

Fig. 4. 3-D visualization of hydrogen concentration and temperature measured from the SPARC-PAR SP5 experiment

2.3 MELCOR analysis

As mentioned above, MELCOR is one of LP codes to model a containment by several CVs linked by flow paths. During a simulation using MELCOR, it exports solutions on every CVs at user-specified time steps. Fig. 5 shows CVs nodalized for an MELCOR analysis of the SPARC-PAR experiment [5].

Normally the evolution of the solutions is plotted along the time of an accident progression for some interesting CVs. But sometimes it is difficult to understand containment-wise behaviors of interesting phenomena.

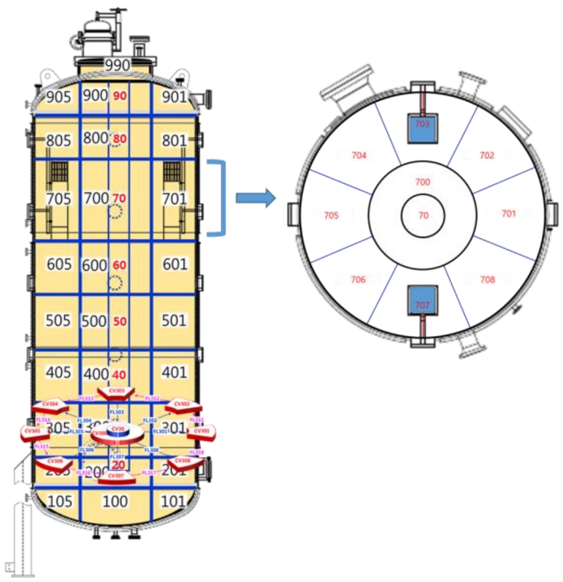

Fig. 5. MELCOR nodalization for an analysis of a SPARC-PAR experiment

Fig. 6 shows hydrogen distributions at 450 s and 1050 s from a MELCOR analysis of the SP2 test, where two PARs in a parallel configuration were installed in the SPARC test vessel. In order to 3-dimensionally visualize the MELCOR data, the software developed in this study and paraview were used. It is clearly seen that hydrogen is stratified in lower part of the SPARC vessel.

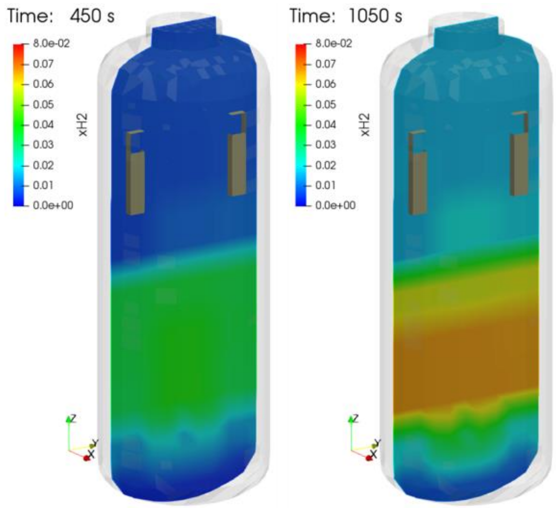

Fig. 6. 3-D visualization of MELCOR data of a SPARC-PAR experiment

3. Conclusions

A methodology and a software tool to 3-dimensionally visualize data from measurement or LP analysis was developed to support an inspection of a global characteristics of thermal hydraulic phenomena in a containment. And the methodology was applied for visualization of a SPARC-PAR experiment and a MELCOR analysis.

This methodology will be used to help understanding global behaviors of hydrogen distributions from MELCOR analysis of a severe accident in a NPP containment.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT) (No. 2017M2A8A4015277)

REFERENCES

[1] R.O. Gauntt, et al., MELCOR Computer Code Manuals, NUREG/CR-6119, SAND2001-0929P, 2001.
[2] Fauske et al., MAAP4 Modular Accident Analysis Program fir LWR Power Plants User’s Manual, EPRI Report RP3131-02, 1994
[3] Na, Y.S, et al., “Experimental Study on a Hydrogen Stratification Induced by Passive Autocatalytic Recombiners”, Korean Nuclear Society Autumn meeting, 2018.
[4] http://www.paraview.org, Kitware
[5] Kim, H.T. et al., “Development of a MELCOR Input for Hydrogen Experiments in the SPARC Test Facility”, Korean Nuclear Society Autumn meeting, 2018