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# The Need to introduce CFD Methodology in Analyze Hydrogen Distribution for Postulated Severe Accidents

Hanbee Na [a*], Jongkwang Lee [b], Sejin Kwon [c], Sukyung Park [a], Kyuntae Kim [a]
[a] *Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, Korea, 34142*
[b] *Hanbat National University, 125 Dongseo-daero, Yuseong-gu, Daejeon, Korea, 306-719*
[c] *Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon, Korea, 34141*
[*] *Corresponding author: hna@kins.re.kr*

## 1. Introduction

After Fukushima Nuclear Disaster, Korean government conducted a comprehensive special safety inspection to examine Korean NPP capabilities to cope with severe accidents, and some items for improvement like an installation of passive hydrogen removal equipment are identified [1]. To follow the government's policy, Korea Hydro & Nuclear Power Co. (KHNP) finished to install Passive Autocatalytic Recombiners (PAR) for all Korean Nuclear NPPs by 2015.

The regulatory requirements for combustible gas control systems in Korea is that mean hydrogen mole fraction shall be lower than 10 %, containment integrity shall be kept from combustion of hydrogen, and detonation and global fast turbulent combustion shall be avoided [2, 3].

KHNP provided some analysis which show hydrogen mole fraction is less than 10 % and detonation and global fast turbulence combustion are avoided for postulated severe accident events which covered over 90 % of CDF (core damage frequency) for each NPP [8].

The results were from MAAP code that can simulate from the initiation of the accidents to hydrogen distribution inside containments. It is a Lumped-Parameter codes in which the transport of energy and mass is possible in only predetermined one direction. Therefore, there has been a long-history dispute whether one-dimensional LP codes could simulate the transportation of hydrogen accurately.

For example, KHNP made a MAAP model to simulate hydrogen distribution in KSNP (Korean Standard Nuclear Plants), and the containment free volume is divided into 27 nodes in which it is assumed all the properties like each molecule mole fraction and temperate are uniform in each node. In addition, the maximum volume size of them is over 22,000 $m^3$, and it is not quite confident that the mole fraction of each molecules and temperature are uniform in the big size space.

As for the stress test results of the Wolsong 1, civil experts asked KHNP to conduct hydrogen distribution analysis using Computational Fluid Dynamics (CFD) methodology, and if needed to install hydrogen ignitors in Wolsong 1 NPP. As a reviewer for KHNP's post actions to the Stress Test, the author also asked KHNP to do CFD analysis of hydrogen distribution, and KHNP finally agreed to analyze it using CFD by 2017.

KHNP submitted a Shin-hanul 1 & 2 Operation License application in 2015, and the author also asked it to do CFD analysis to simulate hydrogen distribution for Shin-hanul 1 & 2. KINS also have a plan to perform CFD analysis of hydrogen analysis separately. Therefore, during Shin-hanul OL reviews, KINS and KHNP will do CFD hydrogen distribution analysis and to compare the results from the CFD and LP code, and they would conclude whether the validity of LP code like MAAP could well simulate hydrogen distribution during severe accident events.

This paper will introduce some LP and CFD codes which have been used or will be used for hydrogen distribution analysis in Korea, and compares pros and cons between LP and CFD methodology. Finally, the first step prototype calculation to see if CFD analysis is possible for hydrogen distribution will be shown.

## 2. Codes for Hydrogen Distribution Simulation

In this section codes for hydrogen distribution simulation for postulated severe accidents are introduce with simple explanation.

### *2.1 MELCOR*

MELCOR is developed by Sandia National Laboratories for US NRC, and it is considered a state-of-the-art code for SA modelling and analysis, and it has reached a reasonably high level of maturity over the years as evidenced from its wide acceptability and its abroad range of applications in regulatory decision support [5]. KINS used MELCOR to do a blind simulation on the hydrogen distribution for HM-2 problem of OCED-THAI project supported by OECD-NEA. [6, 7]

### *2.2 MAAP*

MAAP is an integrated severe accident simulation code which can compute hydrogen generation and predict the distribution of hydrogen inside of containments [8]. MAAP is developed by FAI and owned by EPRI, and it quantitatively predicts the evolution of a severe core damage accident starting from the initiation of the accident to the containment failure [5].

KHNP has used MAAP to design the number and the locations of PARs to meet the regulatory requirements, and Fig. 2 shows the node model for hydrogen distribution analysis of KSNP.

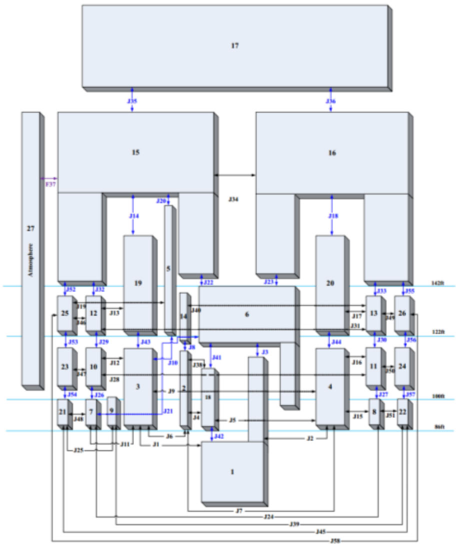

Fig. 1. The Node Model for KSNP to calculate Hydrogen distribution. [8]

*2.3 Gasflow*

Gasflow is developed by KIT and is a finite-volume code based on proven computational fluid dynamics methodology that solves the compressible Navier-Stokes equations for three-dimensional volumes in Cartesian or cylindrical coordinates [5]. This was used to do hydrogen distribution analysis of the APR1400 for the loss of coolant accident sequence by KAERI. Fig. 3 shows hydrogen cloud at 6200 second form the initiation [9].

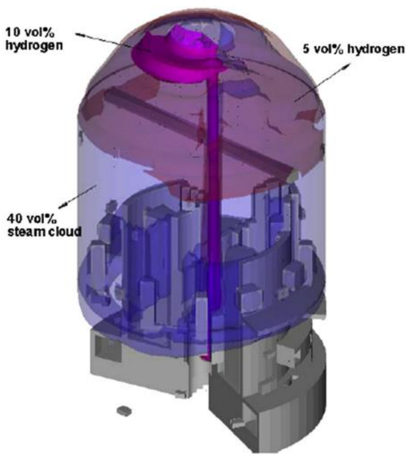


Fig. 3. Hydrogen cloud during the accident obtained by gasflow [9]

*2.4 Fluent*

Fluent is a commercial CFD code which is a general purpose CFD software package supplied by ANSYs, Inc. It is a state-of-the-art computer program for analyzing steady-state and transient flow and heat transfer problems in complex geometries [5].

This code has been chosen by the authors to perform hydrogen distribution for severe accidents, and currently as the early step to introduce CFD into hydrogen distribution analysis very short calculation for a very simple geometry was conducted to see if the availability of CFD.

## 3. Comparison between two methodologies

It has been a long-history dispute which LP code or CFD code is better or suitable to analyze hydrogen distribution in containments. LP codes such as MELCOR and MAAP usually divided containment into 10~30 nodes [10], and the calculation is proceeded under the assumption that all the properties such as hydrogen mole fraction and temperatures are uniform in each node. The advantage of LP codes is that the computational time is much shorter, so it's possible many postulated events and many sensitivity analysis can be conducted.

CFD codes such as FLUENT and Gasflow solves transport equations of fluid mechanics on local instantaneous scale [10] may divides the containment into up to millions nodes, so calculation time surely take a much longer time than that of LP codes. However, it could capture some phenomena like local accumulation of hydrogen which may hurt the integrity of containments.

Because two type the codes have pros and cons, so it is difficult to say which methodology is better than the other. Currently, the only LP codes are used in the design of combustible gas control systems in Korea, and the authors think that sole usage of analysis only from LP codes may lead to misjudgments. For examples, it is possible that the highly hydrogen accumulated cloud would exist somewhere in dome, however, LP code cannot predict these phenomena.

Therefore, the author has realized the need to introduce CFD methodology in hydrogen distribution analysis as a complementary measure to LP methodology and to check the validity of LP codes. As the first step, we calculated a very simple and short case to check the possibility to introduce CFD in SA hydrogen distribution analysis.

## 4. Demo Calculation of hydrogen distribution

As for the demo calculation for hydrogen distribution, we made a very simple geometry which consists of only one room whose size is 10 m X 8 m X 10 m. The geometry is shown in Fig. 4. There are two PARs in the room, and all hydrogen passing through them are assumed to be consumed and to produce some exothermic energy. There is a source location from which hydrogen and steam are generated at the rate of 0.5 kg/m3-s.

The calculations were conducted for the time step of 1, 2 and 4 seconds. The mass fraction of hydrogen and steam at 200, 400, 600 seconds for the three different time steps are shown in Fig. 5 and Fig 6, respectively. We could know that there is a little difference between time steps from the results, so it's possible to increase time step up to 4 second to reduce calculation time in hydrogen distribution analysis.

From these simple and short demo simulations, we could have some confidence that hydrogen distribution analysis in containments can be achieved by CFD methodology. Our future plan for CFD hydrogen simulation is to perform a severe accident analysis of Shin-hanul 1 and 2, and the results would be used to compare with MAAP results.

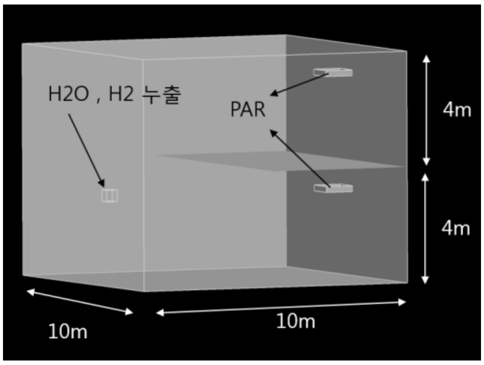


Fig. 4. Geometry for the CFD analysis of hydrogen distribution.

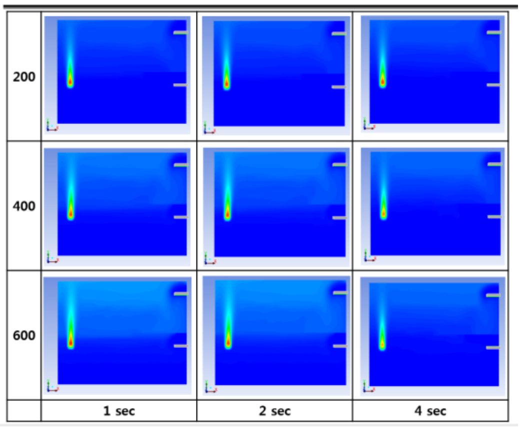


Fig. 5. Mass fraction of hydrogen for the time step of 1, 2 and 4 second

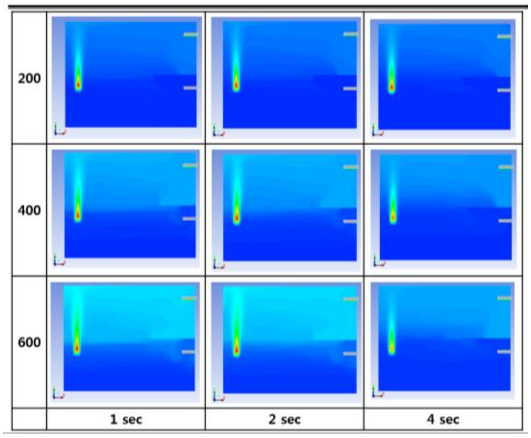


Fig. 5. Mass fraction of steam for the time step of 1, 2 and 4 second

## 5. Conclusions

Because LP codes like MAAP have some immanent disadvantages caused by the assumption that all properties are uniform in each cell, it may need to introduce CFD methodology as a complementary mean in predicting hydrogen distribution for SA in containments. KHNP decided to do CFD Analysis of Wolsong-1 by 2017 and promised to do it of Shin-hanul 1 and 2. KINS also have a separate plan to do CFD simulation of Shin-hanul 1 and 2. As for the first step, very short simulation for the simple geometry was conducted, and we have some confidence to do CFD analysis for Shin-hanul 1 & 2, and these would be crosschecked by MAAP results from KHNP.

## REFERENCES

[1] Policy Issue 0, Report of the Korean Government Response to the Fukushima Daiichi Nuclear Accident, 2011
[2] Standard Review Guide for PWR, KINS, Chap. 19, 2009
[3] Nuclear Safety and Security Commission Notification No. 2014-11, 2014
[4] The Verification Report on Wolsong 1 Stress Test, 2015
[5] NEA/CSNI/R(2014)8, Status Report on Hydrogen Management and Related Computer Codes, 2014
[6] KINS/RR-741, Development of Regulatory Assessment Technology for Safety Issues on Hydrogen Control of Shin-Wolsong 1,2 and Accident Management of Operating Plants, KINS, 2010
[7] S. Schwarz et al, Benchmark on Hydrogen Distribution in a Containment Based on the OECE-NEA THAI HM-2 Experiment, NURETH-13, Japan, Sep. 2009
[8] Severe Accident Hydrogen Safety Analysis Report for Youngkwang 5 and 6, KHNP and KEPCO E&C, 2012
[9] S. Hong et al, Research Efforts for the Resolution of Hydrogen Risk, Nucl Eng Technol Vol. 47, 33-46, 2015
[10] I. Kljenak, Lecture 2 Material, Hydrogen Risk during Severe Accident, 2015