A SIMULATION OF A STEAM CONCENTRATION IN A LARGE BULK SPACE BY USING THE MARS CODE

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1. INTRODUCTION
A steam jet flow injected into a large bulk space has been simulated by using the MARS code, an integrated best-estimate nuclear thermo-hydraulics analysis code (Jeong, et al., 1999).

PANDA facility consists of two large vessels connected by a horizontal pipe, as shown in Figure 1. Among the various series of PANDA tests, the condensation phenomena involved test9 and 9bis cases are selected and simulated by the MARS code. The whole vessel and the connecting pipe are modeled as a Cartesian multi-dimensional grid.

![Figure 1. The view of the PANDA test facility.](image)

Table 1. initial conditions for the test9 and 9bis.

<table>
<thead>
<tr>
<th></th>
<th>Pressure (bar)</th>
<th>Steam injection rate (g/s)</th>
<th>Steam temperature (°C)</th>
<th>Initial vessel air temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test9</td>
<td>1.3</td>
<td>14.01</td>
<td>136.0</td>
<td>108.0*</td>
</tr>
<tr>
<td>Test9bis</td>
<td>1.3</td>
<td>14.02</td>
<td>109.2</td>
<td>76.0*</td>
</tr>
</tbody>
</table>

*: nominal value.

2. MAIN RESULT
Figure 2 shows the MARS nodalization of the PANDA facility. Total 3415 multi-dimensional volumes are used. Figure 3 shows the outlet volume flow rate history for both tests. A qualitative difference between test9 and 9bis is detectable by the MARS calculations. For the 9bis case, experiment and simulation results coherently show an outlet vent flow rate decreasing behavior around 2,800 second.

![Figure 2. MARS nodalization of the PANDA facility](image)

![Figure 3. Comparisons of the vent volume flow rate.](image)

In addition to the vent volume flow rate, the vertical steam concentration profiles for both cases are compared with experimental data.

3. CONCLUSION
Through the assessment calculation, the MARS analysis capability for the multi-compartment space with non-condensible mixing and stratification is successfully validated.

REFERENCES
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keywords: multi-dimensional simulation, system code, MARS, steam concentration, PANDA

ABSTRACT
A steam jet flow injected into a large bulk space has been simulated by using the MARS code, an integrated best-estimate nuclear thermo-hydraulics analysis code. MARS code has been constructed by KAERI by a coupling and modernization of the RELAP5 and COBRA-TF codes. The multi-dimensional analysis capability of the MARS code has been assessed by comparing its results to the results of the OECD-SETH PANDA experiment.

PANDA facility consists of two large vessels connected by a horizontal pipe. The volume of a vessel is approximately 90 m³. A steam jet is injected into the vessel through a 0.153m diameter nozzle located at a middle height of the vessel. Among the various series of PANDA tests, the condensation phenomena involved tests are selected and simulated by the MARS code. The whole vessel and the connecting pipe are modeled as a Cartesian multi-dimensional grid. In spite of a few discrepancies and a restriction of the grid size, the MARS code results show a promising performance for predicting the temperature and steam concentration distributions in a large bulk space.

1. INTRODUCTION
From April 2001, OECD-SETH group launched the PANDA project with 15 member countries in order to provide an experimental data base for the multi-dimensional code assessment activities (G. Yadigaroglu, J. Dreier, 2002). OECD-SETH group expects the PANDA Project will meet the increasing needs of adequate experimental data for a 3D distribution of the relevant variables like the temperature, velocity and steam-air concentrations that are measured with a sufficient resolution and accuracy (O. Auban, et al., 2005). Several CFD codes and nuclear thermo-hydraulic codes are used to assess the PANDA experimental results. The main assessment objectives are to develop and validate the codes that will used to predict the gas concentration and stratification phenomena in a reactor containment of a LWR or a PWR power plant (G. Yadigaroglu, et al., 2002).

PANDA experiments are performed in the Paul Scherrer Institute (PSI) in Villigen, Switzerland. Figure 1 shows the perspective view of the PANDA facility.

The nuclear thermo-hydraulic safety analysis code MARS has been developed to have a multi-dimensional capability (B.D. Chung, et al., 2003). MARS code is originally based on the RELAP5 and COBRA-TF, which were developed by USNRC (J.-J. Jeong, et al., 1999).

Figure 1. The perspective view of the PANDA test facility.
In the extended 3-dimensional momentum equations, the convective terms are for the whole 3 directive velocities (S.W. Bae, et al., 2004). The energy equation is also modified to have a 3-dimensional energy convection.

PANDA experimental results data is used to conduct a validation of the MARS multi-dimensional capability. PANDA tests are categorized into 3 modes, i.e. the high momentum, near wall plume, and free plume tests with respect to the experimental scope.

Within the large vessel, a steam injection nozzle and an outlet vent are arranged for each test case. Among these tests, test 9 and the 9bis case which use a low speed horizontal steam jet flow have been simulated and investigated. Therefore, the important parameters are the steam concentration profiles in both vessels and the connection pipe.

2. PANDA FACILITY AND MARS MODELING
The main facility of the PANDA project is the two 4.0x8.0 m drywell(DW) vessels which are connected by a 1.0m diameter horizontal pipe. Total length of the inter-connection pipe(IP) is 5.0 m and it is curved with a right angle. The whole surface of the vessel and pipe are insulated and a negligible heat is emitted. The surface heat leak is modeled as 43.0 W/m$^2$ uniform. Valves and pipes are connected to supply and control the steam flow from the RPV (O. Auban, et al., 2005)  

Figure 2 shows a plane view of the MARS nodalization schematics for the two main vessels, DW1 and DW2, respectively. The grid size near the jet injection region is smaller than the other bulk regions. The vertical grid size is also designed to have a smaller length scale near a steam injection. The vertical node numbers are 20 and 15 for DW1 and DW2, respectively. The size of the vertical nodes is also adjusted to simulate a stratification of the steam injection region and an inter-compartment transportation.

Figure 2. The plane view of the two panda vessel nodalization schematics; DW1 and DW2

The vertical node number for IP is 2. Consequently, a total of 3415 multi-dimensional volumes are prepared and initial conditions are adequately assigned. Steam jet is injected through a 0.153 m diameter pipe horizontally connected at 1.8 m above the DW1 bottom level. The curvature of the connection pipe has been neglected. Figure 3 shows the MARS nodalization of the PANDA facility.

The main interest of the test9 and the 9bis tests is the effect of a condensation. As shown in table 1, the initial condition of the 9bis test is adjusted to create a condensation of a steam during the test period. In the experiment, the condensation is checked by the vent flow rate. The steam concentration profile in the connection pipe is also an interest for both tests.

MARS simulation is performed to verify the capability of figuring out the differences of both tests and the condensation effects of 9bis test. The problem time is set as 7000 seconds for both calculations.

Table 1. initial and boundary conditions for test9 and 9bis.

<table>
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3. RESULTS
The temperature and concentration profiles are compared between the experiment and calculation along profile lines V1, V2 and V3, as shown in Figure 4.

Figure 4. Schematics for the comparison line V1, V2 and V3.
In addition, steam concentration histories are compared between Test 9 and the 9bis tests at the upper IP position and vent position.

Figure 5. Comparisons of the vent volume flow rate.

Figure 5 shows the outlet volume flow rate history for both tests. A qualitative difference between test 9 and 9bis is detectable by the MARS calculations. For the 9bis case, experiment and simulation results coherently show a outlet vent flow rate decreasing behavior around 2,800 second.

Figure 6. The steam concentration history at the IP top position for both cases.

Figure 6 shows the steam concentration history at the top position of the connection pipe during an early stage of experiment period. In experiment, an abrupt appearance of steam is detected at around 100 second. MARS shows that the steam appears gradually at the top position of the connection pipe. The predicted steam concentration amounts show comparative differences. It can be understood that the vertical node number for IP is insufficient to predict the steam concentration stratification.

Figure 7. Steam concentration profile at DW1 for test 9.

Figure 7 and 8 show the vertical steam concentration profile of DW1 and DW2 for test 9. the molar fraction is normalized. In the DW2, the steam concentration prediction shows differences during an early period of the experiment but the differences are gradually decreased. Because the height of the injection pipe is different from the inter-connection pipe, steam concentration stratification fronts are created at different height for DW1 and DW2. In DW1, the steam concentration stratification front is located at 1.0 m beneath the injection pipe. A steam concentration remains rare at the bottom region beneath the inter-connection pipe in DW2.

Figure 9 and 10 are the vertical steam concentration profiles of the vessel for the Test 9bis. In Figure 9, note that the vessel bottom region concentration prediction shows a good agreement with the experiment. The steam concentration maintains a small quantity during an early period. But at 7,000 second, the steam concentrations for both the prediction and experiment show common
increasing behaviors. It can be interpreted that the steam concentration occurred in the bottom region of DW1 and a re-evaporation of the condensate liquid makes a steam rich condition after 2,900 second.

The concentration increasing behavior after 2,900 second is also found in Figure 10, the case of DW2. But in this case, MARS over-predicts the bottom region steam concentration. Note that a uniform heat leak assumption causes the bottom region wall temperature to be lower than the experiment in spite of the insulation. Thus for the condensation dominant spaces, the re-evaporation effect becomes strong.

Figure 9. Steam concentration profile at DW1 for test 9bis.

Figure 10. Steam concentration profile at DW2 for test 9bis.

4. CONCLUSION

The MARS code, which is consolidated code of the RELAP5 and the COBRA-TF, has been modified to have the multi-dimensional analysis capability.

A benchmark calculation of OECD-PANDA Test number 9 and the 9bis case have been carried out using the multi-dimensional component of the MARS code. The calculation results provide some meaningful spatial distributions and chronological trends for a steam concentration in an air filled bulk space. Especially, the MARS provides a good prediction capability to calculate the vent flow behavior to the condensation of steam.

ACKNOWLEDGEMENT

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