Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Feasibility study of gaseous material collection using CFD in the post-MSSV

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1. Introduction

When a severe accident occurs at a nuclear power plant, the leakage source of radioactive materials from the reactor core is as follows: 1) Leakage of the containment building 2) Steam generator tube rupture (SGTR) 3) Interface system loss of coolant accident (ISLOCA), etc. In the case of Leakage of the containment building, it is possible to prevent overpressure using containment filtered venting system (CFVS) technology. However, in the rare case of a containment bypass accident, there could be an external leak of radioactive material as there are no barriers beyond the CFVS to mitigate such releases, which poses a high risk to the public.

In a previous research on the reduction of radioactive releases, a radioactive material mitigation system was proposed [1,2]. From the bypass accident scenarios evaluated, the thermally-induced steam generator tube rupture (TI-SGTR) accident was selected as representatives and their release characteristics were analyzed [3]. When the main steam safety valve is opened, due to the accident, high pressure and flow rates occur. In order to reduce leakage in this situation, the behavior of the flow through the Main steam safety valve (MSSV) should be analyzed.

In this study, we evaluated the TI-SGTR accident for computational fluid dynamics (CFD) using a scenario where the gas passing through the MSSV enters a suction system, via a vent pipe. ANSYS Release 18.1 program [4] was used to model the vent and suction pipe, along with analyzing the flow in the vent pipe and suction pipe. In addition, structural safety was evaluated based on the stress to the suction pipe of the radioactive mitigation system.

2. CFD analysis preparation

2.1 Release characteristics

In severe accident scenarios, especially TI-SGTR, an analysis of release characteristics should be performed to confirm the mitigation system can be applied. Based on the literature, in the TI-SGTR scenario the core will start to melted after 3 hours [3]. Release of radioactive material can occur about 3 hours after the accident, with a flow rate of 4.8kg/s. After 15 minutes, the flow rate is reduced to 0.25 kg/s. Less than 0.1% of the total material released is radioactive and the rest is dry steam.

2.2 Modeling of vent pipe and suction pipe

When the MSSV is stuck open, gaseous materials are released. There is a narrow inlet pipe connected to vent pipe. The inlet gasses are then released to the environment through the vent pipe. To mitigate these releases, it is assumed that this gaseous material is captured/enters the mitigation system through the suction pipe (Fig, 1). The diameter of suction pipe is 0.75m and additional dimensions are shown in the Fig. 1. Although these dimension are not an exact match to those of a nuclear power plant (NPP), the analysis of this system is representative as all the components are similar to those in an actual NPP.

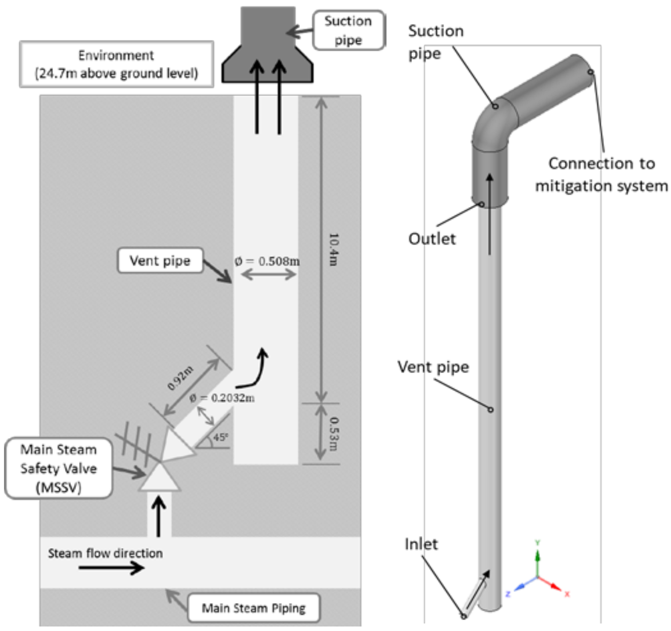

Fig. 1. Schematic of vent pipe and suction pipe model

For the CFD analysis, the ANSYS Release 18.1 was used and included 732,254 tetrahedral elements. The k-epsilon turbulence response model was applied with 5% of turbulence intensity. For the mechanical analysis, ANSYS Mechanical was used and model was made up of 126,282 hexahedral elements,

2.3 Boundary conditions

Inlet boundary conditions were then to release characteristics of the TI-SGTR scenario. The CFD analysis and Structural analysis were performed together using a one-way Fluid-Structure interaction. A summary of the boundary conditions is listed below:

(i) The inlet fluid is dry steam at 925Kelvin,
(ii) The inlet flow rate is 4.8kg/s (17.3 t/h),
(iii) The outlet absolute pressure is 1 bar,
(iv) The suction pipe material is 316 stainless steel and in an adiabatic condition.
(v) The end of the suction pipe is fixed.

3. Result and discussion

3.1 Fluid behavior in vent pipe

The flow from the vent pipe to the suction pipe was analyzed for the steady-state condition. The velocity and pressure distributions in the pipe were also examined. The velocity was 120m/s where the inlet connected to the vent pipe (Fig. 2). However, as the gas flows through the vent pipe, the velocity drops sharply to 50m/s or less. A velocity drop also occurred as the gases entered the suction pipe after being released from the vent pipe. The velocity dropped from 20m/s to 15m/s (Fig. 3). The trend in pressure changes were similar to those found in the velocity distributions. The largest pressure value near the inlet, decreased to less than 1% as it entered the vent pipe (Fig. 2). In the suction pipe, the pressure decreased through the curved section, where the pressure was 150 Pa or less (Fig. 3).

This study assumed the inlet pipe was connected to the vent pipe at a 45degrees angle. However, depending on the shape of the pipe, it can be expected that a higher velocity, pressure drop will occur.

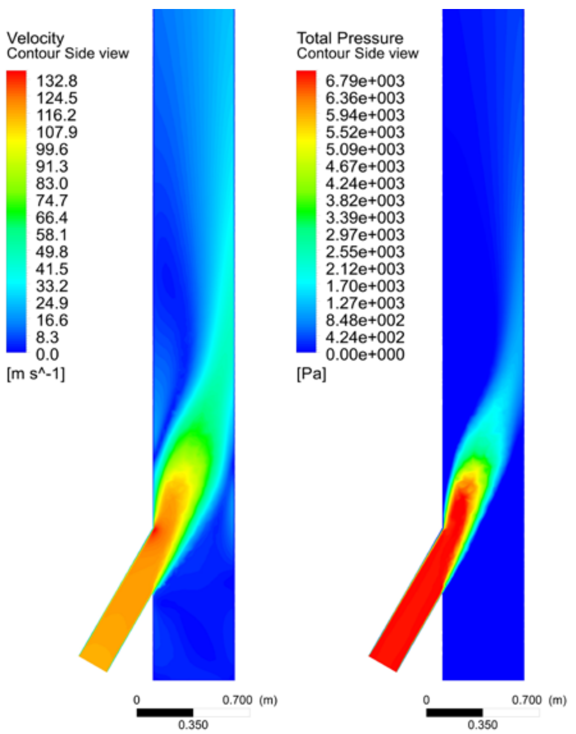

Fig. 2. Velocity and absolute pressure contour on cross section of vent pipe in response to inlet characteristics

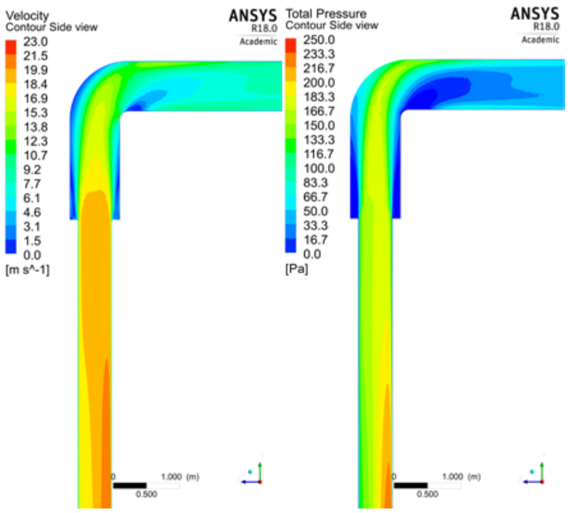

Fig. 3. Velocity and absolute pressure contour on cross section of suction pipe

3.2 Structural analysis of suction pipe

The characteristics of the gaseous material ejected through the vent pipe were confirmed through the previous CFD analysis. At these velocity and pressure conditions, the stability of the mitigation system structure was investigated to determine if the suction system could be maintained. As seen in Fig. 4 the largest deformation appeared at the support section of the suction pipe and at the curved section where gas collision occurred. However, the maximum equivalent strain value was actually as low as 0.002%. In addition, the maximum Von-mises stress was 4.5MPa, which was very small compared with the ultimate strength of suction pipe at 500MPa (Fig. 5).

Though there may be differences in velocity and pressure distribution, depending on the type of suction pipe, these results confirmed that the velocity and pressure were greatly reduced while the gases entered the vent pipe. This is significant because the actual fluid behavior is considerably different from that of the near safety valve.

Based on these result it is possible to successfully apply the suction pipe because the decreases in velocity and pressure expected will result in a small structural impact on the suction pipe itself.

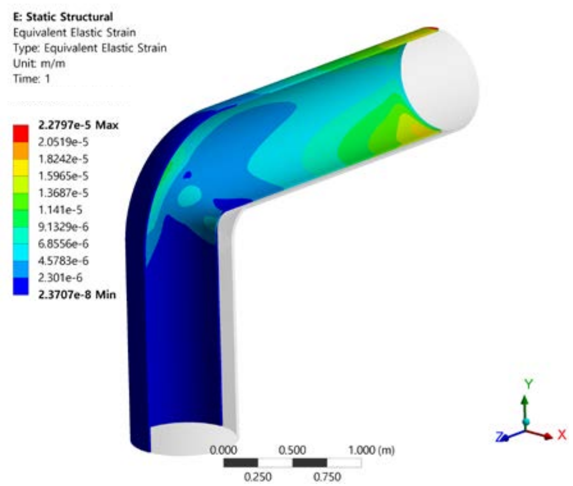

Fig. 4. Equivalent elastic strain distribution on suction pipe

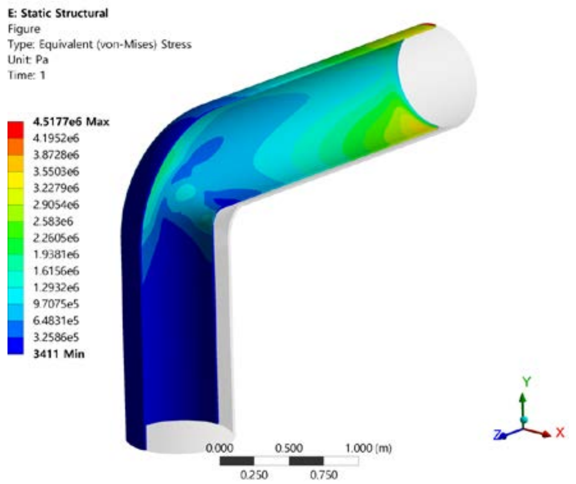

Fig. 5. Von-mises stress distribution on suction pipe

4. Conclusions

In this study, we investigated the feasibility of a mitigation system that minimizes leakage to the environment when radioactive gas release through the MSSV in a TI-SGTR accident scenario.

The results of this study are summarized as follows:

1) A CFD analysis for post-MSSV fluid in the vent pipe was performed and the fluid behavior into the suction pipe through the vent pipe was analyzed together. The maximum velocity and pressure at the inlet were observed but they dropped significantly when entering the vent pipe and suction pipe. Therefore, it was confirmed that there is a large difference between the fluid behavior immediately after safety valve and the fluid behavior when the gases are exhausted.

2) The largest Von-mises stresses and equivalent strains were found in the support and curved sections of the suction pipe, but the values were very small, 1% of the limit. Through this, it was confirmed that the exhausted flow had little effect on the structural safety of the suction pipe.

The simulation model used in this analysis is based on the system design presented in Fig. 1, which is similar, but different from the actual design found in NPPs. However to show that similar results can be obtained when using the actual NPP design, future work will use more accurate input values for the system design and the analysis will include the actual flow in the MSSV.

Acknowledgement

We would like to acknowledge the technical support from ANSYS Korea.

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