Conceptual Design of NaN₃ Inflator for Safety Injection Tanks

Gyunyoung Heo¹, Yong Hoon Jeong², Tae Mi Kim³

¹ Kyung Hee University, Seocheon-dong, Giheung-gu, Yongin-si, Gyeonggi-do, 446-701, Korea, gheo@khu.ac.kr
² Korea Advanced Institute of Science and Technology, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Korea

1. Introduction

Safety Injection Tanks (SITs) play an important role in mitigating the Loss of Coolant Accidents (LOCAs) in Nuclear Power Plants (NPPs). As a LOCA is identified, SITs pull the trigger in a passive manner and promptly supply the boric acid coolant to the core. OPR1000 has four SITs connected to reactor cold-legs, and APR1400 will take the advanced SITs with Fluidic Device (FD), which are directly connected to a reactor vessel. [1] We expect the capacity of the SITs is getting more important since water flow from SITs equipped with fluidic device during LBLOCA can replace the injection from low pressure injection pumps. [2] In designing such a large-capacity SIT, we have three troubles; 1) the excessively large plenum for pressurized N₂ gas, which is about 1/3 of total volume, 2) the difficulties maintaining initially high injection flowrate, and 3) the non-condensable N₂ gas in the coolant, which is about 0.72 g/kg-water at 40°C and 50 bar (~0.58 liter/liter-water at STP). This study proposes a conceptual idea of SITs which are pressurized by the chemical reaction of NaN₃ (Sodium Azide). In order to investigate the feasibility of the idea, we derived an analytical model to find the loading pattern and conducted performance simulation using MARS 3.0 to see the behavior of the SITs.

2. Methods and Results

2.1 Problem-Solving

We took advantage of Axiomatic Design (AD) as a way of finding a solution of the problem we pointed out in the introductory section. The essential benefit of using AD might enable us to find and concentrate on the ‘root-cause’ making trouble. On this subject, there are a lot of achievements in various fields. [3, 4]

We analyzed the Functional Requirements (FRs) and their Design Parameter (DPs) of a current SIT, and populated the Design Matrix (DM) in Equation (1).

\[
\begin{bmatrix}
FR_1 \\
FR_2 \\
FR_3
\end{bmatrix} = \begin{bmatrix}
X & X & \{DP_1\} \\
X & X \& \{DP_2\} \\
X & X \& \{DP_3\}
\end{bmatrix}
\]

(1)

Where

FR₁: Secure enough coolant inventory
FR₂: Provide injection force
FR₃: Secure the quality of the coolant (or Control the solubility of non-condensable gas in the coolant)

DP₁: Size of the SIT
DP₂: Pressurized N₂
DP₃: Solubility of N₂ in the coolant

The design of the current SIT is apparently a coupled design. The usage of N₂ (DP₂) for providing injection force (FR₁) affects the coolant inventory (FR₂), and the securing coolant inventory (FR₃) needs the reduction of N₂ (DP₂), which is contradictory to each other. The X in the DM is therefore the root-cause, and we should eliminate X to make the SIT decoupled. We attempted to lessen the effect of X by reducing the volume of N₂ gas as small as possible or making it zero.

2.2 Pressurization Mechanism

In Figure 1, the SIT we propose does not use pre-pressurized N₂, but take advantage of the chemical reaction of NaN₃. NaN₃ is normally used as an inflator of air-bags in vehicles. As a spark plug ignites NaN₃, it is decomposed into Na and N₂ gas in a few msec so that the pressure inside the tank increases. The DC battery which is charged by external electric sources applies the voltage to the spark plug. The triggering timing is controlled by the pressure of the tank inside. The setpoint of triggering spark plugs and the amount of NaN₃ determines the injection flowrate to a reactor core.

Figure 1. Concept of the SIT using NaN₃

The necessary high flowrate at the beginning from the SIT might be different plant-specifically as well as accident scenario-specifically. Assuming 90% of the SIT is filled with coolant, we simulated the performance of the SIT pressurized by NaN₃ using MARS 3.0. We also derived an analytical model in Equation (2) and (3) to determine the weight of NaN₃ and triggering timing, and coupled it with the simulation using MARS. We
referred all of the parameters used in the simulation to the data-book of APR1400. The chemical reaction of NaN$_3$ and the function of a FD were approximately modeled using a time dependent volume and energy loss coefficients, respectively.

$$n\dot{k}_{int,j} = A_{out} \left[ 2\left( \frac{\Delta P_j}{\rho} - gh \right) \frac{A_{in}^2}{A_{in}^2 + A_{out}^2} \right]$$ \hspace{1cm} (2)

$$P_{in,j} = \frac{nRT_{in}}{V_{in,j}}$$ \hspace{1cm} (3)

Where

- $n\dot{k}_{int,j}$: Discharged flowrate at time $t$
- $A_{out}$: Exit (discharge) area
- $A_{in}$: Inner area
- $\Delta P_j$: Differential pressure of in- and outside at time $t$
- $h_j$: Water level inside a SIT at time $t$
- $P_{in,j}$: Inside pressure at time $t$
- $V_{in,j}$: Volume of gas inside a SIT at time $t$
- $T_{j}$: Inside temperature

Table I shows the triggering timing and the weight of NaN$_3$ used.

<table>
<thead>
<tr>
<th>Seq</th>
<th>Time(s)</th>
<th>NaN$_3$(kg)</th>
<th>Seq</th>
<th>Time(s)</th>
<th>NaN$_3$(kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>350</td>
<td>6</td>
<td>45</td>
<td>210</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>90</td>
<td>7</td>
<td>72</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>110</td>
<td>8</td>
<td>104</td>
<td>300</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>140</td>
<td>9</td>
<td>142</td>
<td>360</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>170</td>
<td>10</td>
<td>187</td>
<td>400</td>
</tr>
</tbody>
</table>

Table 1. Triggering timing and weight of NaN$_3$

Figure 2 shows the flowrate distribution produced by MARS. The proposed SIT supplies the high flowrate of average 900kg/s over 30seconds. Injection is maintained for ~180seconds, which is ~30% longer than the injection time of conventional SITs.

2.3 Miscellaneous Considerations

The Na produced by the decomposition of NaN$_3$ should be able to actively react with water and fiercely release energy, which is undesirable. In order to prevent this reaction, NaN$_3$ should be mixed with KNO$_3$ and SiO$_2$. Considering these chemical compounds, the entire chemical reaction is as follows:

$$2\text{NaN}_3 \rightarrow 2\text{Na} + 3\text{N}_2$$
$$2\text{Na} + 2\text{KNO}_3 \rightarrow \text{K}_2\text{O} + \text{Na}_2\text{O} + \text{N}_2 + 2\text{O}_2$$
$$\text{K}_2\text{O} + \text{Na}_2\text{O} + \text{SiO}_2 \rightarrow \text{Alkaline Silicate}$$

Using the above chemical equations, we are able to determine the weight and volume of chemical compounds. For the simulation depicted, we could get the result in Table 2.

3. Conclusion

We attempted a conceptual design of the SIT pressurized by NaN$_3$ chemical reaction. We will proceed with the detailed theoretical backup and experiments for verifying the feasibility of the proposed idea.

REFERENCES

