Conceptual Design of NaN_3 Inflator for Safety Injection Tanks

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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 N_2 gas, which is about 1/3 of total volume, 2) the difficulties maintaining initially high injection flowrate, and 3) the non-condensable N_2 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 NaN_3 (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).

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & \overline{X} & \\ X & X & \\ & X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \tag{1}$$

Where
FR_1: Secure enough coolant inventory
FR_2: Provide injection force
FR_3: Secure the quality of the coolant (or Control the solubility of non-condensable gas in the coolant)
DP_1: Size of the SIT
DP_2: Pressurized N_2
DP_3: Solubility of N_2 in the coolant

The design of the current SIT is apparently a coupled design. The usage of N_2 (DP_2) for providing injection force (FR_2) affects the coolant inventory (FR_1) and the securing coolant inventory (FR_1) needs the reduction of N_2 (DP_2), which is contradictory to each other. The $\overline{X}$ in the DM is therefore the root-cause, and we should eliminate $\overline{X}$ to make the SIT decoupled. We attempted to lessen the effect of $\overline{X}$ by reducing the volume of N_2 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 N_2, but take advantage of the chemical reaction of NaN_3. NaN_3 is normally used as an inflator of air-bags in vehicles. As a spark plug ignites NaN_3, it is decomposed into Na and N_2 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 set-point of triggering spark plugs and the amount of NaN_3 determines the injection flowrate to a reactor core.

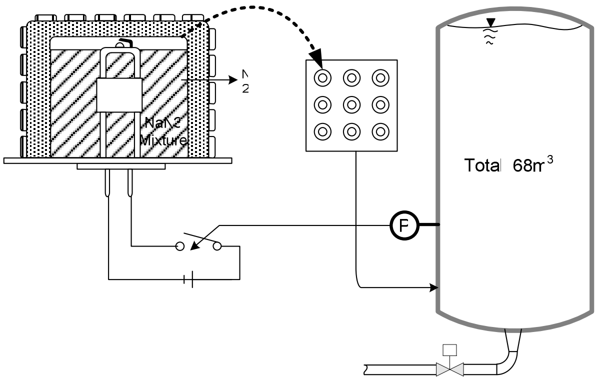

Figure 1. Concept of the SIT using NaN_3

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 NaN_3 using MARS 3.0. We also derived an analytical model in Equation (2) and (3) to determine the weight of NaN_3 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.

$$\dot{m}_{out,t} = A_{out}\sqrt{2\left\{\frac{\Delta P_t}{\rho} - gh_t\right\}\left\{\frac{A_{in}^2}{A_{in}^2 + A_{out}^2}\right\}} \quad (2)$$

$$P_{in,t} = \frac{nRT_{in}}{V_{in,t}} \quad (3)$$

Where

$\dot{m}_{out,t}$: Discharged flowrate at time t

A_{out} : Exit (discharge) area

A_{in} : Inner area

ΔP_t : Differential pressure of in- and outside at time t

h_t : Water level inside a SIT at time t

$P_{in,t}$: Inside pressure at time t

$V_{in,t}$: Volume of gas inside a SIT at time t

T_t : Inside temperature

Table I shows the triggering timing and the weight of NaN_3 used.

Table 1. Triggering timing and weight of NaN_3

Seq.	Time(s)	NaN_3(kg)	Seq	Time(s)	NaN_3(kg)
1	0	350	6	45	210
2	9	90	7	72	250
3	14	110	8	104	300
4	20	140	9	142	360
5	27	170	10	187	400

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:

$2NaN_3 \rightarrow 2Na + 3N_2$
$2Na+2KNO_3 \rightarrow K_2O + Na_2O + N_2 + 2O_2$
$K_2O + Na_2O + SiO_2 \rightarrow$ 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.

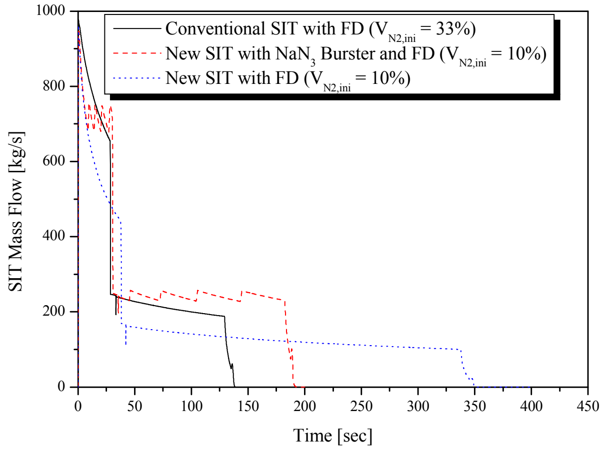

Figure 2. Mass flowrate from the SIT

Comparing with the volume of the N_2 plenum in the conventional SIT (23 m^3), we should be able to take the advantages of securing coolant inventory. Since there is no N_2 gas in the tank, it is favorable in reducing non-condensable gas in the coolant.

As a demerit, we anticipate the reliability related to the ignition of spark plugs, the peak pressure induced by chemical reactions, and the maintenance of the inflators.

Table 2. Required chemical compounds

	Weight (kg)	Volume (m^3)
NaN_3	2,380	1.30
KNO_3	7,520	3.60
SiO_2	1,110	0.50

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

[1] H.J. Chung, I.C. Chu, B.D. Kim, W.M. Park, C.H. Song, J.K. Park, Performance Evaluation of Passive Safety Injection Flow Controllers for the APR1400 Reactor, Proceedings of 10th International Conference on Nuclear Engineering, Arlington, USA, April 14-18, 2002.

[2] Korea Hydro & Nuclear Power Company, Standard Safety Analysis Report for Advanced Power Reactor 1400, Seoul, Korea, 2002.

[3] N.P. Suh, Axiomatic Design: Advances and Applications, Oxford University Press, New York, NY, USA, 2001.