

Analysis of Flashing Model Effects on Containment Pressure and Temperature According to Discharge Flow Energy States

Kum Ho Han, Soon-Joon Hong, Yeon-Jun Choo*

FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea

*Corresponding author: yjchoo@fnctech.com

***Keywords** : flashing, containment

1. Introduction

Containment safety analysis for Design Basis Accidents (DBAs) in nuclear power plants follows two main steps: Mass and Energy (ME) release analysis and containment Pressure and Temperature (PT) analysis. While ME analysis focuses on maximizing the release into the containment, PT analysis applies these release rates to predict the peak containment pressure and temperature under conservative assumptions.

To model the flashing phenomena of the discharge flow, codes like CONTEMPT-LT [1] and CAP provide flashing options. This study evaluates which flashing option—P-Flashing or T-Flashing—provides a more conservative result based on the specific energy state (enthalpy) of the discharge flow.

2. Flashing Option

During a loss-of-coolant accident (LOCA), when the fluid within the reactor coolant system is discharged into the containment, an instantaneous vaporization phenomenon known as "flashing" occurs due to rapid pressure changes. The CONTEMPT-LT and CAP codes, which are used for containment safety analysis, provide flashing options to account for this flashing phenomenon.

2.1 Flashing Option of CONTEMPT-LT

CONTEMPT-LT offers two flashing options: P Flashing and T Flashing. As shown in Eqs. (1)~(3), P Flashing separates the fluid entering the containment into liquid and steam phases. In this process, h_f and h_g represent the saturated liquid enthalpy and saturated steam enthalpy, respectively, corresponding to the total pressure of the containment. In contrast, T Flashing injects all discharged fluid into the containment atmosphere without a separate phase separation process. When T Flashing is applied, phase separation occurs based on the 100% relative humidity of the atmosphere.

$$x_{\text{flash}} = \frac{h_{\text{discharge}} - h_f}{h_g - h_f} \quad (1)$$

$$M_{\text{pool}} = (1 - x_{\text{flash}})M_{\text{discharge}} \quad (2)$$

$$M_{\text{stm}} = x_{\text{flash}}M_{\text{discharge}} \quad (3)$$

2.2 Flashing Option of CAP

The CAP code uses different terminology but includes options that correspond to those in CONTEMPT-LT. Specifically, it features Total Flashing and Partial Flashing options, which correspond to P Flashing, as well as a Flashing OFF option, which corresponds to T Flashing. Both Total Flashing and Partial Flashing separate the discharged fluid into liquid and steam phases according to Eqs. (1)~(3). However, while Total Flashing performs phase separation using the enthalpy corresponding to the total pressure of the containment, Partial Flashing performs the separation using the enthalpy corresponding to the partial pressure of the steam within the containment.

3. Problem Definition and Analysis Cases

To analyze the sensitivity of containment thermal-hydraulic behavior according to flashing options, a conceptual problem was developed by injecting discharge fluid into a conceptual containment. The conceptual containment has a free volume of 10,000 m³ and a height of 10 m. The initial conditions were set to a pressure of 1.0 bar, a temperature of 323.15 K, and a relative humidity of 0%.

Table I: Test Condition Description

Table I: Problem DescriptionCase	Discharge Flow [kg/s]	Enthalpy [kJ/kg]	Spray
1	100.0	3000.0	OFF
2	120.0	2500.0	
3	150.0	2000.0	
4	200.0	1500.0	
5	300.0	1000.0	
6	600.0	500.0	
11	100.0	3000.0	ON after 100 sec mass flow: 50 kg/s temperature 323.15 K
12	120.0	2500.0	
13	150.0	2000.0	
14	200.0	1500.0	
15	300.0	1000.0	
16	600.0	500.0	

The discharge flow and spray information are summarized in Table I. In Cases 1 through 6, no spray is injected, while in Cases 11 through 16, spray is injected starting from 100 seconds. In all cases, an

energy rate of 300 MJ per second is delivered to the containment by the discharge fluid. Case 1 and Case 11 represent cases where superheated steam is injected, while the remaining cases represent cases where two-phase fluid is injected.

4. Results and Discussion

4.1 Analysis of Transient Behavior for Two-Phase Fluid Injection (Cases 3 and 13)

Effect of Flashing Option: The P-Flashing model separates the discharge flow into liquid and steam immediately upon entry. Directly supplying saturated steam to the atmosphere, it causes a rapid rise in atmospheric temperature (Fig. 2) and pressure (Fig. 1). In contrast, T-Flashing assumes the entire discharge fluid is injected into the containment atmosphere and reaches thermal equilibrium. This process separates liquid and steam phases based on 100% relative humidity, resulting in lower initial temperatures and immediate 100% relative humidity (Fig. 3).

Effect of Spray System: Figs 4 through 6 illustrate Case 13 (Spray ON). Before spray initiation, the behavior matches Case 3. Following spray initiation, the containment atmosphere in the P-Flashing case transitions from a superheated to a saturated state, leading to thermal-hydraulic behaviors consistent with those of the T-Flashing case.

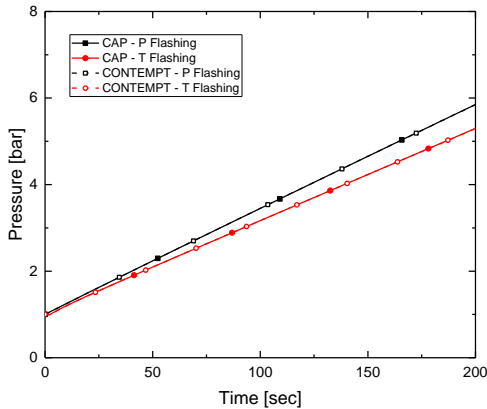


Fig. 1 Pressure behavior – Case 3

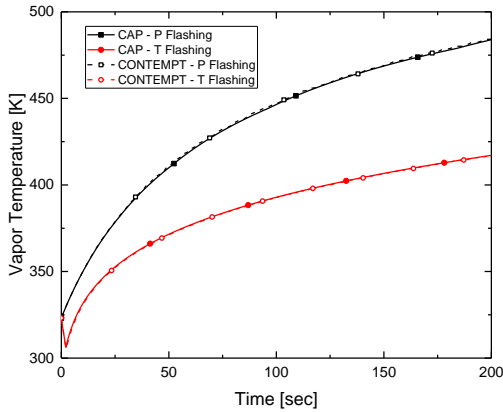


Fig. 2 Vapor Temperature behavior – Case 3

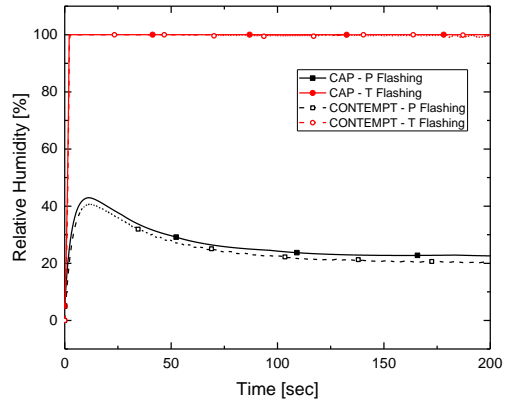


Fig. 3 Humidity behavior – Case 3

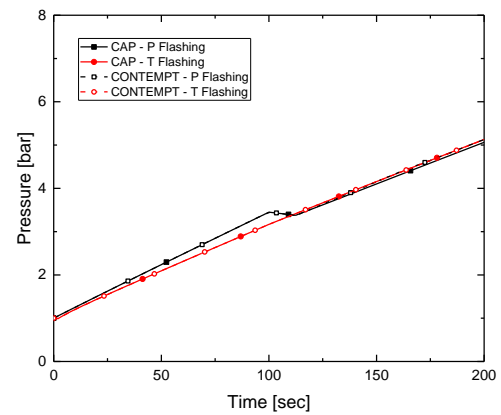


Fig. 4 Pressure behavior – Case 13

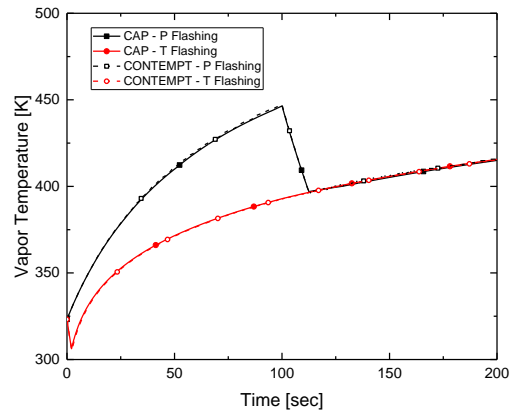


Fig. 5 Vapor Temperature behavior – Case 13

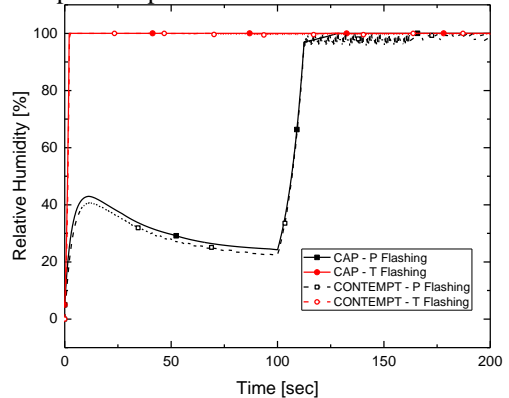


Fig. 6 Humidity behavior – Case 13

4.2 Sensitivity Analysis by Discharge Enthalpy without Spray (Cases 1-6)

In Case 1, where superheated steam ($h=3000$ kJ/kg) is injected, no significant difference was observed according to the flashing options. However, as the enthalpy decreases, it can be confirmed that the application of P-Flashing predicts higher pressure and temperature compared to T-Flashing (Figs. 7 & 8). Notably, under the low-enthalpy condition ($h=500$ kJ/kg), the pressure was predicted to be higher when T-Flashing was applied. This reversal phenomenon is attributed to the fact that while the relative humidity of the atmosphere is maintained at 100% when applying T-Flashing, even in low-enthalpy conditions, most of the injected flow is converted into the liquid phase when P-Flashing is applied.

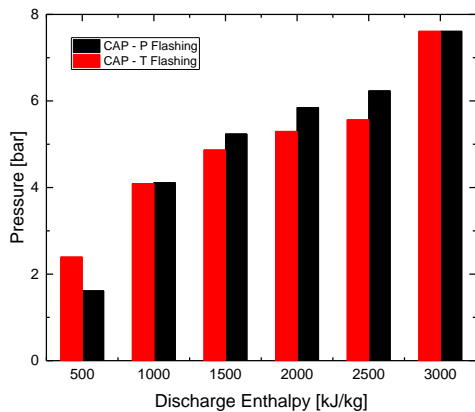


Fig. 7 Pressure sensitivity according to discharge enthalpy without spray

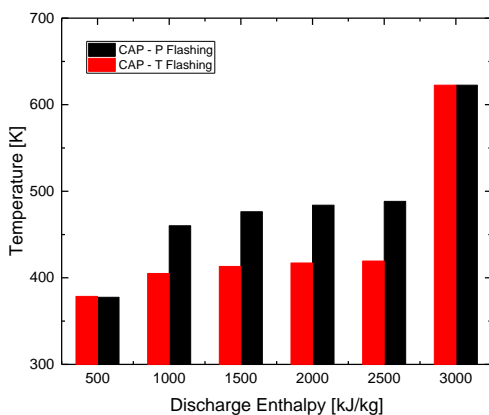


Fig. 8 Temperature sensitivity according to discharge enthalpy without spray

4.3 Sensitivity Analysis by Discharge Enthalpy with Spray (Cases 11-16)

In Cases 11 through 16, where the spray system is operated, it can be observed that the application of the T-Flashing option predicts higher pressure compared to P-Flashing, except for the superheated steam condition ($h=3000$ kJ/kg) (Fig. 9). In contrast to the pressure

behavior, the atmospheric temperature was predicted to be higher when the P-Flashing option was applied (Fig. 10).

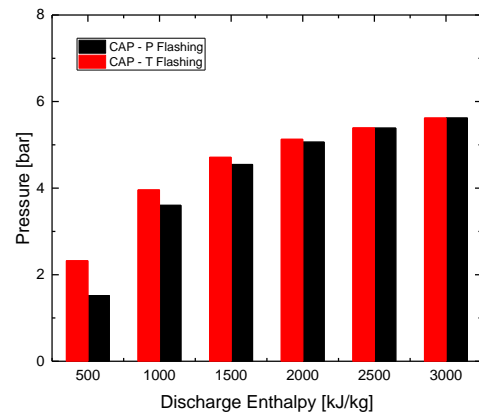


Fig. 9 Pressure sensitivity according to discharge enthalpy with spray

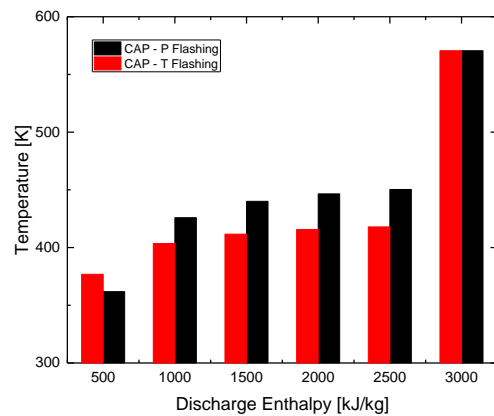


Fig. 10 Temperature sensitivity according to discharge enthalpy with spray

5. Conclusion

In this study, the effects of discharge flow enthalpy and flashing options on the pressure and temperature behavior of the containment were analyzed. When the spray system was not operated, the containment pressure and temperature were generally predicted to be higher when applying the P-Flashing option. Conversely, when the spray system was in operation, applying the T-Flashing option resulted in higher predicted pressure. Unlike the pressure behavior, the atmospheric temperature was still predicted to be higher when the P-Flashing option was applied.

In the containment pressure and temperature analysis of nuclear power plants, it is considered appropriate to apply P-Flashing for conservative analysis when the spray is not operating, while applying T-Flashing is deemed appropriate when the spray system is operational. Although the temperature predicted with T-Flashing is lower than that with the P-Flashing option, the temperature difference is expected to be

insignificant if passive heat sinks are considered, as in actual analysis.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT). (RS-2025-02653359)

REFERENCES

[1] Don W.Hargrove, CONTEMP-LT/028 NUREG CR0255 TREE-1279, 1979.