Analysis of PAR Performance Degradation due to Oxygen Starvation in PWR Using MAAP Code

HoonGoo Oh*, HyoungKi Kim
KEPCO E&C, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, Korea, 39660
**Corresponding author: hgo@kepco-enc.com*

1. Introduction

The potential failure of a Nuclear Power Plant (NPP) containment due to an energetic hydrogen has been a subject of concern for both nuclear regulatory and industry sides worldwide. The concern is that hydrogen, generated during a severe accident condition, could accumulate in the containment and subsequently ignite. To prevent hydrogen accumulation inside the containment, Passive Autocatalytic Recombiner (PAR), one of hydrogen control devices, is installed in generic Pressurized Water Reactor (PWR).

According to OECD/NEA Thermal- hydraulics, Hydrogen, Aerosols and Iodine (THAI) Project, degradation of PAR performance in oxygen starvation condition test was performed. As a result, the recombination rate of hydrogen falls below 50% of unimpaired PAR recombination rate depending on oxygen surplus factor defined as the stoichiometric O2:H2 ratio of 1:2 [1].

In this paper, it is examined for the PAR performance degradation due to the oxygen starvation effect on a NPP application.

2. Methods

In this section, the methodologies and assumptions for investigating the PAR performance degradation due to the oxygen starvation effect are described.

2.1 Analytical Model and selection of accident sequence

This paper uses a lumped parameter code of the MAAP code which is developed by FAI (Fauske & associate, LLC) to various severe accident phenomena.

The plant model parameter used for this analysis is Zion-like plant, which is a large dry PWR. The containment is set up as 11 compartments. In this analysis, one of the compartments which is upper cylinder compartment is selected to check hydrogen fraction until a severe accident proceeds. It is also assumed that the several PARs are installed in this compartment.

The accident scenario used for this analysis is the station blackout (SBO) sequence with pump seal Loss of Coolant Accident (LOCA) and hot leg creep rupture.

2.2 Applying to NPP (O2factor method)

According to the results of THAI project, oxygen surplus factor Φ (compared to the stoichiometric O2:H2 ratio of 1:2) related with PAR performance has been determined. The oxygen surplus factor Φ is defined as Eq (1).

$$\Phi = 2 \times \frac{c_{O2}}{c_{H2}} \qquad \text{Equation (1)}$$

$c_{O2} - Mole\ fraction\ of\ oxygen$
$c_{H2} - Mole\ fraction\ of\ hydrogen$

For unimpaired PAR performance, a minimum oxygen surplus factor between 2 and 3 is required. And also for smaller values of oxygen surplus factor, PAR efficiency and catalyst temperature drop drastically. In the case of oxygen surplus factor Φ = 1, the hydrogen recombination rate falls below 50% of unimpaired PAR recombination rate [1].

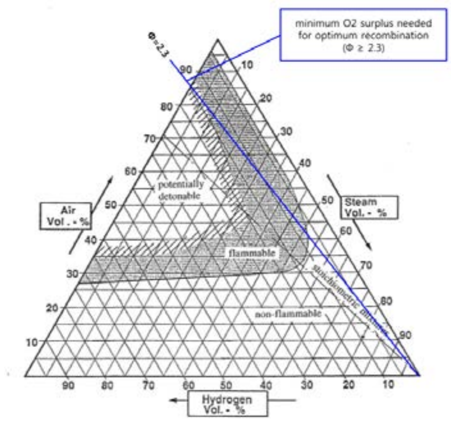

Fig. 1. Ternary diagram : minimum oxygen surplus needed for optimum recombination, resulting from THAI project HR test findings [1]

In order to conservatively and simplify apply the THAI project report to a NPP application, a model was developed to change the hydrogen recombination rate of PAR according to the oxygen surplus factor (Φ) as the following Eq (2).

Equation (2) : Define O2factor

$$\Phi \geq 2.3 \quad : \ \text{O2factor} = 1$$
$$1 \leq \Phi < 2.3 : \ \text{O2factor} = 0.5$$
$$\Phi < 1 \quad : \ \text{O2factor} = 0.25$$

We investigate the effect of the oxygen surplus factor (Φ) to the PAR hydrogen recombination rate and the conditions such as the mole fraction of hydrogen and oxygen at each compartment in MAAP.

3. Results

Fig.2. shows the hydrogen mole fraction in compartment (upper cylinder compartment) between the result of O2factor method case and the result of PAR full performance case. Firstly, analysis results of O2factor case show higher mole fraction of hydrogen than unimpaired PAR performance case. It means that degradation of PAR performance due to oxygen starvation was applied and thus hydrogen removal was reduced accordingly.

As shown in Fig.2, PAR performance begins to degrade when O2factor is less than 2.3. The time of O2factor equal to 2.3 is almost 20 hours after accident beginning and the mole fraction of hydrogen and oxygen at that point was less than 0.01. Although the degradation due to O2factor was applied, the effect was negligible since it was applied with hydrogen already removed sufficiently. And also the composition of the compartment atmosphere at degradation beginning time is the non-flammable state as shown in the Table I and Fig.3.

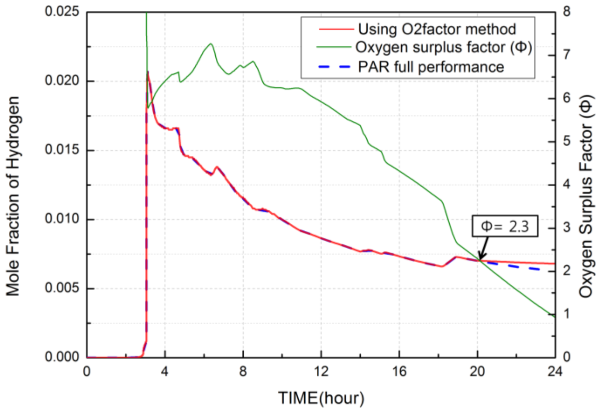

Fig. 2. Hydrogen mole fraction in upper cylinder compartment and Oxygen surplus factor of O2factor method case

Table I: Mole fraction of oxygen, hydrogen and steam in upper cylinder compartment at $\Phi = 2.3$

Oxygen	Hydrogen	Steam
0.008	0.007	0.728

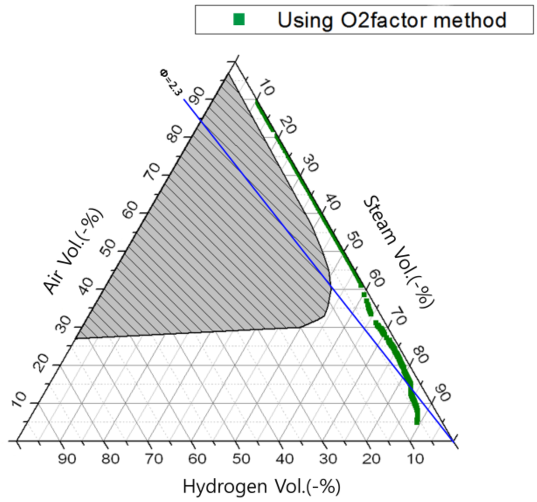

Fig.3. Ternary diagram of O2factor method case

4. Conclusions

During severe accident in PWR, hydrogen can accumulate in the containment and subsequently ignite. PAR, hydrogen mitigation feature, can remove hydrogen by recombination action but it is necessary to examine the negative effect on the hydrogen recombination rate of PAR such as the oxygen starvation.

Using the MAAP code, we confirmed the degradation of the PAR performance due to oxygen starvation during the severe accident in PWR using THAI project report methodologies. As mentioned above, it is already non-flammable state when degradation is beginning. In other words, even if considering the PAR performance degradation due to oxygen starvation in a conservative aspect, it could be negligible on hydrogen control.

In the future, we will investigate the effect of PAR performance degradation due to oxygen starvation to the various types of NPPs and severe accident scenarios.

REFERENCES

[1] NEA/CSNI/R(2010)3, “OECD/NEA THAI Project : Hydrogen and Fission Product Issues Relevant for Containment Safety Assessment under Severe Accident Conditions,” OCED/NEA/CSNI, 2010.
[2] FAI, MAAP5 USER MANUAL, 2016