Implementation of PAR correlations to the MELCOR Code

Hyoung Tae Kim [a*] and Jongtae Kim [a]
Wonjun Choi [b] and Sung Joong Kim [b]
[a]*Accident Mitigation Research Team, KAERI, Daeduk-daero 989-111, Daejeon, Korea*
[b]*Department of Nuclear Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 04763, Korea*
[*]*Corresponding author: kht@kaeri.re.kr*

1. Introduction

In the previous work [1] the SPARC (SPray-Aerosol-Recombiner-Combustion) [2] experiment for hydrogen injection with activation of PAR (Passive Autocatalytic Recombiner) was simulated by the MELCOR 1.8.6 [3]. This lumped code approach is the direct implementation of the manufacturer's empirical parameter correlations for calculating the hydrogen depletion rate.

To extend the manufacturer's PAR correlations as well as the KNT (Korea Nuclear Technology) PAR [4] correlation used in the previous work, other available PAR correlations obtained from the literature survey are implemented to MELCOR code in the present study.

Present commercially available and implemented PAR designs from domestic and foreign vendors are as follows:

- Domestic vendors: a KNT PAR with honeycomb shape and a CERACOM PAR,
- Foreign vendors [5, 6]: a box-type PAR of AREVA (France) and Atomic Energy Canady Limited (AECL, Canada), and a porous bed type PAR of NIS Company (Germany).

In the present work 5 PAR correlations from each manufacturers are identified and the parameters in each PAR correlations could be captured by various control functions of the MELCOR code. Finally a simple benchmark test for PAR actuation in the single volume of the MELCORE is performed. The hydrogen removal results of MELCOR code with these 5 PAR correlations are compared with each other.

2. Overview of PAR Correlations

From the literature survey 5 PAR correlations are identified and implemented to the MECOR inputs. These correlations are hydrogen depletion rate (kg/s) by a PAR.

The generic form of the hydrogen depletion rate (R) by each PAR model is as follow:

2.1 KNT PAR

KNT PAR [4] adopts the shape of a honeycomb to create a greater catalyst surface area and an enhancement of the buoyancy-induced convective flow. The generic form of the hydrogen depletion rate, R (kg/s) by a KNT PAR is as follow:

$$R = 0.66 \times N \times (a_1 + a_2 + x_{h2} + a_3 \times x_{h2}^2) \times \left(\frac{P}{T}\right) \times 10^{-3} \left[\frac{kg}{s}\right] \quad (1)$$

where,

N: multification factor for the size of PAR
Values of constant parameters:
$a_1 = 2.9193$, $a_2 = 9.0852$, $a_3 = 2.3392$
x_{h2}: hydrogen concentration [vol. %]
P: pressure [bar]
T: temperature [K]

Table 1. Multification factor for different size of KNT PAR

KNT Model	N value
KPAR-40	1
KPAR-80	2
KPAR-160	4

2.2 CERACOM PAR

The generic form of the correlation for CERACOM PAR is as follow:

$$R = k \times x_{h2}^{1.1} \times P^{1.2} \left(\frac{273}{T}\right)^{1.5} \times 10^{-3} \left[\frac{kg}{s}\right] \quad (2)$$

where,

k: multification factor for the size of PAR
x_{h2}: hydrogen concentration [vol. %]
P: pressure [bar]

Table 2. Multification factor for CERACOM PAR

CERACOM Model	k value
NP400 (small)	0.05
NP800 (medium)	0.106
NP1600 (large)	0.255

2.3 AECL PAR

The generic form of the correlation for AECL PAR is as follow:

$$R = 0.2778 \times 10^{-3} \times (0.15196 \times x_{h2} + 0.0126 \times x_{h2}^2) \times \left(\frac{298}{T}\right)^{1.10974} \times P^{0.57769} \left[\frac{kg}{s}\right] \quad (3)$$

where,

x_{h2}: hydrogen concentration [vol. %]
P: pressure [bar]
T: temperature [K]

2.4 AREVA PAR

The generic form of the correlation for AREVA PAR is as follow:

$$R = \eta x_{min} (A \times P + B) \tanh(100 x_{min,in}) \times 10^{-3} \left[\frac{kg}{s}\right] \quad (4)$$

where,

$$\eta = \begin{cases} 1, & x_{h2} \le x_{O2} \\ 0.6, & x_{h2} > x_{O2} \end{cases}$$

x_{h2}: hydrogen volume concentration [-]
x_{o2}: oxygen volume concentration [-]
x_{min}: $\min(x_{h2},\ 2.0 \times x_{o2},\ 0.08)$
$x_{min,lim}$: $\max(x_{min} - 0.005,\ 0.0)$
P: pressure [bar]

Table 3. Values of constant parameters for AREVA PAR

AREVA Model	A	B
FR1-380T	3.1	3.7
FR1-750T	6.1	7.4
FR1-1500T	13.7	16.7

2.5 NIS PAR

The generic form of the correlation for NIS PAR [7] is as follow:

$$R = 0.85\,\rho_{h2} \times 0.67 x_{h2}^{0.307} = 1.134 \times x_{h2}^{1.307} \frac{p}{R_u T} \left[\frac{kg}{s}\right] \quad (5)$$

where,
ρ_{h2}: hydrogen density [kg/m^3]
x_{h2}: hydrogen volume concentration [-]
P: pressure [kg/m^2-s^2]
R_u: universal gas constant = 8314 [J/kmol-K]

3. Benchmark Test

3.1 Implementation of the PAR correlations

The MELCOR ESF Package models the phenomena for the various engineered safety features (ESFs) in a nuclear power plant The PAR package constitutes a subpackage within the ESF package, and calculates the removal of hydrogen from the atmosphere due to the operation of PAR devices. Therefore, we analyzed the code input structure of PAR package to adopt the PAR correlations provided by 5 PAR manufacturers.

The MELCOR code adopts the basic Fischer NIS equation form [7] as a default model and its PAR package can handle total gas volumetric flow rate (m^3/s) and the efficiency of the PAR unit. Therefore the final output of control function should be the PAR correlation values divided by the hydrogen density (kg/m^3) in the specified volume occupied by the PAR devices.

3.2 Assumptions for benchmark test

The single volume is defined and a constant flow rate of H_2, 0.262 g/sec is maintained for 1,000 seconds. Two PARs are assigned to the single volume for each simulation.

The pressure and temperature of injection flow is 1 atm. And 30 °C, respectively.

If we need to select the type of the PARs, the small size is selected as: KNT (KPAR-40), CERACOM (NP400), and AREVA (FR1-380T)

3.3 Benchmark test results.

Fig. 1 shows the amount of the hydrogen in the volume of MELCOR when different PAR models are applied to the code. As we assumed the flow boundary condition, cumulative mass of hydrogen for 1,000 seconds is 0.26 kg. Since the hydrogen injection flow rate is higher than the depletion rate by PARs, it shows the peak value of the hydrogen inventory when the injection flow ends at 1,000 second. NIS PAR has the highest performance for hydrogen depletion and the second performance by AREVA PAR. Other three PARs such as KNT, AECL, and CERACOM shows the similar performance.

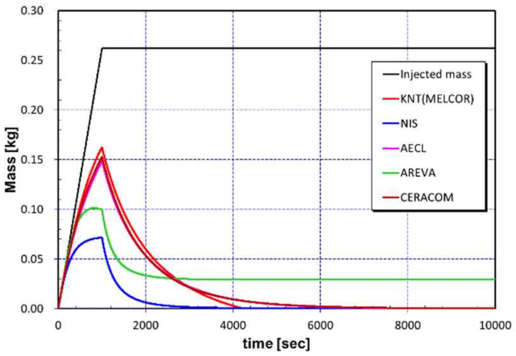

Fig. 1. Comparison of the PAR performances (hydrogen inventory) by different manufacturer's correlations.

3. Conclusions

Present commercially available PARs which provide the different hydrogen depletion correlations are implemented to input of the MELCOR PAR package. For this purpose the appropriate control functions for capturing of the parameters in the PAR correlations are utilized. Finally, the volumetric flow rate and the efficiency of the PAR as the MELCOR input parameters of the basic Fischer NIS equation form, could be derived.

For benchmark test of the present work, the PAR performances by different correlations implemented to the MELCOR are compared. It shows that the each PAR correlations are well implemented to the MELCOR and the characteristics of each PARs can be compared with each other.

The present methodology to implement the manufacturer's PAR correlations to the MELCOR code input can be useful when the containment analysis with actuation of specified PARs is performed.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT) (No. 2017M2A8A4015277)

REFERENCES

[1] H. T. Kim and J. Kim, "MELCOR Analysis of a PAR Experiment in the SPARC Test Facility", Proceedings of the Korean Nuclear Society Spring Meeting, May 23-24, 2019, Jeju, Korea.

[2] J. Kim and H. T. Kim, "Research on a Hydrogen Stratification Induced by PARs Installed in a Containment", Proceedings of the Korean Nuclear Society Autumn Meeting, Oct. 24-26, 2018, Yeosu, Korea.

[3] R. O. Gauntt, et al., MELCOR Computer Code Manuals, NUREG/CR-6119, Vol. 1, Rev. 3, SAND2005-5713.

[4] J. Park, B. Koh, K. Y. Suh, "Demonstrative testing of honeycomb passive autocatalytic recombiner for nuclear power plant", Nuclear Engineering and Design 241 (2011) 4280–4288.

[5] S. Kelm, et al., "Operational Behaviour of Catalytic Recombiners - Experimental Results and Modelling Approaches", Proceedings of the workshop on Experiments and CFD Code Application to Nuclear Reactor Safety (XCFD4NRS), Sept. 10-12, 2008, Grenoble, France.

[6] E. Bachellerie et al, "Generic Approach for Designing and Implementing a Passive Autocatalytic Recombiner PAR-System in nuclear power plant containments", Nuclear Engineering and Design 221 (2003) 151-165.

[7] K. Fischer, "Qualification of Passive Catalytic Module for Hydrogen Mitigation," Nuclear Technology 112 (1995) 58-62.