*Transactions of the Korean Nuclear Society Spring Meeting*
*Jeju, Korea, May 12-13, 2016*

# Flow Accelerated Corrosion: Effect of Water Chemistry and Database Construction

Eun-Hee Lee, Kyung-Mo Kim, Gyeong-Geun Lee, and Dong-Jin Kim*
*Nuclear Materials Safety Research Division, Korea Atomic Energy Research Institute,*
*111, Daedeok-daero, 989beon-gil, Yuseong-gu, Daejeon 34057, Republic of Korea*
**Corresponding author: djink@kaeri.re.kr*

## 1. Introduction

Flow accelerated corrosion (FAC) of carbon steel piping in pressurized water reactors (PWRs) has been a major issue in nuclear industry. Severe accidents at Surry Unit 2 in 1986 and Mihama Unit 3 in 2004 initiated the world wide interest in this area [1-3]. FAC is a dissolution process of the protective oxide layer on carbon steel or low-alloy steel when these parts are exposed to flowing water (single-phase) or wet steam (two-phase) [3]. In a single-phase flow, a scalloped, wavy, or orange peel and in a two-phase flow, tiger striping is observed, respectively. FAC is affected by many parameters, like material composition, pH, dissolved oxygen (DO), flow velocity, system pressure, and steam quality [3]. This paper describes the water chemistry factors influencing on FAC and the database is then constructed using literature data.

## 2. Methods and Results

### *2.1 Mechanism of FAC*

The mechanism of FAC consists of two processes. The first process is dissolution of the protective iron-oxide layer in carbon or low-alloy steel in flowing water [4]. The second process is the transport of dissolved metal ions into the bulk water. The FAC rate is controlled by the diffusion rate of dissolved iron species through the boundary layer of water [4]. Therefore, the flow velocity and local turbulence cause an increase of the FAC rate.

### *2.2 Effect of water chemistry*

In order to mitigate FAC in PWRs, the optimal method is to control water chemistry parameters. Chemistry factors influencing FAC such as pH, corrosion potential, DO and hydrazine ($N_2H_4$) contents were reviewed in this paper using the literature data. The FAC rate decreased with pH up to 10 because magnetite solubility decreased with pH. Corrosion potential is generally controlled by DO and $N_2H_4$ contents in secondary water. Fig. 1 shows the FAC rate of carbon steel for various DO content under AVT condition by using a FAC loop [5]. Hematite film was formed when DO increased to more than 2 ppb. However, magnetite film was formed in the absence of DO. The FAC rate decreased with DO by stabilizing magnetite at low DO content or by formation of hematite at high DO content. Even though $N_2H_4$ is generally used to remove DO, $N_2H_4$ itself thermally decomposed to ammonia, nitrogen, and hydrogen, raising pH. Hydrazine can react with iron and increase FAC rate. Effect of $N_2H_4$ on FAC is rather complex and should be careful in FAC analysis. FAC could be managed by adequate combination of pH, corrosion potential, DO, and $N_2H_4$.

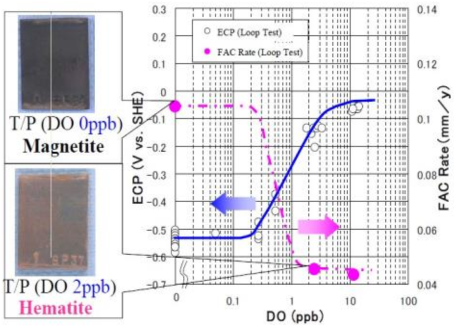


Fig. 1. Behaviors of ECP and FAC rate as a function of DO concentration [5].

### *2.3 Database construction*

Many research institutes in the world are conducting FAC tests using large-scale structural components [5]. EPRI in USA developed a CHECWORKS code to predict the FAC in NPPs, and EDF in France constructed a CIROCO loop to develop and verify a CICERO code. In Germany, FAC tests were conducted using the AREVA-BENSON test facility and results were then used to develop a COMSY code. CRIEPI in Japan used the data obtained from a PRINTEMPS test facility to develop a FALSET code. Therefore, in order to predict FAC occurred in domestic PWRs, it is needed to develop a computer code.

In present work, in order to find test conditions for ongoing a large-scale FAC test loop in KAERI, a database was constructed using experimental data in literature. These results will be applied to develop the computer code in KAERI that can be employed to predict the future corrosion damage caused by FAC. Test parameters and results in literature data were listed in many units; flow velocity (m/s, L/min, kg/h), test duration (h, day), pressure (bar, psi, kPa), and FAC rate (mpy, mg/cm$^2$h, ug/cm$^2$h, weight loss, relative rate). Therefore, the units need to be unified so that the database is useful. In order to digitize the FAC data, OriginPro 9.20 was used. The database was then constructed using the above data entering into Microsoft Excel 2010. Fig. 2 shows the input format and input data in database. The number of input data of test materials was 85 and of obtained results was 1181. Fig. 3 shows a scatter plot between an explanatory variable (Cr, temperature, pH, DO, flow rate) and a response variable (FAC rate). For more accurate analysis and modeling, much work is needed.

| No | Heat no | Cr (wt%) from heat | Water temperature (°C) | raw pH at 25℃ | pH at 25℃ | raw DO (ppb) | DO (ppb) | Flow velocity (m/s) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.03 | 130 | 8 | 8 | <1 | 1 | 4 |
| 2 | 1 | 0.03 | 130 | 8.5 | 8.5 | <1 | 1 | 4 |

| FAC rate (mpy) | FAC rate (mg/cm$^2$h) | FAC rate (μg/cm$^2$h) | FAC weight loss (g) | Surface area (cm$^2$) | raw FAC rate (mm/year) | FAC rate (mm/year) | FAC rate (ratio) |
|---|---|---|---|---|---|---|---|
| | | 1958.2 | | | | 1346.57581 | |
| | | 1867.1 | | | | 1283.92999 | |
| | | 1255 | | | | 863.0133 | |

| No | Source no | Source first author | Source nation | Source name |
|---|---|---|---|---|
| 1 | 1 | Jeong Ho Moon | Korea | Nuclear Engineering and Technology |
| 2 | 1 | Jeong Ho Moon | Korea | Nuclear Engineering and Technology |

| Fe (wt%) | C (wt%) | Si (wt%) | Mn (wt%) | P (wt%) | S (wt%) | Cr (wt%) | Mo (wt%) | Ni (wt%) | Cu (wt%) | V (wt%) | Others (wt%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bal. | 0.15 | 0.19 | 0.64 | 0.003 | 0.014 | 0.03 | 0.01 | 0.06 | | | |
| Bal. | 0.1 | 0.56 | 0.36 | 0.009 | 0.009 | 1.06 | 0.48 | | | | |
| Bal. | 0.09 | 0.21 | 0.49 | 0.012 | 0.008 | 2.03 | 0.97 | | | | |

Fig. 2. Input format and input data in database.

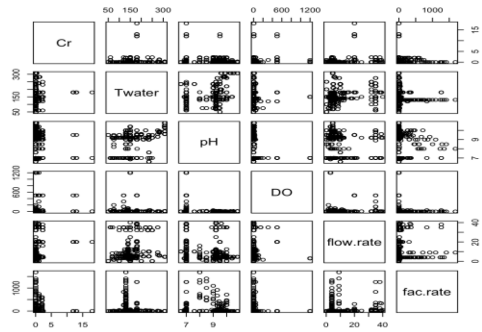


Fig. 3. Scatter plots of FAC data points among various major factors.

## 3. Conclusions

In order to minimize FAC in NPPs, the optimal method is to control water chemistry parameters. However, quantitative data about FAC have not been published for proprietary reason even though qualitative behaviors of FAC have been well understood. A database was constructed using experimental data in literature. Accurate statistical analysis will be performed using this database to identify the relationship between the FAC rate and test environment. Above results will be used to develop the computer code in KAERI, predicting FAC.

## REFERENCES

[1] B. Chexal, J. Horowitz, B. Dooley, P. Millett, C. Wood, R. Jones, M. Bouchacourt, F. Nordmann, P. S. Paul, and W. Kastner, Flow-Accelerated Corrosion in Power Plants, EPRI TR-106611-R1, 2008.

[2] H. Schmidt, W. Kohler, and W. Kastner, High-Pressure Test Facility-25 Years of Operation, Framatome ANP GmbH, 2001.

[3] T. Satoh, Y. Shao, W. G. Cook, D. H. Lister, and S. Uchida, Flow-Assisted Corrosion of Carbon Steel Under Neutral Water Conditions, Corrosion. Vol. 63, No. 8, pp. 770-780, 2009.

[4] V. Kain, S. Roychowdhury, P. Ahmedabadi, and D. K. Barua, Flow accelerated corrosion: experience from examination of components from Indian nuclear power plants, FAC 2010, Lyon, May 4-7, France, 2010.

[5] W. Sugino, D. Akutagawa, T. Ohira, A. Abe, K. Yoneda, and F. Inada, Effectiveness of Water Chemistry Improvement against FAC in PWR Secondary System, FAC 2010, Lyon, May 4-7, France, 2010.