ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 7, Issue 9, March 2018

A High-Temperature Setup of Nuclear Reactor Cooling System for the Study of Zinc Effect on Corrosion in Stainless Steel

Suppamat Makjan[a], Pornthip Boonsri[b], Jatechan Channuie[c], Kotchaphan Kanjana[d]
[a] Department of Chemistry, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand
[b] Department of Chemistry, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand
[c] Thailand Institute of Nuclear Technology (Public Organization), Ongkharak, Nakhon Nayok 26120, Thailand
[d] Thailand Institute of Nuclear Technology (Public Organization), Ongkharak, Nakhon Nayok 26120, Thailand

Abstract*— A high-temperature setup of nuclear reactor cooling system was designed and assembled to study the inhibition effect of zinc(II) on corrosion in stainless steel. The setup consists of a sample reservoir, a high-pressure pump, a sample cell, a temperature control unit and a collecting reservoir. The sample cell was made of glass with high temperature-high pressure resistant properties. The cell itself has glass hooks for hanging stainless steel sheets and connections to thermocouples for temperature control and measurement. Prior to entering the sample cell, the sample solution will be purged by N_2 and heated by a cartridge heater. Sample heating within the cell will be remained by a band heater. The sample cell was also wrapped with an insulation material to keep temperature stable. The test results show that the setup gives flow rate of 2 ml/min. In addition, time taken to raise the temperature up to 50 ℃ and 80 ℃ were about 5 min and 10 min, respectively. In the present work, the in-house flow system was successfully assembled for investigation of corrosion in stainless steel. Therefore, with this setup the information obtained could be useful in understanding the role of zinc injection in the cooling system of the nuclear power plants.

***Index Terms*— Cooling system, Flow system, Nuclear reactor.**

I. INTRODUCTION

Corrosion of the structural materials in nuclear power plants (NPPs) is considered as an urgent issue in nuclear industry. The materials are inevitably exposed to the radiation released directly from the reactor core. In addition to high intensity radiation field, NPPs generally work under high temperature -high pressure conditions increasing corrosion of the fuel cladding and the components of the coolant system [1]. To handle this problem, high corrosion resistant alloys (zirconium alloy (Zr alloy), nickel alloy (Ni alloy) and stainless steel) have been widely used [2]. Most of the stainless steel used for structural components in the primary coolant system are 300 series (304, 308, 309, 316, 321, 347) consisting of 10% Ni, 20% Cr and other elements such as Mo and Ti. The corrosion processes found to damage the nuclear metallic materials are general corrosion (GC), stress corrosion cracking (SCC), environmentally assisted cracking (EAC), irradiation-assisted stress corrosion cracking (IASCC), intergranular-assisted stress corrosion cracking (IGSCC), flow assisted corrosion (FAC), ammonia corrosion (AC) and microbiologically influenced corrosion (MIC) [3-6]. According to the previous studies done in Germany [7], SCC, IASCC and IGSCC were the main corrosion types present in pressurized water reactors (PWRs) and boiling water reactors (BWRs). In these types of nuclear reactors water is used as neutron moderator and coolant. When the cooling water is exposed to radiation, water radiolysis generates new molecules (H_2, O_2, H_2O_2) and free radicals (OH, H, $e^-_{(aq)}$ and HO_2/O_2) [8] causing corrosion of the system. Recently, there are 2 well-known methods for corrosion minimization in NPPs, hydrogen water chemistry and zinc injection. In the former protocol, molecular hydrogen is added to the primary cooling system of the reactors to reduce oxidizing species produced in the coolant water, such as oxygen (O_2) and hydrogen peroxide (H_2O_2), resulting in lower electrochemical corrosion potential (ECP) of the system [9]. In the latter one, zinc in the form of Zn(II) ion has been injected to the coolant to help mitigate corrosion of the materials under radiation field. Previous studies showed that addition of Zn(II) ions in the primary coolant system could improve stabilization of the oxide layer on the material surface. More importantly it was also claimed in these studies that with zinc injection, Co-60 deposition in the materials was dramatically decreased [10, 11]. However, full understanding of the role of zinc in this system is still missing. Due to the harsh conditions, real-time measurements in nuclear reactors are difficult. For any specific problems, therefore experimental setups are required. In general, most of corrosion studies in NPPs focus on oxide formation on stainless steel in aqueous solution under high temperature condition along with the measurement of the electrochemical corrosion potential of the system. In the present research a high-temperature setup of nuclear reactor cooling system was installed for corrosion study to obtain a better understanding of the surface morphologies of stainless steel before and after zinc injection.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 7, Issue 9, March 2018

II. METHODS

A. *Experimental setup*

A high-temperature setup of a nuclear reactor cooling system was designed and assembled to study the inhibition effect of zinc(II) on corrosion in stainless steel. The system consists of a sample reservoir, a high-pressure pump, a sample cell, a temperature control unit and a collecting reservoir as presented in Fig. 1.

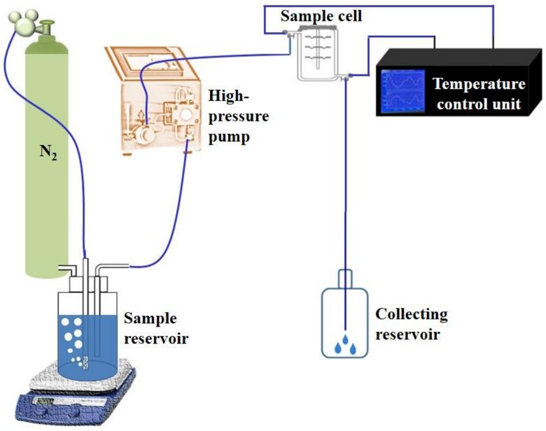

Fig. 1 Diagram of the cooling setup

The detail of the components are following:

1. Sample reservoir and high-pressure pump

The sample reservoir was made of high quality glass with a custom-designed cap. The cap was specially designed for 3 insert tubes: gas inlet (purging), gas outlet (venting) and sample outlet. The N_2-purged sample solution was flowed from the sample reservoir to the high-temperature cell through stainless steel tubing using a high-pressure pump.

2. Sample cell

The sample cell was made of high quality glass with high temperature-high pressure resistant properties (300 °C and 3 bar) and a vacuum cap with clamps. This cell has a number of connections with thermocouples for temperature control and measurement as well as glass hooks for hanging stainless steel specimens (Fig. 2). Moreover, the sample cell was surrounded by an insulated band heater

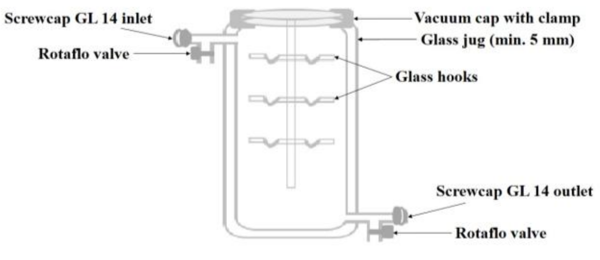

Fig. 2 Sample cell

3. Temperature control unit

Temperature control was successful using a proportional-integral-derivative (PID) controller. PID controlling system is based on the feedback mechanism that consists of 3 correcting terms: proportional, integral and derivative. The proportional term provides a power output value which depends upon the difference between the set point and the current temperature. The integral term is the previous variance from the set point and the additional derivative term is the predicted future variance based on the previous and current variance [12].

4. Collecting reservoir

The collecting reservoir was made of glass and connected to the sample cell outlet via stainless steel tubing for collecting the liquid product.

B. *Testing*

Initially the testing solution in the sample reservoir was purged by N_2 ((Ultra High Purity Grade, Purity min. 99.995%), Labgaz (Thailand) Co., Ltd.) for oxygen minimization. Then the solution was flowed from the sample reservoir to the sample cell via stainless steel tubing using a High Performance Liquid Chromatography (HPLC) pump with dual-piston. Before entering the sample cell, the solution was first heated by a cartridge heater. Subsequently, the testing solution filled up the high temperature cell where the stainless steel specimens hanging inside. Corrosion of the stainless steel specimens was expected to occur in this part of the flow setup. The cell heating was maintained using a band heater which was wrapped tightly by an insulation material to keep temperature stable. The temperature of the solution is measured by thermocouples.

III. RESULTS AND DISCUSSION

Fig. 3 Flow setup of the cooling system

The flow system components were successfully assembled (Fig. 3). The test results showed that the setup gave flow rate of 2 ml/min. In addition, at atmospheric pressure time spent to raise the temperature up to 50 °C and 80 °C were about 5 min and 10 min, respectively. Although the cell could be heated rapidly to reach the setting points, however, it took some time for the cell temperature to stabilize at a given temperature. Temperature stabilization of the cell at 50 °C and 80 °C is demonstrated in Fig.4. It can be clearly seen that at both set points, the temperatures were overshooting before approaching stabilization in *ca.* 100 min. (50 °C) and 60 min. (80 °C).

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 7, Issue 9, March 2018

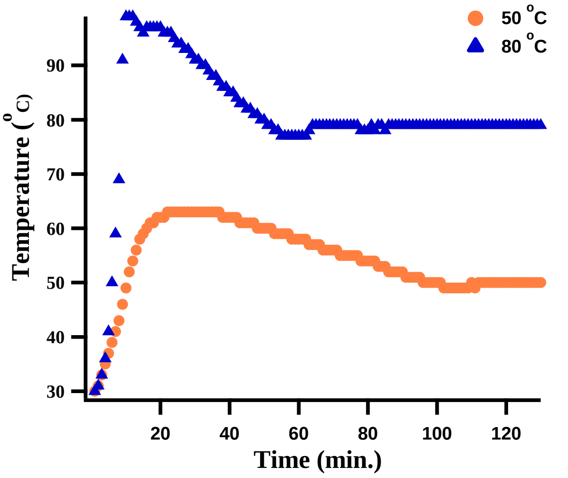

Fig. 4 Graph showing temperature stabilization at 50 °C and 80 °C set points

Based on the test results, the sample cell equipped with glass hooks for specimens hanging was suitable for the study of corrosion effect on the surface morphologies of materials. Moreover, this cell was proved to withstand high temperature-high pressure conditions. Therefore, the in-house flow system can be used for investigation of zinc effect on corrosion in stainless steel.

IV. CONCLUSION

The flow setup for the study of zinc effect on corrosion in stainless steel was successfully assembled and tested. The setup allows experiments to be performed at temperature up to 80 °C with solution flow rate of 2 ml/min. Our future plan is to study zinc effect on corrosion of stainless steel induced by the radiolytic product (H_2O_2) using this setup. The information obtained could be useful in understanding of the role of zinc injection in the cooling system of nuclear power plants.

ACKNOWLEDGMENT

This work has been supported by Thailand Institute of Nuclear Technology. The department of Chemistry, Faculty of Science, Srinakharinwirot University are gratefully acknowledged for providing research facilities. The authors would like to acknowledge the Grants for Research/Academic Presentations Abroad for Faculty Members of Graduate Programs, Faculty of Graduate Studies, Graduate school of Srinakharinwirot University 2018.

REFERENCES

[1] P. Kritzer, "Corrosion in high-temperature and supercritical water and aqueous solutions: a review," J. Supercrit. Fluids., vol. 29, pp.1-29, 2004.

[2] W. Hoffelner, Materials for Nuclear Plants. 1 ed. From Safe Design to Residual Life Assessments. 2013: Springer-Verlag London.

[3] H.P. Berg, "Corrosion mechanisms and their consequences for nuclear power plants with light water reactors," R&RATA, vol. 2, no. 4, pp.57-68, 2009.

[4] D. Feron, Nuclear Corrosion Science and Engineering. 2012, Cambrigde, UK: Woodhead Publishing Limited

[5] F. Cattant, D. Crusset, and D. Féron, "Corrosion issues in nuclear industry today," Materialstoday, vol. 11, no. 10, pp.32-37, 2008.

[6] TECDOC-1505, I.R. "Data Processing Technologies and Diagnostics for Water Chemistry and Corrosion Control in Nuclear Power Plants (DAWAC)," Report of a Coordinated Research Project 2001-2005, 2006.

[7] E. Chajduk, A. Bojanowska-Czajka, "Corrosion mitigation in coolant systems in nuclear power plants," Progress in Nuclear Energy, vol. 88, pp.1-9, 2016.

[8] M. Urquidi-Macdonald, J. Pitt, D.D. Macdonald, "The impact of radiolytic yield on the calculated ECP in PWR primary coolant circuits," J. Nucl. Mater., vol. 362, pp.1-13, 2007.

[9] C. C. Lin, F. R. Smith, R. L. Cowan, "Effects of hydrogen water chemistry on radiation field buildup in BWRs," Nucl. Eng. Des., vol. 166, pp.31-36, 1996.

[10] J.-S. Choi, S.-C. Park, K.-R. Park, H.-Y. Yang, O-B. Yang, "Effect of zinc injection on the corrosion products in nuclear fuel assembly," Nat. Sci., vol. 5, pp.173-181, 2013.

[11] X. Liu, X. Wu, E.-H. Han, "Effect of Zn injection on established surface oxide films on 316 L stainless steel in borated and lithiated high temperature water," Corros. Sci., vol. 65, pp.136-144, 2012.

[12] K. J. Astr¨om, R. M. Murray, Feedback Systems: an Introduction for Scientists and Engineers. Vol. 2. 2006: Princeton University Press.

AUTHOR BIOGRAPHY

Suppamat Makjan received a B.S. degree from Srimakharinwirot University in 2014. Currently she is a graduate student in the Graduate School of Chemistry Science, Srinakharinwirot University, Bangkok, Thailand. Her research project includes zinc effect on corrosion in stainless steel.

Pornthip Boonsri received her Ph.D. in Chemistry from Kasetsart University, in 2013. Currently she is a lecturer at the Department of Chemistry, Faculty of Science, Srinakharinwirot University, Bangkok Thailand. Dr. Pornthip's research areas include both theoretical parts as computational chemistry, computer-aided molecular modeling and drug design, and experimental part as molecular biology, biochemistry, protein NMR.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 7, Issue 9, March 2018

Jatechan Channuie received his B.S. in Physics from Prince of Songkla University in 2008. He received Grad. Dip. in Teaching (Physics) from Srinakharinwirot University in 2009. Later he received a M.S. in Nuclear Technology from the Department of Nuclear Engineering, Chulalongkorn University, and Bangkok, Thailand. He is currently a nuclear scientist at the Division of Nuclear Research and Developments, Thailand Institute of Nuclear Technology.

Kotchaphan Kanjana received her B.S. in Chemistry and a Grad. Dip. in Teaching from Thaksin University, Songkhla, Thailand in 2005 and 2006, respectively. She earned a Ph.D. in chemistry from the University of Notre Dame, USA in 2013. She then joined the Notre Dame Radiation Laboratory as a postdoctoral research associate in 2014. Her research involved high temperature-high pressure flow setups with a Transient UV-visible detection system using a Linear Accelerator (LINAC) and Gas chromatography-mass spectrometry with a Van de Graaff generator (VDG). She is currently a senior nuclear scientist at the Division of Nuclear Research and Developments, Thailand Institute of Nuclear Technology.