Oxide Fouling on Venturi Flowmeter at Nuclear Power Plants: Root Causes and Its Mitigation Method

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1. Understanding the Mechanism of Oxide Fouling

The thermal power of nuclear power plants is calculated by the thermal equilibrium method based on the flow rate of main feed water supplied to the steam generator. A fouling phenomenon occurs at venturi flow meter by accumulation of sludge such as iron oxide generated in the secondary system piping. Thus, this fouling causes the inaccuracy of the measurement of the main feed water flow rate, which may cause an error in calculating the power plant heat output. The output error is about 1% of the power operation, and economic losses are incurred through cleaning or replacement of the main water supply pipe venturi flowmeter during every overhaul period [1].

The charge density of colloidal particles present on the piping surface in secondary system of nuclear power dependent water chemistry conditions (flow rate, oxide concentration, temperature and pH) and following the reaction equation as

$$MOH + H^+ \leftrightarrow MOH_2^+ \quad (1)$$

$$MOH + OH^- \leftrightarrow MO^- + H_2O \quad (2)$$

According to the difference for polarity of the charge density of the colloidal particles present in the aqueous solution under the water-chemistry conditions of a nuclear power plant, the interface of the colloidal particles has an electrical potential. Zeta potential is defined as the difference in the electric potential of colloidal particles (The potential differences between starting point to end point of diffused layer of colloidal particle.). The pH value is defined as a point of zero charge (PZC) under water chemistry conditions when the surface charge becomes the Isoelectrical point of surface (IEPS) because the tendency of positive and negative ions on the surface of colloidal particles is the same. Zeta potential and PZC are indicators representing the bonding energy due to the difference in surface charge between particles and can be suggested as a methodology to explain the fouling phenomenon occurring in the water supply pipe venturi flowmeter.

In the case of the US BWR reactor type, fouling occurred in the local area of the jet pump due to the difference between the charge of the metal oxide film formed on the surface of the jet pump and the surface charge of the colloidal particles existing in the water chemistry condition. This problem was solved by using the difference in the Zeta Potential and PZC of the coating material and the medium existing in the system [2]. Fig 1 shows the electric chemistry properties of colloidal particle surface in the system.

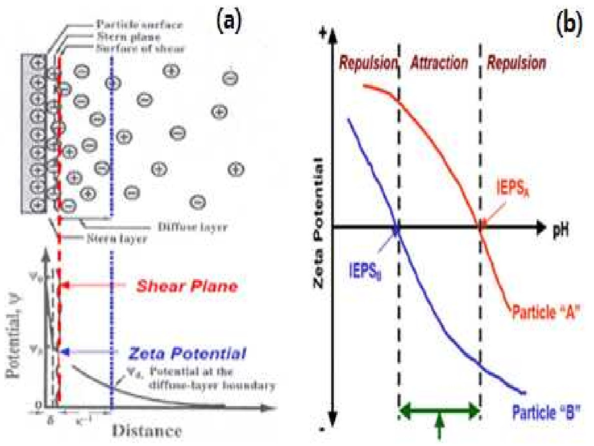

Fig. 1. Schematic diagram of electrical properties on the surface of the colloidal particles (a) and surface charge properties between colloidal particles (b) [2]

The purpose of this study is to mitigate the oxide deposition inside the venturi system by applying anti-fouling coating and thus improves its function. Evaluation of various coating materials and technologies is in progress. They are electroless plating (EP), chemical vapor deposition (CVD), physical vapor deposition (PVD) by using materials (Ti based coating, Cr based coating, Ni based coating, Pd based coating etc.).

In this paper, fundamental mechanism of oxide fouling in high temperature water and previous works on the fouling mitigation approach are presented as (1) development of coating material and technology to prevent fouling of venturi flowmeter in secondary water supply piping in nuclear power plant and (2) development of performance test technology applying optimum coating technology to prevent fouling phenomenon of venturi flowmeter in the secondary system of nuclear power plant.

2. Developing the Anti-Fouling Method

2.1. Control of Surface Charge by Surface Modification

This study is mainly focused on developing the optimized coating technology and material to prevent the venturi fouling by using similar zeta potential behavior compared to on iron oxide (mostly Fe_3O_4) deposited on ventruti pipe at nuclear power plant secondary side water supply system water chemistry condition (pH, temperature, etc.) in 235℃ water [2]. The results shows similar surface charge characteristics to iron oxides (Fe_3O_4, Fe_2O_3) that cause fouling in the system [3-10].

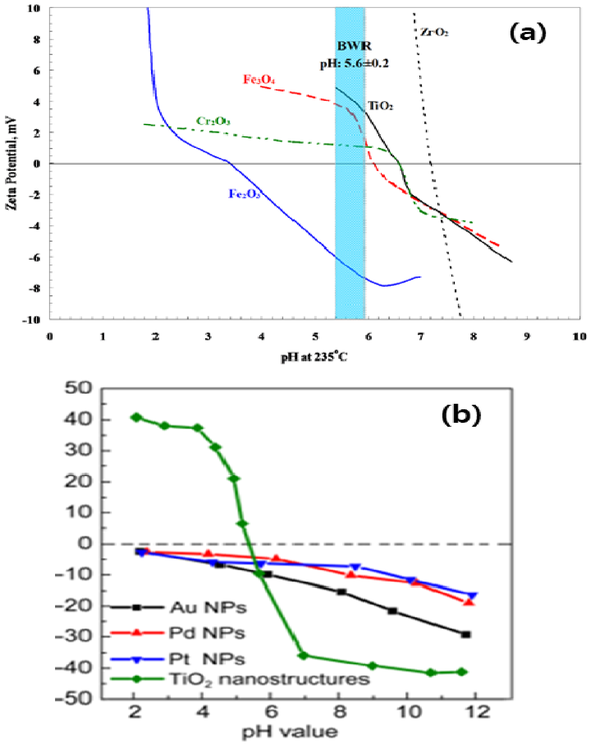

Fig. 2. Zeta potential behavior of various oxides and noble metals (a) in 235℃ water and (b) at 25°C [2, 3]

As stated previously, the fouling mitigation coating methods such as electroless plating, PVD, and CVD are chosen that are already well proven technologies for commercial industrial applications In particular, PVD and CVD technologies can form high-quality of thin films, but with some limit application on complicate geometric designs and products (e.g, venturi flowmeters). On the other hands, the electroless plating coating technology can produce a uniform coating layer on the entire structure even on complicate geometric designs.

Based on the previous literatures, Ti, Cr, Ni, and Pd based coatings are selected as possible candidate anti-fouling coating and prepared to evaluate the fouling mitigation characteristics, and the morphology of coating surface is shown in Figure 3. Details on the characterization of various coatings are scheduled to present in this conference [11].

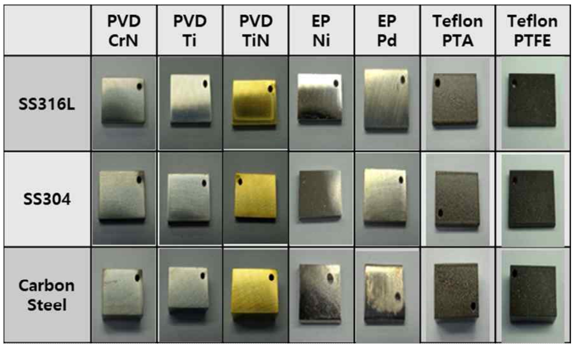

Fig. 3. Coating specimens of various coating method

The zeta potential for various coating samples was measured at different temperatures (25, 50, 80 °C) and pHs (3, 5, 7, 9). As shown in Figure 4, at higher pH (e.g., 9) the negative value was measured, while the zeta potentials of coating are varied. In order to examine the effectiveness of coatings for mitigation of fouling, more measurements are needed at higher temperatures.

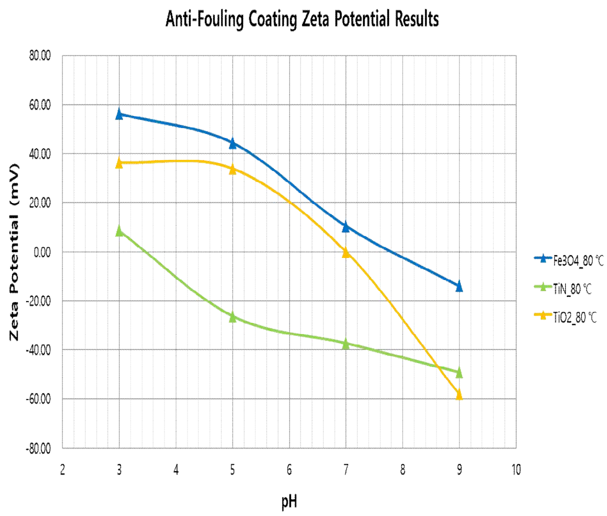

Fig. 4. Zeta potential behavior as a function of pH of various coating materials at 80°C

2.2 Evaluation of Chemical Stability and Performance of Anti-Fouling Coating

In the secondary system of a nuclear power plant, iron ions and iron oxides are released into the system water by fluid accelerated corrosion (FAC) from the surface of a pipe made of carbon steel material, and accordingly, the thickness of the pipe is reduced, leading to accidents leading to breakage in some cases.

Generated by the FAC corrosion products such as iron ions and iron oxide are such as attached to the heat transfer tube surface steam generator degrade the heat transfer is attached to the heat transfer tube support structure by creating a corrosion accelerating environmental stress corrosion cracking in the heat transfer tube, the grain boundary corrosion, fitting It causes corrosion damage. In addition, corrosion products adhering to the supporting structure may block the flow path, causing unstable water level in the steam generator, resulting in output reduction operation [12]. Thus, it is very importance to evaluate the chemical stability of coatings at high flow rate in a simulated secondary side water condition [13, 14] as

- ✓ Temperature : 235 ℃
- ✓ Pressure : 1,200 psig
- ✓ Flow Rate : > 5 m/s
- ✓ Dissolved oxygen : < 5 ppb
- ✓ pH condition : 9.0 (ETA, Hydrazine 60 ppb)

The test facility for simulating the secondary side water chemistry condition shows in Fig 5 and the design conditions of the test facility as follows

- ✓ Temperature, pressure, pH, water chemistry control and monitoring system
- ✓ Magnet drive rotating system for simulating the high flow rate as the flow accelerated corrosion test

Fig. 5. Flow accelerated corrosion test facility at FNC Technology

2.3 Evaluation of Mechanical Stability of Anti-Fouling Coating

The U.S. NRC issued Regulatory Guide, R.G. 1.54, to require maintenance and management of protective paint inside the reactor building. The regulatory guidelines required the application of ASTM D 5144(Standard guide for use of protective coating standards in nuclear power plants) as the basis for application of protective paint, and ASTM D 3359(Standard test methods for measuring adhesion by tape test) and ASTM D 4541-02(Standard test method for pull-off strength of coatings using portable adhesion testers) as the detailed criteria for evaluation of protective paint. Anti-fouling coating developed in this study is a surface coating method performed inside piping. Therefore, it does not fully comply with the technical standards described above.

Technical standards and evaluation methods for coating materials inside piping are not required. In this study, the evaluation methodology presented by NRC was applied to assess the mechanical stability of anti-fouling coating. However, the acceptance criteria used in the evaluation of mechanical stability was intended to be applied at a level with sufficient margin after reviewing previous research data. The acceptance criteria required by ASTM D 5144 is about 2.9 psi (200 mbar) [15, 16, 17]. In this study, 7 ksi (7,000 psi) was applied as the limit of mechanical stability of the anti-fouling coating. The ASTM D 3359 test will be performed by the Korea Laboratory Accreditation Scheme (KOLAS) certification testing agency. And the ASTM D 4541-02 test will be performed after calibration of the full-off test equipment.

3. Work in Progress

The purpose of this study is to develop a method for mitigating the fouling phenomenon occurring at the venturi flowmeter in the secondary side of nuclear power plant. Currently, we are in progress in optimizing the development of optimum coating process by performing the following works

- ✓ Preparation of various coating
- ✓ Measurement of zeta potential and mechanical stability
- ✓ Evaluation of coating at high temperature / high pressure water (chemical stability and anti-fouling property)

4. ACKNOWLEDGMENTS

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