High-Confidence Flow Accelerated Corrosion Screening Technique

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1. Introduction

All carbon steel pipes with fluid traveling through it could potentially be threatened by flowing fluid have a potential threat of Flow Accelerated Corrosion (FAC). FAC in a nuclear power plant (NPP) could cause not only pipe failure leading but fatalities sometimes [1]. It is almost impossible to inspect all carbon steel pipes in NPPs, and FAC prediction programs such as CHECWORKS, WATHEC, and BRT-CICERO have limited capability to in predicting FAC area.

2. Equipotential Switching Direct Current Potential Drop (ES-DCPD) Method

Direct Current Potential Drop (DCPD) technique is a proven technology widely used in the precise measurement of cracks in fracture fields. We have shown that DCPD can be employed to monitor piping wall loss in a short time [2]. Using the DCPD technique, a new FAC screening and inspection approach has been suggested as illustrated in the Figure 1. First, we list up the piping locations susceptible to FAC both by operational experience and existing FAC prediction programs. They would be covered using UT. Piping segments that are not prioritized for UT are roughly checked by Wide Range Monitoring (WiRM) DCPD technology. If WiRM results indicate the presence of FAC-affected area, then UT inspection would be performed in the precise area within a limited time frame [3]. Narrow Range Monitoring (NaRM) DCPD has a good resolution and sensitivity to wall thinning and is applicable to high temperature and radiation environments, which is suitable for online monitoring. Hence areas that require on-power attention can be monitored by NaRM.

In case of a PWR secondary side, the piping is a complex network including grounds, supports, and anchors. Hence it is necessary to confine electric current paths in order to apply DCPD to that complex piping system. The imposed current should not flow outside of the target piping segment. Otherwise, leaked current may adversely affect sensitive electrical equipment at a NPP by degrading the signal quality and the resolution of the DCPD. To prevent external leakage, we developed the Equipotential DCPD method which uses two independent current sources. The Current from each current source can be synchronized. By maintaining both ends equipotential, we can measure zero current outside of the target location [2].

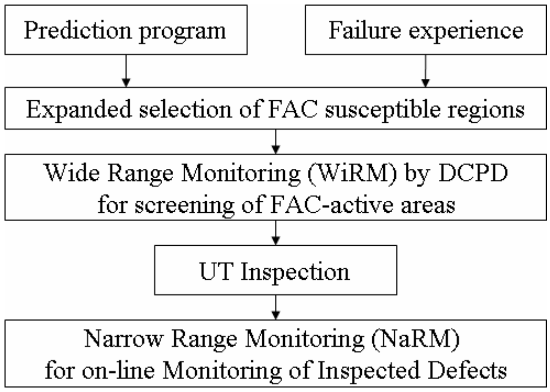

Figure 1 Proposed FAC Screening and Inspection Approach

3. Test Results and Discussion

Low alloy chromium steels are very resistant to FAC. At 1% chromium, the FAC rates of alloyed material are reduced to negligible level [4]. In SFASL test [5], carbon steel contains chromium less than 0.01% was used. Test temperature was maintained as 130oC at an early stage, and increased to 150oC. Flow velocity, DO, and DH were maintained 5m/s, 5ppb, and 150ppb. The pH was changed with 4.1, 3.5, 7.0, and 3.0. And the total test duration was 13,000 minutes. Figure 2 shows test conditions and measured ES-D.C. potential values. The black dot indicates test temperature, and the red dot indicates inlet pH. The blue dot indicates measured D.C. potential, which shows well wall thinning trend. The temperature increased 130 to 150oC, and then the potential change increased. The pH decreased 4.1, 3.5, 3.0, and the potential change increased. At the pH 7.0, the potential shows little changes.

Sanchez-Caldera's Model is a theoretical model that can predict the materials reduction rate through FAC, which is shown in the equation (1) [6].

$$\frac{dm}{dt} = k_g \frac{\theta\left(C_e - C_\infty\right)}{\dfrac{1}{k} + \left(1 - f\right)\left[\dfrac{1}{h_D} + \dfrac{\delta}{D}\right]} \qquad (1)$$

Where, dm represents wearing rate [kg/m^2s], k_g is geometrical factor, 7.5 for elbow piping, C_e is equilibrium concentration of iron species, C_∞ is iron species concentration in the bulk water, θ is porosity and 0.03 below 150 °C, k=Aexp[-Q/RT], the reaction rate constant, f is fraction of oxidized metal converted into magnetite at the metal-oxide interface. f=0.5, h_D is a mass transfer coefficient, δ is oxide thickness, 10 μm, and D is a diffusion coefficient of the dissolved ferrous species.

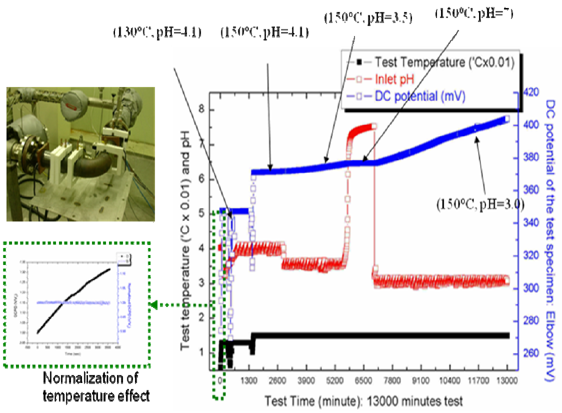

Figure 2. ES-DCPD results with test conditions. Test conditions: 130°C / pH=4.1, 150°C / pH=4.1, 150°C / pH=3.5, 150°C / pH=7.0, 150°C / pH=3.0

In equation (1), k_g is not included in the original Sanchez-Caldera's model. It assumes straight pipe conditions. To apply this model to the complex geometry, such as a piping elbow, k_g is introduced. Kastner's work, which is an empirical model for the FAC phenomena, introduced a geometrical factor. In that model, the geometrical factor for a piping elbow is around 7.5, while the value for straight piping is unity [7].

C_e is equilibrium concentration of iron species. To calculate the solubility of magnetite, Sanchez-Caldera introduced the work of Sweeton and Baes that provides the experimental data on the solubility of magnetite as a function of temperature, hydrogen concentration, and pH [8]. In this work, we acquired the thermodynamic data for ferrous ions from the commercially available computer code, HSC Chemistry. Other values were adopted from references [6]. In this way, all the variables used in the equation can be expressed as a function of temperature, fluid velocity, dissolved hydrogen and pH.

Figure 8 shows measured ES-DCPD values and FAC prediction results. ES-DCPD results show good agreement with predicted thinning calculated by S-C model.

4. Conclusion and Future Work

We showed that the ES-DCPD could be employed in monitoring piping wall loss. The ES-DCPD showed good agreement with UT inspection. ES-DCPD can be applied to a wide area to identify a thinned location. The NaRM method would then be applied to a localized area. It has an advantage over online UT that needs to predict a maximum thinning point exactly. The DCPD NaRM method has good resolution and sensitivity, and it is not affected by temperature and radiation.

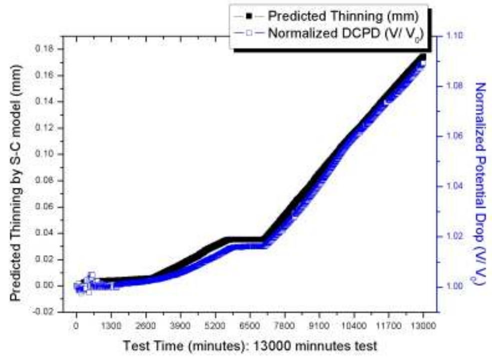

Figure 3. Comparisons of measured ES-DCPD results and predicted thinning rate that is calculated Sanchez-Caldera model

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