Development of Evaluation Technology for Prevention of Two-Phase FAC on Carbon Steel

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1. Introduction

There are many pipelines to be managed from wall thinning by flow accelerated corrosion (FAC) in the secondary system of a nuclear power. FAC is a process in which a normally protective oxide layer on the internal carbon or low-alloy steel piping surface dissolves into a stream of flowing water or a wet steam mixture. In this process, the oxide layer becomes thinner and the corrosion rate increases until the corrosion rate and dissolution rates are equal. In some cases, the oxide layer becomes very thin, exposing the bare metal surface. The damaged carbon steel pipe surface often displays a scalloped or orange-peel appearance in a single-phase flow. On the other hand, a tiger striping pattern is observed in two-phase flow [1].

Recent researches and reports indicate that the FAC problem is prevalent in spite of the development of an inspection method and management skills applying computer programs. Therefore, it is important to mitigate or prevent FAC on the carbon steel, and surface coating technology has been investigated for pipeline systems in a steam flow.

Since the occurrence of a Surry-2 pipe rupture accident, a lot of effort has been made to manage the FAC of carbon steel piping. Some of the chemicals were known as a corrosion inhibitor. Bateman et al. [2] reported that the addition of Ti may decrease the FAC rate of carbon steel by ~ 65 %, TiO_2 was also effective in mitigating the stress corrosion cracking of steam generator tubes under concentrated crevice conditions [3]. A platinum doping method was applied as another mitigation strategy of carbon steel wall thinning [4]. Noble metal, including Pt, had produced the layers of a very high catalyst concentration and this catalytic effect induced a lower corrosion potential for nickel alloys [5].

The object of this study is to evaluate the FAC resistance of carbon steel pipe materials and develop the coating techniques in a high temperature steam-moisture (or water) condition. For this purpose, a small scale test loop for a two-phase condition was designed, and the two-phase FAC resistance of coated and uncoated carbon steel piping materials was evaluated.

2. Methods and Results

2.1. Test loop setup

A closed circuit system consists of a steam generator, reheater, test chamber, heat exchanger, cooling condenser, and makeup tank. The steam generator produces steam for the test in the maximum operation conditions of 213^{o}C at 20 bar with electric power of 48 kW/hr. The steam generated from a boiler is reheated to make a super-heated state (pure steam) by a reheater. The steam pressure and temperature are controlled by the pressure control valve and condenser to set the steam state: steam quality and velocity. After injection into the test chamber, the steam is cooled down to liquid phase flowing through the main condenser shown in Fig 1. A circulation line aside make-up tank monitors water chemistry conditions such as a pH, DO, conductivity.

FAC tests are conducted using specimens of A106B Gr. B carbon steel and P22 low alloy steel. The specimen is a 30 mm x 30 mm rectangular plate with a 3 mm thickness. The specimen is insulated from other test chamber structure using a Teflon guide. Two specimens are tested simultaneously and the thinning resistance is compared between the bare and coated carbon steel surface.

2.2. Evaluation of two phase FAC

The two-phase piping systems that often experience FAC problems in nuclear power plants are as follows:

- High and low pressure extraction steam lines
- Flashing lines to the condenser
- Gland steam (seal steam) systems
- Feedwater heater vents

From the heat source (steam generator), the steam travels through the main steam line and enters the high-pressure turbine, and the bulk of the steam is exhausted from the high-pressure turbine into the cross-under piping, which contains about 20% moisture. These cross-under pipes connect the steam to the moisture separator reheater (MSR), and the mass flow from a high-pressure turbine to MSR is 9,230,679 lb/hr. The cross under piping material is carbon steel (ASTM A515) with a 42-inch diameter (thickness of 15.8 mm). The flow velocity in the cross-under piping is the mass flow per total cross sectional area, and was calculated to be 37.6 m/sec in a steam condition of 185 ^{o}C at 11 bar.

Wall thinning of the carbon steel piping occurs in a single flow and two phase flow including the steam phase. The major water chemistry parameters of a single phase FAC are well known, such as the temperature, Cr content, pH, dissolved oxygen concentration, flow velocity, and geometry. However, the effects of two-phase flows on FAC have not been thoroughly investigated. In two-phase water-steam flows, FAC depends on the steam quality and flow velocity. When the steam quality is low, wall thinning is mainly due to the corrosion process, but for a high steam quality, the degradation process is referred to as liquid droplet impingement (LDI). For LDI, the value of the flow velocity plays an important factor in the wall thinning. When a steam flow is less than about 100 m/s, the damage is mainly due to corrosion, while for a high flow greater than 200 m/s, LDI impacts on the wall as a mechanical erosion process [1]. In this study, the flow velocity is considered to be in the region of more chemical corrosion damage than mechanical erosion induced by LDI; therefore, corrosive parameters such as the water chemistry conditions are important to evaluate the FAC prevention property by the application of coating technology on piping materials.

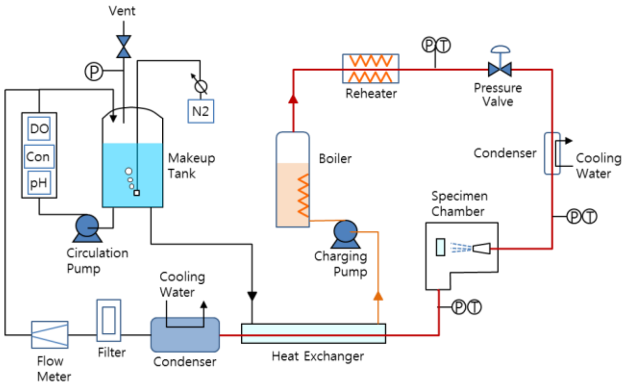

Fig. 1. Schematic of two-phase FAC test loop.

3. Conclusions

The recirculating test loop for FAC simulation in the steam phase was designed and constructed to evaluate the coating integrity on carbon steel pipe materials. The test condition was selected to simulate the environments in the region of a cross-under carbon steel pipeline to MSR, in which FAC rate is accelerated by a two-phase flow. Coating technology applying a nano-sized Pt or Ti element on carbon steel surface is expected to increase the resistance of FAC damage. Using a synchronous two-steam injection system, the effect of an advanced coating process on the piping materials can be evaluated more exactly.

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