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Flow Accelerated Corrosion: Effect of Piping Layout and Test Section Design

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

1. Introduction

Flow accelerated corrosion (FAC) is a pipe wall thinning phenomenon in pressurized water reactors (PWRs) and is a high priority concern. Severe accidents by FAC at Surry Unit 2 in 1986 and Mihama Unit 3 in 2004 initiated world-wide interest in this area [1]. Lines commonly affected by FAC attacks are feed-water lines, extraction lines, condensate drain valves, connection nozzles on the feed-water tank, blow-down lines, etc. [2]. They are composed of many elements, such as elbows, orifices, valves, reducers, and separation and union pipes. Areas suffering from FAC are thus difficult to locate, as FAC occurs only locally under specific conditions of temperature, water chemistry, flow, material composition, geometry of elements, and layout of pipe lines [2]. This paper describes the influence of the piping layout on FAC using data from the literature and a test section is then designed for use in a large-scale FAC test loop in KAERI.

2. Methods and Results

2.1 Mechanism of FAC

The mechanism of FAC consists of two processes [1]. The first process is dissolution of the protective iron-oxide layer in carbon or low-alloy steel in flowing water (single-phase) or wet steam (two-phase). The next is the transport of dissolved metal ions into the bulk water. The FAC rate is therefore controlled by the diffusion rate of dissolved iron species through the boundary layer of water. The flow velocity and local turbulence cause an increase of the FAC rate, indicating geometry factors of the piping elements are very important.

2.2 Effect of piping layout

In 2004, a pipe rupture accident caused by FAC occurred in Mihama nuclear power plant in Japan [1,3]. A schematic layout of the ruptured pipeline, which consists of several curved sections, elbows, and orifices, is presented in Fig. 1. The asymmetric thinning distribution in the cross-section in one of the pipelines behind an orifice (pipeline A) was observed. Fujisawa et al. reported that the mechanism of the above phenomenon is due to the combined effect of swirling flow and orifice bias [3]. Kubo et al. studied the swirling flow generated downstream of three-dimensionally-connected dual 90-degree elbows directly connected to each other [4]. However, the swirl flow did not appear when a straight pipe was inserted between the elbows. Watanabe et al. conducted a numerical analysis for continuous piping elements [5]. They showed that the strongest swirl flow was generated when the elbow is placed downstream of the T-tube. The above results indicate that the generation of the swirling flow depends largely on the piping layout.

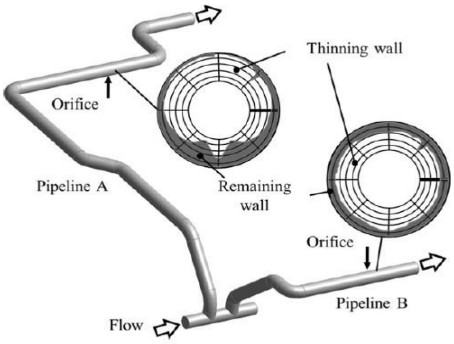

Fig. 1. Schematic layout of pipeline in Mihama PWRs [3].

2.3 Test section design

In this study, in order to identify test conditions for the large-scale FAC test loop in KAERI, a database has been constructed using experimental data in the literature, as shown in Fig. 2. However, relatively few results from tests conducted in piping components, such as elbows, orifices, and valves, are available. Single elbow, orifice, and bend elements were tested in flowing water or wet steam, respectively. Few data from experiments conducted with continuous elements of piping were found.

Cr (wt%) from heat	Water temperature (°C)	pH at 25℃	DO (ppb)	N_2H_4 (ppb)	Pressure (bar)	Test time (h)	Inner diameter (mm)	Orifice diameter (mm)	Distance from orifice inlet (mm)	Mean cross-sectional velocity (m/s)	Geometry	Steam quality (%)	steam velocity (m/s)	liquid velocity (m/s)	FAC rate (μ m/year)	FAC rate (mm/year)
0.04	150	6.1	0.1		15	54	50	24.3	150	3.54	orifice					2.26555
0.04	150	6.1	0.1		15	60	50	24.3	50	4.95	orifice					3.06595
0.04	150	6.1	0.1		15	60	50	24.3	100	4.95	orifice					2.84125
0.04	150	6.3	0.1		15	49	50	20.5	50	3.54	orifice					3.28146
0.04	150	6.3	0.1		15	49	50	20.5	100	3.54	orifice					2.67168
0.04	150	6.3	0.1		15	49	50	20.5	150	3.54	orifice					1.29705
0.04	150	6.3	0.1		15	49	50	20.5	200	3.54	orifice					0.68125
16.26	292	9.7	2		76	2057	350				elbow	26	14.3	6.8	1.7	
16.26	292	9.7	2		76	2057	350				elbow	26	20.1	9.5	1.6	
16.26	292	9.7	2		76	2057	350				elbow	26	31.9	15.1	1.9	
16.26	292	9.7	2		76	2057	350				elbow	26	53	25.1	1.7	
0.001	248	8.68	0.7	10	38.5						90도bend	76				0.12654
0.001	248	8.68	0.7	10	38.5						90도bend	83				0.06675
0.001	248	8.68	0.7	10	38.5						90도bend	88				0.04775
0.001	248	8.68	0.7	10	38.5						180도bend	35				0.63446
0.001	248	8.68	0.7	10	38.5						180도bend	45				0.95469

Fig. 2. FAC test results reported in literature.

It was reported that FAC is largely influenced by the swirling flow [3,4]. This flow is generated in a piping system composed of many curved pipe elements, especially in a three-dimensional layout based on an elbow connection. However, it is difficult to construct flow test sections that can generate a swirl flow and that can be tested with under the operating conditions of PWRs. Thus, a numerical analysis for continuous piping elements was conducted and the wall thinning profile by FAC was evaluated [5].

In our previous paper, a FAC test was performed on a test section with welded pipe (carbon steel and low-alloy steel) under high velocity flow conditions [6]. In this case, as the test section is a straight pipe, as shown in Fig. 3, and no turbulence in the local flow field occurs. In order to evaluate the effect of a swirling flow on FAC, the test section should be well designed to generate the swirl flow. A piping layout with continuous elements (elbow, orifice, valve, etc.) is being designed for the next FAC tests.

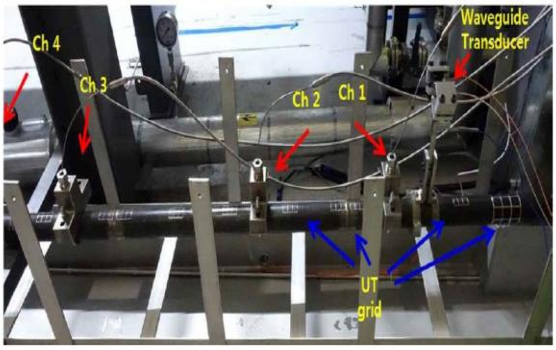

Fig. 3. Schematic layout of pipeline of the test section in FAC test facility [6].

3. Conclusions

The swirl flow that was generated at continuous elements of the piping (elbow, orifice, valve, etc.) affected the trend of FAC and it depends largely on the piping layout. Only a small body of test results for piping components can be found in the literature. Single elbow, orifice, and bend elements were tested in flowing water or wet steam, respectively. Few experimental data were found for continuous piping elements. A piping layout with combinations of the curved sections, the orifice, and the elbows is being designed for the next FAC tests.

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