Hydrodynamic Effects on Flow-Accelerated Corrosion in Elbow Pipes: Insights from Experiments and CFD Analysis

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1. Introduction

Flow-accelerated corrosion (FAC) is a significant degradation mechanism in carbon-steel piping systems of nuclear power plants. Despite extensive research, the correlation between wall thinning and hydrodynamic parameters remains unclear. This study investigates the hydrodynamic factors influencing FAC in elbow sections to identify high-risk locations. Experimental FAC tests and computational fluid dynamics (CFD) analyses were conducted, revealing that the side of the elbow pipe experiences the most severe wall thinning.

2. FAC Test

The FAC test was designed to isolate the influence of hydrodynamic parameters while maintaining constant temperature, water chemistry, and material properties. Unlike temperature and chemical factors, which uniformly affect the pipe surface [1], hydrodynamic parameters vary locally, especially in elbow sections where velocity profiles are non-uniform. The test was conducted twice, each lasting 2000 hours, with a flow velocity of 7 m/s at 150°C. The line pressure, pH, and dissolved oxygen content were controlled at 10 atm, 7, and below 5 ppb, respectively. Ultrasonic testing (UT) was used to measure wall thickness at 88 locations as shown in Fig. 1: 11 axial positions along the flow direction and 8 circumferential positions per axial location.

3. Results and Discussion

Analysis of vortex lines in the cross-section at different axial positions showed a high concentration of vortex structures near the pipe wall, particularly in Axial Positions 6–9. This region corresponds to Position A in Fig. 2, where the highest wall thinning rate was observed. The helicity distribution further confirmed that areas with high circumferential velocity and axial vorticity coincided with maximum wall thinning. The highest helicity values were observed at Axial Position 7 and Circumferential Positions 3 and 9 h, which corresponded to Position A. These findings suggest that helicity, defined as the inner product of velocity and vorticity vectors, is a critical parameter for predicting the location of susceptible wall thinning in the elbows.

4. Conclusion

This study highlights the importance of velocity and vorticity components in characterizing FAC-induced wall thinning. Contrary to conventional assumptions, the highest thinning occurred on the side of the elbow pipe rather than at the intrados or extrados. These findings provide a foundation for developing predictive models for FAC-induced wall thinning in nuclear power plants.

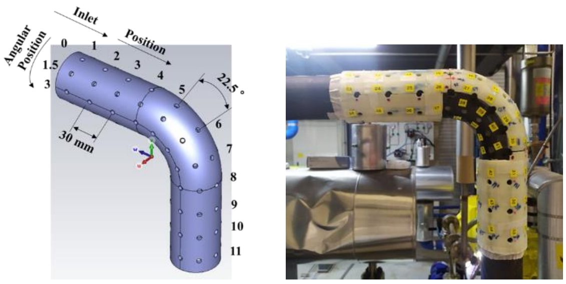

Fig. 1 Illustration of thickness measurement locations and cover to enhance the convenience of thickness measurements

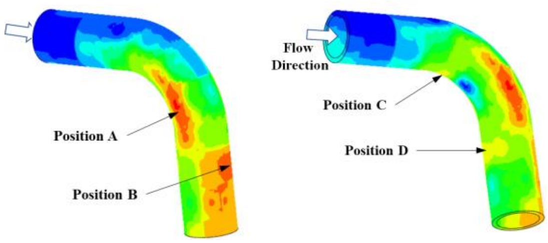

Fig. 2 Thickness reductions after the tests

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