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Intuitional experiment and numerical analysis of flow characteristics affected by flow accelerated corrosion in elbow pipe system

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HIGHLIGHTS

- Wall-thinning erosion of pipelines in plants leads to fatal accidents unexpectedly.
- Flow Acceleration Corrosion (FAC) is a main reason of wall-thinning.
- For industrial safety, it is necessary to verify the tendency of FAC.
- We focused on local wall thinning by FAC with intuitional visualization experiment and numerical analysis in elbow pipe.

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1. Introduction

Most pipes in industrial plants are made of carbon steel. A flow accelerated corrosion (FAC) causes damage in a pressure boundary area and has made an issue of safety and reliability. The FAC results in wall-thinning, which causes a reduction of thickness when a carbon steel machine comes into contact with a fluid flow.

Accidents by FAC have been reported in several power plants around the world since 1981 (Keller, 1978; NRC, 1987, 1988), hence each nation's regulatory authority is exercising strict control over FAC wall-thinning management. In 2004, Japan's Mihama Nuclear Power Plant experienced an accident in pipeline which was identified as a typical FAC-caused pipe wall-thinning (KINS, 2004). As we can see in the case of Mihama, the actual pipeline of the nuclear power plant had an intricate structure composed of elbows and orifices; hence an additional flow such as a swirling flow could be created in the pipeline (NISA, 2005). According to Ahmed, significant amounts of study on the effects of flow chemical characteristics based on FAC in power plants have been done but studies on the hydrodynamic effects of FAC by one- or two-phase flow need to be examined more thoroughly (Ahmed, 2010). To determine the FAC abrasion effect between two neighboring components, Ahmed examined 211 inspection data of 90° carbon–steel elbow. Not only the inner flow velocity effect, but also the distance between the elbow and other components in the upper stream were considered. Based on the inspection data, Ahmed discovered that a closer distance between the two components increased the wear rate of the pipe body of about 70%. Repeated tests at thermo-electronic and nuclear power plants showed that the orifice, valve, tee, elbow or other pipe components in a lower stream were most sensitive to FAC damages because of sudden expansion and contraction of the pipe. This is because of the extreme change in the lower stream as well as unstable additional flow development (Ahmed, 2010).

Because of secondary flow created by pipe installation of a one-phase flow, the other researchers believed that flow separation in a lower stream should be considered as a parameter. In addition, we believe that modeling and analysis should be made by predicting the position of the highest FAC wear rate. For example, Crawford suggested that a secondary flow in an elbow induces pressure drop which severely increases the shear stress (Crawford et al., 2007). He also found that an orifice and valve could amplify the mass transfer rate of pipe wall because its closer location to the lower stream facilitates the creation of turbulence. Chen also confirmed that the mechanism was a major cause of FAC (Chen et al., 2006). Therefore, it is important to identify the main flow streamline and geomet-

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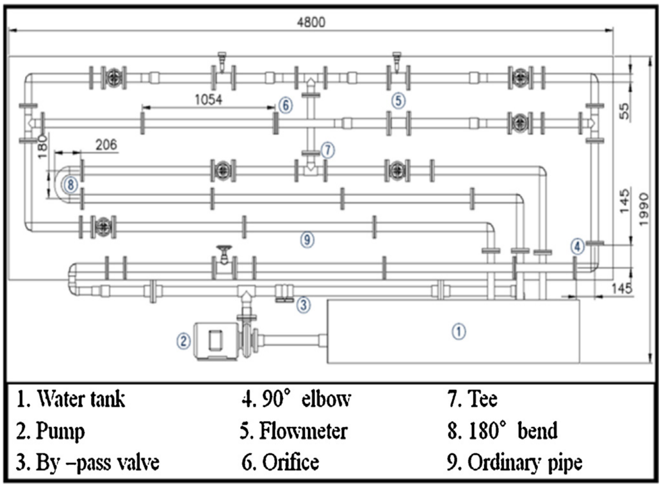


Fig. 1. Schematic diagram of experimental apparatus.

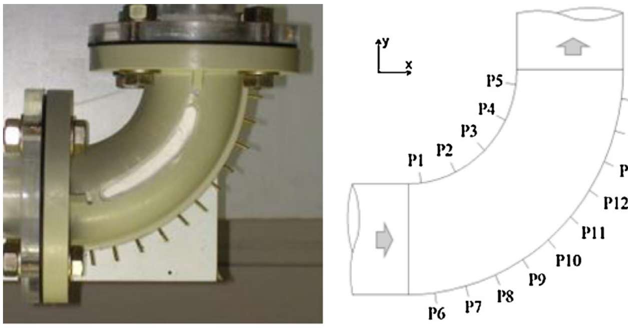
ric parameters required for characterization of FAC damages in a lower stream. The parameters are the following: the geometric structure of components, pipe direction and formation of turbulent flow. These parameters affect surface shear stress and the mass transfer coefficient.

FAC is known to occur in two stages: in dissolution of magnetite on the carbon steel surface at high temperature and during mass transfer. So far, FAC prediction models are mostly designed to calculate the wall-thinning rate of an entire pipe system, including chemical composition, steel ion concentration difference, and component structure (Kastner et al., 1984; Kasrner and Riedle, 1986). In actual working fields, however, most wall-thinning occurs locally. As a result, a hole, leakage, and rupture are made in the local area and thus, such local wall-thinning in a carbon steel pipe cannot be predicted by the existing model. Furthermore, previous studies have been limited to numerical analyses of inside-disturbed flow field.

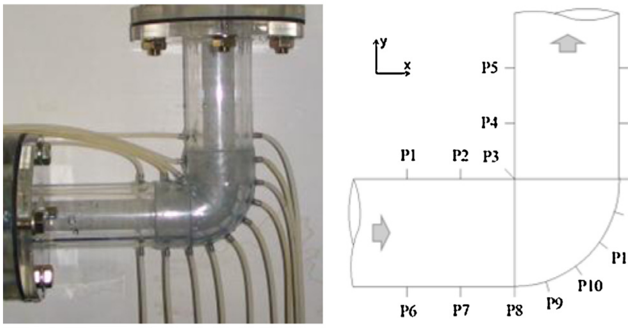
Therefore, this study aims to analyze the actual local wall-thinning inside a pipe component. To do that, we determine a deflected turbulent-flow type and FAC effect based on the shape of the carbon steel elbow which is used to connect two separate pipes at a constant angle. We utilized alkali metallic salt pipe for intuitional wall-thinning flow visualization experiment, after which pressure is measured to verify the validity of local flow prediction and numerical analysis. In addition, the turbulence parameter of numerical analysis is compared with wall-thinning data from the wall-thinning flow visualization in order to validate its correlation with FAC.

2. Experiment and numerical analysis

In this study, the turbulent flow inside of a carbon steel pipe was examined to directly analyze local wall-thinning of the pipe component which related to the actual inner FAC wear rate. To do that, a similar experimental device was developed, as shown in Fig. 1, for 5 components (4 types of tee, orifice, 90°elbow, 180°U and straight line pipes). Among them, the elbow (90°smooth bend and 90°miter bend in this study, called *round* type and *edge* type, respectively), which is widely used for rapid change of flow direction, was selected for pressure measurement and wall-thinning flow visualization in order to experimentally measure the local wall-thinning caused by turbulent flow connected with corrosion to pipe system. Then, pressure measurement was compared with data from the numerical analysis to verify the validity of experiment. Comparison between numerical analysis and experiment for wall-thinning thickness was conducted for all 5 components, however, this paper deals with only for elbow pipe model.



(a) Round type



(b) Edge type

Fig. 2. Photograph and position of pressure measurement for experimental and numerical analysis.

An actual pipe system of a power plant typically has a large capacity, operates at a high temperature and high pressure, hence, limitations are bound to replicate the actual conditions. Therefore, in the case of the elbow model, the pipe system was downscaled by 10:1 with the principle of geometric similarity. Moreover, the same directional flows and scale were applied to the model to establish kinematic similarity according to actual conditions. Furthermore, an approximate similarity principle was applied to the Reynolds number for dynamical similarity, because the actual Reynolds number was too large; a flow was controlled to set the *Reynolds* number to 5.0×10^5.

2.1. Experimental preparation for pressure measurement

The experiment for measuring pressure in pipelines was fulfilled for this study's objective. To minimize the friction and corrosion effects, the pipe was made of an acrylic material having an inner diameter of 40 mm. The experiment was conducted at 20 °C room temperature and atmospheric pressure. The inflow velocity was set to 2.50 and 3.00 m/s and applied to the two types of 90°elbows (round and edge type). In this paper, we present the case of 2.50 m/s as a representative.

To estimate local flow in the elbow pipe, total pressure at the front part of the elbow and the static pressure at the other part for each position were measured by using a digital manometer respectively. Fig. 2 shows an installation of 15 pressure measuring points to the elbow pipe and its connection to the pipeline for the static pressure measurement. Numerical analysis and wall-thinning measurement were used for the pressure measuring points.