

Estimation of Flow Accelerated Corrosion (FAC) in Feeder Pipes using CFD Software Fluent

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Abstract

Flow Accelerated Corrosion (FAC) is a corrosion mechanism induced by a combination of various physical, chemical and hydrodynamic factors that results into wall thinning of piping. Prediction and modeling of this phenomena is needed to account for local and non uniform distribution flow and mass transport characteristics. This can be done by using CFD software FLUENT. In a number of nuclear reactors a feeder wall thinning rate of 0.1084 mm/EPY has been reported. In this study emphasis is given on two objectives. The first one was to perform CFD analysis using FLUENT. Feeder channel of a typical reactor was modeled as it showed the maximum wall thinning rate of 1.1 mm per year. However in this analysis no consideration was given to the chemical treatment of working fluid. The experimental studies of FAC were done at various temperatures in order to determine the threshold temperature for FAC. However, due to experimental limitations no significant FAC was found for water temperatures up to 90°C.

Keywords: Flow accelerated corrosion (FAC), CFD, erosion, pipe bends, FLUENT

INTRODUCTION TO FLOW ACCELERATED CORROSION (FAC)

Flow Accelerated Corrosion (FAC) causes metal loss of carbon steel piping, vessels exposed to flowing water or wet steam and tubing etc which results into wall thinning of component. If neglected, then degraded components can suddenly cause large disasters. Over the years, FAC has caused hundreds of piping and equipment failures in all types of fossil, industrial steam, and nuclear power plants, however, often the cause of the failure was not known by the plant owner. Additionally, the power industry did not fully understand the conditions under which FAC occurred. Therefore it is needed that one should look to find its causes and find out the methods to control it. FAC was identified as a distinct corrosion mechanism some twenty years ago when in 1986, an elbow in the condensate system ruptured at the Surry Nuclear Power Station [1]. The failure caused four fatalities and tens of millions of dollars in repair costs and lost revenue. FAC was found to be the cause of the failure. Because of the deaths involved and the high degree of regulation applied to the nuclear power plants, a comprehensive overall approach was needed. An intensive international cooperative effort was initiated to understand the parameters which affect FAC. The strategy was that understanding FAC would allow the development of technology to help plants find damage before failure occurs, and the measures to control it.

METHODOLOGY

The methodology of studying the FAC studies was based on following guidelines:

- Selection of KANUPP feeder for analysis
- Modeling and solution of selected feeder by using FLUENT
- Estimation of FAC in selected feeder
- Experimental setup design to study FAC at low temperature

In a typical nuclear reactor there are hundreds of feeder pipe assemblies with similar number of inlet and outlet feeder pipes. Each pipe connects to a reactor channel at one end and to an inlet or outlet header manifold at the other. Over the years, wall thinning is observed in many feeders that were inspected. In order to estimate FAC in the feeder pipes, outlet feeder is selected because maximum wall thinning is observed in such feeders. Detail description and hydrodynamic data of a typical channel is given in Table 1. Here it should also be noted that outlet feeder side is selected because at this side elevated temperature is present as compared to any other position in feeder arrangement.

Table 1: Parametric description of Feeder Pipe

<i>Sr. No.</i>	<i>Parameter</i>	<i>Detail</i>
1	Operating temperature at full power	567 °F
2	Mass flow rate	27.41 lb/sec
3	Inlet Velocity of fluid	8.3 m/sec
4	Density of fluid	784.4 Kg/m ³
5	Nominal thickness	5.54 mm
6	Thinning rate	0.1084 mm/EFPY

MODELING OF FEEDER BY USING CFD SOFTWARE FLUENT.

Solid geometry is developed by using drawing software Pro-Engineer. GAMBIT is used for meshing. Hex core mesh is used in order to lower cell counts and improve the quality; this type is generally used for flow volumes with complexity near the walls [2].

Meshed file that has generated was imported and solved in FLUENT, segregated solver, 3D space, implicit formulation, cell based gradient option and absolute velocity formulation at steady state condition is set for analysis. Selecting viscous K-ε model with appropriate boundary conditions that simulate the feeder was modelled, developed and solved.

The velocity contours and velocity vectors are shown in Figure 1 and 2 respectively.

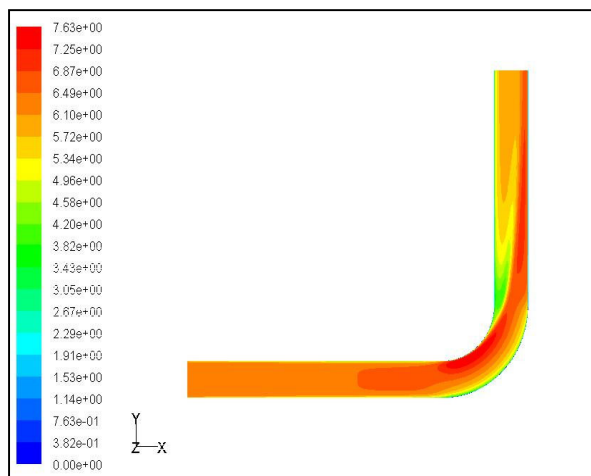


Figure 1: Contours of velocity magnitude (m/sec) zoomed at bent or a typical feeder

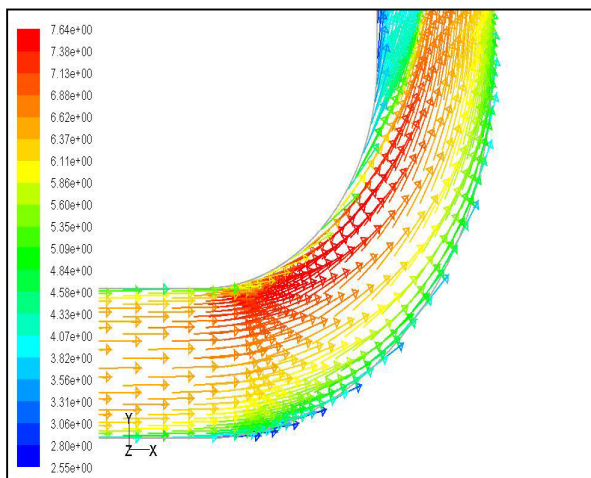


Figure 2: Contours of fluid velocity vector

ESTIMATION OF FAC IN SELECTED FEEDER

By using Discrete Phase Model wall thinning rate can find by using FLUENT. The erosion rate is defined as [3].

$$R_{erosion} = \sum_{P=1}^{N_{particles}} \frac{m_p C(d_p) f(\alpha) v^{b(v)}}{A_{face}} \quad (1)$$

Where $C(dp)$ is a function of particle diameter, f is the impact angle of the particle path with the wall face, $f(\alpha)$ is a function of impact angle, v is the relative particle velocity, $b(v)$ is a function of relative particle velocity, and A_{face} is the area of the cell face at the wall. Default values for FLUENT; $C = 1.8 \times 10^{-9}$, $f = 1$, and $b = 0$. The erosion rate as calculated above is displayed in units of removed material per area per time, i.e., mass flux. The functions C and f have to be specified in consistent units to build a dimensionless group with the relative particle velocity and its exponent. To compute erosion rate in terms of length/time (mm/year, for example) either define a custom field function to divide the erosion rate by the density of the wall material or include this division in the units for C and/or f .

The equations describing some of the erosion models can be modified to appear in the form of the general equation describing the erosion rate, Equation (1). For example, the Tulsa Angle Dependent Model described as [3]

$$ER = 1559B^{-0.59} F_s V^{-1.73} f(\alpha) \quad (2)$$

Can be rewritten in the form of Equation (1) with the following substitutions:

$$V^{1.73} = V^{b(v)} \quad (3)$$

$$1559B^{-0.59} F_s = C(d_p) \quad (4)$$

Where ER is the erosion rate, B is the Brinell hardness, and F_s is particle shape coefficient.

In FLUENT 6.3, data base does not contain data regarding to feeder case thus need user defined functions file formation. In our feeder case by using Equation (2) erosion rate can find at any point on bent. From Figure 2 maximum velocity vectors at bent having velocity magnitude of 7.64 m/s. Considering a Brinell number of 495 for 2.75mm diameter particles, erosion rate is estimated as 1.1 mm/year. A variety of particle size may be present in the coolant loop due to pipe corrosion and erosion phenomena. The erosion rate can find out at any point in feeder by taking velocity vector magnitude from velocity vector contours. Results that obtained in this way do not representing the effect of chemical addition in working stream that is a common practice in plant to prevent corrosion thus obtained results may show a large difference from values obtained from plant data.

EXPERIMENTAL SETUP DESIGN TO STUDY FAC AT LOW TEMPERATURE

In order to find out threshold temperature for FAC or low temperature FAC study, experimental setup is designed at atmospheric pressure so that experiment can perform below 100°C. Layout of experimental setup is shown in Figure 3.

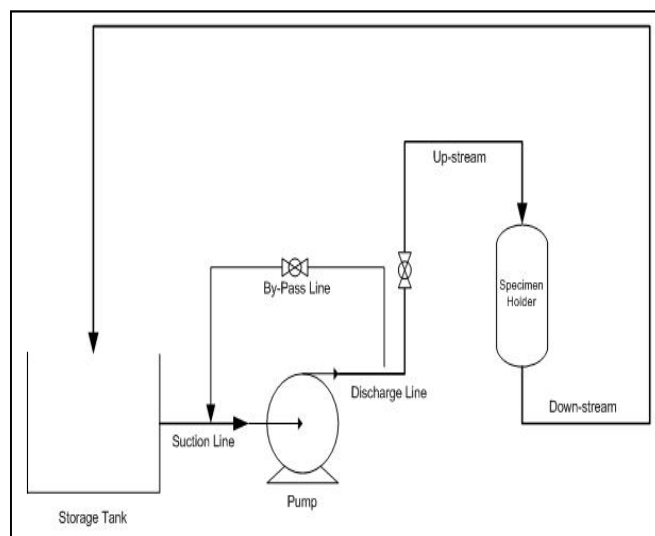


Figure 3: Experimental setup layout for determination of threshold temperature for FAC.

Four coupons were placed in specimen holder for analysis. Working conditions after achieving steady state operation are listed in Table 2. These working conditions remained almost constant during experiment and this data is helpful in taking results of experiment. Steady state condition achieved after 30 minute of pump startup. The change in water chemistry with respect to time is given in Table 3.

Table 2: Working conditions in experiment.

<i>Sr. No.</i>	<i>Parameter</i>	<i>Condition</i>
1	Coupon material	M.S.
2	Coupon area	51.0 cm ²
3	Temperature	90 °C
4	Total running time	12 hrs
5	Working pressure	1 atm
6	Flow rate	0.2947 lit/sec
7	Fluid velocity	1.338 m/sec

Table 3: pH and Conductivity behaviors at different time during experimental run

<i>Sr. No.</i>	<i>Time (hrs)</i>	<i>pH</i>	<i>Conductivity (µs)</i>
1	0	9.32	28.8
2	2	9.29	44.6
3	4	9.26	51.9
4	6	9.26	55.2
5	8	9.25	59.9
6	10	9.24	63.2
7	12	9.24	67.8

This behavior is shown in Figure 4.

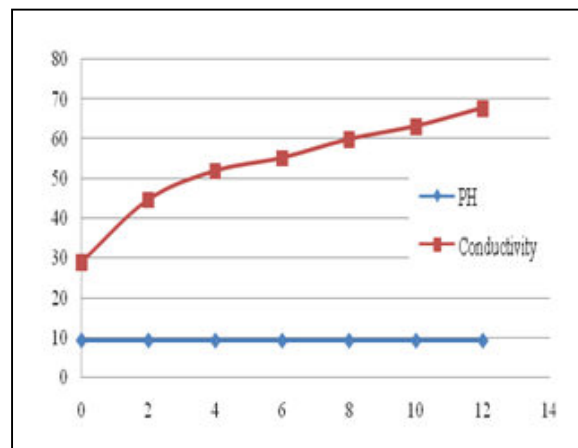


Figure 4: pH and Conductivity behavior at different time during experimental run.

RESULTS

CFD analysis of the feeders gave an insight into the flow behavior inside the bends. The followings may be concluded from CFD analysis:

- FLUENT analysis of feeder gave the maximum wall thinning rate of 1.1 mm per year, while the reported data suggest a maximum wall thinning rate of 0.1084 mm per EPY.
- However, the wall thinning estimations in this study was in absence of chemical treatment of working fluid. Also the difference is due to neglecting the welding points in feeder geometry development and ignoring the chemical addition effect during model development.

- Corrosion rate of 1.3941, 1.6317, 1.3326 and 1.1939 g per cm² per year is observed in mild steel for coupon no 1, 2, 3 and 4 respectively, at 90°C while the pH range is 9-10 and flow rate of 0.2947 lit per sec.
- Maximum corrosion rate observed is 1.6317 g per cm² per year and is in coupon no 2 from top from flow entrance point).
- No evidence of FAC observed on coupons surface and no remarkable wall thinning was measured. However studies suggest that there is no need to do FAC studies below 90°C.
- High corrosion rate in coupon is due to the reason that at higher temperature hydrazine decomposes and thus it does not scavenge oxygen properly from system.

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