NUMERICAL METHODOLOGY TO DETERMINE FLUID FLOW PATTERN WITH CORROSION IN PIPE BENDS USING COMPUTATIONAL FLUID DYNAMICS SOFTWARE

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ABSTRACT

Flow-accelerated corrosion (FAC) is the most common failure in production and processing industries and nuclear power plants. The simulations were performed using Computational Fluid Dynamic (CFD) simulations of the flow in elbows of the Flow Accelerated Corrosion (FAC) test loop and using the FLUENT commercial software. The model geometry and mesh were created using the ANSYS FLUENT 14.0. The objective is to establish the relationship between the fluid flow patterns and corrosion behaviour within the pipe bend. The paper presented the results of the simulations of the flow in form of velocity vectors for two types of pipe bend, both mitred bend and smooth bend with three different Reynolds numbers 37387, 49850 and 62313 respectively. From the results obtained, it was observed that the mitre bend produces more wall shear stress, turbulent intensity and turbulent kinetic energy compared to the smooth bend and thus predicted to produce more corrosion However, with realizable k-ε model, more significant differences are evident when compared with RNG k-ε model and standard k-ε turbulence model. The maximums in both turbulent intensity, wall shear stress as well as turbulent kinetic energy now appear on the outer radius, near the elbow exit. Also, the simulation is used to obtain the FAC rate of the various elbows. The result shows that the FAC rate of the outward bend of the elbow is two-orders than the inward bend of the elbows.

Keywords: turbulent intensity, computational fluid dynamics, corrosion, bends, pipes.

INTRODUCTION

Flow-accelerated corrosion (FAC) is a phenomenon that causes the loss of iron from the wall of piping, vessels, and equipment made of carbon steel. It has been reported that the piping made of carbon or low-alloy steel have been suffering from continuous wall thinning in pressurized water reactors (PWR's) and CANDU type reactors. Smith *et al*. and Shoyi *et al*. show that the FAC phenomenon occurs at the temperature ranging from 100 to 260 ℃ , and the maximum of FAC rate appears at 150 ℃ [1-2].

FAC phenomenon of various materials has been studied [3-10]. and that copper, chromium, molybdenum can inhibit the FAC and was put forward [11]. Since the accident of piping rupture happened at Surry Unit 2 in 1986, the wall thinning in piping systems has emerged as one of hot issues. Recently, the thinning of feeder pipes in CANDU reactors has been more and more identified as an FAC impact [12].

Many researchers have proposed some models and simulations to predict the FAC rate. These models and simulations are based on the mass transfer theory, and the calculated results are in accordance with the laboratory experiments. For example, in 1980, a prediction model about FAC rate, which assumed that when the dissoluble Fe_3O_4 met the condition of the equation of Swecton and Bases, then the flux of dissolved Fe^{2+}, could be employed to express the FAC rate. This model emphasized the FAC process of electrochemical reactions and mass transfer [13]. However, this model cannot explain the relationship between temperature and FAC rate, the proposed the MIT model on the basis of [13] considered that the structure of the corrosion product could influence the FAC rate, and this model could explain the relationship between temperature and FAC rate [14]. But some parameters including the thickness of oxidation film and porosity were difficult to measure in the MIT model. Although these models are more consistent with the experimental data, they could not explain the FAC phenomenon of the elbow.

The idea of inner flow region called boundary layer which could be defined as a very thin region of flow near wall where viscous forces and rationality cannot be ignored. The boundary layer thickness was the main parameter to be considered in the boundary layer solution. This thickness depended on the Reynolds number along the flat surface. However, the value of this Reynolds number depends on the free-stream velocity and the distance from front wall of bend [15].

SECONDARY FLOW

Secondary flows imply a primary flow. Here, vorticity always plays an essential role, for example when its direction is modified by the flow (flow in a bend) or when vorticity is added at the boundaries. In some instances, the secondary flow is a region separated from the primary flow by a streamline that attaches to smooth

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surfaces or sharp edges. In all instances the performance is affected, and it is imperative to include the correct physics in any model of such flows. The entire range of Reynolds numbers is affected.

Consequently a secondary flow occurs in which the fluid near the central plane moves outward and the fluid near the bottom and top walls of the pipe moves inwards towards the centre of curvature of the central axis. This in turns modifies the axial velocity.

A vortex phenomena is a spinning, often turbulent, flow of fluid. Any spiral motion with closed streamlines is vortex flow. The motion of the fluid swirling rapidly around a centre is called a vortex. The speed and rate of rotation of the fluid in a free (irrotational) vortex are greatest at the centre, and decrease progressively with distance from the centre, whereas the speed of a forced (rotational) vortex is zero at the centre and increases proportional to the distance from the centre [16]. In fluid mechanics, a distinction is often made between two limiting vortex cases. One is called the free (irrotational) vortex, and the other is the forced (rotational) vortex. Secondary flows are always caused by an imbalance between a static pressure field and the kinetic energy in the flow. An example is the well documented horseshoe vortex, where the incoming boundary layer flow meets a stagnation line which causes a motion of the fluid along the wall, and subsequently the formation of a vortex. The important observation herein is that the strength of the vortex is mostly determined by the starting conditions and the further development of the vortex is determined by the conservation of its angular momentum. In a rotating system the analogy is that the vortex flows are principally generated by the meridional flow field while the centrifugal and Carioles forces only act to change the vortex vector direction [16].

SIMULATION RESULTS AND DISCUSSIONS

The residuals in the governing equations had all fallen below 10^{-4} after a total of 4260 iterations had been performed, at which point the solution was considered converged. In addition to monitoring the residuals, the mass flow rate at the outlet was computed every couple of hundred iterations and compared to the (specified) mass flow rate at the inlet, 3.368 kg/sec.

Table-1. Operating parameters.

Temperature (^oC)	**Pressure** (MPa)	**Flow velocity** (m/s)	**Material**	**Electrical conduct.** (μ S/cm)	**Concentratio n of dissolved** O_2 (ppm)
20	1.01325×10^5	1.5, 2.0 and 2.5	Water	34.9	3.1

A dimensionless variable for the called the Reynolds number which is simply a ratio of the fluid dynamic forces and the fluid viscous forces, was used to determine what flow pattern will occur. The equation (1) shows the Reynolds number (R_e), where v is the fluid velocity; D is the diameter of the pipe μ is the viscosity and ρ is the density of water respectively.

$$R_e = \frac{\rho VD}{\mu} \quad (1)$$

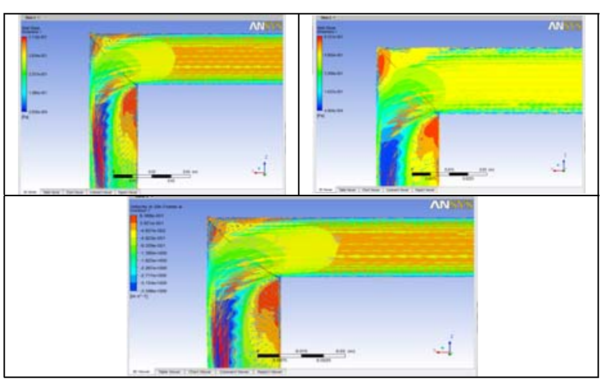

Figure-1. Turbulence intensity in mitre bend with various fluid flow 1.5, 2.0 and 2.5 m/s.

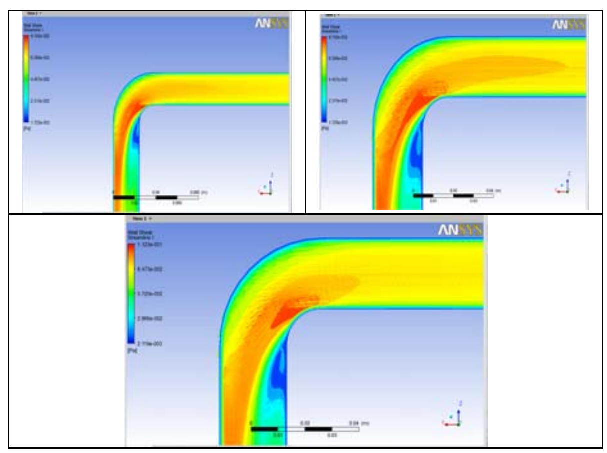

Figure-2. Turbulence intensity in smooth bend with various fluid flow 1.5, 2.0 and 2.5 m/s.

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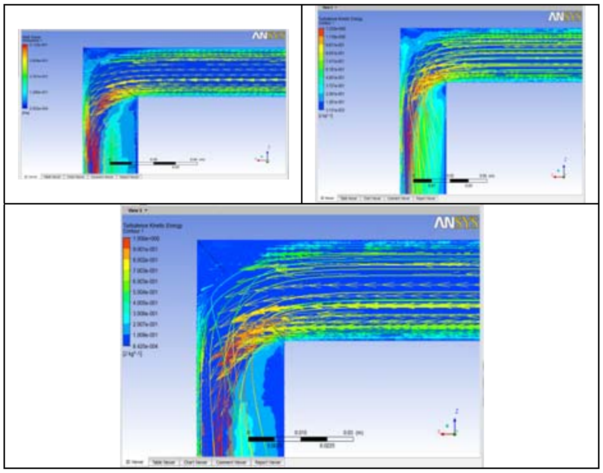

Figure-3. Turbulence kinetic mitre bend with various fluid flow 1.5, 2.0 and 2.5 m/s.

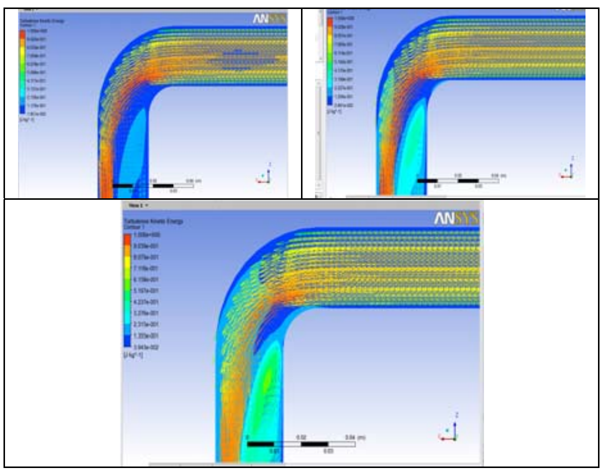

Figure-4. Turbulence kinetic mitre bend with various fluid flow 1.5, 2.0 and 2.5 m/s.

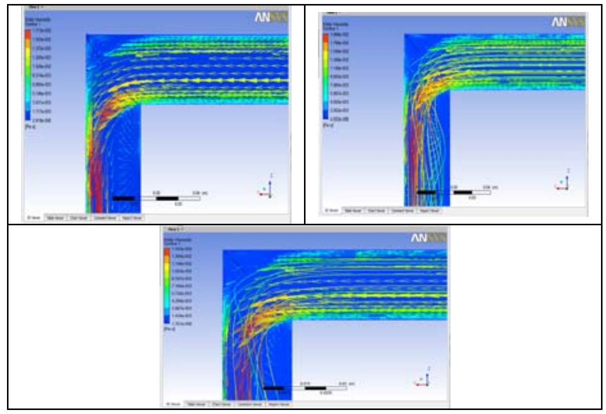

Figure-5. Eddy viscosity of mitre bend with various fluid flow 1.5, 2.0 and 2.5 m/s.

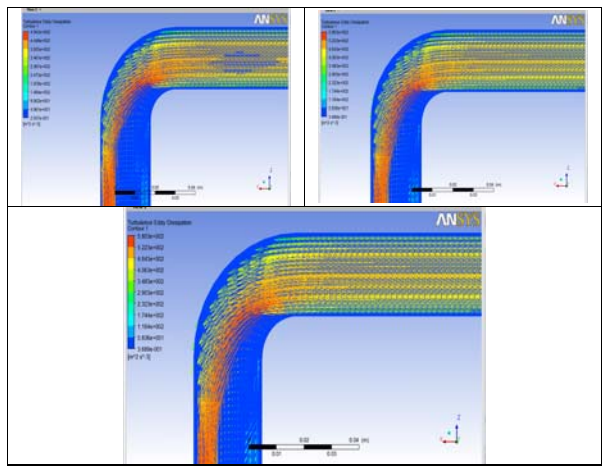

Figure-6. Eddy viscosity smooth of bend with various fluid flow 1.5, 2.0 and 2.5 m/s.

Table-2. Summary of results analysis (Value produces from the various fluid flow velocities in Table-2).

Description	**Velocity** (m/s)	**Mitre bend**	**Smooth bend**
Wall Shear Stress (Pa)	1.5	7.55618	6.41352
	2.0	12.1734	10.3341
	2.5	19.2715	15.3563
Turbulence Kinetic Energy (J/kg)	1.5	0.15406	0.13015
	2.0	0..23309	0.16531
	2.5	0.5305	0.25445
Eddy viscosity (Pa)	1.5	0.17145	0.13812
	2.0	0.19981	0.16569
	2.5	0.23329	0.19236

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From the graph in Fgure-7 to Figure-9, it was observed that the values of mitre bend produced were significantly higher than the values of smooth bend.

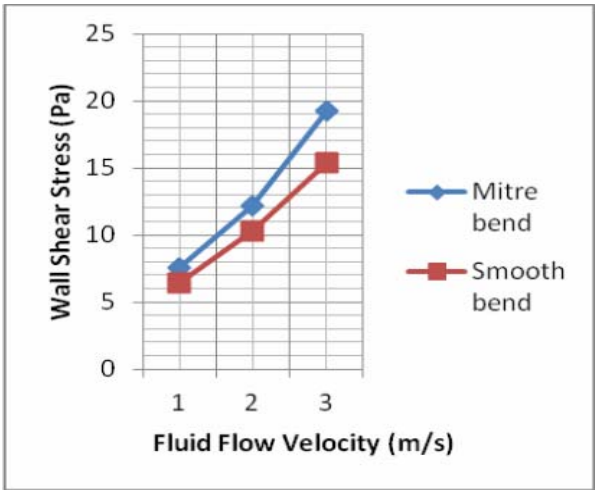

Figure-7. Graph of wall shear stress against fluid flow velocity.

From, the wall shear stress graph, it was noted that the mitre bend produce 16 to 200 % more shear stress when compared to the smooth bend as shown Figure-7.

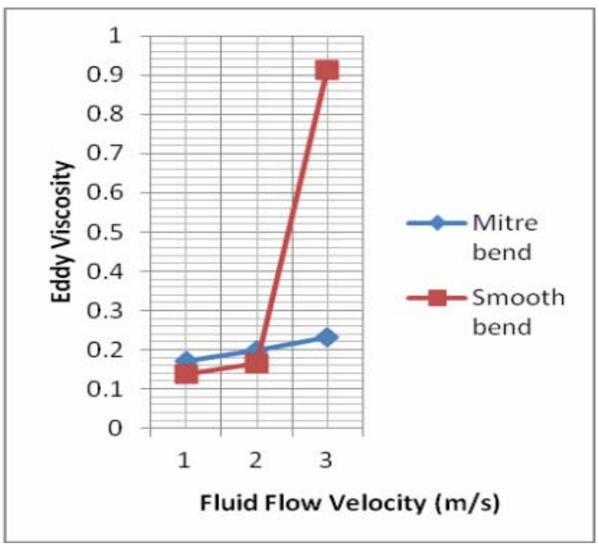

Figure-8. Graph of eddy viscosity against fluid flow velocity.

While, for the Eddy viscosity graph, the mitre bend produces 22 to 92 % more viscosity than smooth bend which means that the viscosity produced by mitre bend was very much high amount of viscosity produced by smooth bend at the same fluid flow velocity.

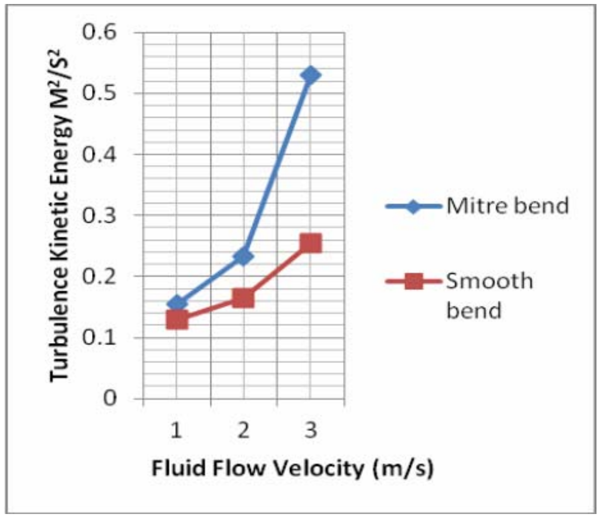

Figure-9. Graph of turbulence kinetic energy against fluid flow velocity.

Also, for the turbulence kinetic energy, the mitre bend produced 29 to 55% more turbulence kinetic energy compared to the smooth bend as shown in Figure-9.

From the simulation results, the mitre bend will get corroded easily as results of cavitation, flow induced corrosion and impingement compared to the smooth bend as the mitre bend shows higher values of parameters that contributed for the corrosion to occur.

Furthermore, as per the effect of increasing velocity on the probability of erosion-corrosion to occur, it can see almost all values of wall shear stress, Eddy viscosity and turbulence kinetic energy were very much increase in fluid flow velocity. From the graph of wall shear stress against fluid flow velocity, every increase in velocity resulting in 55 to 200% more shear stress at mitre bend and 52 to 160 % more shear stress at smooth bend.

While for the relationship between turbulence kinetic Energy with fluid flow velocity, it can be seen that as the velocity increases, the turbulence kinetic Energy were not that affected much in the mitre bend with average of 30 % difference. The graph shows that the turbulence kinetic Energy increased up to 29 to 55 % more as the fluid velocity increases. This shows that the designs of the mitre bend maintains turbulence intensity as the fluid velocity increases from 1.5 m/s to 2.5 m/s. So the predicted corrosion rate caused by the turbulence in mitre bend will not show significant difference when the fluid flow velocity increases.

The increase of fluid flow velocity affects the Eddy viscosity in similar manner with on how it effect on the wall shear stress. When the velocity increases, the Eddy viscosity increases up to 22 to 92 % more at mitre bend and 20 to 90 % at smooth bend.

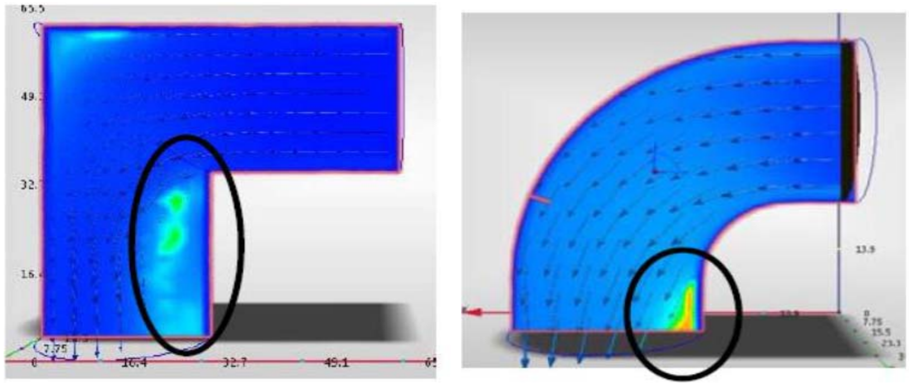

Figure-10. Predicted areas where corrosion to occur in both mitre and smooth elbows.

CONCLUSIONS

The behaviour of fluid flow pattern and the affected parameters such as wall shear stress turbulence intensity and turbulence kinetic energy were conducted numerically. In this study, the flow pattern with the corrosion in pipe bend was related which focused on two type of pipe bend.

However, from the results of the simulation, the conclusions were drawn vis-a-viz: Mitre bend produce 55 -200 % more shear stress and 52 - 160 % more turbulence intensity compared to smooth bend and thus are predicted to produce more corrosion within pipe; increases in fluid flow velocity from 1.5 m/s to 2.5 m/s produced 20 -200 % more shear stress and 29 - 55% increases in turbulence intensity and thus causes more corrosion within the elbow pipe and the wall shear stress and turbulence intensity occurred mainly on pipe elbow.

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