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NUMERICAL ANALYSIS OF RELATIONSHIP BETWEEN FLUID FLOW PATTERN ON CORROSION BEHAVIOUR IN PIPE BENDS

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Abstract:

One problem facing today's production and processing, desalination and nuclear power industries is flow-accelerated corrosion in pipe elbows. The simulations are being performed using the AUTODESK Simulation 2013. The objective is to establish the relationship between the fluid flow patterns and corrosion behaviour within the pipe bend. 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 number 37387, 49850 and 62313 respectively. From the results obtained, it is 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- model, more significant differences are evident when compared with RNG k- model and standard k- 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.

Keyword: Mitre bend, Smooth bend, Wall shear stress, Turbulent intensity, Corrosion

1.0 INTRODUCTION Flow-accelerated corrosion (FAC) is a phenomenon that causes the loss of iron from the wall of pipe, 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. Scholars have proposed some models to predict the FAC rate. These models are based on the mass transfer theory, and the calculated results are in accordance with the laboratory experiments. For instance, Berger *et al* put forward a prediction model about FAC rate, which assumed that when the dissoluble 3 4 met the condition of the equation of Swecton and Bases, then the flux of dissolved 2+ could be employed to express the FAC rate. This model emphasized the FAC process of electrochemical reactions and mass transfer. However, this model could not explain the relationship between temperature and FAC rate (Berger, *et al*.,1980 and Muhammadu, *et al*., 2013).

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When fluid, in this case water, /simulated seawater passes through pipe elbow, the interaction between centrifugal and viscous forces creates a strong secondary flow in the plane normal to the pipe axis. This secondary flow consists of two counter-rotating vortices, one in either half of the pipe cross section. The scouring action of these vortices is believed to accelerate the processes of corrosion of the pipe wall; this in turn may lead to excessive vibrations, and possibly create a breach in the wall itself (Pietralik, 2012 and Muhammadu, *et al*., 2016).

This paper presents Computational Fluid Dynamics (CFD) simulations of the flow in both mitre and smooth bends. The simulations were performed using the AUTODESK 3-D 2013 software Inc. The goal of the simulations is to gain a better understanding of the phenomena influencing the corrosion that occur within the pipe elbow. This also describes the model geometry and the mesh used as indicated in Figure 1.

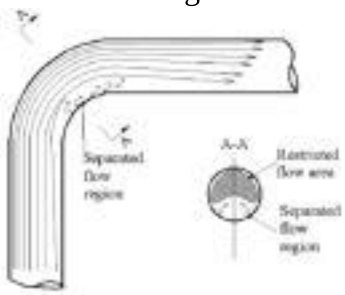


Figure 1: The flow structure of the elbow.

The idea of inner flow region called boundary layer which could be define 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 (Ablikim, *et al*., 2013, Muhammadu, *et al*., 2014 and Hashimoto, *et al*., 2015).

2 .0 AUTODESK CALCULATION

The Autodesk software 2013 was used to calculate the elbow system, which sets up a 3Dmodel according to the structure of Figure 2. The mesh type was T-grid, and k-e turbulent model is used in the calculation process. Inlet boundary condition is set as velocity-inlet, and outlet boundary condition is set as pressure-outlet. SIMPLEC was adopted when calculating pressure and velocity coupling, and standard discretization was used as pressure discretization.

Momentum equations, turbulent kinetic energy and turbulentkinetic energy dissipation are applied in the second-order windward discretization. The operating parameters as in Table 1.

The symmetrical distribution of the velocity magnitude of the elbow system and the elbow cross-section of u¼458 was shown in Figure3.Figure 3 show that the flowing core shifts to the outward bend of the elbow, and the velocity of the inward bend of the elbow is greater than that of the outward bend of the elbow. The mass transfer coefficient of the cross-section of = 45°.

Table 1: Operating parameters used for simulation.

Temperature (°C)	Pressure (MPa)	Flow velocities (m/s)	Material/ Fluid	Electrical conductivity (S/cm)	Concentration of dissolved oxygen (ppm)
125	0.2	1.5, 2,0 & 2.5	Water	34.9	3.1

A dimensionless variable for the Reynolds number which is simply a ratio of the fluid dynamic force and the fluid viscous forces, is used to determine what flow pattern will occur. The equation for the Reynolds number is

= (1)

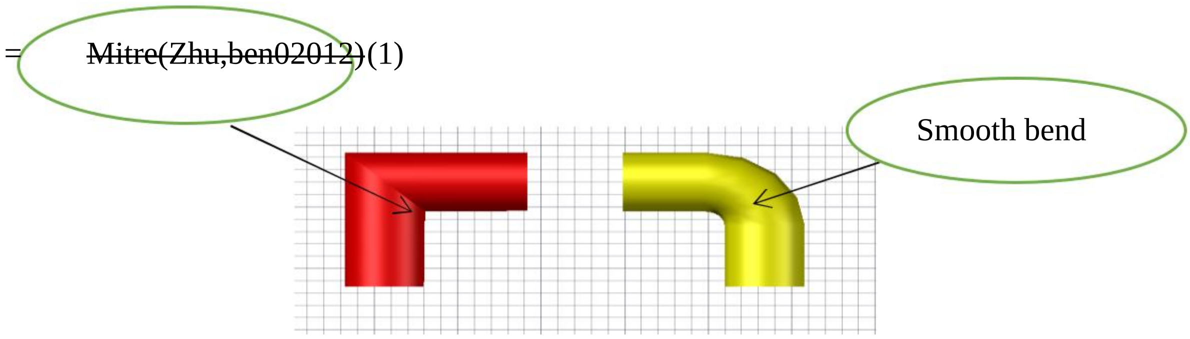


Figure2: Mitre bend and smooth bend

The Figure 2 indicates the schematic diagram various bends.

3. TURBULENT INTENSITY MEASUREMENTS

Turbulence Intensity is a scale characterizing turbulence expressed as a percent.an idealized flow of fluid with absolutely no fluctuations in fluid speed or direction would have a turbulence intensity value of 0%. This idealized case never occurs on earth. However, due to how Turbulence Intensity is calculated, values greater than 100% are possible.

Turbulence Intensity (T. I.) is defined in the following equation:

T. I. = /U (2) Where represent the Root-mean-square (RMS), or standard deviation, of the turbulent velocity fluctuations at a particular location over a specified period of time, and U represents the average of the velocity at the same location over same time period respectively or

T.I.= (2a)

The intensity of the velocity fluctuation will be measured or represented also. The flows in elbows are entirely in the regime.

Turbulence Intensity: (3)

From the definition of , given as the standard deviation of the set of "randow" velocity fluctuations, 1′ (equation 2a). Similar definitions apply to the lateral and vertical velocities, v(t). A larger indicates a higher level turbulence. The shearing force F acts on the area on the top of the element. Thus, the wall shear stress, which is equal to force per unit area, that is Wall shear stress, =

(4)

Where F = force and A = area. The deformation which this shear stress causes is measured by the size of the angle Ø and is known as shear strain. Using the experimental result that shear stress is proportional to rate of shear strain, then

= constant × (5)

The term is the change in velocity with respect to y, or the velocity gradient, and may be written in the differential form . The constant of proportionality is known as the dynamic viscosity, , of the fluid giving:

= (6)

Because the turbulent motions associated with the eddies are approximately random, this can characterize them using statistical concepts. In theory the velocity record is continuous and the mean can be evaluated through integration. Below an overbar is used to denote a time average over the time interval t to t + T, where T is much longer than any turbulence time scale, but much shorter than the time-scale for mean flow unsteadiness, e.g. wave or tidal fluctuation.

Mean velocity: $\bar{u} = \frac{1}{T}\int u(t)\,dt$

$= \frac{1}{N}\sum u_i$ (7)

Where $\int u(t)$ dt is continuous record

and $\frac{1}{N}\sum$ is equal to discrete, equi-spaced point

Turbulent Fluctuation:

$u'(t) = u(t) - \bar{u}$ (continuous record) (8)

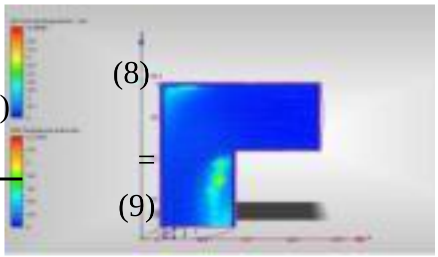
$= u_i - \bar{u}$ (discrete points)

Turbulence strength: $= \sqrt{\overline{u'^2}} = \sqrt{\frac{1}{N}\sum u_i'^2}$ (9)

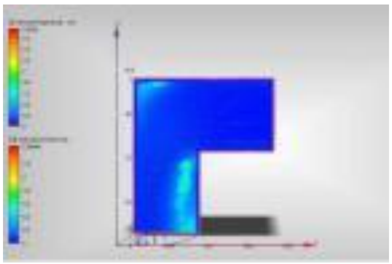
Where $\sqrt{\overline{(\;)^2}}$ represent the continuous record and $\sqrt{\frac{1}{N}\sum_{i=1}(\;)^2}$ represent the discrete, equi-spaced points respectively.

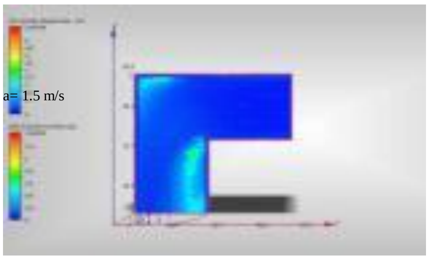
4.0 SIMULATION RESULTS AND DISCUSSION

The residuals in the governing equations had all fallen below 10^{-4} after a total of 3250 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, 2.379 kg/sec. as shown in Figures 3 to 10 respectively.



b=2.0 m/s

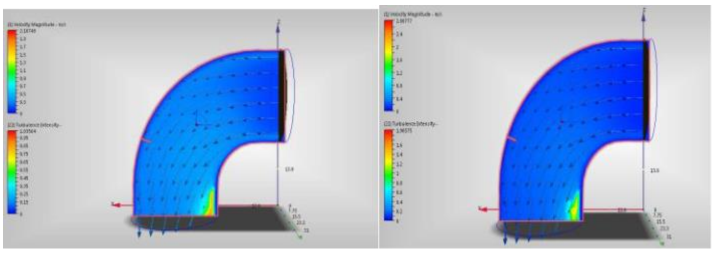




a= 1.5 m/s

c=2.5 m/s

Figure 3: Turbulence intensity in Mitre bend with various fluid flow 1.5 m/s, 2.0 m/s and 2.5 m/s.



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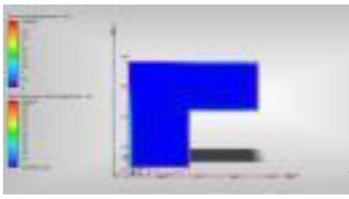
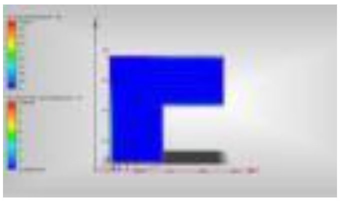


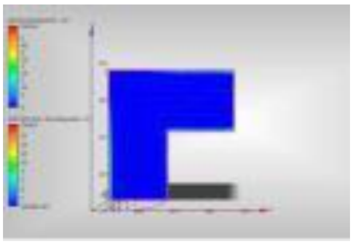
a=1.5 m/s b=2.0 m/s

c=2.5 m/s

Figure 4: Turbulence intensity in Smooth bend with various fluid flow 1.5 m/s, 2.0 m/s and 2.5 m/s.

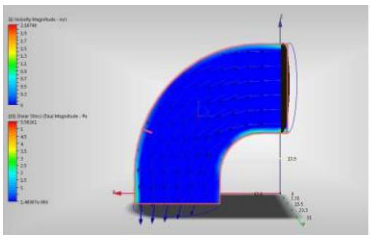


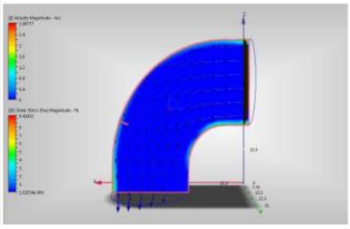
a=1.5 m/s b=2.0 m/s



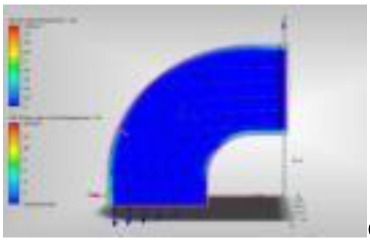
c=2.5 m/s

Figure 5: Wall shear stress in Mitre bend with various fluid flow 1.5 m/s, 2.0 m/s and 2.5 m/s.



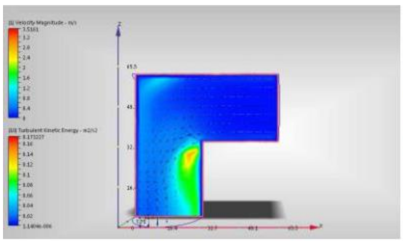


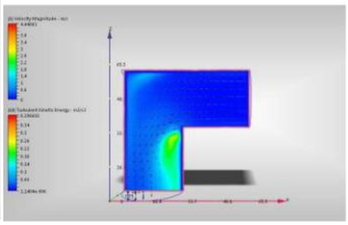
A=1.5 m/s b=2.0 m/s



c=2.5 m/s

Figure 6: Wall shear stress in Smooth bend with various fluid flow 1.5 m/s, 2.0 m/s and 2.5 m/s.





a=1.5 m/s b=2.0 m/s

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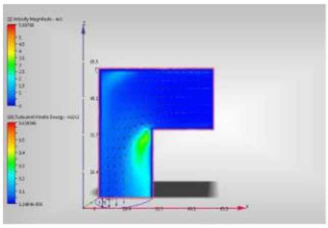


c=2.5 m/s

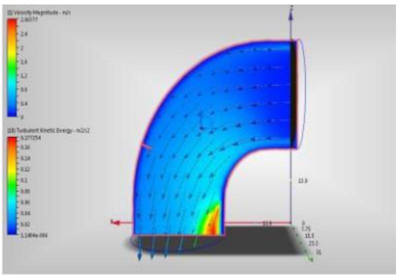
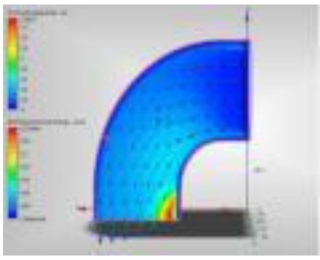
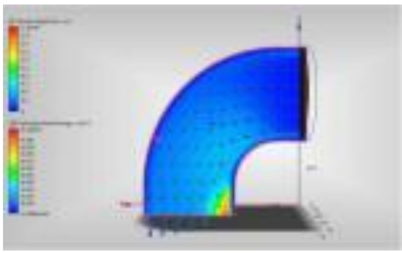


Figure 7: Turbulent Kinetic Energy in Mitre bend with various fluid flow 1.5 m/s, 2.0 m/s and 2.5 m/s.



a=1.5 m/s b=2.0 m/s



c=2.5 m/s

Figure 8: Turbulent Kinetic Energy in Smooth bend with various fluid flow 1.5 m/s, 2.0 m/s and 2.5 m/s

In Figures9 to 11, it was observed that the values of mitre bend produced were significantly higher than the values of smooth bend.

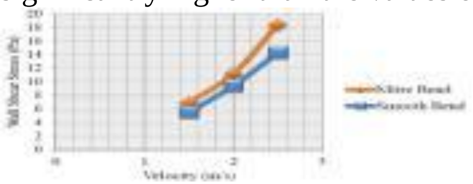


Figure9: Graph of Wall Shear Stress against Fluid Flow Velocity

From, the wall shear stress graph, it was noted that the mitre bend produce 18 to 29 % more shear stress when compared to the smooth bend as shown Figure 11.

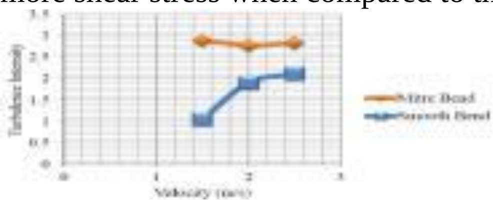


Figure10: Graph of Turbulence Intensity against Fluid Flow Velocity

While, for the turbulence intensity graph, the mitre bend produces 33 to 175 % more intensity than smooth bend which means that the turbulence produced by mitre bend could almost triple the amount of turbulence produced by smooth bend at the same fluid flow velocity as shown in Figure 10.

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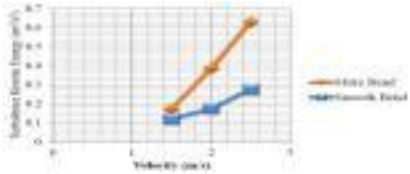

Figure11: Graph of Turbulence Kinetic Energy against Fluid Flow Velocity

Also, for the turbulence kinetic energy, the mitre bend produced 44 to 128 % more turbulence kinetic energy compared to the smooth bend as shown in Figure 11.

From the simulation results, the mitre bend will get corroded easily as results of cavitation 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, turbulence intensity and turbulence kinetic energy were directly proportional to the increase in fluid flow velocity. From the graph of wall shear stress against fluid flow velocity, every increase in velocity resulting in 60 to 64 % more shear stress at mitre bend and 51 to 71 % more shear stress at smooth bend.

While for the relationship between turbulence intensity with fluid flow velocity, it can be seen that as the velocity increases, the turbulence intensity is not affected much in the mitre bend with average of 3 % difference. A different phenomenon occurs at the smooth bend where the turbulence intensity is directly proportional to the increase of fluid flow velocity.

5.0 Effect of fluid flow velocity on the wall shear stress, turbulence intensity and turbulence kinetic energy

The effect of increasing velocity on the probability of erosion corrosion to occur, it can be seen almost all values of wall shear stress, turbulence intensity and turbulence kinetic energy are directly proportional to the increase in fluid flow velocity. From Figure 11, the graph of wall shear stress versus fluid flow velocity, every increase in velocity resulting in 60 to 64 % more shear stress at mitre bend and 51 to 71 % more shear stress at smooth bend.

Also, the relationship between turbulence intensity with the fluid flow velocity, it could be observed in Figure 12 that as the velocity increase, the turbulence intensity were not that effected much in the mitre bend with average of 3 % difference. A different phenomenon occurs at the smooth bend where the turbulence intensity is directly proportional to the increase of fluid flow velocity. The graph shows that the turbulence intensity increases up to 11 to 80% more as the fluid velocity increase. This show that the designs of mitre bend maintains turbulence intensity as the fluid velocity increase from 1.5m/s to 2.5 m/s.

The increase of fluid velocity affects the turbulence kinetic energy in similar manner with on how it's effect on the wall shear stress. When the velocity increases, the turbulence kinetic energy increases up to 61 to 124 percent more at mitre bend and 47 to 56 percent at smooth bend as shown in Figures 10 to 11. This shows that the turbulence kinetic energy is directly proportional to the velocity of fluid flow. Therefore, by increasing the velocity, the corrosion caused by the turbulence kinetic energy should also be increasing, which agrees with Zhang, et al., (2013)

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The corrosion was predicted to be occuring on the area circled as shown in Figures 12 to 13.

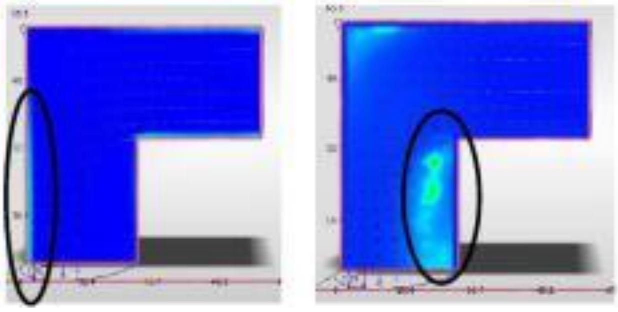

Figure 12: Predicted area for corrosion to occur at mitre bend

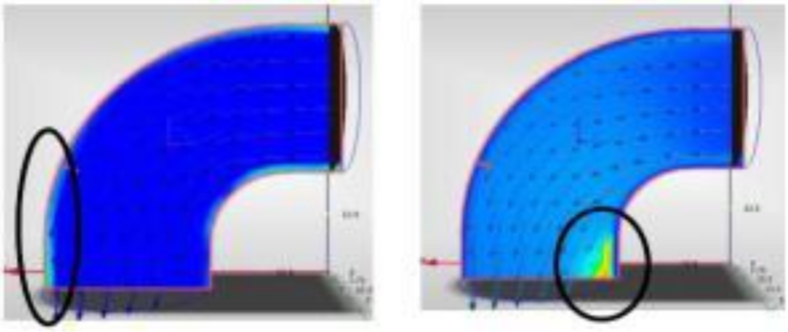

Fig. 13: Predicted area for corrosion to occur at smooth bend

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. From the results of the simulation, the conclusions were drawn as follows:

1. Mitre bend produce 18 – 29 % more shear stress and 33 – 175 % more turbulence intensity compared to smooth bend and thus are predicted to produce more corrosion within pipe.

2. Increases in fluid flow velocity from 1.5 m/s to 2.5 m/s produced 51 – 71 % more shear stress and 2 – 11 % increases in turbulence intensity and thus causes more corrosion within the elbow pipe.

3. The wall shear stress and turbulence intensity occurred mainly on pipe elbow.

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