

Predicting Effects of Corrosion Erosion of High Strength Steel Pipelines Elbow on CO₂-Acetic Acid (HAc) Solution

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Abstract . Simultaneously effect of erosion combined with corrosion becomes the most concern in oil and gas industries. It is due to the fast deterioration of metal as effects of solid particles mixed with corrosive environment. There are many corrosion software to investigate possible degradation mechanisms developed by researchers. They are using many combination factors of chemical reactions and physical process. However effects of CO₂ and acid on pipelines orientations are still remain uncovered in their simulation. This research will investigate combination effects of CO₂ and HAc on corrosion and erosion artificial environmental containing sands particles in 45°, 90° and 180° elbow pipelines. The research used theoretical calculations combined with experiments for verification. The main concerns are to investigate the maximum erosion corrosion rate and maximum shear stress at the surface. Methodology used to calculate corrosion rate are Linear Polarization Resistance (LPR) and weight loss. The results showed that at 45°, erosion rate is the more significant effects in contributing degradation of the metal. The effects of CO₂ and HAc gave significant effects when flow rate of the solution are high which reflect synergism effects of solid particles and those chemical compositions.

Keywords: Errosion corroison, Acetic Acid, CO₂ Corrosion, elbow pipline.

1. Introduction

Piping system in oil and gas industrial is a crucial part to transfer the fuel from oil well to the station in order to process for refinery. Many factors are needed to be considered especially in the designing stage for the piping system [1]. Crude oil is a complex mixture of hydrocarbons species which determines oil characteristics. Some major factors such as erosion and erosion corrosion acting on the wall especially at the bend area can cause massive damages to the system [2]. This formation of surface protective film also has effects in contributing corrosion. It depends on the corrosion resistance of the metal. For instance, carbon steel pipe that immersed in sea water is usually formed a layer of rust. However, the protective film is to be removed due to the damage caused by erosive fluid, such as sea water contained sand particle. The corrosive environment reacts chemically to the bare surface of the steel pipe and results in the corrosion rate to be increased [3-5]. The mechanical forces can promote the material surface erosion as well as degradation in surface properties due to the cause of corrosion. The typical mechanical actions often happened are abrasive of slurry, impinging liquid, droplet, bubbles and cavitation on the material surface. In addition, the faulty workmanship is one of the factors involving erosion and corrosion, or a present of corrosive fluid flowing through the material surface. In most case, oxidation of metals forms a protective film to protect the surface [6]. The synergy effect of erosion and corrosion is occurred simultaneously and the erosion corrosion rate would increase significantly. Analytical data shows that components in crude oil varied with main components classified as: carbon, hydrogen, nitrogen, sulfur and their compounds. Studies have demonstrated that those multi species factors can govern the corrosion process in many ways and in several mechanisms [7, 8]. Many efforts have been made for understanding CO₂ corrosion mechanism



to improve the predictions. But, to date, the reported model available does not represent combining parameters such as HAc. and CO₂ on different pipe orientation. There are limited studies in the literature to observe those mixed effects.

2. Methodology

2.1 Materials

In material selection as inputs in CFD, it will be used parameters conditions as presented in Table 1.

Table 1. Sizes of sand particles

Sizes of sand particles	Value
Minimum diameter	50 μm
Maximum diameter	500 μm
Mean diameter	250 μm
Standard deviation	70 μm

2.2 Erosion Simulation

CFD software is used to predict the maximum erosion rate in three types of elbows. Commercially available CFD software, CFX used as the erosion prediction software. This software was developed by ANSYS and is applicable for most fluid flow analysis in any virtual environment. The erosion simulation procedure has three major steps that are flow modeling, particle tracking, and erosion prediction. There are five major tasks have to be done to obtain the simulation results. The tasks are following the sequence that started from geometry, meshing, setup, solution and results.

2.3 Theoretical Method for Calculating Erosion Rate

The theoretical result of 45° elbow is calculated by using equation which according Det Norske Veritas Recommended Practice RP O51 whereas the calculation for 90° and 180° is based on Salama equation [9].

2.4 Cell Solutions

Simulation of flow condition was conducted using rotating cylinder electrode (RCE). A cylindrical working electrode was screwed onto an electrode holder at the center of the cell for rotating in the RCE. The Linear Polarization Resistance (LPR) technique was used to measure the corrosion rate. The procedure is similar to ASTM Experimental test G 5- 94[10].

2.5 Linear Polarization Resistance (LPR) Method for Corrosion Rate Calculation

Linear Polarization Resistance (LPR) is used electrochemical method of monitoring corrosion as well as other processes such as material polarization resistance. LPR method consists of three electrodes which are working electrode, working electrode and counter electrode.

3. Results and Discussion

3.1 Theoretical Models model of Corrosion Erosion

The theoretical results of maximum corrosion erosion rate acting on the surface of 45° elbow are presented at Table 2. The results are considered the mechanical and chemical action which is the effect of erosive fluid wear on the material surface in certain fluid velocity and impingement angle. In Table 2 compares the result of theoretical and experimental data respectively. As can be seen that corrosion erosion rate increases with increasing velocities. Possible reasons for increasing metal loss are turbulence flow regime that causes more impingements of particles to the metal surface [4, 11]. Based on experimental investigation, increasing of corrosion erosion is dominantly by caused the increase of shear stress acting on the metal surface [12]. It means that under these conditions, both mechanisms of removal metal loss and corrosion were interact each other [13]. The average theoretical

erosion rate at the 45° elbow is 6.2 mm/year whereas the analytical erosion rate is 4.8 mm/year. The difference between these two values is 1.34 mm/year which has standard error of 22%.

Table 2. Theoretical result* of maximum erosion rate at 45° pipeline elbow with several fluid velocities as compared with experimental works [14]

Velocity (m/s)	Erosion rate (mm/year)	Corrosion rate (mm/y)	Corr-erosion rate (mm/y)	Corr-erosion rate (mm/y)
0.5	1.5	0.6	2.1	3.5
1.0	3.4	0.65	4.2	4.2
1.5	5.3	0.75	6	5
2	7.3	0.75	8.5	5.5
2.5	9.4	0.76	10.1	6

* Theoretical result is calculated based on DNV RP O501 standard.

3.2 Comparison with Corrosion Erosion Software (Norsok)

Figure 1 describes comparison among corrosion erosion rate as calculated by Norsok software, experimental works and theoretical methods. It can be seen that accuracy of theoretical method is less than Norsok and experiments data. It concluded that, there is still need more parameters should be considered in building expressions theoretical methods. This observation supports previous research that erosion affects corrosion by create additional metal distribution through accelerating mass transfer process should be accounted.

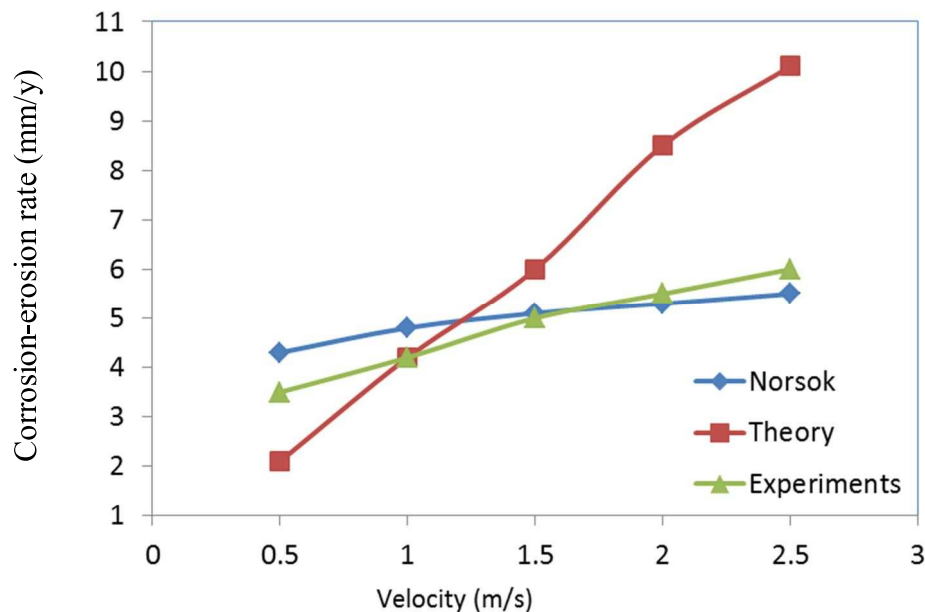


Figure 1. Comparison corrosion erosion as calculated using Norsok, theory and experiments.

3.3 Effect of HAc on Erosion Corrosion of Elbow Pipeline

The corrosion rate as a function of different velocity and HAc concentration is shown in Table 3. As observed in the table, corrosion rate increases significantly with increasing velocity and the effect is more dominant at 100 ppm of HAc concentration. At 50 ppm of HAc concentration, the corrosion rate increases slowly. At higher velocity and higher HAc concentration, the effect of rotation speed caused the corrosion rate to increase significantly. The higher corrosion rate may be related to electrochemical and hydrodynamic effects of the solution. Increasing the HAc concentration and rotation speed

accelerate the electrochemical reaction transfer [15]. A faster rotation speed can also reduce thickness of the boundary layer of water next to a metal surface. This thinner boundary layer allows the dissolved species to corrode the metal surface more quickly [6, 16].

Table 3: Experimental results effects of HAc on corrosion erosion

Velocity (m/s)	Maximum erosion rate density (mm/y)	Corrosion rate at 50ppm HAc	Corr-erosion rate (mm/y), 50 ppm HAc	Corr-erosion rate (mm/y), 100 ppm HAc
0.5	1.5	1.2	2.7	3.3
1	3.4	1.4	4.8	5.3
1.5	5.3	1.6	6.9	7.4
2	7.3	1.8	9.1	9.5
2.5	9.4	1.9	11.3	11.7

3.4 Corrosion Erosion Rate at Different Elbow

Table 4 shows CFD simulation calculation of corrosion erosion at 45°, 90° and 180° elbow at 0.5 m/s. Based on the table, the highest corrosion erosion happened at 45° pipeline elbow. From investigation using CFD, it is caused by significantly increase of shear stress at 45° compared 90° and 180°. In the other words, corrosion erosion is dominated by impact of shear stress. Investigating critical location, it shown that highest corrosion erosion was occurred at the wall that facing toward the fluid inlet which shows that synergy of erosion and corrosion is occurred simultaneously. Therefore, the erosion area is more critical when corrosion is initiated while the surface has start eroded.

Table 4. Comparison between Simulation result.

Elbow types	Velocity (m/s)	Maximum corrosion erosion rate (mm/year)	
		CFD result	Experimental result
45°	0.5	1.9	2.3
90°		1.5	1.1
180°		1.6	1.9

4. Conclusions

Erosion was the dominant factor that govern the reaction process in CO₂/HAc system. At the higher flow rate conditions, the domination effects of erosion will increase. Behavior of corrosion erosion reaction consisted of chemical reaction and physical loss. It was found that there is synergism between corrosion and erosion. The corrosion process can be accelerated with the presence of HAc. The more HAc the corrosion erosion increase. Effects of HAc are more significant at higher concentration. Comparing effects of elbow, the 45° elbow give the highest erosion corrosion rate. The higher elbow angle, there are no significant effects on increasing erosion corrosion. This may relate to combination of shear stress in longitudinal and normal directions. The other possibilities are due to mass transfer coefficient that can interfere erosion process.

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