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Analysis of pit and its effect on electrochemical corrosion reaction in oil and gas pipelines

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A parametric pit design in the outer surface of the oil pipeline buried under the soil atmosphere is investigated. This study analyzes the effect of pit size and corrosion contours to evaluate the metal degradation due to various characteristics that impact the corrosion on the oil pipeline. A 3D design of the model has been chosen, and its geometry is modeled in COMSOL MULTIPHYSICS, and appropriate meshing is done before computing to analyze impact of pit size and electron current density in oil pipeline. The behaviour of the pit design was then analysed using various parameters such as electron current density, corrosion rate, the impact of the pit size in localized area. The current findings in the study shows that risk of metal degradation and the depth of the pit size gives a relationship for corrosion in the localized area and the risk for pitting corrosion can be reduced by improving pipeline condition monitoring.

Keywords: Autocatalytic, Electrochemical, Pitting, Quenched, Tempered

India is recognized as the few vivid spots of the world economy, which is adding growth to the global GDP, whereas iron and steel industries or the metal sector is the backbone of a country. To sustain the growth of an economy, the most crucial part is to plug the leakages of the industry, and one such leakage of the metal sector is corrosion. The yearly loss of the consumption of fixed capital in the fiscal year was more than 4.2 lakh Crores consisting of all the sectors[1], whereas 25% of the total failures in oil and gas industries is due to the corrosion of the metal equipments and mainly in the welded joints[2]. The corrosion in the oil pipelines primarily degrades the metal, and most of the products are unrecovered as corrosion is an irreversible process.

Pre-accident analysis is a crucial aspect of the emergency oil spills problem[3]. The leading causes of oil pipelines accidents are pipeline corrosion (including internal and external), construction defects, mechanical damage (including excavation work), diversions, unauthorized functions, third party activity, oil pipelines' operational imperfection, manufacturing defects of pipes and equipment, natural disasters, and the most important of them is corrosion[4].

Corrosion is a natural process that forms the oxides, hydroxides, carbonates or sulphides of the metal. It is a redox reaction that takes place, and it takes the form of an electrochemical reaction with its environment[5]. The metal reacts with the environment and forms more stable electrochemical compounds that are irreversible in nature. Most of the researches are done to reduce the corrosion rate in the pipelines to decrease the failure in oil pipelines[6]. Different models have been designed over the years to study various characteristics of corrosion. There are multiple types of corrosion, and one such form of corrosion is pitting corrosion that impacts and corrodes most parts of the oil and gas industries and gives considerable losses to these industries[7]. Most of the failures in oil and gas industries are due to pitting corrosion because it's challenging to observe the pit in oil pipelines. As they are difficult to observe, they can create accidental damage to the environment, products and human resources[8].

Pitting corrosion is generally the formation of cavities on the surface of the metal due to the electrochemical reaction between the metal surface and the environment around it, especially soil when transportation pipelines are on land. One such issue in determining the pit corrosion is that one cannot assess the intensity of the corrosion with the metal loss. It is one of the most dangerous forms of corrosion because it is not easy to assess this type of corrosion, and it is autocatalytic in nature. Pitting corrosion propagates in three steps: initiation of pits, Propagation of pits and termination of pits. It occurs in most materials, including alloys such as stainless steel and aluminium alloys.

Experimental section

The material property of the model

Most of the materials used in the oil pipelines are alloys. The materials used are different grades of steel, and the atmosphere for the oil pipelines can be air in the atmosphere, water in the oceans or sea or be it soil in the land. There are various types of soil with different properties. The material used for the analysis of pits in the pipeline model and pitting corrosion is P122 steel.

Grade P122 Alloy Steel Seamless Pipes are Carbon Steel Pipes with the subsequent addition of chromium, molybdenum, and sometimes vanadium, known as chrome-molybdenum Pipes. ASTM Specification alloy steel Pipes are used for high-temperature service applications. Seamless Alloy Steel Pipes, according to ASTM A335 Grade P122 are reheated and furnished in full annealed, isothermal annealed or normalized quenched and tempered condition[9].

Table 1 — Composition of the material in wt%

Elements	Composition(wt%)
Fe	Bal.
Cr	10.3
Mo	0.4
W	1.9
Ni	0.34
Cu	0.7
V	0.2
C	0.12
Si	0.15
Mn	0.63
Nb	0.055
N	0.06
Al	0.02
B	0.002
P	0.014
S	0.001

Table 2 — Conductivity of the soil with salinity

EC (dS/m)	Salinity Class
0 <2	Non-saline
2 <4	Very slightly saline
4 <8	Slightly
8 <16	Moderately saline
≥ 16	Strongly saline

Composition of material

Grade P122 Alloy Steel consists of the elements provided in Table 1, and its wt% is also given in it.

Composition of Soil

dimension (mm) of the oil pipeline is given in Table 3 and dimensions of pit in Table 4.

Meshing and Boundary Conditions

Electrochemical Analysis

The primary current distribution is between the pit, which behaves as an electrode in Fig. 2, and the soil that behaves as the electrolyte and the current between them, as shown in Fig. 3 is known as electrolyte current density that helps to study the corrosion rate of the reaction. The current density of the reaction depends on the conductivity of the soil by the following relationship.

$\hat{J} = \sigma E$

where,

$\hat{J}$ is electrolyte current density

σ iis conductivity of the soil

E is Electric field

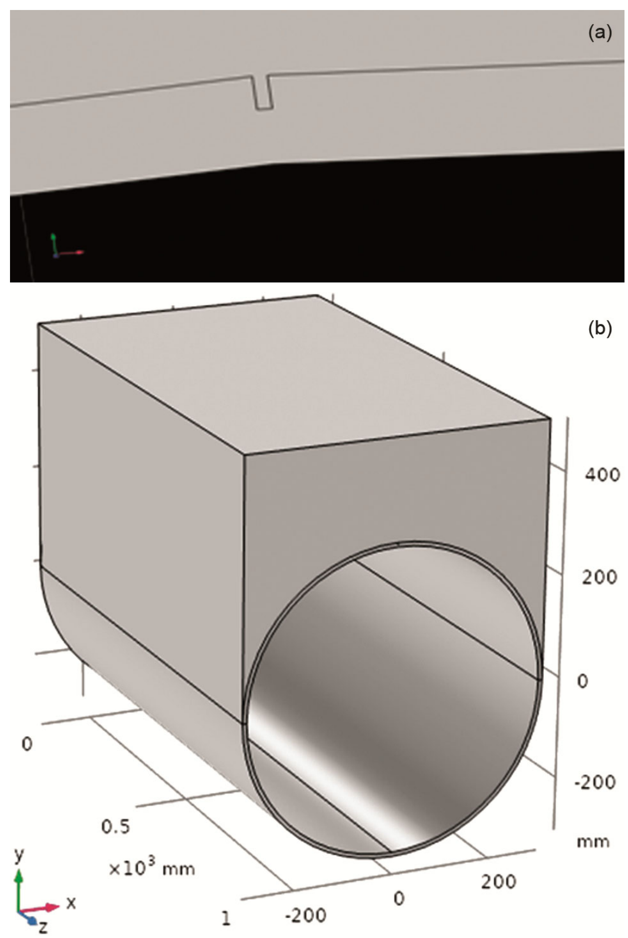

Fig. 1 — Isometric view of the geometry of Pipeline and soil

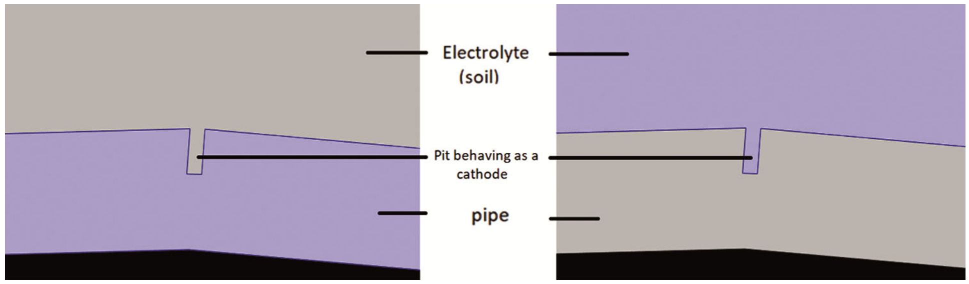

Fig. 2 — Schematic view of the cathode as a pit and soil as electrolyte

Table 3 — Dimensions of the geometry of oil pipeline

Dimensions	(mm)
Length	1000
Outer diameter	610
Inner diameter	594
Thickness	8

Table 4 — Dimensions of the pit

Dimensions	(mm)
Depth	1-7
Outer radius	0.5-1.5
Plane	XY

Table 5 — Boundary conditions for the electrochemical reaction

Boundary conditions	Values
Current density	10^{-10}A/m^2
Initial potential	-0.440v
Electrolyte conductivity	0.1 S/m

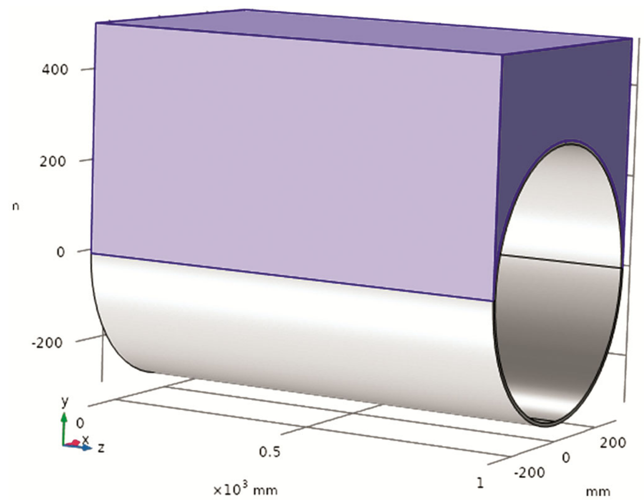

Fig. 3 — Soil as a electrolyte and current density in the dark shaded portion

The current density is directly proportional to the conductivity of the soil, and conductivity is directly proportional to the nature of the soil, be it acidic, basic or saline. The higher the *p*H, the more is the conductivity of the soil, the higher is the current density, and more is the oxidation of the metal, and the higher is the corrosion rate.

Boundary conditions

Such as electrolyte current density, electrode potential and electrolytic conductivity is given as follows in Table 5.

Results and Discussion

The simulation was done in COMSOL Multi-physics with different defect depths of the pit at 1mm, 3mm, 5mm, 7mm and with the varying radius of 0.5mm, 1mm, 1.5mm. The metal degradation of the localized adjacent area increases as the depth of the pits increases, but there is no effect of the varying radius of fixed depth. In Fig. 4 with an increase in the pH of the soil will increases the conductivity of the soil and increasing the current density of the reaction increases the corrosion rate. The evaluation methods typically used in the oil industry based on analysis of historical data to model and predicts corrosion defect growth on the pipeline. The corrosion defect on pipeline is time-dependent growth in service environments. The electrolytic current density vector is shown in Fig. 4a and vector current direction towards pipeline outer surface across the pit can predict the corrosion current.

An electrolytic potential that requires corrosion to occur based on current simulation model is shown in Figure 4b. It can be seen that adjacent to pipe outer surface the potential was higher while away from pipeline i.e. towards the soil the potential was lower. Therefore, the interface area between soil and pipeline outer surface are considered as most severe to influence corrosion. It was difficult to control the corrosion potential and corrosion current by external means in un-protected pipeline as evidenced in various pipeline industries. In Figure 6c the magnified view of interface is shown to visualize the actual potential required for corrosion. The red colour is severe and blue colour is not severe in simulation. Therefore, the corrosion potential was severe as seen in Fig. 4c.

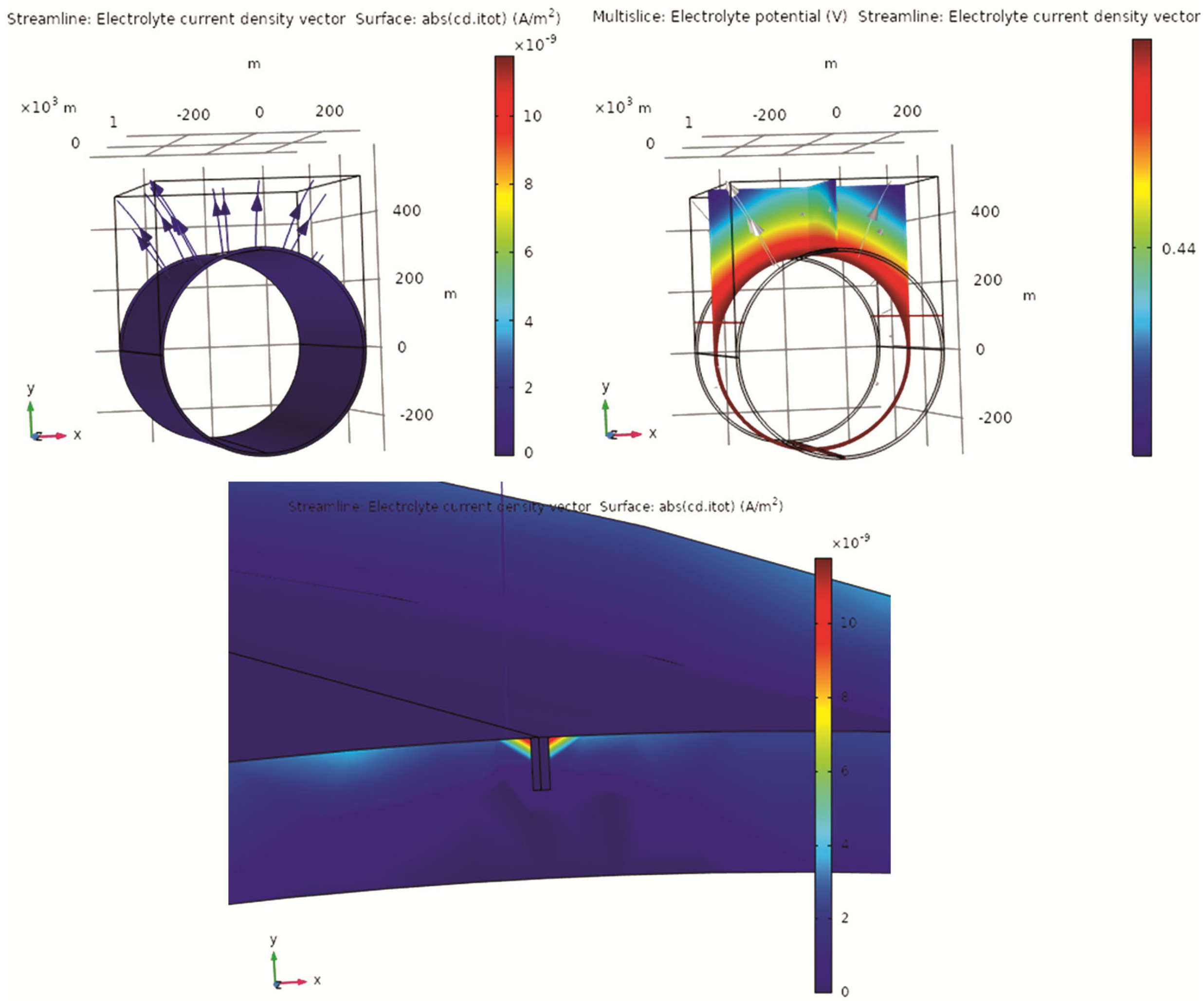

Fig. 4 — a) electrolyte current density vector b) Electrolyte potential c) electron current density around the pit

Prediction of corrosion defect growth of corroded pipelines as a function of time may remain a challenge to oil industry. Generally many results demonstrated that growth rate of the corrosion defect followed the order of defect depth >defect length >defect width. Generally, with increased defect depth, the local stress may increase. Under the operating pressure, the yield stress shall be exceeded, causing pipeline failure. FEA modelling has conducted for investigating interaction of many defects in near adjacent with due consideration on effect of steel grade and the electrochemical behaviour condition of the pipelines. Figure 5 show the more is the pit's depth; the higher is the contour (greenish-blue color) in different parts located around the pit which represents the metal degradation is severe.

Many work suffered from limitation that many developed models considered the corrosion defect growth at circumferential - defect width and radial - defect depth directions, while the defect growth along the longitudinal direction - defect length may not included. Also, models did not have the ability to predict failure pressure of the pipeline as a function of exposure time. At the same time, pipelines are generally under a multi-axial stressing condition at external or internal depends upon complex service. The pipelines mostly under longitudinal stresses which resulted not only from internal pressure but also ground stress in many unstable geotechnical regions. It is known that 2-Dimensional FEM based multi-physics field coupled model was developed by many researchers to predict the corrosion defect growth under the complex effect of stress and electrochemical corrosion reactions. Parametric effects including internal operational pressure, corrosion reactions, defect geometry and material steel grade, were quantitatively

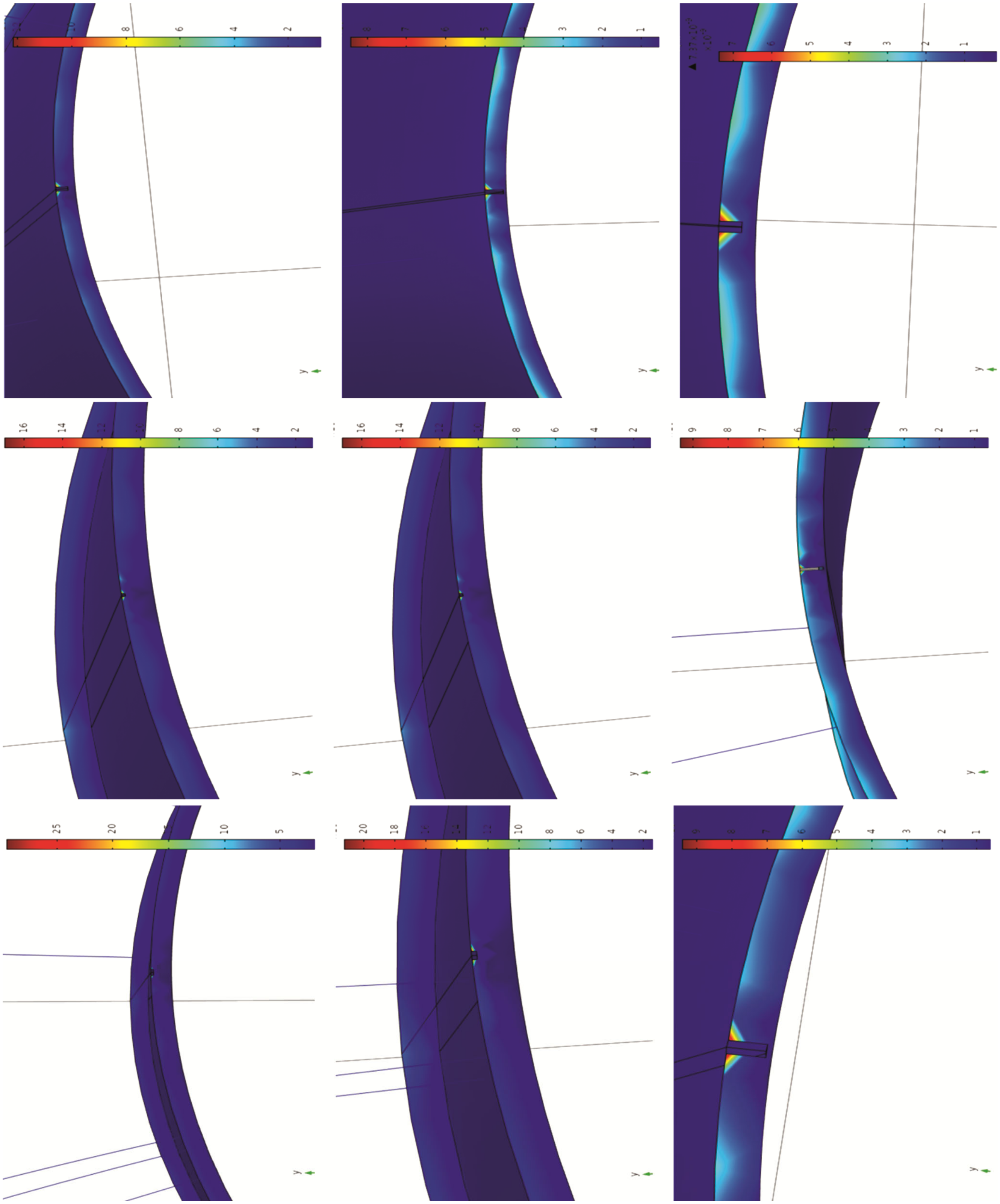

Fig. 6 —Variation of electron current density with increase in depth size, increase in corrosion rate with increase in degradation or material around the pit with different pit depth(1mm, 3mm, 5mm, 7mm) and different radius(0.5mm, 1mm, 1.5mm) of the pit

investigated. More importantly, the corrosion rate which defined as the anodic reaction rate of pipeline steels, at the defect determine by time function.

Effect of stress on accelerated corrosion defect growth was reported at mainly at depth and length directions. The presence of any additional tensile stress may further increase the defect growth rates in all three directions. Under specific stresses, the maximum defect depth increase slightly while initial defect length increases but defect length and width are almost independent of the initial defect length of the corrosion. Hence, initial defect length is not important as other factors like internal pressure or axial tensile stress to affect the defect growth on pipelines.

The electrochemical corrosion mapping is clearly evidence in this study was useful for oil and pipeline operators to evaluate the inspection methodology assessed for pipeline integrity and also making quick decision in for further service. With increasing depth now it is very well known that criticality of pipeline may increase, hence proper inspection techniques may be explored to avoid leakage with an immediate effect[10-12]. While increasing various parameters associated with corrosion are difficult to interpret in actual service but any modification or alteration further worsen the situation.

Hence to avoid major accidents and leakages, this study may be useful to know how important parameters that influences the failure. Among corrosion pit depth, pit width, corrosion current and corrosion voltage it can be seen corrosion pit depth was more influence in leakage process. Although corrosion current and corrosion voltage were constant because of soil and its interaction but it may alter depends on various other environmental factors.

Figure 5 shows increase the trend of pit depth with corrosion rate or in terms of corrosion potential. With increase in pit radius the corrosion not varied much but still corrosion may occur. However, with increase in pit depth the corrosion will definitely will occur as it is evidenced in corrosion rate (Fig. 5). One cannot isolate the corrosion current in the surface of the pipeline as many pipelines are long enough to carry the impressed current. But many new techniques are available to protect the surface by isolation which is beyond the scope of this article. The pit developed in the pipeline outer surface is considered as critical during periodic inspection and if such pit or reduced thickness was not detected will lead to failure of pipeline.

Also one can see that no significant corrosion appears in pipeline for lower pit depth and radius. The pit radius considered in this study is not sharp while actual pit also generally shows similar characteristics. If pit depth (Fig. 5) is higher than pit radius then chance of pit to failure might be likely occurs whereas if pit depth is less than pit radius no pit growth has been occurred. All this condition was incorporated in this model to obtain some useful information and to avoid pipeline failure. The results obtain in this study have increase the understanding of electrochemical parameters influence on pipeline corrosion and also interface with soil (Fig. 5). Basically the corrosion trend is shown in results (Figs 4 & 5) to understand the locations of severity in entire pipeline. The corrosion rate can be predicted based on actual measurements and might be compared with present study but requires extensive study. Therefore we initially report such case study to understand the behaviour and later might report actual test results compare with modelling results.

Conclusion

The performance of the material strength was performed under pitting corrosion when an electrochemical reaction takes place between the pipeline material surface and the atmosphere i.e. an environment. The results of the analysis were concluded that as the depth of the pit increases, the degradation of the material around the pit and other parts increase due to the increase or local rise in current density, but as the radius of the pit increases, it does not affect the corrosion rate. This investigation was successful with the aim to find the relationship between the depth of the pit and material degradation. This study also useful in making quick decision on crude oil and natural gas pipeline operation, and improve the pipeline integrity.

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