ANSYS Structural and Fluid Flow Analysis in a LPG Transporting Corroded Pipeline

M. Jayandran, A T. Ravichandran, D. Surrya Prakash

Abstract*: Oil and Gas Industries most challenging issue is corrosion over pipelines. Due to this corrosion, flammable liquids, gas would leak results in massive damage and fatalities due to explosion. This leakages starts when the initial corrosions cracks occurs over the surface of pipeline. Due to internal fluid pressures, this minor corrosion rupture would develop and pin hole leak would be initiated. Through this pin hole flammable fluid would start to leak and unconfined vapor cloud (UVC) would be developed outside pipeline ambient area. If this pin hole leak not maintained and controlled immediately as a chronic effect it may end up either as deformation of pipeline or complete puncture of pipeline results in massive release of flammable liquid in the atmosphere which may leads to ONSITE and OFFSITE Fire emergency. As an active monitoring technique, through simulation software the fluid flow dynamics inside the corroded pipeline would be analyzed. Along with this fluid flow analysis near the corroded area, pipeline structural behavior also to be analyzed. The minimum pipeline thickness (t min) has calculated in which the bursting and deformation thickness has identified. By doing this analysis, the fluid flow behaviors near the corroded area of the pipeline and the structural response of the pipeline can be studied. This data would be helpful for safe designing of pipeline to transport flammable fluids like Liquefied Petroleum Gas (LPG), Petrol.

***Index Terms*: Fluid Flow Dynamics, LPG, Pin Hole Leak, UVC**

I. INTRODUCTION

Oil and gas products are transported in various methods from the source point to designation point. In case of crude oil refinery, the products to be domestically transported offsite through tanker lorries. In oil rig the crude oil is pumped through pipelines. Mostly, in refineries the crude oil to refinery is pumped through pipelines from near ports. In the process units like Distillation columns, Fluid catalytic cracker unit, LPG processing plants, reforming unit and the intermediate products would be transported through pipelines only. The pipelines would run in different directions, geometry and elevation. To avoid climatic impacts the pipelines may run under the ground as buried services. To maintain appropriate pressure head, pipeline may run as overhead over the pipeline support structures. As a normal elevation to connect to the specific reactor or tank especially for gas products the pipeline will run above the ground level but not in much elevated conditions. The pipeline standards would vary and to be selected depends on the type of transporting material. So, pipeline networks are very essential to transport hydrocarbons. But the major issue with these pipelines is, they undergo a severe electrochemical reaction called corrosion. This electrochemical process would degrade structural integrity of the pipeline, ruptures the pipeline wall. The prolonged internal stress due to the fluid flow in this corroded pipeline leads to deformity, puncture and at extreme level the pipeline may burst. In these scenarios, flammable hydrocarbon may leak & cause severe explosions leads to property damage and fatalities. To overcome this catastrophic scenarios, proactive maintenance to be planned very effectively. To do this planning, some systematic approach has discussed like corroded pipeline structural analysis modeling, fluid flow dynamics analysis near the corroded area and calculating minimum pipe wall thickness. By doing this analysis, the behavior of corrosion and its structural impact over flammable carrying carbon steel pipeline can be understood which would be helpful for further proactive corrosion monitoring and safe pipe design.

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II. PROBLEM DEFINITION

The atmospheric corrosion effect is an unpredictable phenomena and it may affect in any arbitrary position of the pipeline. The intensity of corrosion and the level of impact it would cause over the pipeline cannot be determined by visual inspection. The general corrosion monitoring technique can help us to determine the level of corrosion. But with that data, the structural impacts cannot be determined easily. By applying strength of material load bearing calculations, the structural integrity can be analyzed for a static structure like pillars, roof structures. But in case of pipeline the structural impact over the surface and the internal impacts due to the fluid flow both to be analyzed. As the corrosion is chronic process, the structural impacts for different levels of corrosion cannot be executed in real time. It would be also be a challenging task to visualize and quantify the internal fluid flow dynamics near the corroded area of pipeline..

III. PROPOSED METHODOLOGY

To overcome the above challenge, simulation and modeling software can be applied. The Structural impact and the Computational fluid flow dynamic study over the corroded pipeline would help to understand the fluid flow and its impacts inside the pipeline. To do this study the following assumptions are considered:

(i) LPG carrying Seamless Carbon Steel has considered for the analysis (i) The external atmospheric corrosion has only considered in the selected LPG terminal site. (iii) The pipeline which is running inside the LPG terminal premises ONSITE only has considered. (iv) Internal corrosion has

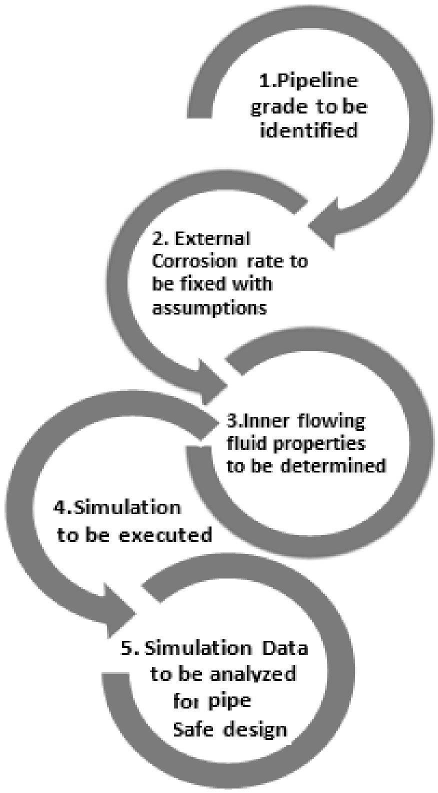

Fig. 1: Proposed Methodology

considered to be less significant. Because the study has conducted on Domestic LPG Filling Unit in which only treated LPG has allowed to flow through the pipeline. (v) The corrosion rate of 4 mm per year has considered and pin hole puncture has meshed over the surface of the modeled pipe line.

IV. SIMULATION DATA

To transport LPG, Seamless Carbon Steel pipeline is mostly used. ASTM A106 grade pipeline of diameter varies between 40 mm to 300 mm with the schedule 80, 40, 20 has generally used to transport LPG. The properties of pipeline which has used for simulation as follows: To proceed with structural analysis, in DN 50 mm Carbon steel pipeline on the flat surface area a small spherical puncture has meshed near one extreme end of pipeline where the fluid starts to flow and the analysis has initiated. To execute the structural analysis ANSYS Static structural module has selected. To simulate Fluid flow dynamics, ANSYS Fluent Fluid flow module has selected.

Table I: LPG Pipeline Specifications

DATA	SPECIFICATIONS
LPG Pipeline Standard	ASTM A106 Grade B /IPSS Standards
Transport Material	LPG (Butane /Propane)
Internal Operating Pressure (Pipeline)	6 kg/cm^2
LPG Flow Velocity	2 m/sec
Internal Temperature	30 °C to 70 °C
External Pipe exposed	Atmosphere (1 atm Pressure)
External Temperature	Normal Ambience Temp 30 °C to 40°C
Pipeline Specifications	
Pipeline Material	Seamless Carbon Steel Pipe
Nominal Diameter	DN 40 to DN 300
Schedule	80,40,20
Wall Thickness	3.9 mm to 7.1 mm
Weight	5.44 kg/m
Transverse Area	697 mm^2
Length of Pipe	Internal(1.8 ft) External (1.61 ft)
Yield Strength min., psi	35,000
Tensile Strength min., psi	60,000
Volume	0.0233 ft^3/ft
Number of Threads per inch of Screw	11

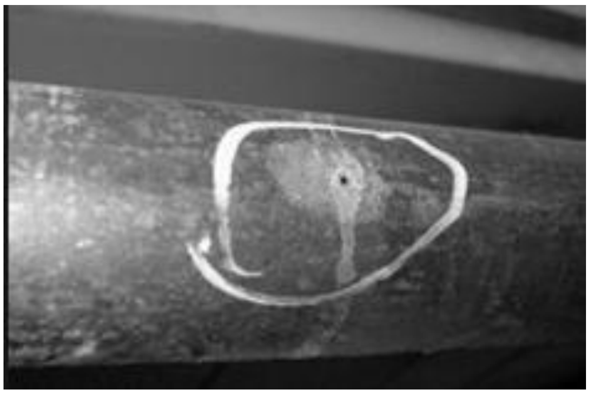

Fig. 2: Pin Hole Corrosion

In case of ANSYS Fluent Flow, an attempt has made to model the pipeline in CATIA and imported to ANSYS. LPG is the internal fluid considered and its flow impact in CFD simulation. While doing this simulation, the mechanical properties and fluid dynamic properties has analyzed. Equivalent Elastic strain and Equivalent (von-mises) Stress has considered. In Fluid flow dynamics, Pressure Contour and Wall shear across the corroded pipeline has considered. This analysis has done in ANSYS to understand the impact of initial level of corrosion effect i.e, Pin Hole Corrosion.

V. ANSYS STATIC STRUCTURAL ANALYSIS

After selecting ANSYS Static structural work bench, Material Data for Steel has selected from the library and the pipeline properties have uploaded. After this Geometry has option has selected and

DN 50 mm pipeline has sketched and pin hole has drafted in an arbitrary position of pipeline. In static structural option, load and boundary condition has entered as follows: The model has designed in such a way that one end has fixed i.e., connected to the tank and in other end the fluid is flowing forward. As a load factor the internal LPG operating pressure has entered. Then in Solution option, Total deformation, Equivalent Elastic strain and Equivalent stress has selected. Equivalent strain is the form of strain in which the distorted body return to its original position when the deforming force is removed. Equivalent Von mises stress values use to determine predict yielding in a ductile material. Total deformation is the sum of all directional displacements of the systems. These properties have analyzed and the simulation result as follows:

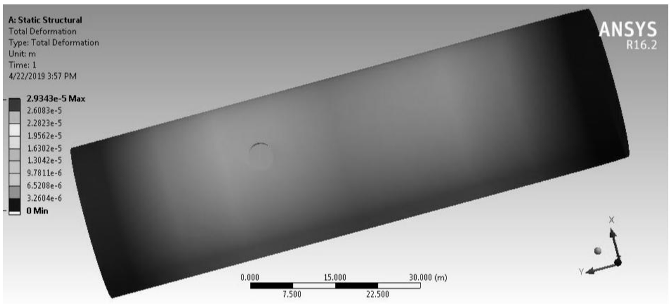

Fig. 3: Total Deformation Simulation

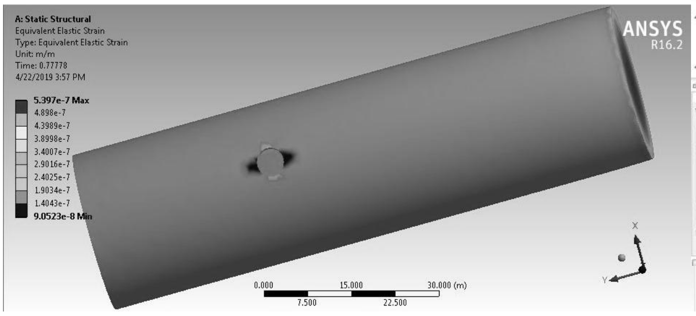

Fig. 4: Equivalent Elastic Strain Simulation

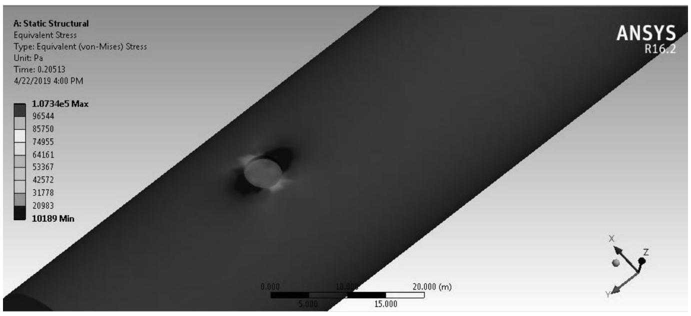

Fig. 5: Equivalent von-Mises Stress Simulation

The following data had gathered near the corroded area: The Total Deformation varies between 1.3042 e-5 to 2.823 e-5 m. Equivalent Elastic Strain ranges between 9.0523e-8 to 3.4007e-7 m/m. Equivalent von-Mises stress ranges between 10189 to 31778 Pa. Based on the properties of Carbon steel pipes (Table 3.1), it is evident from the simulation results that the initial pin hole leak not causing significant impact with the pipeline structure.

VI. ANSYS FLUENT FLUID FLOW ANALYSIS

The carbon steel pipeline without corrosion (60.33 mm outer diameter as per the specification) has modeled in CATIA. The carbon steel pipeline with corrosion (60.33 -4 = 56.33mm) has modeled in CATIA.4mm should be considered as flat surface area and the damage is minimal as we are considering the initial stage of corrosion over the pipeline. These two models imported in ANSYS – Fluent (Fluid Flow) module. To fine tune the corrosion, Meshing has done and two schemas have created. The two schemas namely 1. Carbon Steel pipeline With Corrosion 2. Carbon Steel Pipeline without Corrosion has created in ANSYS. Further stages have proceeded with the steps Geometry, Mesh, Setup (Materials (Carbon Steel), Boundary Condition (LPG Properties) and then analysis has triggered on this two schemas. In Boundary conditions, LPG Fluid flow properties mainly velocity has entered.

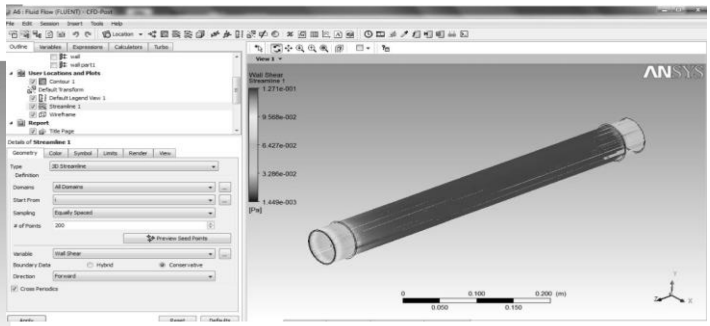

Fig. 6: Pressure Contour – Non Corroded Pipe

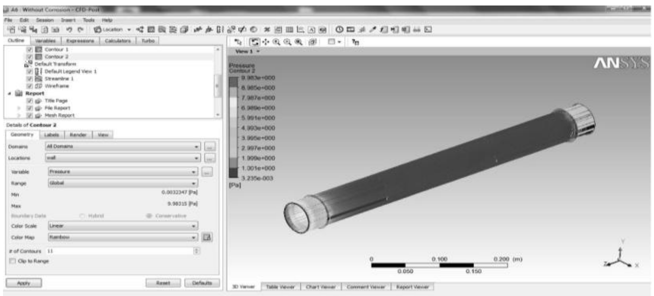

Fig. 7: Pressure Contour – Corroded Pipe

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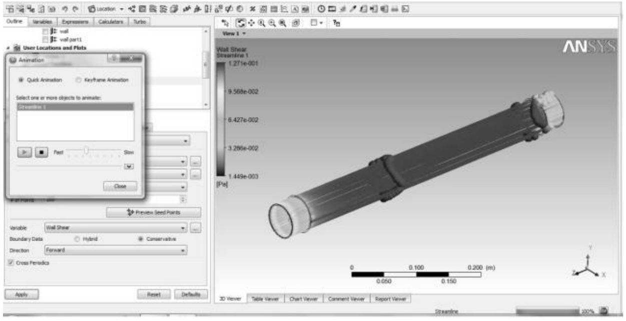

Fig. 8: Wall Shear – Non Corroded Pipe

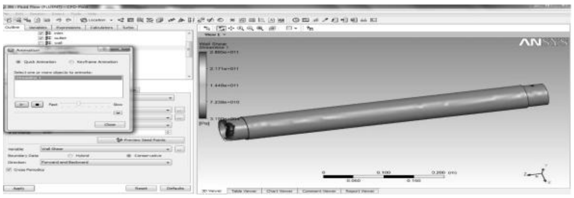

Fig.9: Wall Shear – Corroded Pipe

The two significant contours plot has considered 1. Pressure Contour near the corroded area & 2. Wall Shear of the Pipeline near the corroded area. To understand the effects visually, contours precisions have fine-tuned and simulated. The corrosion defect mesh has created near the inlet point and it is quite evident that the pressure contour is more for the corroded pipe near the entry point comparing with non-corroded pipe. The internal fluid (LPG) flow simulation results as follows: internal fluid pressure on the walls of the non-corroded pipeline is 1.449e-003 and in corroded pipe is 3.235e-003. It indicates that the fluid is imposing little high pressure on the walls of the pipe which has corroded. In non-corroded pipe, the fluid flow is normal with wall shear of 1.449e-003 Pa. In case of corroded pipe the wall shear is 3.150e+004 Pa and in CFD simulation it has observed that fluid flow is not uniform.

VII. MINIMUM PIPE WALL THICKNESS

The minimum pipe wall thickness calculation would help to determine the thickness at which the pipeline may deform and later would burst out. This can be calculated using Barlow formula and corrosion monitoring threshold can be fixed accordingly. The minimum pipe wall thickness of LPG carrying seamless carbon steel pipes can be determined as below:

Minimum Pipe Wall Thickness (T bmin) for Bursting

Tbmin = Do*P/2 St where:
Outside diameter of the pipe (Do) in mm
LPG Fluid pressure in the pipe (P) in psi
Tensile strength of the pipe material (St) in psi

Minimum Pipe Wall Thickness (T dmin) for Deformation

Tdmin = Do*P/2 Sy where:
Outside diameter of the pipe (Do) in mm
LPG Fluid pressure in the pipe (P) in psi
Yield strength of the pipe material (Sy) in psi

Table II: Minimum Pipe wall Thickness Calculation

Pipeline Specification	ASTM A106 Grade B
Material	Seamless Carbon steel
Diameter	DN 50 to 150 mm Sch 40
LPG Fluid Pressure inside the pipe	85 psi
Tensile Strength	60,000 psi
Yield Strength	35,000 psi
Minimum Pipe Wall Thickness for Bursting (T $_{bmin}$)	**0.043 mm**
Minimum Pipe Wall Thickness for Deformation (T $_{dmin}$)	**0.073 mm**

VIII. RESULTS AND DISCUSSIONS

It is very evident form the ANSYS structural analysis that the normal initial pin hole is not causing major structural impacts but the ANSYS Fluent is clearly indicating that the internal fluid flow is causing more impact to the pipeline structural integrity. The wall shear is more for corroded pipe and possible reason is Pin Hole Leak from the corroded area, which would be justified as below:

- The Internal Operating Pressure of the LPG transporting Pipeline in commercial terminal is 6 kg/cm^2 (5.8 atm) and the external Pressure is 1 atm (as the Pipeline exposed to Atmosphere). Naturally, due to difference in pressure, leakage towards outside is easily possible in case of any structural damage in the pipeline.
- LPG is heavier than air and when it expose to atmospheric pressure, it will leak in gas form with more turbulence.
- This pin hole leak leads to build up of LPG Vapor cloud slowly and continuous, chronic accumulation may leads to Unconfined Vapor Cloud explosion near the corroded area of the pipeline.
- As a proactive monitoring, the structural analysis and simulation to be done. The impacts near the corroded area of various intensities to be studied. The minimum wall thickness to be calculated. This data to be considered for safe design.

IX. CONCLUSION

LPG (Liquefied Petroleum Gas) is the most flammable gas which is transported through pipeline grids for different domestic and industrial purpose. Atmospheric corrosion over the pipeline is unavoidable as these pipelines are exposed to ambient environmental conditions. Structural and

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Fluid flow simulation analysis over the corroded pipelines would give better understanding about the behavior of internal flowing LPG over the inner wall of pipe. Determination of Minimum wall thickness would help us to understand the thickness at which the atrophic pipeline damage would occur. This data would be helpful for safe designing of pipeline as well as useful for proactive corrosion monitoring techniques.

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