REPORT
ON
INTERNSHIP PROGRAM ATF PIPELINE INSPECTION LUCKNOW, U.P.

(from 01/July/2021 to 31 /July/2021)

SUBMITTED BY- **MONIKA SHARMA**
ROLL NUMBER- **18105012**

INDUSTRIAL & PRODUCTION ENGINEERING (IPE),
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SUBMITTED TO :
PROF. KAILASH KUMAR BORKAR

DEPARTMENT OF INFORMATION TECHNOLOGY,
SCHOOL OF STUDIES IN ENGINEERING & TECHNOLOGY GURU GHASIDAS VISHWAVIDYALAYA, BILASPUR (C.G)
(Established under Central Universities Act 2009, No. 25 of 2009)

CERTIFICATE

RAMBARAN SINGH APEX PRIVATE LIMITED

Ref. No : RBSAPL/ Trng./ 001/ 21 Date : 02 August, 2021

To Whomsover it may Concern

This is to Certify that Ms. Monika Sharma , a student of Industrial and Production Engineering (2018-22) under Guru Ghasidas Central University, Bilaspur, Chhattisgarh has successfully Completed ONE month's Internship programme in our Organisation and ATF Pipeline Project Site, Lucknow,Uttar Pradesh during the period from 01/July/2021 to 31 /July/2021.

During the Internship, she has been found to be punctual, Sincere to her assignments and Inquisitive.

We wish her Success in her future endeavors.

For RAMBARAN SINGH APEX PVT. LTD.

02-08-21

Vijay Kumar
Dy. General Manager - H R

Head Office : At & P.O. - Keshawe, Dist. - Begusarai - 851134 (Bihar)
Phone - (06243) 242562, Fax : (06243) 242565 Email Id: horbe@rbs.ind.in
CIN : U45309BR2017PTC036078 GSTN : 10AAICR6033R1Z4

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CONTENTS

ABSTRACT

Oil and gas (O&G) pipelines are expensive assets that cross through both ecologically sensitive and densely populated urban areas. The pipeline failure may have potentially significant consequences for both natural and human environments. Inspection and maintenance processes of O&G pipelines should be governed by efficient policies in order to maintain their integrity.

The objective of this paper is to conduct a state-of-the-art review of maintenance policies of O&G pipelines to investigate their advantages, limitations, and associated implementation issues. Maintenance policies can be categorized into corrective, preventive,predictive, and proactive. Corrective maintenance policies (1940s) were based on a "repair when broken"philosophy.

Economic considerations shifted practice towards preventive maintenance (1970s to 1990s);later with improved inspection techniques and environmental regulations, predictive and proactive or risk-based maintenance (RBM) policies were developed. This review explicates different methodologies forRBM and related issues, e.g., uncertainties and variability, conservative assumptions, etc.

Uncertainties associated with investigation and prediction of defects have been more frequently reported in the literature so far. Moreover, existing studies primarily focused on reducing the likelihood and cost of failure, whereas consideration of environmental factors in overall risk has been a relatively less addressed issue.

Keywords: Inspection and maintenance; oil & gas pipelines; maintenance policies; time-based maintenance; condition based maintenance; risk-based maintenance.

INTRODUCTION

RAMBARAN SINGH APEX PVT. LTD. is a full service **pipeline inspecting** and consulting company providing quality and cost efficient services with an emphasis on safety and environmental compliance. Our management team works in conjunction with the client to ensure integrity. completing construction and bringing the pipeline into service. There are two general types of energy pipelines – liquid petroleum pipelines and natural gas pipelines. Within the liquid petroleum pipeline network there are crude oil lines, refined product lines, highly volatile liquids (HVL) lines, and carbon dioxide lines (CO2) and we are experts in both. Product is gathered from wells in the ground and sent through gathering pipelines to a facility where it's processed or refined. Pumps or compressors move it through the system at a safe pace.

Oil and gas (O&G) pipelines are expensive assets that cross through both ecologically sensitive and densely populated urban areas. If pipelines are not well maintained, they may fail with potentially significant consequences that could have severe, long-term and irreversible impacts on both natural and human environments.
The scope of the review primarily focuses on inspection and maintenance (I&M) policies of O&G pipelines reported in peer-reviewed literature.

The main objectives of the review are to

i)outline, in support of the subject, a general review of maintenance policies for industrial and infrastructure assets to evaluate their applicability for oil and gas pipelines;

ii) conduct a state-of-the-art review of maintenance policies of O&G pipelines to investigate their practicality,advantages, and limitations; and

iii) identify uncertainties affecting the decision making process for maintenance of O&G pipelines and highlight less addressed issues to improve the existing practices.

To achieve this objective, the following topics are discussed in the review:

·a comprehensive review has been conducted to investigate the evolutionary process of maintenance policies for different types of infrastructure including bridges, power plants, offshore platforms, underground constructions, pipelines, and ocean structures·pipelines are considered as infrastructure systems, whereas individual segments and auxiliary equipment such as valves, filters are treated as industrial assets; therefore, a brief review of maintenance policies of industrial assets has also been carried out;·The policies suitable for Oil and & Gas pipelines are discussed in detail, and a brief overview of pipeline inspection and monitoring methods has also been conducted.

What are pipelines?

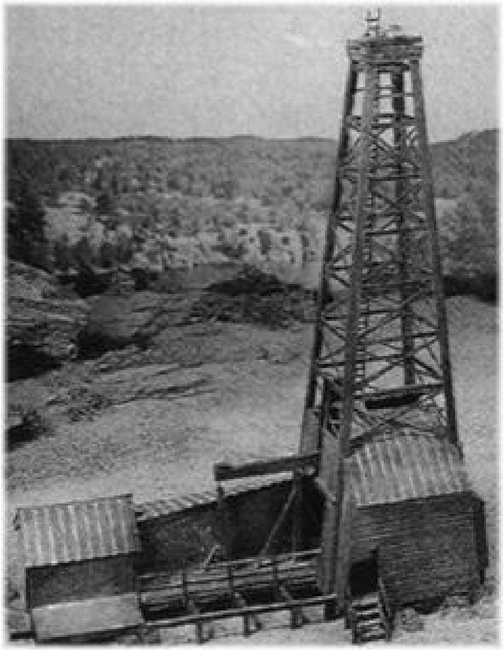
The energy transportation network of the United States consists of over 2.5 million miles of pipelines. That's enough to circle the earth about 100 times. These pipelines are operated by approximately 3,000 companies, large and small. Although pipelines exist in all fifty states, most of us are unaware that this vast network even exists. This is due to the strong safety record of pipelines and the fact that most of them are located underground. Installing pipelines underground protects them from damage and helps protect our communities as well.

Why Do We Need Them?

Pipelines play a vital role in our daily lives. They transport fuels and petrochemical feedstocks that we use in cooking and cleaning, in our daily commutes and travel, in heating our homes and businesses, and in manufacturing hundreds of products we use daily.

Natural gas provides for nearly 25% of our country's *total energy consumption*, and petroleum provides for nearly 40%. This requires the transportation of huge volumes of hazardous liquids and gas, and the most feasible, most reliable and safest way to do so is through pipelines.

Oil and Gas Exploration



Petroleum and natural gas flow upward naturally through the Earth's crust as a result of pressure from the natural gas and water. Oil seeps to the Earth's surface along fault lines and cracks in subterranean rocks and gathers in pools, where it is recognized as tar, asphalt, and bitumen. Along the way much of it gets trapped in the pores of subterranean rocks. The areas where it is trapped are known as reservoirs. To extract oil and natural gas from these reservoirs, exploration and production companies must locate the reservoirs and drill wells into the earth to bring the products to the surface. The most widely accepted theory says that fossil fuels were formed when organic matter (such as the remains of a plant or animal) was compressed under the earth, at very high pressure for a very long time. This compression, combined with high temperatures found deep underneath the earth's surface, break down the carbon bonds in the organic matter. As we go deeper and deeper under the earth's crust,

the temperatures get higher and higher. At low temperatures (shallower deposits), more oil is produced relative to natural gas. At higher temperatures, however, more natural gas is created, as opposed to oil. That is why natural gas is usually associated with oil found in deposits that are 1 to 2 miles below the earth's crust. Deeper deposits, even further underground, contain primarily natural gas and in many cases pure methane.
These new technologies have driven an incredible increase in the success rate of locating oil and natural gas reservoirs. However, the process of exploring these reservoirs is still characterized by uncertainty, due to the complexity of searching for something that is often thousands of feet below ground. Ultimately, exploration companies must drill to determine whether oil or natural gas actually lies underground.

Pipeline Inspection

Condition evaluation and probability of failure for pipelines are the most important factors for effective maintenance decision-making.
(i) Traditional deterministic/ mechanistic approach based on standards and codes such as ASME B31G and modified B31G; and
ii) the probabilistic/statistical approach based on the stochastic character of structural and environmental factors are used to assess the probability of pipeline failure:
The deterministic approach is a process to assess the condition of pipelines by getting data from inspection tools, whereas the probabilistic approach uses the data to predict the future probability of failures. ASME B31G provides industrial guidelines (ASME, 2009) of safe working pressures based on the pipeline dimensional parameters obtained through inspection The DNV-RP-F101 recommends the probabilistic assessment approach for the assessment of corroded pipelines subject to internal pressure and internal pressure combined with longitudinal compressive stresses . Pipelines are inspected by internal or intrusive inspection and external or non-intrusive inspection processes. The most common processes for pipeline inspections are pigging, hydro-testing, and external and internal corrosion assessments . Pigging techniques are used for cleaning and internal condition monitoring/ inspection for longer length pipes. The pigging process was established in the 1960s. The pig is a cylindrical shaped electronic device with condition monitoring capabilities. Pigs equipped with condition monitoring systems are also known as smart pigs or inline inspection tools. Smart Pigs are the most commonly used tool in the pipeline industry . Further types of smart pigs are the magnetic flux leakage and the ultrasonic pigs. The basic components of a smart inspection PIG (magnetic flux leakage type) are shown in .It consists of drive packed which moves PIG in the pipeline, flux loop generates the magnetic flux and recorder package, equipped with sensors, records the variation in flux location.

These pigs have been used to find metal loss, cracks, pits shape, length and maximum pit depth, and wall thickness due to corrosion and erosion. The crack detection pigs are the most recent development of the inspection methods. The ultrasonic crack detectors, transverse magnetic flux leakage, and elastic wave pigs are used to detect circumferential and longitudinal cracks . Industrial standard API 1163 provides in-line inspection system qualification.

In addition to pigging, the condition of the pipeline can be assessed from operational parameters such as pressure, flow rate, and physical dimensions. Geometry tools have been used to determine the physical shape and geometry conditions of the pipelines, e.g., caliper tools and pipe deformation tools. Mapping tools, integrated with a global positioning system, are used to locate valves, equipment positions and for mapping of pipelines. Low-frequency long-range guided wave inspection technique is used to map corrosion and erosion in pipes. Hydrostatic testing is a process to pressurize the pipeline above the normal operating pressure, which detects manufacturing and metal loss defects; this test is carried out at the manufacturing stage and the completion stage before operations. Axial flaws such as stress corrosion cracking, longitudinal seam cracking, selective seam corrosion, long narrow axial corrosion, and hydrostatic testing better detects axial gouge than by pigging

A pipeline system is a combination of pipelines, valves, and connected rotary auxiliaries such as compressors, pumps, and their prime movers. The vibration induced by the rotary auxiliaries also affects the pipeline integrity. Vibration monitoring is the most popular technique to monitor the condition of the rotary auxiliaries .Other techniques for condition monitoring of rotary auxiliaries are sound or acoustic monitoring , oil analysis or lubricant monitoring, electrical temperature and physical condition monitoring .

Technological advancements have significantly improved the inspection processes; however, different types of uncertainties are involved in an inspection process, such as the probability of miss detection of small holes, wrong assessment of defect existence and size, etc.

The inspection process of selected small segments of a pipeline with such deficiencies is known as imperfect inspection; it may lead to costly maintenance or poor safety.

Despite the deterministic/mechanistic approach to estimate the pipeline condition, the probabilistic/statistical approach is also discussed in the literature based on the models trained on data obtained through deterministic methods. The pipeline condition data is either obtained from the field or from the laboratory experimental work. The prediction accuracy depends on the accuracy of ILI tools and data quality obtained from the field. The influencing factors on corrosion growth rate, such as soil properties, temperature, sulfate ion, CO_2 partial pressure, chloride ion concentration, wall shear stress, water content, corrosiveness, pH, concentration and flow rate of carrying fluids are heterogeneous in nature

Pipeline Coatings

The purpose of pipeline coating is to reduce the necessary CP-current. Bare Pipe would draw too much current. Today's external coating types are usually either from Fusion Bonded Epoxy (FBE) or three-layer (Polyethylene) PE. Internal coating is used for different circumstances.

- Gas lines: Reduction of gas friction
- Oil Lines: Prevention of internal corrosion

Internal Coatings

The primary reason for applying internal coatings is to reduce the friction and therefore enhance flow efficiency. Besides, the application of internal coatings can improve corrosion protection, pre-commissioning operations and pigging operations. An effective coating system will provide an effective barrier against corrosion attack.

External coatings

Oil and gas pipelines are protected by the combined use of coatings and Cathodic Protection. The coating systems are the primary barrier against the corrosion therefore highly efficient at reducing the current demand for cathodic protection. However, they are not feasible to supply sufficient electrical current to protect a bare pipeline. Cathodic protection prevents corrosion at areas of coating breakdown by supplying electrons.

In-Line Inspections (Smart Pig)

Overview:

The pipeline industry has, for many years, used scrubbing and scraping devices to clean the inside of their piping systems. These devices – called “pigs” – reduce build-up of waxes and other contaminants along the pipe’s interior.
Sophisticated and sensitive in-line inspection (ILI) tools travel through the pipe and measure and record irregularities that may represent corrosion, cracks, laminations, deformations (dents, gouges, etc.), or other defects. Because they run inside the pipe in a manner similar to the scrubbing and scraping devices known as pigs, these in-line inspection tools are often referred to as smart pigs.”
Smart pigs are inserted into the pipeline at a location, such as a valve or pump station, that has a special configuration of pipes and valves where the tool can be loaded into a receiver, the receiver can be closed and sealed, and the flow of the pipeline product can be directed to launch the tool into the main line of the pipeline. A similar setup is located downstream, where the tool is directed out of the main line into a receiver, the tool is removed, and the recorded data retrieved for analysis and reporting.

Magnetic Flux Tools:

There are two types of tools commonly used for inspections of hazardous liquid pipelines based on magnetic flux measurements.
A Magnetic Flux Leakage (MFL) tool is an electronic tool that identifies and measures metal loss (corrosion, gouges, etc.) through the use of a temporarily applied magnetic field. As it passes through the pipe this tool induces a magnetic flux into the pipe wall between the north and south magnetic poles of onboard magnets. A homogeneous steel wall – one without defects – creates a homogeneous distribution of magnetic flux. Anomalies (i.e., metal loss (or gain) associated with the steel wall) result in a change in distribution of the magnetic flux, which, in a magnetically saturated pipe wall, leaks out of the pipe wall. Sensors onboard the tool detect and measure the amount and distribution of the flux leakage. The flux leakage signals are processed, and resulting data is stored onboard the MFL tool for later analysis and reporting.
A Transverse MFL/Transverse Flux Inspection tool (TFI) identifies and measures metal loss through the use of a temporarily-applied magnetic field that is oriented circumferentially, wrapping completely around the circumference of the pipe. It uses

the same principle as other MFL tools except that the orientation of the magnetic field is different (turned 90 degrees). The TFI tool is used to determine the location and extent of longitudinally-oriented corrosion. This makes TFI useful for detecting seam-related corrosion. Cracks and other defects can be detected also, though not with the same level of reliability. A TFI tool may be able to detect axial pipe wall defects – such as cracks, lack of fusion in the longitudinal weld seam, and stress corrosion cracking – that are not detectable with conventional MFL and ultrasonic tools.

Ultrasonic Tools:

There are two types of tools commonly used for inspections of hazardous liquid pipelines based on ultrasonic measurements.

Compression Wave Ultrasonic Testing (UT) tools measure pipe wall thickness and metal loss. The first commercial application of UT technology in ILI tools used compression waves. These tools are equipped with transducers that emit ultrasonic signals perpendicular to the surface of the pipe. An echo is received from both the internal and external surfaces of the pipe and, by timing these return signals and comparing them to the speed of ultrasound in pipe steel, the wall thickness can be determined. Of particular importance to successful deployment of a UT tool is pipe cleanliness, specifically the removal of paraffin build-up within the pipe. This is especially important for crude oil lines. The use of a cleaning pig is recommended prior to use of UT tools.

Shear Wave Ultrasonic Testing (also known as Circumferential Ultrasonic Testing, or C-UT) is the nondestructive examination technique that most reliably detects longitudinal cracks, longitudinal weld defects, and crack-like defects (such as stress corrosion cracking). Because most crack-like defects are perpendicular to the main stress component (i.e., the hoop stress), UT pulses are injected in a circumferential direction to obtain maximum acoustic response.

Shear Wave UT is categorized as a liquid coupled tool. It uses shear waves generated in the pipe wall by the angular transmission of UT pulses through a liquid coupling medium (oil, water, etc). The angle of incidence is adjusted such that a propagation angle of 45 degrees is obtained in pipeline steel. This technique is appropriate for longitudinal crack inspection.

Geometry Tools:

Geometry tools use mechanical arms or electro-mechanical means to measure the bore of the pipe. In doing so, it identifies dents, deformations, and other ovality changes. It can also sense changes in girth welds and wall thickness. In some cases, these tools can also detect bends in pipelines. The remediation criteria depend on both the depth and orientation of dents, so geometry tools that are used to detect deformation anomalies such as dents, should be the type that provide both the orientation, location and depth measurement of each dent. This type of tool can be used in both hazardous liquid and natural gas pipelines.

Summary:

Each of the in-line inspection tools described above has advantages and disadvantages when it comes to measuring pipe for defects that could affect integrity. In selecting the tools most suitable for in-line inspections, pipeline operators must know the type, thickness and material of the pipe being measured; the types of defects that the pipe might be subject to (e.g., internal corrosion, external corrosion, weld cracks, stress corrosion cracks); and the risk presented by the pipe section being measured.

Managing corrosion and metal loss: industry leading inspection technology and expertise

Our solutions date back to the development of magnetic flux leakage tools in the 1960s, and we've continued to invest to evolve technological capabilities and help pipeline operators meet the highest levels of safety and performance that science can provide.

From the moment a pipeline is commissioned, it begins to deteriorate. No matter what cathodic protection system or coatings are used, or which product is in the pipeline, corrosion will eventually compromise pipe wall integrity. Operators require accurate defect detection, sizing and classification to determine actual growth rate and manage corrosion. We provide a range of magnetic and ultrasonic inspection technologies that each offer unique advantages. Your technology selection decision will be aligned with your objectives and underlying threats.

Crack management: reliable detection, location and sizing of crack-like features

Although a crack may be almost invisible to the eye, it can still weaken a pipeline enough to cause catastrophic failure. The types of cracks most likely to develop in operating pipelines are stress corrosion cracks (SCC), fatigue cracks, hydrogen-induced cracks and sulfide corrosion cracks. They can occur in the base material of the pipe, in welds and in the heat-affected zone adjacent to welds. Cracks can also appear in substandard axial and girth welds, and can occur in conjunction with other flaws such as dents, gouges and corrosion.

We've focused on finding solutions to your challenge to locate, identify, characterize and monitor the many types of cracks that may compromise pipeline integrity. Our technologies can inspect older pipelines, which have a propensity for weld-related cracks (seam, hooks). For accurate location and highlighting of cracks most likely to fail, our inspection capabilities can identify stress corrosion cracking (SCC) and cracks of unknown gestation. We also can employ recognized engineering techniques to predict rupture pressure when adjacent crack(s) interact, if extensive SCC crack fields are populated with both critical and subcritical cracks.

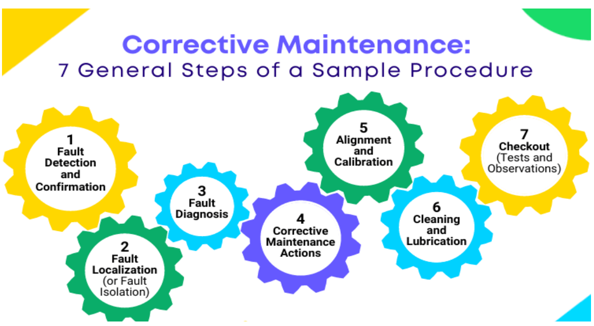
Inspection and Maintenance Policies for O&G Pipelines

In general, O&G pipelines are considered to be one of the safest modes of transporting petroleum products due to their low accident frequency. However, with aging, these assets deteriorate and need repairs. An efficient maintenance decision includes two important considerations:selection of the right pipe at the right time, and selection of an optimal maintenance strategy implemented using a cost efficient technology .

The causes of failure of a pipeline can be classified into two broad categories, i.e., external and internal. The external causes of failures include first, second and third party accidents, device failure and malfunctioning, natural disasters, extreme weather temperature variations, and improper installation and repairs .

The internal causes of failure are corrosion, erosion, material defects, weld crack, fatigue, and vibrations . Mechanical damage and corrosion are the most common causes of failure of O&G pipelines in Western Europe and North America . The researcher has also taken other factors into consideration, such as vibrations and third party activities. Although advancements in metallurgical and manufacturing technologies have overcome some of these issues, maintenance strategies still play a key role in improving the reliability of pipelines and economically mitigating risks

In this review, the pipeline inspection and maintenance policies are reviewed as industrial assets as well as infrastructure assets. As an industrial asset, pipelines are considered as single unit repairable systems. Although no literature was found specifically on inspection and maintenance policies of the pipeline as a single unit, Hongzhou Wang (2002) presented a comprehensive review of the published literature on preventive maintenance policies for single unit systems. He identified age, the number of repairs or failure limit, time in service and condition of an asset as the main decision factors when selecting the inspection and maintenance policy. In recent research, “risk” is considered as the main criteria for selection of inspection and maintenance intervals and policy. Most of the studies have presented risk-based inspection and maintenance (RBIM) policies to address issues related to maintenance of oil & gas pipelines. The maintenance policies developed for O&G pipeline integrity management along with the risk-based policies are discussed in the following sections.



Corrective Maintenance

Corrective maintenance is considered the most cost-effective policy where the maintenance actions are taken before the failure has occurred.

Preventive Maintenance

In preventive maintenance policies, periodic repair or replacement is implemented when the unit is in operating conditions before failure. These policies are based on the scientific data analysis approach. Operation research methods were introduced in the PM policies for consistent decision-making. Moreover, most of the industrial preventive maintenance practices rely on experts' experience and recommendations from the original equipment manufacturers (OEM). The PM policies have further been classified by age, time in service, and a number of repairs or failures.

Predictive Maintenance / Condition-based Maintenance

Condition-based maintenance (CBM) or condition based inspection and maintenance(CBIM), first introduced in 1975, uses a condition monitoring / inspection process to improve decision making for preventive maintenance. CBM assumes that a system is subject to a random deterioration process. The main objective of the CBM is to perform a real-time assessment of the equipment to enhance its reliability and to reduce the unnecessary maintenance costs Generally, in the CBM policy, the condition of the system is monitored through perfect inspection at regular intervals.The condition analysis is used for future maintenance decisions The condition monitoring / inspection processes are conducted in two ways: an online process during operation and an offline process during shutdown time.

The intervals for this process can be determined on a fixed, continuous, or risk basis. Continuous monitoring can be highly expensive, therefore, in most cases equipment failure is assessed based upon certain conditions, signs or indications. predictive methods. The diagnostic approach provides an early warning to management about failure. Sometimes, abnormal behaviour of equipment does not show any sign of failure; in this case, equipment performance seems satisfactory until complete failure. In Such cases when the diagnostic approach is unable to predict the failure, the prognostic approach can predict the failure before its occurrence. The prognostic approach can be more cost-effective as it facilitates better planning and maximum utilization of equipment and prevents unexpected failure .

Proactive Maintenance / Risk-based Maintenance

Risk management is a systematic approach to characterize existing system risk, decrease the probability of harmful events and/or to reduce the harmful consequences of the occurred event. A typical risk assessment model begins with hazard identification followed by the modeling of causes, estimation of the likelihood of effects and estimation of impacts by qualitative, quantitative or semi-quantitative methods. Risk models

estimate absolute and relative risk, major risk contributors and compare risk factors. Stages of risk analysis are hazard analysis, consequence estimation, likelihood estimation, risk estimation, risk acceptance criteria and maintenance planning.Since 2000, the terms risk-based inspection (RBI) and risk-based maintenance (RBM) have been used interchangeably. However, recently a new generation of terminologies have been adopted, such as reliability-centered maintenance and condition-based maintenance (CBM). Therefore, risk-based maintenance and risk-based inspections are not separate topics anymore. Both the terminologies refer to the same set of actions .

Decision-making challenges under Uncertainties for Proactive Maintenance Policies

This section addresses the uncertainties influencing the effectiveness of decision-making process for risk-based maintenance policies, e.g., uncertainties in internal and external degrading process, variability in inspection results, conservative assumptions for unknown data, the subjectivity of the decision-maker opinion, budgeting and costing for maintenance and imperfections in the investigation and prediction of defects. Availability and accuracy of inspection and operational data may significantly influence the decision-making process . Both probabilistic and statistical approaches have been used to deal with uncertainties in the degradation process . Financial constraints and uncertainties due to variations in the limited budget of maintenance was also taken into account.

Summary and Conclusions

The review focuses on peer-reviewed literature published for inspection and maintenance policies for oil and gas (O&G) pipelines. More than a hundred research articles were reviewed to understand the evolution of maintenance policies, their implementation, and associated issues for O&G pipelines. It was found that 50% of the studies were related to both the O&G pipelines, 30% accounted for oil pipelines only, and the remaining were specific to gas pipelines. Gas pipelines are single-phase flow pipelines, whereas oil pipelines are three phase flow pipelines. The internal and external threats affect the integrity of O&G pipelines. The studies revealed that oil pipelines are more vulnerable to failure due to internal corrosion as compared to gas pipelines.

The failure of gas pipelines may have widespread consequences due to rapid spread in the environment;however, failure of oil pipelines may have long-lasting environmental effects. Integrity can be improved by inspection, testing, and analysis followed by appropriate and timely maintenance. A good maintenance decision means the selection of the right pipe at the right time and the application of the optimal maintenance strategy and technology in a cost effective manner.

This review of literature broadly categorises the maintenance policies as corrective policies, preventive policies, predictive policies, and proactive policies. Maintenance decisions help to overcome the possible threats of failure due to metal loss, external damages, manufacturing errors, human operational mistakes and the age of the asset. Therefore, implementation of the maintenance policies is a multi-criteria decision process. Corrective maintenance policies were implemented in the early 1940s based on the principle of "*repair when broken*.

In the early 1950s, it was determined that repair after failure is not a feasible policy, particularly for oil and gas pipelines due to severe economic and environmental impacts in case of failure. Meanwhile, awareness about environmental concerns led to environmental protection laws that compelled the pipeline operators to maintain safe and leak-free pipeline operations.

As a result, the 1960s can be considered the era of preventive maintenance policies which adopted the concepts of preventive overhauls, i.e., repair of equipment/unit at fixed and scheduled intervals depending upon age or time. Incorporating the condition assessment results transformed preventive maintenance into predictive or condition-based maintenance in the 1990s. This review also reveals that predictive maintenance policies improved cost effectiveness in the decision-making process for integrity management of the O & G pipeline industry.

Since 2000, the integration of likelihood of failure and the resulting consequences shifted the predictive maintenance into proactive maintenance policies (i.e., also known as risk-based maintenance (RBM) policies). RBM policies for O&G pipelines are the most discussed in the most recent literature.

A number of qualitative, semi-quantitative, and quantitative methodologies for RBM were reported in the literature. Deterministic and probabilistic methods and their combinations are the techniques used for risk analysis. However, expert judgement is the factor that most significantly influences the results of risk analysis. The reported issues related to the implementation of RBM policies include uncertainties and variability, conservative assumptions, the subjectivity of the decision-makers' opinions, and imperfections in the inspection data. In this paper, more than 50 articles covering RBM policies have been reviewed, and uncertainties are categorised into four types:

i) uncertainties due to lack of data in quantitative models,

ii)subjectivity in qualitative models,

iii) investigation and prediction of the defect, and

iv) variability of inspection results.

The review revealed that about 50% of the studies on RBM policies addressed the uncertainties associated with investigation and prediction of defects, followed by 24% studies that took into account the uncertainties due to subjectivity in qualitative models. So far, uncertainties due to the variability of inspection results are the least (i.e., 8%) addressed in published literature.

The primary focus of most of the existing studies is on reducing the probability of structural failure and reducing repair and maintenance costs. O&G pipelines pass through diverse land uses and environmental settings ranging from ecologically sensitive natural areas to densely populated urban areas, and may have severe, long-term, and irreversible impacts in case of pipeline failure. In this regard, a relatively less addressed issue in RBM policies is consideration of environmental and land use related factors for estimating the consequence part in overall estimated risk.

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