

The Impacts of Corrosion in Weld joints and Surfaces of Oil and Gas Pipelines: A Review

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Abstract: Corrosion of metals is the deterioration of metals as a result of chemical, electrochemical or biochemical interactions with the environment. Corrosion failures of welds occur in spite of the fact that all the industry codes and standards have been followed. In oil and gas pipelines, formation of internal and external surface corrosion is inevitable. Failures and consequent problems due to corrosion increase with time. Oil and gas pipeline leakages due to corrosion have caused serious damage and losses to the environment and the industries involved. Corrosion related failures constitute 33% of all failures in oil and gas industry. These failures have led to heavy loss of human lives and properties. This paper presents a review on corrosion threats to welded oil and gas pipelines focusing on formation, detection, prevention and management of corrosion where the formation of different types of corrosion, the corrosion prevention methods, inspection and control methods have been presented. For safe working of pipelines the preventive measures should be observed.

Keywords: Corrosion, Oil, Gas, Pipelines, Welding, inspection, Corrosion prevention. Pigging, SCADA.

I. INTRODUCTION

Material deterioration and how to prevent has been of interest since mankind was first able to apply nature's resources [1, 2]. It was early noticed that the materials changed, they seemed to change in properties and structure. Something around the applied resource made it deteriorate. There are reports about material deterioration as far back as 412 B.C. The documents, written on papyrus, described measures to mitigate the problems of bacterial and animal attacks using arsenic and sulphur mixed with Chian oil. New recipes to control these, and new problems, were made through the centuries. When steel was first used to construct ships, a new problem was riced. One started to notice another type of decay, namely rust. Due to the applicability of steel both on land and sea, the interest in the subject of corrosion has been high for many years. There has been so much research, in all types and forms, that the information is vast. Especially in engineering this problem has been of great importance. The prevention of wastage of metals has become a concern, maybe the greatest except for the wastage of human life [1, 2]. It is only

through the elimination of waste and the increase in national efficiency that one can hope to lower the cost of living, on the one hand, and rise the standards of living, on the other. The elimination of waste is a total asset. It has no liabilities [2].

The oil and gas industry involves upstream, downstream and pipelines which constitute production, pipelining, transportation and refining [3]. In the search for new sources of oil and gas, operational activities have moved to harsher environments in deeper high-pressure/high-temperature wells and deep water. These have created increased challenges to the economy of project development and subsequent operations wherein facilities integrity and accurate prediction of materials performance are becoming paramount [4]. Carbon steels are the metals that were used in oil and gas industry until 1980s. Developments of deep, hot, gas wells in the 1980s led to the use of corrosion-resistance alloys (CRAs), and this trend continues as industry becomes involved in deeper and more aggressive environment. Nonetheless, the most used metal in oil and gas production is carbon steel or low-alloy steel, and nonmetallic materials are rarely used [3, 4]. The industry continues to lean heavily on the extended use of carbon and low-alloy steels, which are readily available in the volumes required and are able to meet many of the mechanical, structural, fabrication, and cost requirements. Their technology is well developed and they represent an economical materials choice for many applications [4]. However, a key issue for their effective use is their poor general and CO₂ corrosion performance. Given the conditions associated with oil and gas production and transportation, corrosion must always be seen as a potential risk. The risk becomes real once an aqueous phase is present and is able to contact the steel, providing a ready electrolyte for the corrosion reaction to occur [4].

Increased emphasis on reliability also contributes to the use of newer or more corrosion-resistance materials. Many oil and gas fields that were designed with anticipated operating lives of 20-30 years are still economically viable after more than 50 years. Unfortunately, this tendency of prolonged life of oil and gas fields creates corrosion and reliability problems and causes the management to become reluctant to spend additional resources on maintenance and inspection [3]. Corrosion, therefore, remains a major operational obstacle to

successful hydrocarbon production, and its optimum control and management is regarded necessary for the cost effective design of facilities and their safe operations. It has wide-ranging implications on the integrity of many materials used in the petroleum industry [4].

These trends have all led to an industry that tends to design for much longer production lives and tries to use more reliable designs and materials. The previous tendency to rely only on inspection and maintenance is being supported by the trend to design more robust and reliable systems. The reduction in available trained labour for maintenance also drives this trend [1].

Welding is one of the most important processes for fabricating metallic structures [1, 5]. The study of welding metallurgy has long been addressed by academia, industry, and organizations such as the American Welding Society (AWS) and the Edison Welding Institute (EWI) in the United States (US) and the Welding Institute in the United Kingdom (UK). Similarly, extensive research has been carried out on the fundamentals of corrosion and the various types of corrosion that can render a structure useless. *Corrosion of Weldments* explores both of these important disciplines and describes how the welding process can influence both microstructural and corrosion behavior [5]. Welded joints frequently present critical corrosion behaviour [6].

Weldments can experience all the classical forms of corrosion, but they are particularly susceptible to those affected by variations in microstructure and composition. Specifically, crevice corrosion or galvanic corrosion, pitting, stress corrosion cracking, intergranular corrosion, and microbiologically influenced corrosion must be considered when designing welded structures [5, 6, 7].

According to the data of "Transneft" JSC in Russia for instance, main causes of leaks of oil from pipelines are as follows: mechanical damage of oil pipelines - 33% of all accidents; corrosion (internal and external) - 53%; defects of pipes - 4%; defects of welding - 3%; errors in operation - 6%; others - 1%. Significant role of corrosion in premature destruction of pipelines is marked out by the majority of studies and analytical reports. One of the most characteristic mechanism is stress induced corrosion cracking (SCC) [8]. The stress concentrations can be highly generated by weld joints. In some cases the residual stress may exceed the tensile stress of the material, resulting in worsening of SCC susceptibility of the material [9]. Therefore, it is essential to ensure the integrity of a welded joint against corrosion during their long use in welded structures including oil and gas pipelines [10].

This paper intends, to provide the review on the impacts of corrosion in the pipeline weld joints and surfaces. It gives the trend on the use of oil and gas pipelines worldwide. It indicates the different types

of corrosion which might be occurred in the pipeline. Then it gives the inspection methods and methods that can be used to protect the pipelines against corrosion. Finally the paper gives the conclusions.

II. OIL AND GAS PIPELINES

Pipelines play a very important role as a method of long-distance transportation of gases and liquids from their sources to the consuming centres [8, 11, 12]. Pipelines are safest for transportation of oil and gas [13]. For instance the length of gas pipelines in the United States (US) in 2013 reached 1,984,321 Km and length of pipelines transporting oil and petrochemicals– 240,711 Km. In Russia there is a developed network of pipeline transportation of natural gas, oil and petrochemicals: total length of main pipelines exceeds 200,000 Km and length of field pipelines reaches 400,000 Km. Total length of pipelines of various purposes in 120 world countries is, approximately, 3,500,000 Km [8]. The diameter of Pipelines can be anywhere from 6 to 48 inches (15-120 cm) in diameter [14]. The pipeline system is one of the biggest engineering structures of XX century. Main and field oil and gas pipelines are potentially dangerous engineering objects, which require special attention during their installation, repair and reconstruction, as well as during their operation, because their destruction can cause ecological disasters and danger to lives of people. Defects taking place during construction of a pipeline, generally, lie in limits, which are acceptable according to corresponding standards. However, a pipeline, which is in operation, will inevitably experience large defects at some part of its service life [8]. In spite of the fact that rated service life of main pipelines exceeds 30 years, technological nature and complicated conditions of operation of pipelines (influence of corrosion media, displacement of soils etc.) cause accumulation of damage in walls of pipes well before the end of rated service life (Table 1) [8].

Table 1: Pipes defects and service life relationship

Service life	less than 10 years	10-20 years	20-30 years
Ratio of pipe with defects, %	11.9	25.6	35.3
Including dangerous defects, %	0.05	0.34	0.44

The data presented in Table 1 shows that volume of repair works increases with increased age of network of main pipelines. For example, welders of affiliate companies of "Gazprom" JSC in Russia annually produce more than 200 thousands weld joints during repair works [8].

In the US, corrosion is one of the leading causes of failures in onshore transmission pipelines (both oil and gas). It is also a threat to gas distribution mains and services, as well as oil and gas gathering

systems [15]. In the US, the annual cost associated with corrosion damage of structural components is greater than the combined annual cost of natural disasters, including hurricanes, storms, floods, fires and earthquakes [16].



Fig.1 Corrosion damage on a pipe's wall [8]

III. TYPES OF CORROSION

Metals and their alloys (e.g. steel) that have undergone corrosion lose their strength, ductility and other mechanical properties. Corrosion attacks are frequently responsible for most materials failures [17]. The following are the types of corrosion.

A. Uniform corrosion – attack corrosion

This is the most common form of corrosion. It is characterized by corrosive attack proceeding evenly over the entire surface area, or a large fraction of the total area caused by an electrochemical or chemical reaction. The effects of this is a deterioration of the product, causing it to get thinner and eventually fail. It has the biggest effect on the wastage of metal on a basis of tonnage. Though corrosion is not desirable in any way, this type of corrosion has a bigger concern economically compared to the more aggressive types of corrosion [1, 18, 19, 20].



Fig. 2 Uniform Corrosion [18]

B. Galvanic corrosion

Galvanic corrosion, resulting from a metal contacting another conducting material in a corrosive medium, is one of the most common types of corrosion [21]. It occurs when an electrochemical process happens between two dissimilar metals [1, 22]. The least noble metal usually takes the role as an anode, and therefore loses electrons, which again causes a layer of oxide to form on this metal. The metals have to be in an electrolyte for this to happen, which means that a conducting solution has to be present. The more noble metal usually does not show signs of corrosion. It is this principal that used on outboard motors on boats. A lump of zinc is attached close to the part of the motor that is submerged, this is called a sacrificial anode. The

term galvanic corrosion is usually reserved for the process between two dissimilar metals [1].



Fig. 3 Galvanic Corrosion [23]

C. Crevice corrosion

This type of corrosion often happens in confined spaces, where a solution is trapped. One can think of seals like a nut on a bolt. A stagnant solution can be trapped in the interface between the material and the nut. It causes crevices to form, and is much localized making it a very serious type of corrosion [1, 24, 25]. The crevices in which crevice corrosion happens may be formed by: The geometry of the structure, e.g. riveted plates, welded fabrications, threaded joints; Contact of the metal with non-metallic solids, e.g. plastics, rubber, glass; Deposits of sand, dirt or permeable corrosion products on the metal [24].



Fig. 4 Crevice corroded stainless steel [26]

D. Pitting corrosion

It is extremely localized form of corrosion. Pits, as the name indicates, form rather quickly in the material, and can be the reason to catastrophic failure. The pits can be isolated or be so close together and look like a rough surface. The pits can be small or large in size, usually small. The pit may be described as a cavity or hole with the surface diameter about the same or less than the depth. It is difficult to detect, predict and design against and failures due to pitting corrosion often happens extremely sudden. Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system. [1, 20, 25, 27]. Pitting corrosion, which, for example, is almost a common denominator of all types of localized corrosion attack, may assume different shapes. Pitting corrosion can produce pits with their mouth open (uncovered) or covered with a semi-permeable membrane of corrosion products. Pits can be either hemispherical or cup-shaped [27].

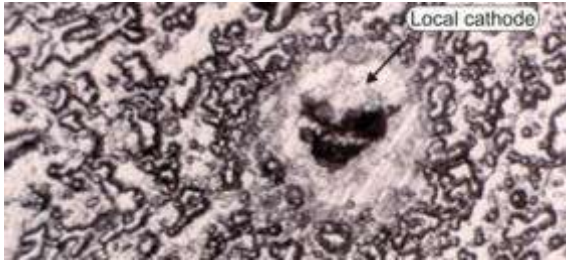


Fig. 5 Pitting Corrosion on a pipe [27]

E. Intergranular corrosion

The microstructure of metals and alloys is made up of grains, separated by grain boundaries. Intergranular corrosion is the localized attack along the grain boundaries, or immediately adjacent to grain boundaries, while the bulk of the grains remain largely unaffected. This form of corrosion is usually associated with chemical segregation effects (impurities have a tendency to be enriched at grain boundaries) or specific phases precipitated on the grain boundaries. Such precipitation can produce zones of reduced corrosion resistance in the immediate vicinity [28].

The attack is usually related to the segregation of specific elements or the formation of a compound in the boundary. Corrosion then occurs by preferential attack on the grain-boundary phase, or in a zone adjacent to it that has lost an element necessary for adequate corrosion resistance - thus making the grain boundary zone anodic relative to the remainder of the surface. The attack usually progresses along a narrow path along the grain boundary and, in a severe case of grain-boundary corrosion, entire grains may be dislodged due to complete deterioration of their boundaries [25, 28].

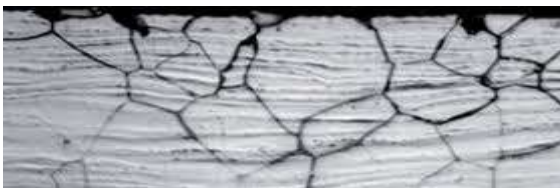


Fig. 6 Intergranular Corrosion [25]

F. Erosion corrosion

The erosion-corrosion degradation of materials is a complex phenomenon because it emanates from the combined effects of mechanical forces (caused by flowing fluid in the presence and absence of solid particles destroying the surface layer/base metal) and electrochemical or chemical dissolution of metallic ions which can be enhanced by mass transfer increases at the surfaces. This damage results in more material loss than the sum of the losses caused by pure mechanical erosion and pure electrochemical corrosion [29]. The consequences and costs associated with CO₂ corrosion and erosion-corrosion damage in oil and gas facilities are enormous and cannot be over-emphasized. The UK

Piper-Alpha disaster of 1988 [29, 30] and the BP Gulf of Mexico oil spill [29, 31] are typical examples. Kermani and Harr [29, 32] in an industry-wide survey in 1980s showed that corrosion-related failures constitute 33% of failures in oil and gas industry and that 28% of these failures are attributed to CO₂-corrosion. A summary of the analysis is shown in Fig. 8. They maintained that the cost of corrosion to the BP Group gives a reasonable estimation of such corrosion costs and can be viewed in terms of capital expenditure (CAPEX); operating expenditure (OPEX); replacement expenditure; lost revenue; Health, Safety and Environment (HSE); and drilling costs [29]. The rate of corrosion may be controlled by the speed of the fluid [1].



Fig. 7 Riser bend suffering from erosion-corrosion [33]

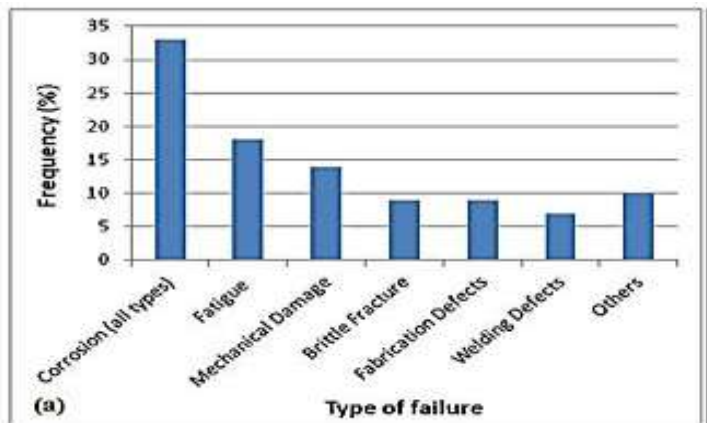


Fig. 8 Survey of selected number of failures [29].

G. Stress corrosion cracking (SCC)

Stress corrosion cracking (SCC) refers to crack propagation due to an anodic reaction at the crack tip. The crack propagates because the material at the crack tip is consumed by the corrosion reaction. In many cases, SCC occurs when there is little visible evidence of general corrosion on the metal surface, and is commonly associated with metals that exhibit substantial passivity [1]. In order for the crack to propagate by this mechanism, the corrosion rate at the crack tip must be much greater than the corrosion rate at the walls of the crack. If the crack faces and crack tip corrode at similar rates, the crack becomes blunt. Under conditions that are favourable to SCC, a passive film (usually an oxide) forms on the crack walls. This protective layer suppresses the corrosion reaction on the crack faces. High stresses at the crack tip cause the protective film to rupture locally, which exposes the metal surface to the

electrolyte, resulting in crack propagation due to anodic dissolution [1].

Therefore, SCC in pipelines is a type of Environmentally Assisted Cracking (EAC). EAC is a generic term that describes the formation of cracks caused by various factors combined with the environment surrounding the pipeline. Together these determinants reduce the pressure carrying capacity of the pipe. When water (electrolyte) comes into contact with steel, the minerals, ions and gases in the water create corrosion that attacks the steel. These chemical or electrochemical reactions may result in general thinning, corrosion pits and/or cracks [11, 34].



Fig. 9 Stress Corrosion Cracks on a pipe [35]

H. Carbon Dioxide Corrosion

Carbon dioxide (CO_2) is found in oil and gas fields in varying concentrations. Dry CO_2 , be it in gas phase or a supercritical fluid is not corrosive to metals and alloys. However, in presence of water-containing produced fluids, severe corrosion of the infrastructure may result due to the formation of carbonic acid (H_2CO_3). Corrosion of materials in contact with CO_2 -containing fluid is dependent on various factors. These include: (i) Concentration of CO_2 (and other components like H_2S), (ii) water chemistry, (iii) operating conditions, and (iv) material type [36, 37].

IV. CORROSION PREVENTION

Corrosion has been identified as the main challenge affecting the efficiency of the oil and gas pipelines. The disadvantages of corrosion point to the need to devise ways of overcoming the threat, especially in preventing the occurrence of accidents resulting from fractures and leakages. Low-carbon steel has been associated with susceptibility to oxidation in the presence of electrolytes, water and carbon dioxide. External corrosion is also a factor of contact with soil, which also supports oxidation. Therefore, one of the basic methods of controlling external corrosion is through coating and cathodic protection [15, 38].

A. Cathodic Protection (CP)

Cathodic protection is the application of current to the pipeline to disrupt the movement of electrons from the anode to the cathode. It creates a cathodic field over the pipeline, which implies that the anodes in the exposed surface are non-reactive. The pipe acts like a cathode, which implies the lack of

movement of electrons. In addition, cathodic protection leads to the development of deposits that protect the steel since they are alkaline in nature [11, 15, 38, 39, 40]. There are two main methods of cathodic protection. **The sacrificial anode protection method** which involves connecting the pipe with an external metal that has a relatively higher activity than steel. The metal is then placed away from the pipeline but within the electrolyte (soil). The result is that current will flow to the metal since it reacts more than steel. Therefore, the sacrificial metal undergoes corrosion thereby protecting the oil and gas pipeline from corrosion. **The impressed-current anode method** involves the introduction of direct current between the pipeline and anode. The purpose is to attract current away from the pipeline, which prevents corrosion. Therefore, cathodic protection involves the disruption of the movement of current from the anode to the pipelines through the electrolyte. Its use and application depends on the nature of the pipeline system, and the geological characteristics of the area under consideration [15, 38, 40]. However, the method cannot be effective on its own because it would be costly to match the current required to the entire stretch of the pipeline [15].

B. Coatings

The most effective method to prevent corrosion on new pipelines is to use high performance coatings, applied to a surface abrasive blast cleaned to a white [41] or near white metal surface finish, in conjunction with effective CP. An intact coating that prevents contact of electrolyte with the steel surface will prevent external corrosion. The surface abrasive blast cleaning promotes good coating adhesion. All coatings contain some defects or holes, referred to as holidays, that expose the bare pipeline steel to the underground environment. The function of the CP system is to protect these bare areas from corrosion [11, 15].

Inadequate coating performance is a major contributing factor in the corrosion susceptibility of an underground pipeline [42]. The specification states that, the function of such coatings is to control corrosion by isolating the external surface of the underground or submerged piping from the environment, to reduce CP requirements, and to improve (protective) current distribution. Coatings must be properly selected and applied, and the coated piping must be carefully installed to fulfill these functions [11].

The following are the common coatings that are used on underground pipelines:

Bituminous enamels are formulated from coal-tar pitches or petroleum asphalts and have been widely used as protective coatings for more than 65 years. These enamels are combined with various combinations of fiberglass and/or felt to obtain mechanical strength for handling. The enamel

coatings have been the workhorse coatings of the industry, and when properly selected and applied, they can provide efficient long-term corrosion protection [11, 43].

Asphalt mastic pipe coating is a dense mixture of sand, crushed limestone, and fiber bound together with a selected air-blown asphalt. These materials are proportioned to secure a maximum density of approximately 2.1 g/cm³. This mastic material is available with various types of asphalt. Selection is based on operating temperature and climatic conditions to obtain maximum flexibility and operating characteristics. This coating is a thick (12.7 to 16 mm), extruded mastic that results in a seamless corrosion coating. Extruded asphalt mastic pipe coating has been in use for more than 50 years [11, 43].

Liquid Epoxies and Phenolics. Many different liquid systems are available that cure by heat and/or chemical reaction. Some are solvent types, and others are 100% solids. These systems are primarily used on larger diameter pipe when conventional systems may not be available or when they may offer better resistance to operation temperatures in the 95°C range.

Generally, epoxies have an amine or a polyamide curing agent and require a near-white blast cleaned surface [44]. Coal-tar epoxies have coal-tar pitch added to the epoxy resin. A coal-tar epoxy cured with a low-molecular-weight amine is especially resistant to an alkaline environment, such as that which occurs on a cathodically protected structure. Some coal-tar epoxies become brittle when exposed to sunlight [11].

Extruded plastic coatings fall into two categories based on the method of extrusion, with additional variations resulting from the selection of adhesive. The two methods of extrusion are the crosshead or circular die, and the side extrusion or T-shaped die. The four types of adhesives are asphalt-rubber blend, polyethylene copolymer, butyl rubber adhesive, and polyolefin rubber blend.

To date, of the polyolefins available, polyethylene has found the widest use, with polypropylene being used on a limited basis for its higher operating temperature. Each type or variation of adhesive and method of extrusion offers different characteristics based on the degree of importance to the user of certain measurable properties [11].

Fusion-bonded epoxy (FBE) coatings are heat-activated, chemically cured coating systems. The epoxy coating is furnished in powdered form and, with the exception of the welded field joints, is plant applied to preheated pipe, special sections, connections, and fittings using fluid-bed, air spray, or electrostatic spray methods. Fusion-bonded epoxy coatings were introduced in 1959 and were first used as an exterior pipe coating in 1960 and currently are the coatings most commonly used for new installations of large diameter pipelines [43, 45, 46,

47]. These coatings are applied to preheated pipe surfaces at 218 to 244°C [11].

Tape. Field and mill-applied tape systems have been in use for more than 30 years on pipelines. For normal construction conditions, prefabricated cold-applied tapes are applied as a three-layer system consisting of a primer, corrosion-preventive tape (inner layer), and a mechanically protective tape (outer layer). The function of the primer is to provide a bonding medium between the pipe surface and the adhesive or sealant on the inner layer. The inner-layer tape consists of a plastic backing and an adhesive. This layer is the corrosion-protective coating; therefore, it must provide a high electrical resistivity, low moisture absorption and permeability, and an effective bond to the primed steel surface. The outer-layer tape consists of a plastic film and an adhesive composed of the same types of materials used in the inner tape or materials that are compatible with the inner-layer tape. The purpose of the outer-layer tape is to provide mechanical protection to the inner-layer tape and to be resistant to the elements during outdoor storage. The outer-layer tape is usually a minimum of 0.64 mm thick [11, 43].

Three-Layer Polyolefin. Three layer polyolefin pipeline coating was developed in the 1990s as a way to combine the excellent adhesion of FBE with the damage resistance of extruded polyethylene and tape wraps. These systems consist of an FEB primer, an intermediate copolymer layer, and a topcoat consisting of either polyethylene or polypropylene. The function of the intermediate copolymer is to bond the FBE primer with the polyolefin topcoat [11, 43].

Wax coatings have been in use for more than 50 years and are still employed on a limited basis. Microcrystalline wax coatings are usually used with a protective overwrap. The wax serves to waterproof the pipe, and the wrapper protects the wax coating from contact with the soil and affords some mechanical protection. The most prevalent use of wax coatings is the over the ditch application with a combination machine that cleans, coats, wraps, and lowers into the ditch in one operation [11]. The advantages of wax coatings are ease of application and flow of the coating onto the irregular structure [48].

Polyurethane Thermal Insulation. Efficient pipeline insulation has grown increasingly important as a means of operating hot and cold service pipelines. This is a system for controlling heat transfer in above- or belowground and marine pipelines. Polyurethane insulation is generally used in conjunction with a corrosion coating, but if the proper moisture vapor barrier is used over the polyurethane foam, effective corrosion protection is attained [11, 49].

Concrete. Mortar linings and coatings have the longest history of use in protecting steel or wrought

iron from corrosion. The alkalinity of the concrete promotes the formation of a protective iron oxide (passive) film on the steel. This protective passive film can be compromised in underground applications by permeation of chlorides into the coating. Typically, external application is usually employed over a corrosion-resistant coating for armor protection and negative buoyancy in marine environments [11, 43].

Metallic (Galvanic) Coatings. Pipe coated with a galvanic coating, such as zinc (galvanizing) or cadmium, should not be utilized in direct burial service. Such metallic coatings are intended for the mitigation of atmospheric type corrosion activity on the substrate steel [11].

C. Corrosion Inhibitors

Corrosion inhibitors are chemical compounds that are added to a fluid to reduce the rate of corrosion in materials in contact with the fluid. For example, an inhibitor will be injected into the stream of hydrocarbons (oil or gas) near to the wellhead to reduce corrosion in the steel of the pipeline. The composition of the flow from the wellhead can vary greatly, with the water content varying from between 1 and 99%, for example, and this has a significant effect on the natural corrosion potential in the untreated system. Other factors, such as temperature and pressure also affect corrosion rates.

While corrosion inhibitors are effective against CO₂ and H₂S, if oxygen is present they are either ineffective or require very high concentrations to achieve the desired inhibited corrosion rate [15, 37, 50, 51, 52, 53]. In these conditions, scavengers are used to remove the oxygen. Also, any water injected into the well would be treated to remove oxygen before injection.

V. INSPECTION AND CONTROL OF CORROSION

There are different methods used in the inspection of oil and gas pipelines, and their choice depends on the nature and location of the pipeline, as well as the motives of the assessment [38]. On existing pipelines, there are three methods to detect corrosion: hydrostatic retesting, field investigation programs (direct assessment), and in-line inspection (ILI) [11].

A. Direct Assessment (DA)

As a part of condition monitoring programs, pipeline companies commonly use field investigation (DA) programs [11]. DA is essentially a structured process approach that doesn't impede a pipeline operation [55]. The overall condition of the coatings and pipelines is assessed, and it is determined whether corrosion is present on the system. Models are sometimes developed to predict the likelihood of the presence and severity of corrosion or cracking. This information is then used to prioritize the system for direct examination,

hydrostatic testing, in-line inspection, recoating, or pipe replacement. Dig programs and the associated models are not generally considered as a replacement for hydrostatic testing as a means to ensure the integrity of a pipeline [11].

B. Hydrostatic Testing

Hydrostatic testing is one of the quality-control measures used to ensure that installed pipeline systems are fit for service. Qualification of the individual components of the pipeline for the intended service is an integral part of the design process. Hydrotest loads are one of the loads a pipeline system experiences in its service life, and these loads are also considered in the design process [54]. Hydrostatic testing involves pressure testing the pipeline with water at a pressure that is higher than the operating pressure, typically 125% of the maximum operating pressure (MOP) of the pipeline. This is the most common method to ensure the integrity of a pipeline and establish a safe operating pressure, regardless of the types of flaws present in the pipeline. Any flaws that are larger than a critical size at the hydrostatic retest pressure are removed from the pipeline. However, subcritical flaws remain in the pipeline after a hydrostatic retest. If the defects are growing with time, as might be the case with corrosion, the pipeline is generally periodically retested to ensure integrity [11].

C. In-line inspection (ILI) tools

They are also referred to as smart or intelligent devices known as PIGs, are devices that are propelled by the product in the pipeline and are used to detect and characterize metal loss caused by corrosion and cracking. There are two primary types of metal-loss ILI tools: magnetic flux leakage (MFL) tools and ultrasonic tools (UT) [2, 56].

Magnetic flux leakage tools. Among various pipeline inspection technology MFL inspection is the most widespread and perfect one. It has well Effect in ordinary defect detection, such as loss of metal [57]. MFL is the method which can detect cracks in both the axial and circumferential directions, although it is susceptible to the pipe wall and other factors. MFL techniques have evolved in the pipeline inspection industry since the 1960s [58]. They measure the change in magnetic flux lines produced by the defect and produce a signal that can be correlated to the length and depth of a defect. In recent years, the magnetics, data storage, and signal interpretation have been improved, resulting in improved mapping of the flaw and a decrease in the number of unnecessary excavations [11]. There are two types of these tools, high resolution MFL and standard resolution MFL. The main difference between the two is in the number of sensors and the amount of resolution [59]. The high-resolution MFL tool is typically capable of readily detecting corrosion pits with a diameter greater than three

times the wall thickness. Once detected, these tools can typically size the depth of the corrosion within +10% of the wall thickness with an 80% level of confidence. The MFL tool can be used to inspect either liquid product pipelines or natural gas pipelines. Figure 10 shows a typical MFL tool. The wire brushes in the front of the tool are used to transfer the magnetic field from the tool to the pipe wall. The ring of sensors between the wire brushes are used to measure the flux leakage produced by defects in the pipe. The drive cups are the mechanisms that are used to propel the tool by the product in the pipeline. The odometer wheels monitor the distance traveled in the line and are used to determine the location of the defects identified. The trailing set of inside-diameter/outside-diameter sensors (ID/OD sensors) is used to discriminate between internal and external wall loss [11].

Ultrasonic tools (UT) utilize large arrays of ultrasonic transducers to send and receive sound waves (ultrasonic pulse) that travel through the wall thickness, permitting a detailed mapping of the pipe wall [11, 59]. Ultrasonic tools can indicate whether the wall loss is internal or external. The typical resolution of a UT is +10% of the pipe wall thickness with an 80% level of confidence. Ultrasonic tools are typically used in product pipelines (those carrying crude oil, gasoline, and the like) since the product in the pipeline is used as the required couplant for the ultrasonic sensors. This tool can be used to inspect natural gas pipelines, but requires introducing a liquid (such as water) into the pipeline for an ultrasonic couplant [11]. Internal cleaning of the pipeline using special cleaning pigs has also been used primarily to ensure the required low levels of hydraulic resistance [60].



Fig. 10 Magnetic flux leakage (MFL) tool for detection and sizing of corrosion defects in a pipeline [11, 61]

D. Process control systems

A process control system is used to monitor data and control equipment on the whole oil and gas system.

Pipeline Control Centre: The pipeline control center is the heart of pipeline operations. Information about the pipeline's operating equipment and parameters is communicated into the control center, where operators use computers to monitor the pipeline operation. Pipeline monitoring is accomplished through a computerized system known as a Supervisory Control and Data Acquisition (SCADA) system. It gathers data from pipeline sensors in real-time from remote locations

in order to control equipment, conditions and implement corrective action [16, 62]. Many pipeline operators have their 24-hour emergency phone number connected directly to the pipeline control centre. The SCADA system continuously monitors the volume in the pipeline and provides line balance reports. Most SCADA systems offer multiple computer screens so that an operator can instantly check operations and facts at any location. SCADA is normally associated with telemetry and wide area communications, for data gathering and control over large production sites, pipelines, or corporate data from multiple facilities. With telemetry, the bandwidth is often quite low and based on telephone or local radio systems. SCADA systems are often optimized for efficient use of the available bandwidth. Wide area communication operates with wideband services, such as optical fibers and broadband internet. Remote terminal units (RTU) or local controls systems on wells, wellhead platforms, compressor and pump stations, are connected to the SCADA system by means of the available communication media. [14].



Fig. 11 Pipeline controlled using SCADA System [63]

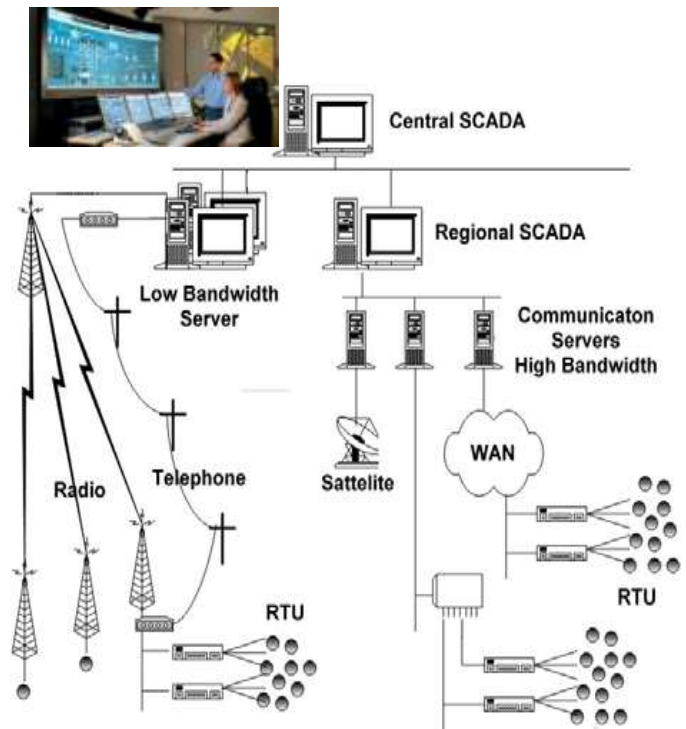


Fig. 12 SCADA system topology [14, 64]

VI. CONCLUSIONS

The impacts of corrosion in weld joints and surfaces of oil and gas pipelines have been presented. The paper has indicated that, corrosion is an emerging issue that requires urgent attention, effective prevention and regular inspection and control. It has been clearly seen that, the sustainability and efficiency of pipelines in the distribution of oil and gas from their sources to the consuming centres can be affected by corrosion. The study has shown that, corrosion related failures constitute 33% of all failures in oil and gas industry. Corrosion leads to mechanical reduction of the strength of oil and gas pipelines, which leads to leakages and other problems. Leakages are dangerous because they expose populations to the risk of explosions and fires, as well as damaging the surrounding environment. Corrosion control should be an ongoing, dynamic process. The keys to effective corrosion control of pipelines are quality design and installation of equipment, use of proper technologies, and ongoing maintenance and monitoring by trained professionals. An effective maintenance and monitoring program can be an operator's best insurance against preventable corrosion related problems. Furthermore, as it has been reported that annual cost associated with corrosion damage of structural components is very high worldwide, investing in the new technologies of detecting and inspecting corrosion in the pipelines which can provide a good foundation of prevention and control is very important.

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