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RADIOGRAPHIC EVALUATION OF WALL THICKNESS, CORROSION AND DEPOSITS IN PIPELINES

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DECLARATION

I hereby declare that, with the exception of properly recognized references to other people's research, this thesis is the product of my individual research work and no portion of it has been submitted for another degree at this University or anywhere else.

…… Date……

SANDYSON OWUSU – POKU

(Student)

I hereby certify that the preparation of this project has been supervised in accordance with the rules set out by the University of Ghana for the supervision of thesis work.

…… ....…….....

Dr. Kwaku A. DANSO PROF. Christian P. K. DAGADU

(Principal Supervisor) (Co-Supervisor)

Date……. Date……

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DEDICATION

I gracefully dedicate this Master's Thesis with love and honour to the Stronghold of my life: God, my Parents and my Siblings.

Firstly, to God Almighty

For grace and favoured and also being my source of strength, divine health, knowledge and innovative ideas that necessitated the achievement of this goal.

To my superb Parents,

Mr. Maxwell Owusu and Mrs. Beatrice Osei – Akoto for their financial support, guidance, encouragement and prayers which always acted as a catalyst in my academic pursuit. I am really proud to call you my parents.

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To all my lecturers from time past and present, in great appreciation for their inspiration and passion for knowledge.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Material
BIS	British International Standard
CRP	Coordinated Research Project
DWT	Double Wall Technique
GAEC	Ghana Atomic Energy Commission
IAEA	International Atomic Energy Agency
IQI	Image Quality Indicator
IS	Inside Step
JIS	Japanese International Standard
NDE	Non-Destructive Examination
NDI	Non-Destructive Inspection
NDT	Non-Destructive Testing
NIST	National Institute of Standard Testing
OS	Outside Step
RT	Radiographic Technique
SFD	Source Film Distance
SNAS	School of Nuclear and Allied Sciences
SS	Stainless Steel
TRT	Tangential Radiographic Technique

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ABSTRACT

Non-destructive testing (NDT) is a group of inspection techniques used to detect, locate and assess flaws in materials without affecting, in any way, their continued usefulness or serviceability. NDT has the ability to inspect castings, weldments and measure wall thicknesses in an accurate and comprehensive manner. In this study, NDT techniques were used to inspect large diameter pipes that are used for transporting substance in the form of liquids and gases in industries. The aim of the investigation was to use NDT techniques to inspect pipes for corrosion and deposit and to evaluate the remaining wall thickness of the pipes. The double wall technique (DWT) and tangential radiographic technique (TRT) were used to evaluate remaining wall thickness, deposits and corrosion in the pipes. The DWT technique was used to inspect corrosion and deposits in the pipes while TRT technique was used to evaluate the penetrated wall thickness of the corrosion attack in tangential position. Two steel pipes having known varying wall thicknesses ranging from 4.00 mm to 13.00 mm with diameter of 150.00 mm were examined to authenticate the accuracy and reliability of the tangential method that was used to measure the remaining wall thickness. The tangential configuration resulted in a higher material thickness, which therefore required more time of exposure compared to the DWT method. The exposure angle of the source to the tangential part of the specimen was approximately seventy-seven degree (77^{o}). This angle was calculated using the values of source-to-film distance and the outer diameter of the experimental pipe. The measurements for the remaining wall thickness was done with the TRT. This is irrespective of whether the test pipes were insulated or not insulated. The film generated was compared with a normal pipe piece that was not machined to serve as control. From the radiograph obtained, six (6) and seven (7)

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indications rounded depicting pitting corrosion were revealed on the radiograph of the internally fabricated pipe and externally fabricated pipe respectively. The interpretations obtained from radiographs after the TRT was employed showed that recorded wall thickness obtained from the film is about twice the value of the calculated true wall thickness. The maximum standard deviation of the measured thickness from the radiograph was 0.1414 and a standard error of 0.07 for the externally fabricated pipe. And a maximum standard deviation of 0.085 for the internally fabricated pipe. From this research, the DWT and TRT were successful in the evaluation of corrosion, deposits and wall thickness of the pipes used.

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CHAPTER ONE (1)

1.0 INTRODUCTION

1.1 Background

Non-destructive testing (NDT) refers to techniques, which are used to detect, locate and assess discontinuities or flaws in materials or structures or fabricated components without affecting in any way their continued usefulness or serviceability (Alex, Solomon, & Charles, 2014). NDT is also known as Non – destructive Inspection (NDI) and Non – destructive Evaluation (NDE). In NDT, different physical phenomena are employed. These physical phenomena includes; electromagnetism used for magnetic particle testing, acoustic emission used for ultrasonic testing and penetration of hard energy radiation through materials used for industrial radiography testing.

NDT continues to be pivotal in the progress made in the scientific technology and industries in recent times. During the manufacturing of industrial machines, NDT is used to inspect all the products of the manufacturing processes involved (castings, weldments and rolling). The reliability and safety of industrial machinery in the process industries are significantly affected by procedures of degradation (Agency, 2005).

Corrosion can cause severe mechanical failures leading to large economic losses, environmental pollution, or risk of personnel injuries. Early detection through proper diagnosis is a preventive measure to reduce such failures. The attraction of NDT is that the technique can be used whilst the machine is online or operational. Hence plans can be made for component replacements, repairs, deposit removal and shutdowns when related defects

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are identified. Putting preventive and corrective measures in place reduces the environmental impacts of industrial disasters.

Pipelines are essential infrastructures that play a significant role in a nation's economy. Industries specifically the petroleum and mining sectors use pipelines as a means of transporting chemicals in the form of liquids and gases from one point to another. Most of these pipes are made of metals, such as cast iron and steel that are buried in the soil (Agency, 2005). These pipes are usually covered by thick insulation materials, such as asbestos, nylon cloth, concrete or lime and fiber wool. This is because the media transported generally have elevated pressure, toxic and combustible properties. Due to their long-term service and exposure to aggressive environment in the soil, the metal pipes age and deteriorate resulting in unexpected high rate of failures. In the report of (Hou, Lei, Li, Yang, & Li, 2016) they stated that there was high rate of pipes failure due to bursting in Canada and Australia. As it is well appreciated, the consequence resulting from the increasing rate of pipe failures do not only pose economical concerns but also results in environmental impacts such as flooding, etc. Wall thickness is one of the significant parameters of pipelines that needs to be monitored and evaluated. Among the NDT techniques, only the radiographic technique ensures inspection during the investigation phase without expensive removal of insulation material. Radiographic methods can be also be implemented even in elevated temperature settings. (international atomic energy agency, 2005).

Excluding some noble metals (such as gold, silver, rhodium, platinum, etc.), all other metals are subjected to corrosion-induced deterioration. Buildings, boats, machines, machinery for power plants, petroleum and many more are subjected to environmental

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(corrosion) attacks. Although corrosion cannot be completely avoided by itself, it can be regulated in a way that does not achieve the seriousness of the related issues.

Corrosion often makes pipes unserviceable and may have to be replaced ultimately making resulting cost of corrosion elevated as reported by (Burch & Collett, 2005). Therefore, to extend the service life of pipes, there is the need to put measures in place to control corrosion.

1.2. Statement of Problem

The inspection of pipelines for corrosion, deposits as well as measuring the remaining wall thickness have been a major industrial challenge over the years. This is particularly problematic for pipelines covered with insulators. International Atomic Energy Agency (IAEA) is actively encouraging the use of non-destructive testing (NDT) technology industrial applications that include radiography testing (RT) and other associated techniques to ensure the safety and reliability of industrial equipment in operation. One major parameter to be examined and measured in the pipeline or piping industries is the thickness of the pipe wall. Large pipes (with a diameter greater than 150 mm) with or without insulation are preferably used in nearly all process industries; corrosion and deposit in these pipes are of imperative industrial concerns to which solutions must be found for both economic and safety reasons.

Ghana seeks to be an industrial nation in the Sub-Saharan Region, under the Millennium Development goal of the United Nations Industrial Development Organization (Vienna 2004), which is to grow and expand her industrial base especially the process industries. Since majority of these industries will rely on pipes of such nature in their operations, it is

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envisioned that corrosion and deposits in industrial pipes will be a foremost setback in plant assessment life in the years to come.

1.3. Objective

To employ the use of industrial radiographic techniques in the inspection of corrosion, deposits and to measure remaining wall thickness in pipelines with large diameters.

This research's specific objectives are:

- Identification and evaluation of corrosion and deposit on the pipe walls and assessing the pipe wall thickness.
- Inspection of inner wall corrosion to make industries aware of related risk of misinterpretation and failure of pipe component.
- Using statistical tool to evaluate and analyze the radiographic parameters of the pipe.

1.4. Relevance and Justifications

For safety and reliability of industrial equipment and installations, corrosion and blockage in industrial pipes need to be critically attended to in the process industry. This is because they can significantly influence the performance of these equipment and installations. To determine the amount of accumulated deposits in pipelines using NDT method, radiography is the most effective method to consider. Also, radiography has the added advantage of being able to inspect the pipelines without the costly removal of insulation material often in harsh plant environment conditions (for example high pressure, elevated temperature).

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Pipelines are essential means of transporting liquids and gases in the process industries. This implies they carry all manner of substances ranging from non-toxic to toxic. Broken or corroded pipes that may be transporting dangerous substances such as chemicals or gas and oil, may cause severe environment impacts. These environmental impacts can be curb when inspections are performed periodical to ascertain the integrity of pipes. Therefore, it is imperative to evaluate wall thickness, inner wall corrosion and deposit in pipes especially pipes with large diameter (most used) by industrial radiography techniques to address the confronting challenges in the processing industries.

This research will present a baseline data for the investigated pipes. Database can be generated for the industrial laid pipes so that periodically, these pipes can be monitored to access their conditions (wall thickness, deposits and corrosion), so that timely interventions can be effected against industrial associated disasters.

1.5. Scope and Delimitation

The scope of this research comprises of the evaluation of the tangential radiographic technique (TRT) and double wall radiographic technique (DWT) using Ir-192 to assess wall thickness, simulated deposits and corrosion attack on carbon steel pipes with diameter 153 mm with and without insulation. Two steel pipes were used for this research. One of the pipes was internally machined in a stepwise manner (erosion corrosion) with pits (pitting corrosion) and the other similarly machined in a stepwise manner externally and pitted.

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1.6. Structure

The framework for the study is as follows; Chapter One (opening chapter) presents introductory notes on NDT testing, specifically radiographic testing with importance on its industrial applications in pipelines in the process industries and some difficulties confronted within this sector. The second chapter (Chapter Two) reviews related literature justifying this chosen research thesis topic. Chapter Three gives detailed explanations on the techniques and equipment used in collecting data and its analysis. Chapter Four, gives an elaboration on the collected data from the study either in figures or in tables and elucidated. Also, the significance and implications of the results obtained as compared with other relevant published works is discussed in this same chapter. The last chapter (Chapter Five) presents the conclusions deduced from this research and recommendations for further works in future.

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CHAPTER TWO (2)

2.0. LITERATURE REVIEW

This section gives a summary of the relevant literature in relation to what is known about this research topic and the loopholes in knowledge that must be sealed. To a larger extent, this section provides justification for the topic as stated in chapter one of this thesis.

2.1 Industrial Radiography

Industrial radiography testing (RT) is the examination of the structure of materials by non-destructive methods which involves utilizing ionizing radiation to make radiographic images (Radiography, 2011). Radiography in general is applied in numerous fields such as engineering, medicine, among others. Industrial radiography remains one of the most important techniques in NDT. Although, RT is the oldest approach in NDT, it remains the most widely used method because it offers enormous advantages over other NDT modalities (Quinn & Sigl, 1980).

Specifically, RT is a technique used to inspect hidden flaws or the inside view of a material under test by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate the material (Hijazi, n.d.). Projections from X-rays or gamma rays are made on test sample and the intensity of the radiation that penetrates and passes through the material is either captured by radiation sensitive film (Film radiography) or by a planer array of radiation sensitive sensors (Real-time radiography). The film is chemically processed after the exposure, thus obtaining a film called a radiograph. The film is viewed and interpreted against an illuminator. The film demonstrates the part's dimensional characteristics (Hellier, 2003).

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Due to the high penetrating power of gamma rays and X-rays, they are capable of penetrating through matter. These rays are attenuated as they pass through matter. The attenuation depends on the density and thickness of the matter at point of interaction. Hence, the intensity of the rays emerging from the matter differs. When this disparity is detected and recorded, generally on radiograph, the ability to see within the material is made possible. RT involves the use the penetration and attenuation features of high energy radiations to inspect and evaluate materials for hidden flaws.

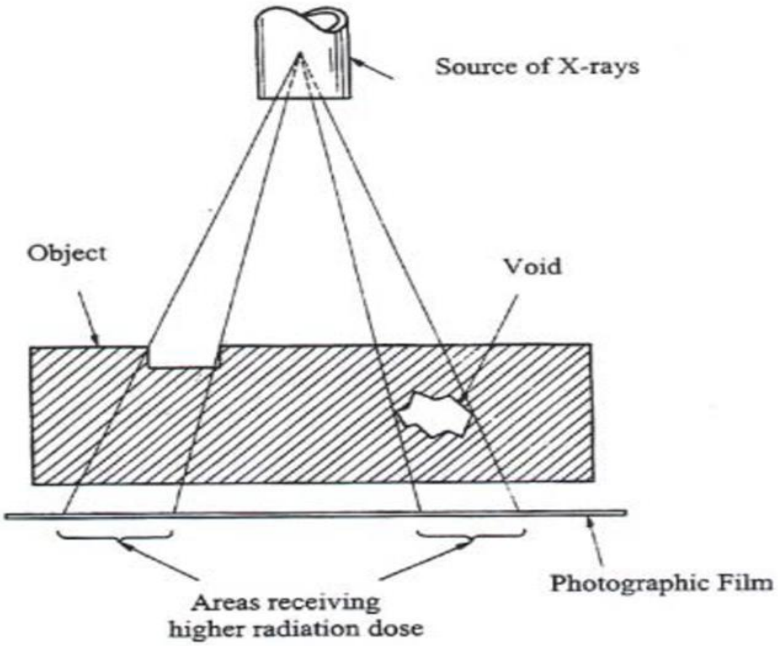


Fig 2.1: A classical radiography set-up (international atomic energy agency, 2005)

Fig 2.1 above gives an illustration of the absorption characteristics of radiation as used in the radiographic process. Materials being examined absorb radiation from the X-rays or gamma rays source directed onto it. In areas with less thickness or discontinuity, considerable absorption takes place. The image (latent) formed on the radiograph as a result

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of the passage of radiation through the material turn out to be a shadow picture of the material after film processing. This is because considerable radiation passes through the material in areas with discontinuous and less thick. Their corresponding areas of the radiograph are darker compared to areas without the discontinuity. X-rays are effective for materials with small thickness only and gamma rays are useful for thicker materials because the penetration power of x-rays is less than that of gamma rays(Burch & Collett, 2005).

2.1.1 Sources of Radiation

A radiation source is central to the Industrial Radiography testing method. This is because the penetrating power of these radiation sources is what is used to assess the material under study. Common radiation sources used for Industrial Radiography testing are X-ray and gamma ray sources which are both examples of electromagnetic radiation. X-rays and gamma rays vary only in their wavelengths and manner in which they are generated. The half-lives of radiation sources are shown in table 2.1

2.1.1.1. X – Ray Sources

They are produced by specially designed high vacuum tubes (X-ray tubes). This vacuum tubes use high voltage to accelerate electrons that are released by a hot cathode at a high velocity. The accelerated electrons move at high velocities and collide with a metal target, the anode thus creating the X-rays (Hijazi, n.d.). The intensity and penetrating power of the X-rays are determined by the current (mA) and voltage (kV) that is applied. X-rays can transverse relatively thick objects less absorbed or scattered. Therefore, it has the ability to

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take inner images of visually opaque objects. The penetrating depth is dependent on the various orders of magnitude over the X-ray spectrum. In X-ray machines, the energy and intensity are usually adjustable. Generally, X-ray penetrating power ranges for normal focus tubes (1 - 4 mm focus size) are from 200 W up to 4 kW, tube currents from 1mA to 8mA and an accelerating voltage from 30kV up to 450kV. Unfortunately, most of this power is dissipated into thermal energy which requires strong cooling of the anode target in the tube and only a fraction not larger than 1% is converted into X-ray energy by the generation of bremsstrahlung in the tube target (Agency, 2005). This is illustrated in fig 2.2 below.

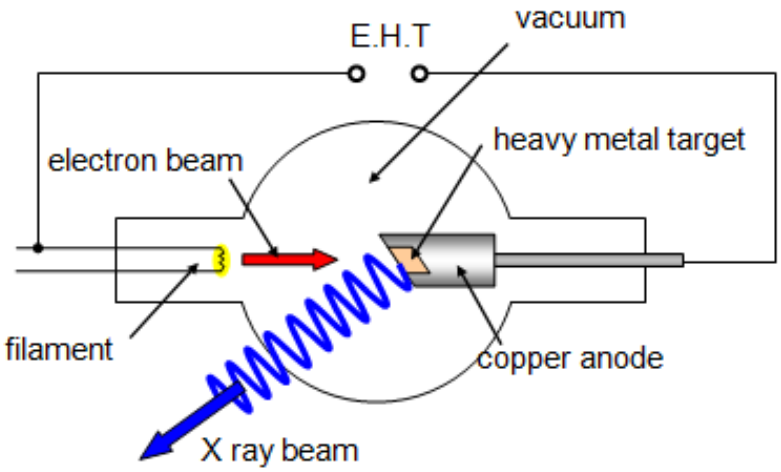


Fig 2.2: Illustration of X-ray mechanism

2.1.1.2. Gamma Ray Sources

Gamma radiation is one of the three types of emissions from natural radioactivity. Alpha and beta particles are the other two types. Gamma rays differ from X-rays their production and wavelength ((Hijazi, n.d.). Gamma rays are generated as a result of an excited and unbalanced nucleus being disintegrated. It is impossible to alter the energy of gamma

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radiation sources. Also, the intensity cannot be controlled for a given source because the rate of disintegration cannot be changed. The energy of the gamma radiation is dependent on the radioactive source's nature and is fixed for a specific source. In non-destructive testing, radioactive isotopes which emit gamma radiation are used similar to an X-ray device (Harara, 2003).

When examining thicker materials, Gamma-rays radiography gives better results compared to X-ray. Affordable radioisotopes that emit gamma radiations are available. Also, this test can be performed within a very short period and hence this method is becoming more popular. Its use requires practical field applications with no need for electrical power and cooling. Typically, a transport container made from depleted Uranium is used for radiation protection. National licenses and International guidelines regulate the handling and transportation of gamma sources with Member States responsible for their compliance to their applicable governing standards (Janeiro & Janeiro, 2005).

In RT, gamma-ray sources used are either in metallic form (Iridium-192, Cobalt-60). These radiography sources are of cylindrical shape, of sizes varying from $1mm \times 1mm$ to $4mm \times 4mm$. They are doubly encapsulated in stainless steel casings so that only the gamma radiations emitted by the source are made used off. So long as these metallic capsules are in good condition, there is no chance of any contamination. These metallic capsules serve to absorb any beta radiation emitted by the source (Agency, 2005).

To reduce the pipe's outer diameter (OD) burn-off, a filter can be produced in front of the tube window to minimize the burn-off impact (Vaidya, Atomic, Atomic, & Authority, 2006). (Agency, 2005) publication discovered iridium – 192 as the radioisotope (among

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available radioisotopes) of choice due to its ability to give the best image definition. Fig 2.3 shows how gamma source is contained.



Fig 2.3: A container containing gamma radiation

Table 2.1: Isotope Characteristics.

Isotope	Cobalt-60	Iridium-192
Half-Life	5.3 yrs.	75 days
Chemical Formula	Co	Ir
Gammas Energies (Mev)	1.33 1.17	0. 60 0.47 0.31

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2.1.2 Radiation Attenuation in Materials

Gamma rays intensity beam undergoes localized attenuation as it moves through a material. This is because of the scattering and absorption of the gamma radiation. This intensity of determined by the formula:

$$I = I_o e^{-\mu t} \quad \text{(2.1)}$$

Where

I = transmitted radiation intensity

I_o = incident radiation intensity

μ = linear absorption coefficient of the material under study. The value are dependent on the radiation energy and the material's atomic number.

t = specimen's thickness

The equation above is applicable for narrow beam geometry only. This is because broad beam geometry is mainly found in practical applications. Hence, this formula is used:

$$I = BI_o e^{-\mu t} \quad \text{(2.2)}$$

Where:

B in equation 2.2 is known as "Build-up factor". This represents the scattered radiation contributions.

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The above Beer's Law is true for mono-energetic radiation and narrow beam geometry (very good beam collimation, only radiation absorption) usually not encountered in practical applications. Practically speaking, primary radiation and scattered radiation both affect the film exposure. This additional exposure can be considered such as an additional —build-up factor. This is expressed as:

$$I = BI_O e^{-\mu_{eff} t} \quad \ldots\ldots (2.3)$$

This concept implies a constant scatter background like in the case of flat plates or welds inspection and not inspection of pipelines. This is due to the large range of penetrated wall thicknesses involved. As it can be seen clearly from fig 2.1, the scatter contribution is strongest in the center of the pipe, where the distance between object and detector is smallest. The scatter contribution diminishes with increasing distance of the pipe center line. Therefore the concept of a common build-up factor is not valid for pipe geometry (Agency, 2005).

Effective attenuation coefficient (μ_{eff}) is better for this geometric set-up. Scatter contributions are considered directly by the attenuation coefficient in Beer's Law:

$$I = I_O e^{-\mu_{eff} t} \quad \ldots\ldots (2.4)$$

In practice, effective attenuation coefficient (μ_{eff}) will depend on the energy of the radiation, the wall thickness (because of radiation hardening in the object) and the geometrical set-up used for inspection (this determines the scatter contribution). They will always be smaller than the theoretical μ as obtained for the mono-energetic narrow beam

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energy or from theoretical models like data available from the National Institute of Standards and Technology (NIST) (Agency, 2005).

2.1.3 Geometric factors

Radioactive sources generate a certain blurred picture of the samples due to their fixed dimension. The specimen's unclear image (or partial surrounding shadow) is technically referred to as the "penumbra" or "unsharpness". The size of the radioactive source(s), source-to-film distance (SFD) and the specimen's thickness (d) influences the value geometric unsharpness (Ug).

Relating to these parameters, the general formula used is as follows:

$$U_g = \frac{sd}{(SFD - d)} \quad \ldots \quad (2.5)$$

To detect fine flaws, it is necessary to maintain U_g to a minimum.

2.1.4. Films/Detectors

The film is covered on both sides of the base of the cellulose triacetate or polyester with a delicate emulsion of silver halide as shown in fig 2.4. The particle size of the silver halide determines the speed of the film. The finer the particles of the film, the slower the speed of the film. Comparatively, resolutions are lower in faster films than slow films although fast films reduce time of exposure. For this reason, unless otherwise required, there is preference for medium speed films with medium contrast and speed (Zirnhelt et al., 2003).

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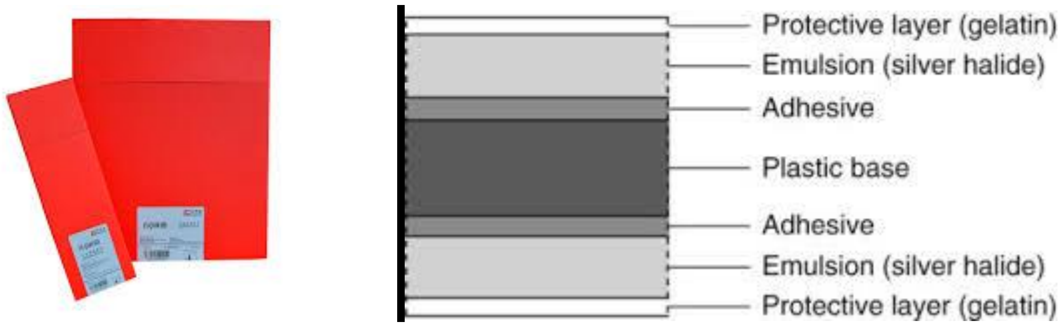


Fig 2.4: Films and image receptor

The film is used energies exceeding 120 kV in combination with lead foils known as intensifying screens. The use of the screens improve film density hence reducing the time of exposure. They also stop the spread of radiations with long wavelengths from getting in touch with the film. Dispersion of the radiations lowers the contrast

Fengqi (2005) emphasizes the point that the unique method of computer aided film digitalization or image processing must be used to evaluate corrosion and deposit more accurately and effectively. The film processing system uses high-resolution camera, radiographic illuminator and a computer with a unique software.

2.1.5. Optical density

A significant characteristic a quality radiographic film is its density (D). It is computed by the formula:

$$D = \log_{10}\frac{I_O}{I_t} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.6)$$

Where

D = is the film density

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I_o = incident radiation intensity

I_t = transmitted radiation intensity

Due to accessibility, the branded films used by CRP respondents providing a nice comparison of image quality results of distinct kinds of films. This is per the IAEA technical report on corrosion and deposit evaluation was directed in 2005. It was not proven that fine grain films were always the ideal choice for residual wall thickness measurement although they provided excellent resolution and definition. It further established the fact that better evaluation of inner diameter (ID) of the pipe wall extremities, higher density film up to 4 (in the center of the pipe) was needed (Agency, 2005).

According to Ekinci et al (2005) review on his report, he sta3ted that a film density of approximately two (2) was sufficient to disclose the discontinuities, but greater densities up to four (4) were needed for a definite definition of the inner diameter extremity. The source-to-film distance was chosen to reduce penumbra and thus enhance the definition (Ekinci, et al., 2005).

2.1.6 Quality of radiographs

These three (3) parameters characterize radiographic image:

- The optical density
- the contrast
- the resolution

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The optical density of a specific object is determined by the time of exposure and the speed of the film. The object, radiation and film characteristics regulate the contrast to a film. Film image resolution is primarily affected by film's quality and geometric unsharpness (Agency, 2005). A combined effect of these parameters determines overall if the picture from the film can reveal expected discontinuities. An image quality indicator is used to verify its capacity.

2.1.7 Image quality indicator (IQI)

An IQI serves to check the radiographic quality and the method employed during exposure. An IQI is properly placed on a test material, followed by taking the exposure. IQI varieties are suggested according to distinct norms and are used in industrial radiography (Zirnhelt et al., 2003). The most frequently used penetrameters are:

- ASTM and AFNOR (different designs) are plates with holes
- DIN, ISO and GOST (Russian) are the wire types
- BIS (Indian) is the step type with hole
- The extra unit called a contrast meter is used by the Japanese norms JIS.

2.2. Pipe Tangential Radiography (TRT)

TRT is an excellent method for evaluating corroded pipes' residual wall thickness and evaluating deposit size. In this method, the longitudinal section of the pipe is projected onto a film with a profile view of the pipe wall. This allows direct assessment of the pipe wall thickness. In the evaluation, the central portion of the image formed is overlooked. In order to obtain the correct image at a tangentially, a higher energy than that of the energy

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used in DWT is required (Rastkhah, et al., 2004). Higher energies of gamma radiation is needed due to the setup of TRT which leads to accumulated material thickness for the penetrating rays. Creation of proper geometric relationships must be made between the specimen, the source and the film for to correct interpretation the radiographic image (Agency, 2005).

This method's most significant application is the absolute measurement of the pipe's wall thickness. This is because the wall thickness is seen almost like a longitudinal segment of the pipe in the tangential radiography profile. Correlation must be done cautiously to ensure that only the pipe wall parts lying tangentially are taken into consideration (Zscherpel, Bellon, & Nimtz, 1998). Minor rotation will result in a distinct image segment. The source of radiation commonly used in tangential radiography is Iridium-192 radioisotope for pipes with diameter less than 250 mm. The Co-60 radioisotope is predominantly used for thicker pipes or outer diameter (OD) pipes higher than 250 mm. Because of their soft energies, tangential radiography technique is not habitually done with X-rays or Se-75. The tangential image necessitates harder gamma radiation since the tangential radiography technique setup results in higher material density to be penetrated by the rays (Zscherpel, Onel, & Ewert, 2000).

Discussions from the IAEA technical report (2005), suggested that even though tangential radiography requires films that are slow and have low contrast, it generally generate films with higher contrast, and the advantages obtained from grains may be lost in the inaccuracy of the image's border markings. Medium-sized grain films that are not used in weld radiography are the recommended films in TRT when pipes are thickly insulated and the time of exposure is short. This is due to that fact that TRT is not a highly sensitive method

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in any situation. It has been discovered that the accuracy in the assessment wall thickness does not correlate with the highest IQI sensitivity (Agency, 2005).

Lee and Kim (2005), said that tangential pipe region needs much more time of exposure compared to film density-thickness relation technique. They further expounded on the fact that TRT can be explored for pipes with less than 300 mm outer diameter and in the quantitative thickness assessment using film density variation, gamma-ray is a better source of radiation compared to X-ray. The experimental results obtained in their work according to the suggested film density ratio was from 1.0 to 3.5(Lee & Kim, 2005).

Tennakoon (2005), concluded in his report that tangential radiography technique can be used with a fair degree of accuracy to assess the remaining wall thickness of insulated and non-insulated pipes. For corrected thickness measurement, an average value must be recorded of various wall shadow thicknesses. The technique can also be used to measure deposits in straight pipelines (Tennakoom, 2005).

Harara (2005), compared the measurement of results acquired on the same test pipe through TRT, ultrasonic and other destructive tests and had the same findings. These findings verified with high accuracy shows that the TRT is useful in assessing the present state of insulated and non-insulated pipes (Harara W. , 2005). The potential for this radiographic technique could lead to faster inspection time per pipe and shorter maintenance time for chemical and energy plants.

J. Munoz et al commented in their report that the findings of tangential radiography offer a slightly greater value than the actual thicknesses (measured using other methods). The accuracy is lower when the true wall is near to the critical thickness of the wall. The report

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further revealed that tangential radiography gives better accuracy than the double wall method and they complement each other. The findings acquired differed in the range of 3 – 8% from the actual wall thickness (Munoz & M.Vargas, 2005).

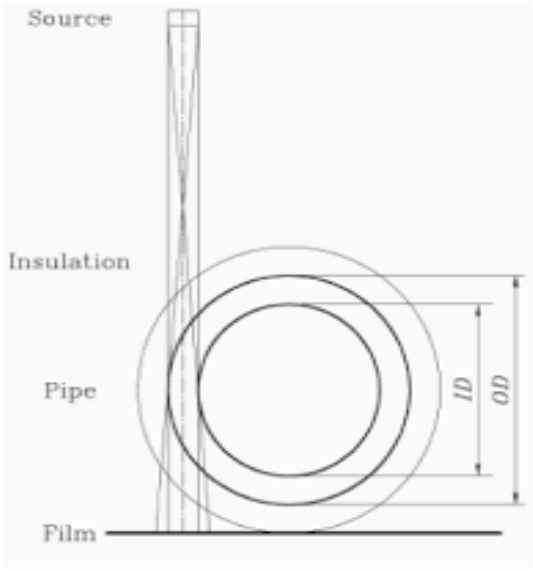


Fig 2.5: Tangential radiography setup

2.2.1. Tangential Radiography Technique and Evaluation of Wall Thickness

The use of NDT in assessing the residual wall thickness remains pivotal in chemical plants structural integrity. Although ultrasonic testing has generally been used for these assessments, it is not cost effective for insulated pipelines. This is because the insulators (which are very expensive) will have to be removed before this technique can be used. Also, it is subjected to inspection of small sample areas. This makes it difficult in detecting metal losses in small localized areas. The use of RT has helped overcome these challenges (Lee & Kim, 2005).

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TRT is a preferred method for evaluating corrosion and deposits in pipelines. Tangential radiography (or radiographic profile) offers a full and accurate image of the thickness and discontinuities of the metal pipe. This technique uses x-rays or gamma rays at a tangential angle to the edge of the pipe through the insulation. The set-up for a pipe radiographed by tangential technique is illustrated in fig 2.5 and fig 2.6. The figure demonstrates the appearance of two walls with various kinds of corrosion. After the application of the gamma radiation, the development of the resulting film is done in a darkroom shoot is applied and the film developed in the darkroom. Fig 2.7 shows a developed film. It is necessary to interpret the imaged formed and evaluate the pipe thickness (IAEA, 1999).

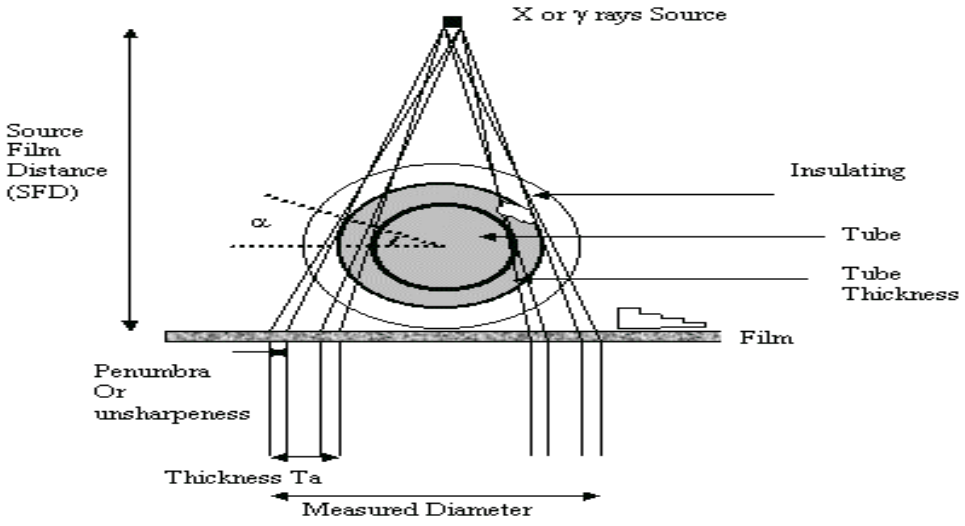


Fig.2.6 Tangential radiography set-up for pipe inspection

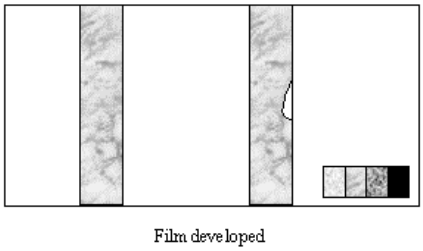


Fig 2.7: Developed film.

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Drai et al (2005) investigated three pipes within the range of 200 mm – 400 mm OD from France with the remaining measured wall thickness being accurate and all discontinuities detected. Default sizing was provided with a maximum 2 mm deviation. With a maximum deviation of 5 mm and 1.5 mm, the three pipes from Syria and Turkey were assessed respectively (Dria, Benchaala, Zergoroug, & Badidi Bouda, 2005). This provided an avenue for inter-comparison and also confirmation of results from all the NDT laboratories.

2.2.2. Source-to-Film Distance Determination

The gamma radiation is positioned away from the test pipe to ensure the projection the two walls of the pipe onto the film. The penumbra or unsharpness appears on the film as a results of the finite dimension of the radiation source used. The geometric unsharpness (Ug) value is determined by the equation below:

$$U_g = \frac{s(0.5OD+d)}{SFD-(0.5OD+d)} \quad \ldots \ldots (2.7)$$

Where:

- SFD represents source-to-film distance
- Ug represents geometric unsharpeness
- OD represents outside diameter of tube
- d represents thickness of the insulator
- s represents source size

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The formula demonstrates that the relationship between SFD and Ug is inversely proportional. A fairly lengthy source-to-film distance is needed to reduce the fuzzy impact. Experience has shown that the optimal SFD is the source size of 8 – 10 pipe outer diameters (Onel, Ewert, & Willems, 2000).

2.2.3. Radiation Exposure Angle Determination (α)

By altering the source-to-film distance, the operator can arrange the position of the pipe to reveal potential discontinuities onto the film with optimal contrast and resolution parameters. The exposure angle α of radiation is expressed in the equation:

$$\alpha = \frac{\cos^{-1}(0.5OD)}{SFD - 0.5OD} \quad \text{(2.8)}$$

This α is a function of SFD and OD of the pipe.

2.2.4. Real Pipe Thickness Evaluation by Geometry

The measured pipe wall thickness on the radiograph(w') in the equation below is not precisely the true thickness of the pipe wall (w) because of the fuzzy impact. Precise assessment of the true thickness of the walls of the pipe is essential to assessing the residual thickness of the pipe. Thus, evaluating the rate of corrosion or deposits (Agency, 2005). Relationship between w' and w is expressed as:

$$\mathrm{w} = \frac{(\mathrm{f}-\mathrm{R})}{\mathrm{f}} . w' \quad \text{(2.9)}$$

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Where

w' represents measured wall thickness of pipe from film

w represents the true wall thickness of the pipe

f represents the source-to-film distance

R represents the radius of the pipe

When the SFD is comparatively short, the distinction between w' and w (magnification correction) is important. In order to obtain high accuracy, this correction must be taken into consideration. The issues experienced that influence the accurate assessment of the true thickness of the pipe wall are as follow:

- Geometric projection impact; the film is placed on the pipe and not flattened.
- The edges of the pipe gives fuzzy effect.
- Experience of operators affect the boundaries on the pipe edges

2.2.5. Maximum thickness transmitted

The gamma radiations penetrate various thicknesses of the pipe projection during TRT inspection of the pipe. The minimum thickness of the transmitted pipe is zero, which occurs at tangential points of the pipe. The inside diameter of the pipe is the highest transmitted thickness. This important difference in transmitted thickness results in film exposure high differences. Because the thinnest portion causes an image to be too dark (burn-off) and the

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thickest portion causes an image to be too bright, it is very important to select the optimal energy source and exposure parameters (Lee & Kim, 1999).

Depending on their energy, gamma rays penetrate distinct metallic thicknesses. Table 2.2 provides typical transmitted ultimate thickness values for various sources of X-ray and gamma rays. This table helps to select an appropriate source of gamma rays for optimum inspection of the pipe wall.

Table 2.2: Maximum Transmitted Thickness.

<table>
<tr><td>Pipe OD, mm</td><td>25</td><td>50</td><td>75</td><td>114</td><td>159</td><td>219</td><td>426</td><td>630</td></tr>
<tr><td>Pipe wall thickness, ( ) mm</td><td>4</td><td>4</td><td>6</td><td>10</td><td>14</td><td>20</td><td>14</td><td>20</td></tr>
<tr><td>Max. Transmitted thickness, mm</td><td>16</td><td>28</td><td>40</td><td>62</td><td>90</td><td>126</td><td>150</td><td>270</td></tr>
<tr><td>Applicable Radiation Source</td><td colspan="5">X-ray</td><td colspan="3"></td></tr>
<tr><td></td><td colspan="6">Se-75 Ir-192</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4">Co-60</td></tr>
<tr><td></td><td colspan="4"></td><td colspan="4">Linear Accelerator</td></tr>
</table>

Fig 2.4 shows the theoretical intensity curve versus pipe cross section. The figure shows a typical line plot across the tube diameter in TRT of the optical density. Inflection points a and b can be measured as actual thickness of the pipe wall.

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Fig 2.8: A plotted line displaying optical density across the diameter of the pipes in tangential radiography.

Measurement of the true wall thickness of the pipe can be computed between point a and b.

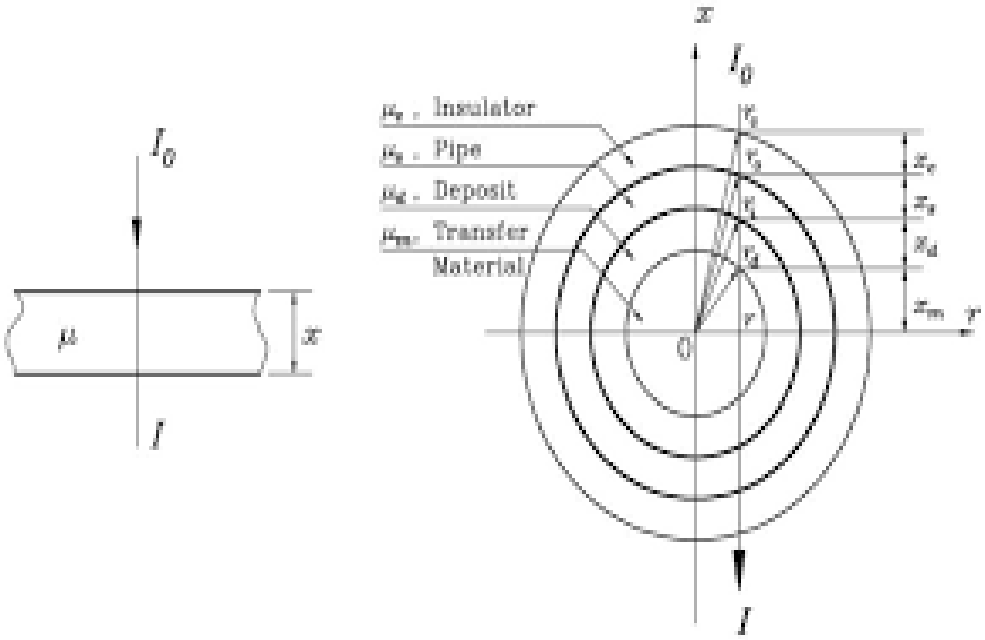


Fig 2.9: A diagram showing attenuation coefficients for different layers in an insulated pipe having internal deposits.

Higher energy radiation selection enables the reduction in contrast. Higher contrast would stretch the low-density area within the pipe diameter corresponding to the wall, which makes it challenging to determine the wall thickness. (Boateng, Danso, & Dagadu, 2013)

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research stated that "lower radiographic contrast that are obtained at higher radiation energy has better linearity". In sections of pipelines with high probability of corrosion occurrence, the remaining wall thickness can be assessed using TRT. This method can also be employed to detect deposits as well as corrosion inside the pipe. The maximum transmitted thickness the gamma ray passes through the pipe at any given point is shown in the equation below.

$$L_{max} = 2w\sqrt{\frac{D_a}{w-1}} \quad \ldots \quad (2.10)$$

Where

L_{max} = the maximum transmitted thickness.

D_a = the pipe's outer diameter.

w = the pipe's thickness

In Fig 2.8, the theoretical intensity curve versus pipe cross section describes a typical line plot across the pipe diameter in TRT of the optical density. The actual pipe wall thickness is assessed using the points of inflection between a and b. If radiation beam is passed through an insulated pipe with deposit, the formula of penetrated radiation intensity (I) is, as follows:

$$I = I_0 e^{-2(\mu_c X_c + \mu_s X_s + \mu_d X_d + \mu_m X_m)} \quad \ldots \quad (2.11)$$

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Where:

X_c, X_s, X_d and X_m are the thickness traversed in the insulation, steel, deposit and material being transported respectively. μ_c, μ_s, μ_d and μ_m are the attenuation coefficients of the insulator, steel, deposit and transported matter respectively.

Using geometry principles in tangential radiography setup, the thickness traversed in every layer can be calculated with respect to a certain coordinate (r):

- Penetrated insulation thickness: $2X_C$

Where $X_C = \sqrt{r_C^2 - r^2} - X_S - X_d - X_m$ …. …. … … …. … …. …. …. …. (2.12)

- Penetrated steel thickness: $2X_S$

Where $X_S = \sqrt{r_O^2 - r^2} - X_d - X_m$ … … …. …. …. …. …. …. …. …. …. …. …. (2.13)

- Penetrated deposit thickness: $2X_d$

Where $X_C = \sqrt{r_i^2 - r^2} - X_m$ … … … … … … … … … … … … … … … … … … (2.14)

- Penetrated material thickness: $2X_m$

Where $X_m = \sqrt{r_d^2 - r^2}$ … …. …. …. …. …. …. … … …. …. …. …. … … … (2.15)

r_c = insulation radius

r_i= inner diameter radius

r_d= deposit radius

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Using the general equation of transmitted radiation intensity, the specific formula for different types of piping can be derived as follows:

For uninsulated empty pipe (X_C=0, X_d=0, X_m=0)

$$I = I_O e^{-2\mu_s X_s} \quad \ldots\ldots (2.16)$$

For insulated empty pipe (X_d=0, X_m=0)

$$I = I_O e^{-2(\mu_c X_c + \mu_s X_s)} \quad \ldots\ldots (2.17)$$

For insulated empty pipe with deposit (X_m=0)

$$I = I_O e^{-2(\mu_c X_c + \mu_s X_s + \mu_d X_d)} \quad \ldots\ldots (2.18)$$

The limits of TRT are based on maximum penetrable pipe wall thickness (L_{max}) depending on the energy of the radiation. L_{max} can be used to determine the maximum thickness of the pipe wall at specified diameter.

2.3.0. Double Wall Technique (DWT)

This method is appropriate for bigger pipes where TRT is not relevant. The radiation source is maintained perpendicularly to the axis of the pipe. Usually, two exposures are done by rotating the pipe 90 degrees after the first exposure.

Kulkarni et al (2005) in their report mentioned that, the double wall radiographic technique is effective when the insulating material's radiation absorption is less than the pipe's absorption. Density of lower wall area compared with that at different steps showed the total material thickness at the flaws location. Subtracting the single wall thickness from the

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thickness of the step block resulted in the pipe residual wall thickness at one side of the pipe (Kulkarni, Valdya, & Shah, 2005).

Ekinci et al (2005) in their attempt to validate the protocol for corrosion and deposit reported that density measurement is an alternative method for evaluating of residual wall, thickness of deposit and depth of pit. This is based on the measurement of sound and pitted areas of radiographic densities using graphs of density thickness. The material thickness influences the radiation that reaches the film. Discontinuities or thinning of material wall enables the passage of more radiation and thus creates regions of greater density on the film. They further revealed in their report that the density-thickness curve can be determined through presentation of the step block with the material similar to the pipe, covering the thickness ranging up to twice the pipe wall, and lastly correlation of each step's thickness. They concluded that DWT gave the average readings of the pipe wall thickness without the estimations of minimum and maximum thicknesses. They stated that tangential and double wall measurement techniques are very effective for the evaluation of remaining wall thickness, depth of pits and deposits and can be regarded complementary for each other.

The contrast between the internal diameters of the pipe wall extremities will be lower in the operating pipelines because of the distinction in densities between the pipe and the liquid within the pipe is lower compared to the empty pipe. Deposit determination in the operating pipelines is also hard due to the very marginal difference in density between the deposit and the fluid (Ekinci, et al., 2005).

Hamzah et al (2005) in their report investigated the film density and thickness correlation method and estimated the accuracy of the assessment as a results of the marginal change

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in thickness. In the concluding remarks, they stated that the thickness and density relationship technique should be investigated to study the reliability of the assessment owing to insignificant thickness changes (Hamzah, Muhammed, & Sayati, 2005).

2.4 Corrosion and some types

Corrosion is the deterioration of a material by reaction with its environment. The rate corrosion of pipelines is quantified as “mils per year” (abbreviated as mpy). The severe impacts corrosion remains a global challenge. Some of these impacts lead to shutdown of plant, waste of valuable resources, costly maintenance, safety concerns and inhibition of technological progress (Roberge & Pierre, 1999)(Baxter, Hastings, Law, & Glass, 2008) . In April, 1992 a sewer explosion in Guadalajara, Mexico claiming the lives over 200 people (Up Front, 1992). Aside the fatalities recorded, these blasts led to the damage of over 1600 buildings, injuring 1500 people in the process. Upon investigations, the explosion was traced to the installation of a water pipe by a contractor several years before the explosion that leaked water on a gasoline line lying underneath. Corrosion of the pipeline subsequently resulted in gasoline leaking into the sewers.

By estimation, about 20% of losses due to corrosion could have been avoided by the application of existing knowledge in corrosion prevention. These losses have also increased the demand for applied research, education, information, transfer of knowledge and technology, and technical development on the subject matter of corrosion.

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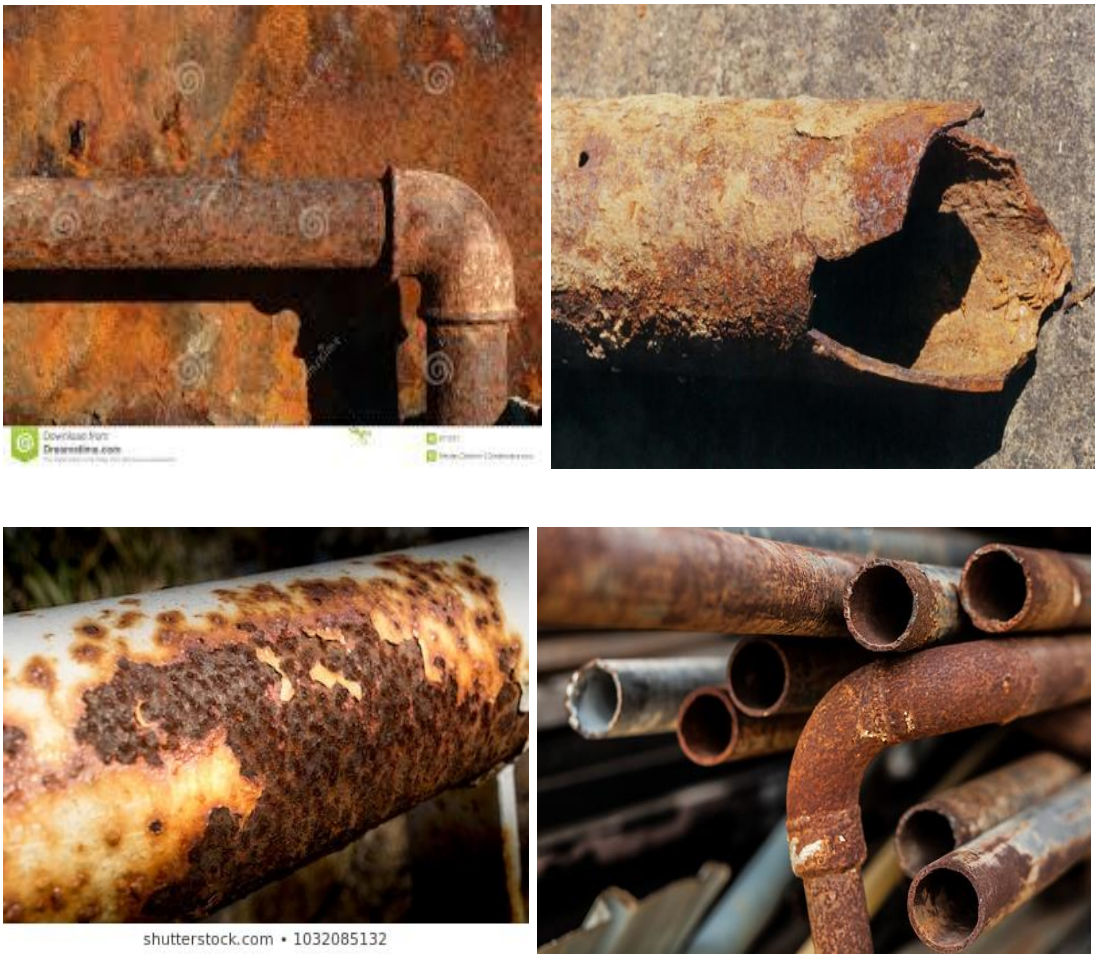


Fig 2.10: Corroded pipes

2.4.1 Crevice Corrosion

This is type of corrosion attacks the crevices of materials. The crevice must be wide enough for liquid to penetrate into it, but as a consequence of the mechanism, it must also be narrow; a condition for the corrosion to start is that the liquid in the crevice is depleted of oxygen. The mechanism is shown in fig 2.11. This implies that liquids in the crevices are stagnant and the diffusion of oxygen into these crevices are slower than the usage of oxygen in these places (Baxter et al., 2008).

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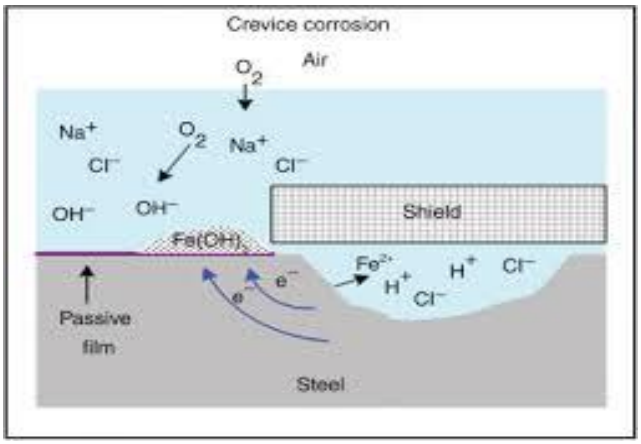


Fig 2.11: Illustration of the mechanism of crevice corrosion

2.4.1. Pitting Corrosion

Pitting corrosion or pitting is a type of extremely localized corrosion that leads to the creation of small holes in metals as illustrated in fig 2.12. The driving force of pitting corrosion is the depassivation of small area, which becomes anodic while an unknown but potentially vast area becomes cathodic; leading to very localized galvanic corrosion (Baxter et al., 2008). This form of corrosion occurs on more or less passivated metals and alloys in corrosive media containing chloride, bromide, iodide or perchlorate ions. The type of material, temperature, concentrations of aggressive species and pH are factors that affect pitting potential. Pitting is characterized by pits with a radius of the identical order of magnitude or less than the pit depth. These pits may vary in shapes. Deep pits may develop without being detected, because they are usually narrow and often covered by corrosion products (Kuhlmann, 2000)(Roberge & Pierre, 1999). The quantity and size of pits on a specified material can vary considerably between different materials and on a given material from one area to another.

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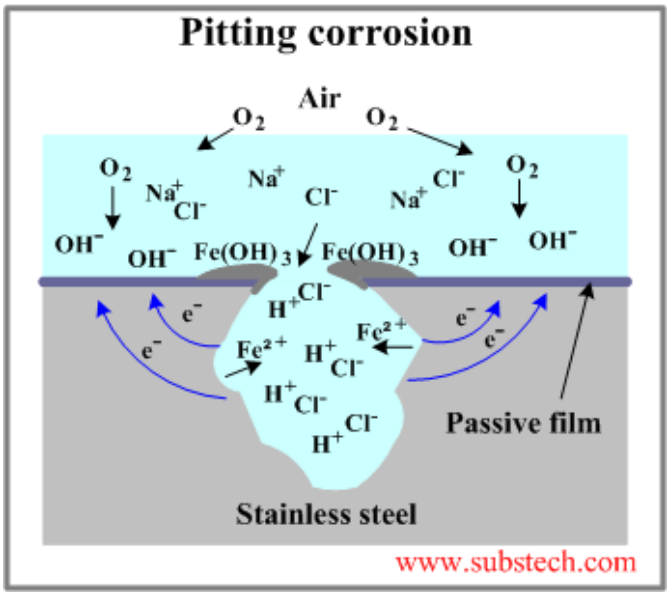


Fig 2.12: Illustration of the mechanism of pitting corrosion

2.4.2. Erosion Corrosion

Erosion corrosion arises from the combined action of chemical attack and mechanical abrasion or wear as a consequence of fluid motion. Virtually all metal alloys, to one degree or another, are susceptible to erosion and or corrosion. This is especially harmful to alloys that passivate by forming a protective surface film; the abrasive action may erode away the film, leaving exposed a bare metal surface. If the coating is not capable of continuously and rapidly reforming as a protective barrier, corrosion may be severe as seen in fig 2.13. Relatively soft metals such as copper and lead are also sensitive to this form of attack. Usually it can be identified by surface grooves and waves having contours that are characteristic of the flow of the fluid (Bardal, n.d.) (La & Fig, n.d.)

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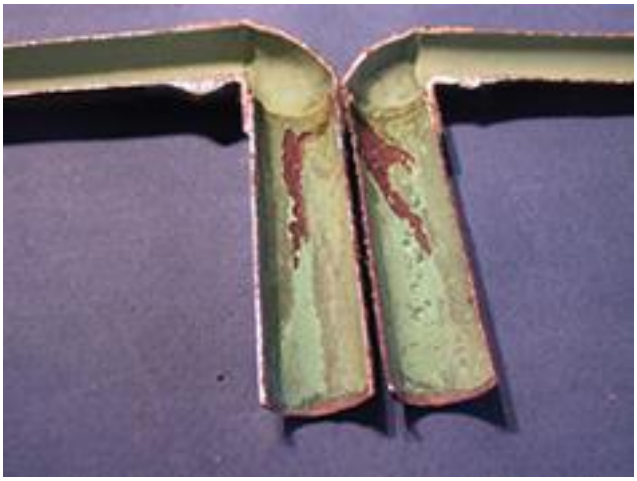


Fig 2.13: A pipe undergoing erosion corrosion

The nature of the fluid can have a dramatic influence on the corrosion behavior. Increasing fluid velocity normally enhances the rate of corrosion. Also, a solution is more erosive when bubbles and suspended particulate solids are present. Erosion and or corrosion is commonly found in piping, especially at bends, elbows, and abrupt changes in pipe diameter positions where the fluid changes direction or flow suddenly becomes turbulent. Propellers, turbine blades, valves, and pumps are also susceptible to this form of corrosion (Callister & Wiley, n.d.). One of the best ways to reduce erosion and or corrosion is to change the design to eliminate fluid turbulence and impingement effects. Other materials may also be utilized that inherently resist erosion. Furthermore, removal of particulates and bubbles from the solution will lessen its ability to erode.

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CHAPTER THREE (3)

3.0 MATERIALS AND METHODOLOGY

3. 1. Introduction

This chapter gives a description of the materials and methods used for this research work and the procedure used to take measurements from the radiographs. Experimentation for this study took place at the Ghana Atomic Energy Commission (GAEC) Non-destructive testing laboratory located at Kwabenya in Accra.

3.2. Preparation of Test Blocks

Mild steel pipes with diameter greater than 150.00mm were used as test pipes. These steel pipes were obtained from factory process industries.



Fig 3.1: Used mild steel pipes to be fabricated.

Fabrications of the test pipes were done in accordance with the drawings developed during the first Coordinated Research Project meeting (CRP) on the validation of protocols for

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corrosion and deposit evaluation in large diameter pipes by radiography which was implemented from 2002.

Type and size of defects considered were as follows:

- Step pipes with holes (pits) inside and outside - one pipe specimen with machined steps inside and other pipe specimen with machined steps outside. "t" is the pipe wall thickness before introducing steps or any discontinuity.
- Each step chosen to range from 0 to 0.7 t in steps of 10% wall thickness; precision in wall thickness shall be ± 0.1 mm.
- Diameter of hole equal to remaining wall thickness, minimum of 3.00 mm.
- Depths of holes ranging from 0.50 mm to 3.00 mm spaced at different circumferential positions; holes were to be flat bottom.
- Where steps were located on the inside surface of the pipe, material was to be removed by grinding or machining to a depth of 15% of maximum wall thickness of the pipe, forming a flat surface. Length covering all the steps. Precision was to be ± 1% (Agency, 2005).

3.3. Test Parameters

3.3.1. Outside Step (OS)

- OS1: Outside step with remaining wall thickness t1 corresponding to removal of approximately 10% wall thickness, t1 = w – s, s = 0.1 * w, rounded to nearest half mm.

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- OS2: Outside step with remaining wall thickness t2 corresponding to removal of approximately 20% wall thickness, t2 = w – 2 * s, s = 0.1 * w, rounded to nearest half mm.
- OS3 to OS7 defined in a similar way (OSi: Outside step with remaining wall thickness ti, ti = w – i * s) (Agency, 2005).

3.3.2. Inside Step (IS)

- IS1: Inside step with remaining wall thickness t_1 corresponding to removal of approximately 10% wall thickness t_1 = w – s, s = 0.1* w, rounded to nearest half mm.
- IS2: Inside step with remaining wall thickness t_2 corresponding to removal of approximately 20% wall thickness, t_2 = w – 2 * s, s = 0.1 * w, rounded to nearest half mm.
- IS3 to IS6 defined in a similar way (ISi: Inside step with remaining wall thickness t_i = w – i * s) (Agency, 2005).

3.3.3 OH: outside hole (Minimum hole diameter 2 mm)

- OH 1: Outside hole on OS1, with diameter = t1, t1= w – s, s = 0.1 * w, rounded to the nearest half mm
- OH2: Outside hole on OS2, with diameter = t2, t2 = w – 2 * s
- OH3 to OH7 defined in a similar way (OHi: Outside hole with diameter = ti, ti = w – i * s),

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For each, three different series are defined corresponding to 10%, 20% and 50%, identified as follows:

- H1-10: Outside hole on OS1, with diameter = t1 depth = 0.10 * t1
- OH1-20: Outside hole on OS1, with diameter = t1 depth = 0.20 * t1
- OH1-50: Outside hole on OS1, with diameter = t1 depth = 0.50 * t1
- OHi-10: Outside hole on OSi, with diameter = ti depth = 0.10 * ti
- OHi-20: Outside hole on OSi, with diameter = ti depth = 0.20 * ti
- OHi-50: Outside hole on OSi, with diameter = ti depth = 0.50 * ti

3.3.4. IH: inside hole (Minimum hole diameter 2 mm)

- IH1: Inside hole on IS1, with diameter = t1, t1 = w – s, s = 0.1 * w, rounded to nearest half mm
- IH2: Inside hole on IS2, with diameter = t2, t2 = w – 2 * s
- IH3 to IH 7 defined in a similar way (IHi: Inside hole with diameter = ti, where ti = w – i * s)

For each step, three different series of holes are defined corresponding to 10%, 20% and 50%, identified as follows:

- IH1-10: Inside hole on IS1, with diameter = t1 depth = 0.10 * t1
- IH1-20: Inside hole on IS1, with diameter = t1 depth = 0.20 * t1
- IH1-50: Inside hole on IS1, with diameter = t1 depth = 0.50 * t1
- IHi-10: Inside hole on OSi, with diameter = ti depth = 0.10 * ti
- IHi-20: Inside hole on OSi, with diameter = ti depth = 0.20 * ti

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- IHi-50: Inside hole on OSi, with diameter = ti depth = 0.50 * ti

3.3.5 Flat Area (FA)

The flat area is located on the outer surface covering the length where steps were introduced on the inside surface (Agency, 2005). Material removal to 15% w.

3.3.6. Ground Patch (GP)

The ground patch is located on the inside surface covering the length where steps were introduced on the outside surface (Agency, 2005). Material removal to 15% w.

3.4 MANDATORY AREAS OF INTEREST

The following areas of inspection were considered to be mandatory parts of the test procedure

Double Wall Technique (DWT) (with and without insulation)

- Flat area in the center
- Ground patch in the center
- Series 10% holes in the center
- Series 20% holes in the center
- Series 50% holes in the center

Tangential Method (TRT) (with or without insulation)

- Classical undisturbed method

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- Flat area outside adjusted (max 15% wt)
- Ground patch inside tangential adjusted (max 15% wt)
- Series 10% holes outside adjusted
- Series 20% holes outside adjusted
- Series 50% holes outside adjusted

The test pipes were carefully fabricated at the mechanical workshop of the Ghana Atomic Energy Commission (GAEC) on both the internal and external surfaces of the pipe, with wear between 1000 μm to 1300 μm (39.4 mil – 51.2 mil) to depict corrosion. In some segments, the pit penetration levels were ranging between 0.50 mm to 3.00 mm with diameters starting from 3.00 mm to 7.00 mm. These were created by the use drill bits during the machining process.



Fig 3.2. Front view of pipe piece fabrication using the lathe machine

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Fig 3.3. Side view of pipe piece fabrication using the lathe machine.

From the Coordinated Research Project drawings, the parameters of the test blocks fabricated for this research work are shown in the tables below.

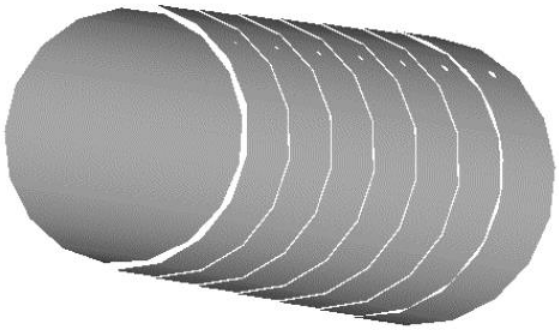
Table 3.1: Parameters of Interiorly Fabricated (machined) Pipe.

INTERIOR MACHINED PIPE LENGTH OF PIPE = 302.00 mm						
Step	Step Block Thickness (mm)	Pits (Drill) Diameter (mm)	Pits Depth (mm)	Outer Diameter (mm)	Inner Diameter (mm)	Step Block Length (mm)
Step 1	4.50	3.00	0.50	163.00	154.00	49.00
Step 2	6.40	3.20	0.80	163.00	150.20	49.00
Step 3	7.50	4.00	1.20	163.00	148.00	49.00
Step 4	8.50	4.50	1.60	163.00	146.00	49.00
Step 5	9.40	5.00	2.00	163.00	144.20	49.00
Step 6	10.50	6.00	2.50	163.00	142.00	57.00

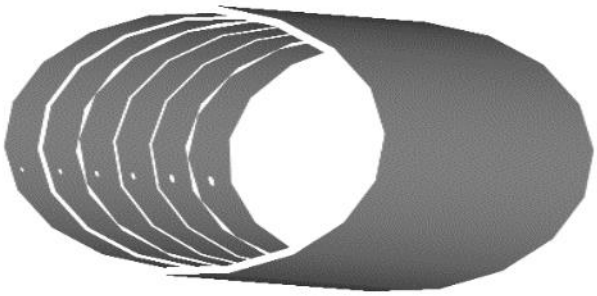
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Table 3.2: Parameters of Exteriorly Fabricated (machined) Pipe. EXTERIOR

MACHINED PIPE LENGTH OF PIPE = 400.00 mm						
Step	Step Block Thickness (mm)	Pits (Drill) Diameter (mm)	Pits Depth (mm)	Outer Diameter (mm)	Inner Diameter (mm)	Step Block Length (mm)
Step 1	4.00	3.00	0.50	164.60	156.60	55.00
Step 2	5.05	3.20	0.80	166.70	156.60	55.00
Step 3	6.25	4.00	1.20	169.10	156.60	55.00
Step 4	7.30	4.50	1.60	171.20	156.60	55.00
Step 5	8.40	5.00	2.00	173.40	156.60	55.00
Step 6	9.45	6.00	2.50	175.50	156.60	55.00
Step 7	10.60	7.00	3.00	177.80	156.60	70.00



PICTORIAL VIEW OF EXTERIOR MACHINED PIPE



PICTORIAL VIEW OF INTERIOR MACHINED PIPE

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Fig 3.4. Pictorial view of both externally and internally machined pipe.



Fig 3.5. Internally fabricated pipe.

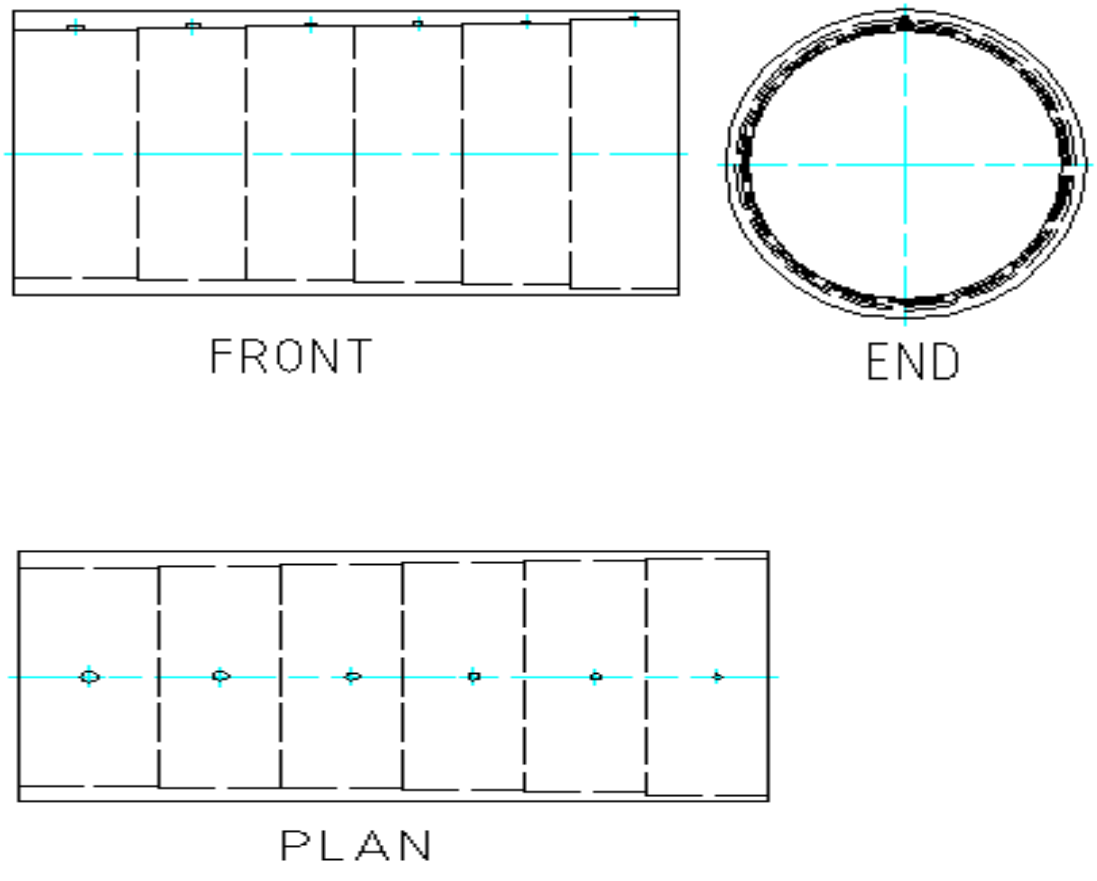


Fig 3.6. Orthographic views of the internally machined pipe.

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Fig 3.7. Externally fabricated pipe.

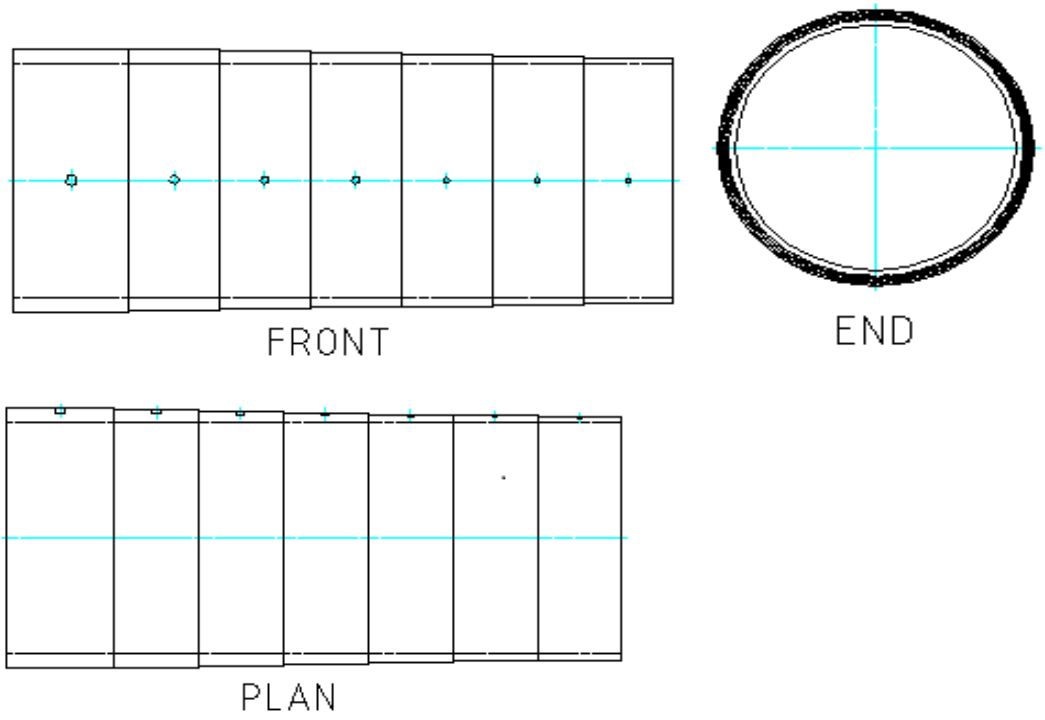


Fig 3.8. Orthographic views of the externally machined pipe.

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3.4.1. Insulation and Deposit Material

The deposit material used in this project is moist sand. This was prepared from sand mixed with water in the internal diameter of the pipe. This is to simulate the deposit left in pipes when the pipe is operational. The thickness of the deposit cast in the test pipe ranged from 10.00mm to 45.00mm in a non-uniform manner.



Fig 3.9: Moist sand in the exteriorly machined pipe.

The insulation material used in this work is a fiber wool and aluminum foil insulator, obtained from a petrochemical industry with approximately 20.00mm thickness. An insulator conserves the temperature and other thermodynamic properties of the media that is being transported. It also protected the pipe surface from environmental attack.

3.5 Radiographic method

3.5.1. Gamma-Ray Source (GAMMAVOLT – SU50)

- RADIOA K TIV
- Type B(U) D/DB-0009B

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- Weight 16kg/ U(depleted) 12.1kg
- Activity 185 GBq (5 Ci), Ir-192
- Film Structurix vacupa AGFA, with D4 Pb screen.

3.5.2. Tangential Technique

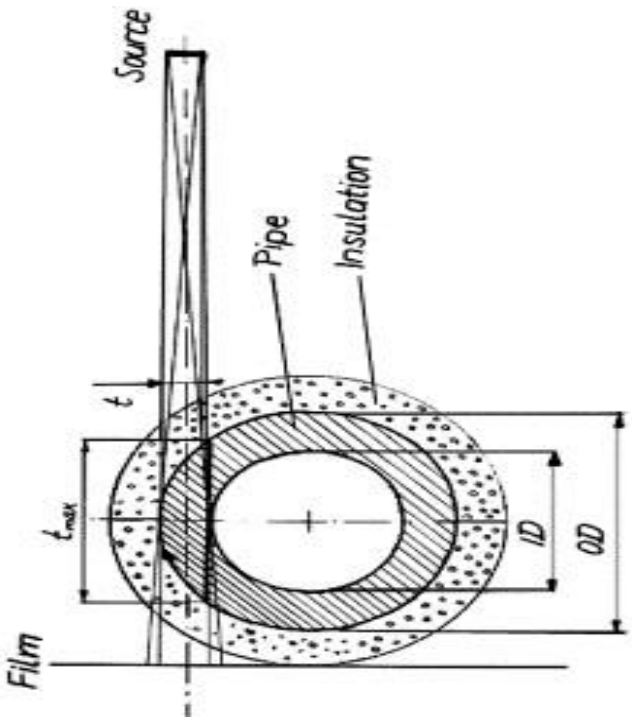


Fig 3.10 Test arrangements for Tangential Radiography (IAEA, 2005)

The TRT arrangement for the pipe is as shown in fig 3.10 above. The gamma radiation (Iridium 192) was placed tangentially to the pipe wall due to its large diameter. The gamma source was collimated to prevent backscatter and also focus the beam onto the target area. The activity of the source was 45 curies (Ci) during the period of the experiment. SFD of 150.00mm and 300.00mm were alternated both for insulated and non-insulated test pipe for the externally fabricated and 410.00 mm SFD was used in both the insulated and non-

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insulated test pipes for the interiorly fabricated pipe. The exposure times were 40 seconds for both insulated and non-insulated exteriorly fabricated pipe and 30 seconds for both insulated and non-insulated interiorly fabricated pipe. An angle of exposure of 70 and 77 degrees was used for exteriorly machined pipe and interiorly machined pipe respectively. This was derived by using equation 2.8. The film was placed circumferentially around the pipe. The projections of the residual wall thickness and the locations of the pits were obtained on the film by orientation of the source and pipe.

Measurements of the wall thickness for both sides of the pipe were recorded in single exposure using this method. Observations of corrosion and deposits was done by shading of the TRT between both sides. The radiation's tangential paths within the pipe walls were able to project the location of the edges and thickness of the pipe to be assessed. Deposits located at the base of the pipe, thinning occurring at the base of the pipe as well as other discontinuities related to corrosion and deposits were detected (Agency, 2005).

3.5.3. Double Wall Technique

In the DWT, the source was placed perpendicularly with respect to the pipe axis projecting the double wall of the pipe on the radiographic film. This is as illustrated in set-up for in the fig 2.1 above. In this technique, the steps fabricated on the pipe to depict erosion corrosion and the sizes of the included pits were seen on the film. A SFD of 300.00 mm was maintained for the insulated pipe as well as the non-insulated pipe during the exposures with exposure times of 20, 24 and 30 minutes. This exposure time was as a result of the activity (5 curies) of the source used for this experiment.

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The density transmission used in DWT setup was the classical density measurement radiography where the gamma rays penetrate through two walls of the pipe tube placed between source and film. The steps were kept on the side of the pipe to compare the density with the defect density. Nevertheless, this technique is effective for only pipes without insulation or with non-metallic thin layer of insulation having negligible radiation absorption.

3.6 Film Processing

After the radiographic exposure, the manual processing of the film began with the darkroom. The darkroom was sited at a reasonable distance from the exposure area. The exposure film was processed in the dark room with the purpose of making the latent image produced by the radiation becomes visible. Critical care was taken in processing the films since all the procedures that are involved in making a radiograph are important. Also, this was to eliminate processing errors that could have made an otherwise worthwhile radiograph useless. Although, there are five (5) different stages in film processing, each stage is dependent on the preceding stage to ensure that a well processed film is obtained.

3.6.1. Developing

This is the first stage in film processing. This process began the moment the exposed film was put into in the developer solution (mixture of hydroquinone, sodium carbonate and sodium sulfite). At this stage, silver halide grains in the film are converted to metallic silver. The radiation exposed portions of the grains developed more rapidly. The amount of silver

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halide that was converted is a function of time, chemical strength and temperature of the developer solution. The temperature of the developer solution was about 20^{o}C and the development time used was 5 minutes.

3.6.2. Stop Bath

This is the second stage of film processing. After developing the film in the developing solution, the film is placed in the stop bath. Its function was to halt the developing process as described in the first stage by diluting and removing the residual developer from the film with water. This helps prevent uneven development and film streaking. Also, it neutralized the developer's alkaline remnants, thereby enabling fixing stage function appropriately.

3.6.3. Fixing

This is the third stage in film processing. The fixer (a mildly acid solution) served to dissolve and remove the silver bromide from the unexposed portions of the film without upsetting the exposed portion. Also, it hardened the emulsion gelatine making warm air drying possible. When the film was initially placed in the fixer solution, the film became clouded. This was as a result of the dissolution of the silver bromide crystals, leaving behind the silver metal. The film cleared with time, although this was dependent on the strength of the fixer solution, (Atomic & Agency, 1992). The time taken for this process was 2 minutes.

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3.6.4. Washing

Washing is the fourth stage in film processing. This was done to remove the fixer from the emulsion. The film was immersed in running water to ensure that the entire emulsion surface was in contact with constantly changing water. This procedure insured that the last wash any film received was with fresh water.

3.6.5. Drying

Drying is the final stage in film processing. This was done after washing by hanging the film in a position where air circulated freely.

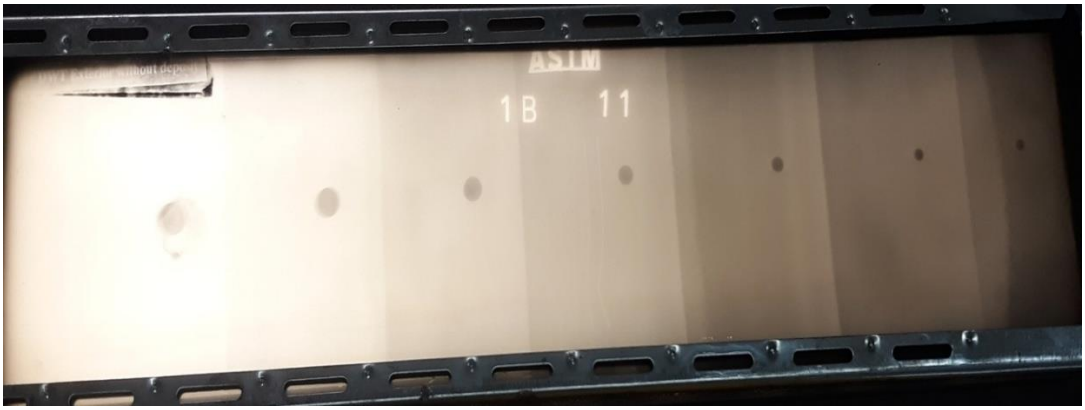


Fig 3.11: A processed film

3.7.0. Procedure for Evaluation

Steps used to evaluate both the TRT and DWT were based on the IAEA certified procedure.

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3.7.1. Tangential Radiographic Technique Evaluation

- The external and internal wall positions were located.
- Internal wall position was observed to obtain thickness in a direction perpendicular to the pipe axis. A visual enhancing aid (magnifying) was used.
- The procedure was repeated at least 5 times per step.
- Calculations were made to obtain the mean value, the standard deviation and standard error for the readings obtained (Agency, 2005).

3.7.2. Double Wall Technique Evaluation

- The films obtained from the double wall technique were examined
- Detection of corrosion and deposits were noticed in both insulated and non – insulated test pipes.

3.8.0. Density Readings of Radiograph

The densitometer used to read the transmission density of the gamma ray films was the Dandong Xinke Electrical Equipmnt CO., LTD XK - 800. The XK – 800 has the advantage of accurate reading, good stability and it is easy to operate. It has a density measuring range from 0D to 5D with accuracy within 0.05D over an area of 4.00 mm in diameter. The film was simply placed on the viewer (emulsion side up) and the probe on the film where the reading was required and the reading appeared on the 3 digit LCD screen. Error in the densitometer was checked to zero (with the aid of the viewer and the knob) to reduce

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systematic error (bias error), hence no correction factor were to be made on the densitometer readings.

The density readings were carried out by two different persons. This was to help deal with random error(s). Every area of interest was read at least six times. The areas of interest read from the radiograph were the depths and diameters of the pits and the densities of the step block (uniform corrosion)

For the tangential radiographic technique, the inner and the outer wall positions were identified and thickness obtained with theaid of a magnifying glass and their densities measured. With the double wall technique, the density at the center of each step block, drilled hole (pit) was recorded. The mean value, standard deviation and standard error were calculated for these measurements.



Fig 3.12: Densitometer

3.9.0. Data Verification and Validation

This referred to the mode of data rejection and acceptance of the density and thickness values measured on the radiograph. Lee and Kim (2005), in their work obtained good

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radiographic image with density values ranging from 1.00 - 3.50. The CRP protocol suggested that for steel pipe with diameter of 152.00 – 508.00 mm and wall thickness range of 2.00 – 30.00 mm using iridium source, the acceptable range of radiographic film density values should be in the range of 1.50 - 4.00 from which the image can be interpreted effectively. Films that were found to be too dark were rejected and poorly processed films were also discarded since they could influence the reliability of the obtained data.

3.10 Statistical Evaluation of Density Values

3.10.1. The Arithmetic Mean

Calculations were done to obtain the mean (X) values of the measured densities, pit depth and diameter. This was done to establish the measure of central tendency. Since this type of average is frequently used in physical applications. The sample space(n) for each reading is seven (6). The average values of the measured parameters were calculated from equation 3.1.

$$X = \frac{1}{n}\sum_{i=1}^{n} x_i \quad \text{..... 3.1}$$

3.10.2. The Standard Deviation

The Standard Deviation (s) is the measure of the dispersion of a frequency distribution that is the square root of the arithmetic mean of the squares of the deviation of each of the class frequencies from the arithmetic mean of the frequency distribution.

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$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - X)^2}{n}} \quad \text{..... (3.2)}$$

For normal distribution, confidence interval with a particular confidence level is intended to give the assurance that, if the statistical model is correct, then taken over all the data that might have been obtained, the procedure for constructing the interval would deliver a confidence interval that includes the true value of the parameter set by the confidence level.

3.10.3. The Standard Error (Uncertainty)

The standard deviation of sampling distribution in a statistical data is often its standard error (σ_x). This establishes the margin of error in the instrument readings with respect to the measured data.

$$\sigma_x = \frac{S}{\sqrt{n}} \quad \text{..... 3.3}$$

The relative percentage error for each sample distribution shows the percentage measure of error with respect to the mean density values.

$$R_{\%} = \frac{\sigma_x}{X} \times 100\% \quad \text{..... 3.4}$$

3.10.4. Error (Uncertainty) Estimation on Mean Density Values.

The measurement uncertainty was evaluated for the density readings taking into consideration each of the various sources of uncertainty in the readings. The standard error

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(σ_x) and the sensitivity coefficient (c_i) were evaluated for the density readings of each pit or step block. In this case the sensitivity coefficient ($c_i = 1$) of the densitometer is assumed to be unity. The combined standard uncertainty $U_C(E)$ was evaluated from the equation below.

$$U_C(E) = \sqrt{\sum_{i=1}^{n}(c_i * \sigma_x)^2} \quad \text{..... 3.5}$$

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CHAPTER FOUR (4)

4.0 RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses and interprets the relevance of the results obtained from the radiographic film readings of both interior and exterior machined pipes with or without insulation. The interpretation comprises the observations from double wall technique and results from tangential technique for each of pipe condition and their significance with respect to relevant published articles. The limitations of this experimental procedure are also stated.

4.2 Determination of Corrosion and Deposits using Industrial Radiographic testing (Double Wall Technique).

4.2.1 Determination of Corrosion

Corrosion in pipelines and flow lines has always been a major concern in the process industries (petroleum companies, mining companies, among others). This attack is predominantly characterized by the development of severely corroded regions parted with sharpen steps from surrounding areas with having less attacks.

Conveying fluids within piping systems can present flaws of internal corrosion, erosion, or combination of both. Depending on the severity and degree of the internal damage or deterioration, the pipe work may leak or be in threat of leaking. Therefore, it is very important that information regarding the ability of the sustained damage is obtained. This will help accommodate the axial stresses which, in complex pipe systems, can be

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significant.

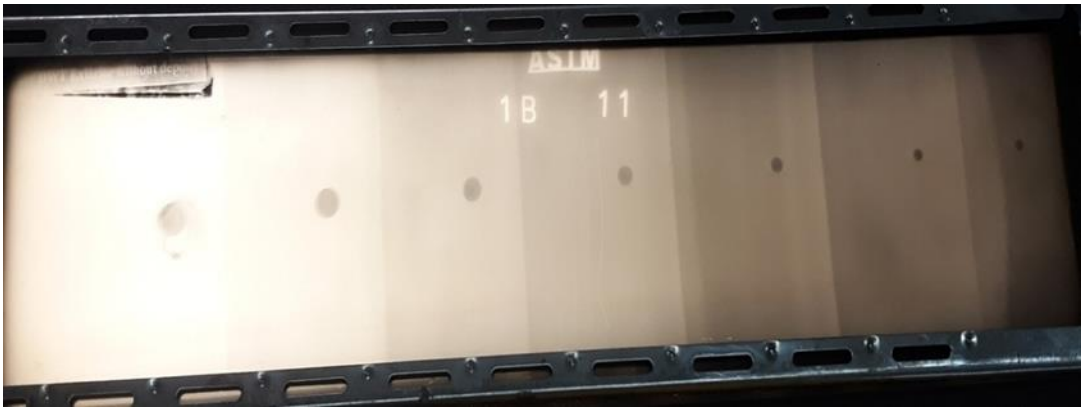


Fig 4.1: Radiograph showing all the seven corrosion indications.

As stated in the CRP, that industrial radiography testing is a method of NDT that is capable of detecting corrosion in pipelines with or without insulation (Agency, 2005). This knowledge was employed in this research to test and classify the corrosion that may be detected in the test pipe that was fabricated using the double wall technique. DWT was able to identify the degree (extent) of pit propagation.

The film generated was compared with a normal pipe piece that was not machined to serve as control. From the radiograph obtained, six (6) rounded indications and seven (7) indications rounded were revealed on the radiograph of the internally fabricated pipe and externally fabricated pipe respectively. Ranging between the least pipe thickness and the maximum thickness of the pipe. These represented corrosions and specifically pitting corrosion. This type of discontinuity poses severe hazard on the integrity of the pipe, because, usually they propagate vertically through the walls of the pipe and within a short period can exceed the critical wall thickness (maximum wall thickness loss). Because of the propensity of damage to the pipe, the precision and accuracy in reading the optical densities of these kinds of discontinuity can never be compromised.

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Also, the corrosion attacks along the pipe wall were detected and identified as uniform corrosion on each step block from the radiograph. The parts of the test pipe with extreme corrosion recorded the maximum readings whereas the slightest corroded part recorded the minimum readings. The nature of attack such as this is generally noticed with the unaided eyes and can rarely cause industrial accident. However, if it is left unattended for a period of time can lead to industrial chaos.

Both pitting corrosion and uniform corrosion were identified in the internally machined as well as externally machined. This comprehensively affirms the success rate of double wall method in industrial radiography.

4.2.2. Determination of Deposits

In the determination of deposits in the test pipes, the exposure time was extended. The extensions made in the exposure time was imperative as a result of the attenuation coefficient of the moist sand and the thickness of material (relaxation length). An elevation in the thickness of deposits is directly proportional to a decrease in the orifice of the transport media because of the impedance of the flow path of the pipe by the accumulated deposits; hence increasing the pressure of the flowing media. The rate of corrosion becomes aggravated as a results of uncontrolled flow pressure within the pipe system.

Industrial piping that predominantly rely on constant pressure habitually need to be inspect their pipelines to determine the rate of deposit accumulation. Hence, enabling them monitor pressure fluctuations. And also prevent deep pits that may develop without being detected due to them being narrow and often covered or sealed with deposits and corrosion products.

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This metal loss may be localized as in the case of corrosion underneath a pipe support

4.2.3. Determination of Corrosion and Deposits in an Insulated Pipe.

Pipe insulators are mostly used to conserve the thermodynamic properties of the transporting media. It also serves to reduce the environmental attacks on the surface of the pipe. Internal profile assessment of insulated pipes becomes problematic when using other NDT methods other than RT. Kulkarni et al (2005) in their report mentioned that, the double wall double image radiographic method is useful when insulating material's radiation absorption is less than the pipe's absorption. DWT was used to successfully assess corrosion and deposits in the insulated pipes during the experiment.

4.3. Tangential Radiographic Technique for Externally and Internally Machined Pipe

Remaining wall thickness evaluation continuous to be a major industrial problem in the process industries. This is especially difficult with pipes that are insulated because of the costly removal of these insulations during measurement of remaining wall thickness. The use of industrial radiographic testing has helped eased the process of measuring remaining wall thicknesses of pipes with or without insulation and providing permanent records that can be reviewed periodically.

According to the CRP, the preferable industrial radiographic method is TRT. TRT gives a detailed pipe profile from experimentation from which a measured wall thickness from the film can be obtained and used to compute for the true wall thickness using the equation 2.9

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Two steel pipes having known varying wall thicknesses ranging from 4.00 mm to 13.00 mm with diameter of 150.00mm were examined to authenticate the accuracy and reliability of the tangential method that was used to measure the remaining wall thickness

Fig 4.2 and Fig 4.3 provide comparison between measured wall thickness from the film, the calculated true wall thickness and the ultrasonic thickness gauge measurement that served to validate the results of the calculated true wall thickness

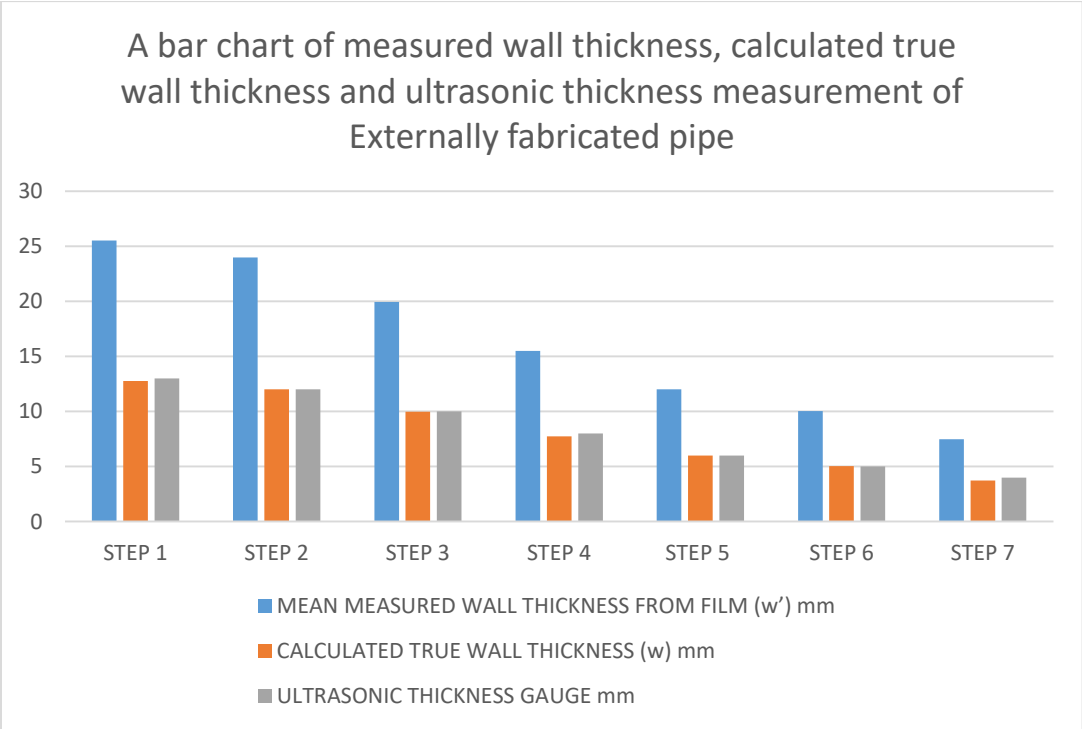


Fig 4.2: A bar chart of measured wall thickness, calculated true wall thickness and ultrasonic thickness measurement of externally fabricated pipe.

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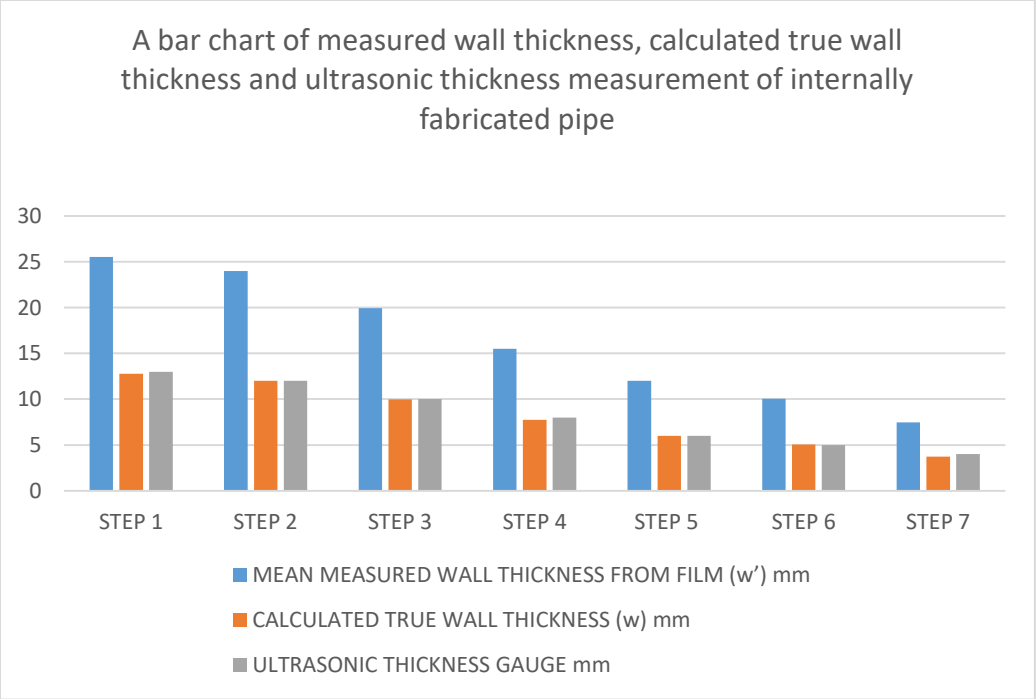


Fig 4.3: A bar chart of measured wall thickness, calculated true wall thickness and ultrasonic thickness measurement of internally fabricated pipe

4.4 Comparative Analysis of Results

4.4.1. Comparison between Measured wall thickness from film and Calculated True wall thickness for externally fabricated Pipe by Tangential Radiographic Method.

From Fig 4.4, the recorded wall thickness obtained from the film is about twice the value of the calculated true wall thickness. The maximum standard deviation of the recorded thickness from film was 0.1414 with a standard error of 0.07.

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The overestimation of the measured wall thickness from the film (radiograph) was as a results of magnification factor. This overestimation of the measured wall thickness from film can be used to accurately predict the true wall thickness if due calculations are taken into consideration.

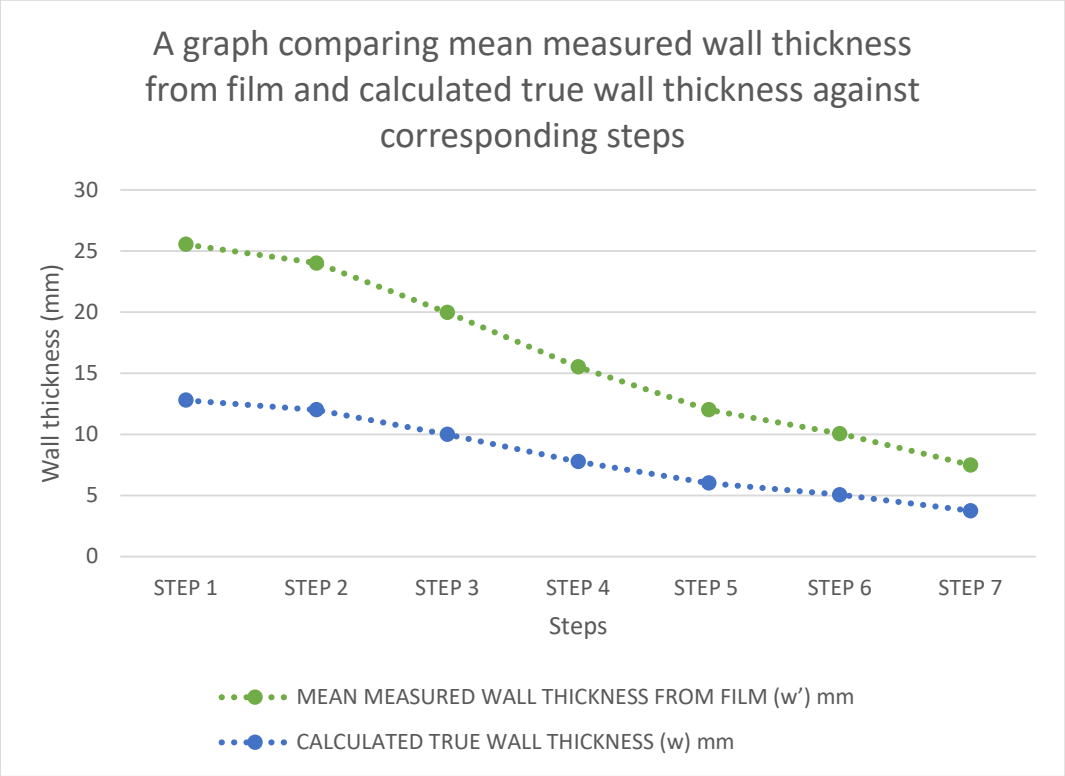


Fig 4.4: A graph comparing mean measured wall thickness from film and calculated true wall thickness against corresponding steps

4.4.2. Comparison between Calculated True wall thickness and Ultrasonic thickness gauge measurements for externally fabricated Pipe.

After the experiment, the true wall thickness calculated was compared with the thicknesses obtained using ultrasonic thickness gauge. The ultrasonic thickness readings were to serve as validations for the experimental procedure.

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From the results obtained in both thicknesses, there was not any significant difference between the ultrasonic thicknesses and that of the calculated true wall thicknesses. Fig 4.5 shows how closely related the results of the calculated true wall thickness and the ultrasonic thickness measurements are. With the maximum difference between the two different methods being 0.26 mm and the minimum difference being 0.02 mm. the insignificant difference indicates the importance of tangential radiography method in measuring the external wall thickness of pipelines in process industries. Some of the advantages of the tangential radiography methods over the ultrasonic thickness is its ability to inspect pipelines with insulators without the costly removal of the insulations and also provision of permanent records.

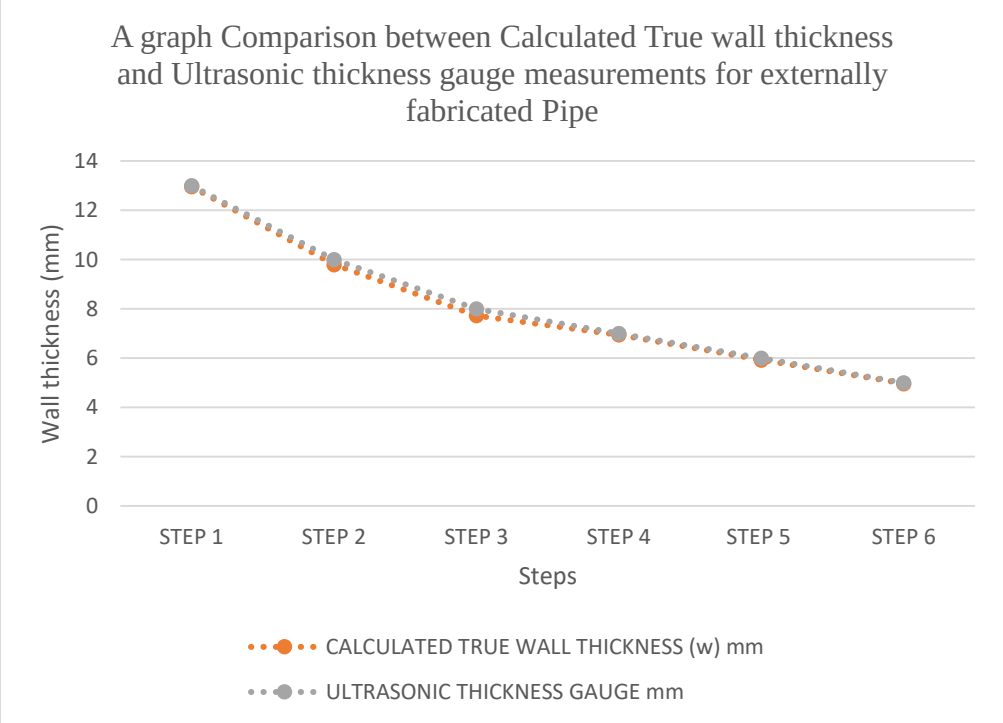


Fig 4.5: A graph Comparison between Calculated True wall thickness and Ultrasonic thickness gauge measurements for externally fabricated Pipe.

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4.4.3. Comparison between Measured wall thickness from film and Calculated True wall thickness for internally fabricated Pipe.

The combined action of chemical attacks and mechanical abrasions or wear as a consequence of fluid motion leads to erosion – corrosion. Most metals\ alloys are susceptible to erosion – corrosion. Some of these metals rely on the protective surface film for corrosion protection. These types of metals are particularly vulnerable to corrosion. Examples of these metals include; Aluminium, Lead and Stainless Steel. The corrosion attack occurs as a results of the failure of the protective film to form because of the erosion caused by suspended particles.

Most pipelines in process industries are manufactured with stainless steel. Internal corrosion (erosion – corrosion) leads to reduction in the wall thickness of the pipelines. This is because pipelines in such industries are mostly subjected to high velocity fluids. Gradual reductions in the pipe thickness leads breaks in the pipelines resulting in spillage.

Fig 4.6 compares the measured wall thickness from the radiograph (film) to that of the calculated true wall thickness. From the graph, the measured wall thickness from the radiograph is found to be approximately 1.22 times the value of the calculated true wall thickness. With a standard deviation ranging from 0.047 to 0.085.

From this analysis, the remaining wall thickness of pipelines in the process industries can estimated.

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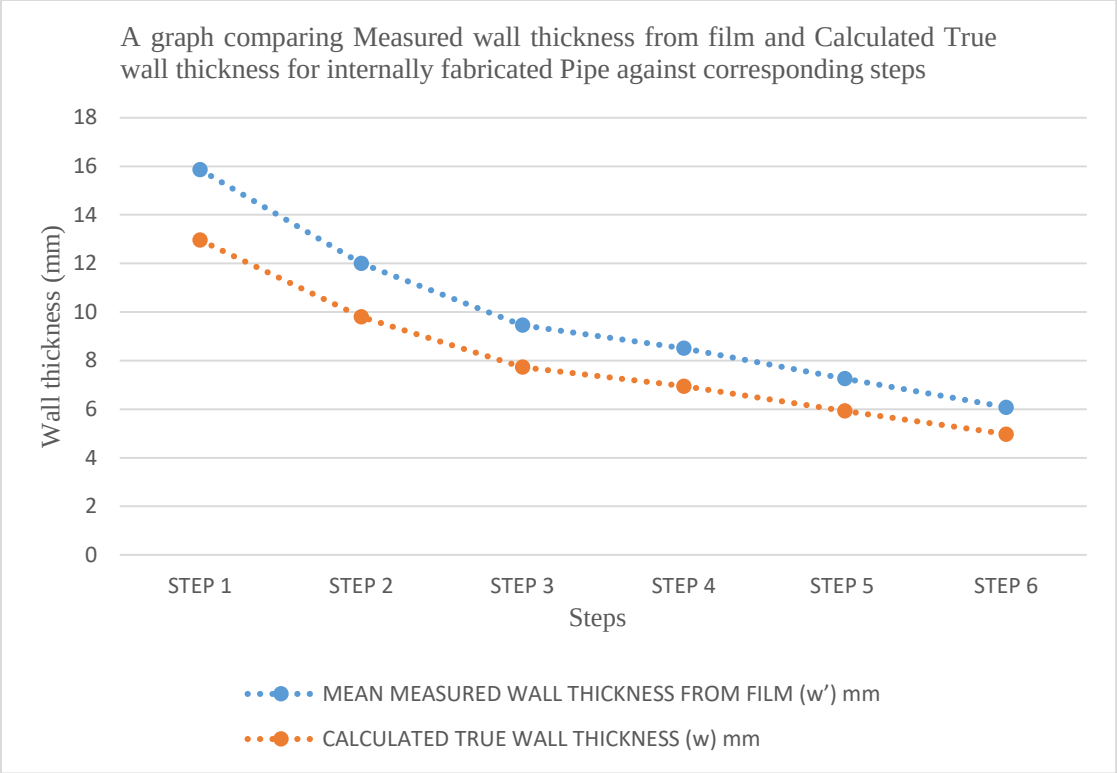


Fig 4.6: Comparison between Measured wall thickness from film and Calculated True wall thickness for internally fabricated Pipe

4.2.4. Comparison between Calculated True wall thickness and Ultrasonic Thickness gauge measurements for internally fabricated Pipe.

Comparison between the true wall thickness calculated and the ultrasonic thickness gauge measurements were made for the internally fabricated pipe after the experiment. With the ultrasonic thickness readings serving as validations for the experimental procedure used.

The similarities between the remaining wall thicknesses obtained from both the true wall thickness and ultrasonic gauge measurements were noticeable. With no significant difference between the ultrasonic thicknesses and that of the calculated true wall

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thicknesses. The maximum difference between the two different methods being 0.27 mm and the minimum difference being 0.03 mm. This insignificant difference indicates the significance of tangential radiography method in measuring the internal wall thickness of pipelines in process industries. Some of the advantages of the tangential radiography methods over the ultrasonic thickness is its ability to inspect pipelines with insulators without the costly removal of the insulations and also provision of permanent records.

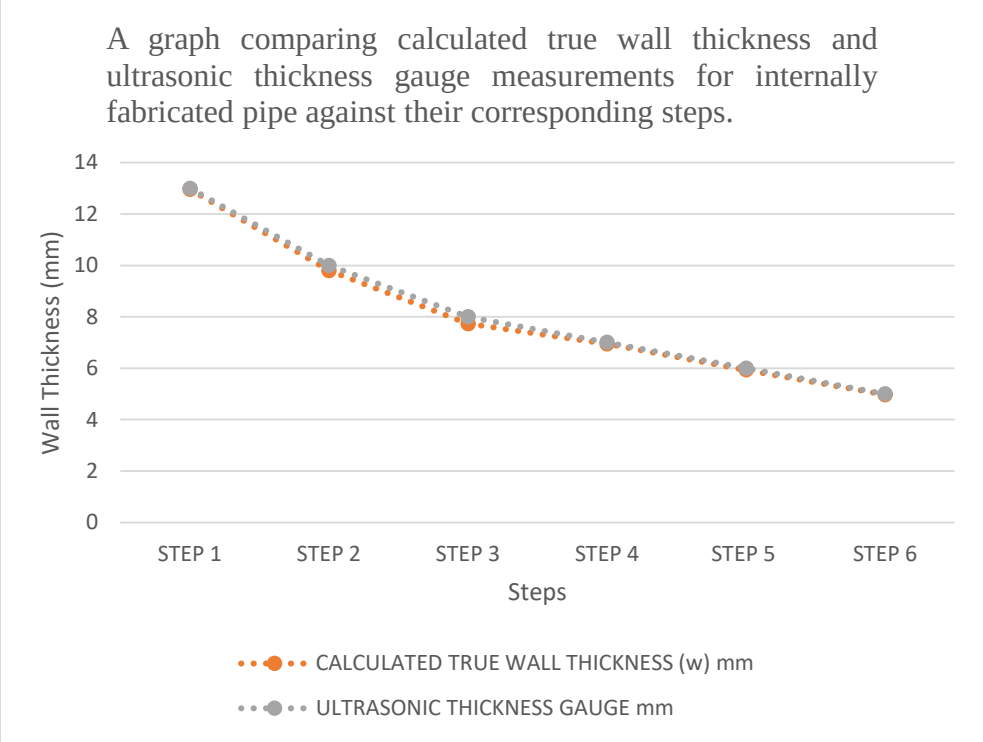


Fig 4.7: A graph Comparison between Calculated True wall thickness and Ultrasonic thickness gauge measurements for internally fabricated Pipe.

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CHAPTER FIVE (5)

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The DWT and TRT techniques were extensively explored in this research work to effectively evaluate remaining wall thickness, corrosion and deposits in pipes. On the whole, the DWT was used predominantly to examine for corrosion and deposits in the experimental pipes whereas the TRT was used primarily to evaluate the remaining wall thicknesses of the experimental pipes. The TRT setup led to increased material thickness which required more exposure time compared to the DWT method.

The exposure angle of the source to the tangential part of the specimen was approximately eighty-seven degree (77^{o}) and which is calculated using the values of SFD and the OD of the experimental pipe. The magnification correction in this study was very important in justifying the high accuracy of the radiographic readings because of the relatively short SFD (150 mm, 400 mm).

DWT was able to identify both pitting corrosion and uniform corrosion in the internally fabricated pipe. This was true for the externally fabricated pipe as well. This affirms the double wall technique's success rate in the detection of corrosion in pipelines. During the determination of deposits in pipelines experimentation, there was an increase in the exposure time. The increase in the time of exposure is because of the deposit (mixture of sand and water) attenuation coefficient and the material thickness (relaxation length).

Similar to the insulated external machined pipe, the insulating material's absorption or

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attenuation coefficient had no or negligible impact on the density measurements. This implies that when the need arises, pipelines can always be insulated and will never interfere with any assessment method to access their internal profile (condition).

The measurements for the remaining wall thickness was done with the tangential radiographic technique (TRT). The use of TRT has eased the challenges involved in measuring the remaining wall thickness in pipelines. This is irrespective of whether the test pipes were insulated or not insulated. The interpretations obtained from radiographs after the TRT was employed, the maximum standard deviation of the measured thickness from the radiograph was 0.1414 and a standard error of 0.07 for the externally fabricated pipe. And a maximum standard deviation of 0.085 for the internally fabricated pipe.

From the graphs obtained ass shown in chapter four of this work, it showed that the TRT method will be effective for pipelines with greater thicknesses. The TRT method was successful in evaluating the remaining wall thickness of the test pipes

The findings of this study indicate that regular inspection of the internal corrosion of large diameter pipes will allow process industries to estimate the lifespan of pipes and save excessive maintenance costs through shorter inspection times.

With guidelines developed in the IAEA coordinated research project, the two methods investigated have been effective in assessing corrosion attacks, depositing on the pipe walls and estimating the pipes ' remaining wall thickness and their associated risk of misinterpreting the pipe component's failure. The statistical interpretation (analysis) of the research outcomes obtained can be used reliably to establish reference points for evaluation of pipes, from which effective corrosion and deposit can be monitored. And also, the

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remaining wall thickness can be assessed.

5.2 RECOMMENDATION

The recommendations for this study are;

1. The pipe dimension (pipe thickness and diameter, pit depth, radiographic film density etc.) can be encoded to serve as a bench mark data for future radiographic evaluations on pipelines with diameter of 150mm.
2. This procedure should be repeated for thicker (15.00 mm) pipelines since the standard deviation decreased with increasing thickness in study.

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REFERENCES

Alex, C. C., Solomon, A. B., & Charles, C. O. (2014). We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 % Control of a Proportional Hydraulic System. *Waste Water - Evaluation and Management*, *2*, 283–302. https://doi.org/10.5772/32009

(ASTM), A. S. (2000). ASTM standard G46: standard recommended practice for examination and evaluation of pitting corrosion. In wear and erosion: Metal Corrosion (Vol. 03.02.) of Annual Book of ASTM standard. 175-181.

Atomic, I., & Agency, E. (1992). Industrii ! Radiography ibr Industrial Radiography, (3).

Bardal, E. (n.d.). SC - E LS SC - E LS.

Baxter, R., Hastings, N., Law, a., & Glass, E. J. . (2008). [No Title]. *Animal Genetics*, *39*(5), 561–563.

Boateng, A., Danso, K. A., & Dagadu, C. P. K. (2013). Non-Destructive Evaluation Of Corrosion On Insulated Pipe Using Double Wall Radiographic Technique. *Chemistry and Materials Research*, *3*(4), 73–83. https://doi.org/2225- 0956

Bingler,T. Aesch, P. Popinet, C. (2005). *Coordinated research programme on validation of protocols for corrosion and deposit determination in pipes by Radiography.* Murepas, France.

Burch, S., & Collett, N. (2005). Recommended practice for the rapid inspection of small bore connectors using radiography. Retrieved from https://scholar.google.com/scholar?cluster=9097476176817184776&hl=en&as_sdt=

University of Ghana http://ugspace.ug.edu.gh

2005&sciodt=0,5

Callister, W. D., & Wiley, J. (n.d.). MATERIALS SCIENCE AND ENGINEERING Sixth Edition.

CLAPP, W., & Clark, D. (1949). *Engineering Materials and Processes...* Retrieved from http://pdf2289.zgopdf.com/engineering-materials-and-processes_24234930.pdf

Dria, Benchaala, R., Zergoroug, A., & Badidi Bouda, M. (2005). Corrosion and Deposit Determination in pipes by Rdiography.

Ekinci, S., Aksu, M., Bingoldag, M., Dogruoz, M., Kurtcebe, M., Yildirim, T., . . . Yilmaz, S. (2005). *validation of protocol for corrosion and deposit in pipes by radiography.* Istanbul, Turkey: Havalimani.

Fengqi, H. (2005). *Validation of protocols for corrosion and deposit determination in pipes by radiography.* Beijing, China.

Hamzah, A., Muhammed, A., & Sayati, S. A. (2005). Validation of protocol for Corrosion and Deposit Evaluation to pipes by Radiography.

Harara, W. (2003, October). Corrosion evaluation and wall thickness measurement on large diameter pipes by tangential radiography using a Co-60 gamma ray source.

Harara, W. (2005). *Evaluation of Corroaion and deposit in pipes by radiograph.* Syrian Arab Republic.

Hellier, C. J. (2003). Handbook of Non-destructive Evaluation . New York, USA: McGraw- Hill.

Hijazi, D. A. (n.d.). Advantages and Disadvantages Nature of Penetrating Radiation, 1–47.

University of Ghana http://ugspace.ug.edu.gh

Retrieved from https://eis.hu.edu.jo/ACUploads/10526/Radiographic Testing.pdf

Hou, Y., Lei, D., Li, S., Yang, W., & Li, C. Q. (2016). Experimental Investigation on Corrosion Effect on Mechanical Properties of Buried Metal Pipes. *International Journal of Corrosion*, *2016*. https://doi.org/10.1155/2016/5808372

IAEA. (1999, May 17-20). Second RCM report on validation of protocols for corrosion and deposit determination in pipes by radiography.

International Atomic Energy Agency, I. A. E.A (2005). Development of protocols for corrosion and deposits evaluation in pipes by radiography. *Atomic Energy*, (April), 1–114.

international atomic energy agency. (2005). Non-destructive testing for plant life assessment. *Atomic Energy*.

Janeiro, R. De, & Janeiro, R. De. (2005). - aben isbn: 85-99141-01-5.

John Zirnhelt, Isaac Einav & Silvia Infanzón. (2003). *Radiographic Evaluation of Corrosion and Deposits.* Rio de Janeiro : An IAEA Co-ordinated Research Project.

Kuhlmann, U. (2000). [No Title]. *Journal of Molecular Biology*, *301*(5), 1163–1178.

Kulkarni, P., Valdya, P. R., & Shah, B. (2005). *Validation of protocols for Corrosion and Deposit Evaluation pipes by Rdiography.* Mumbai, India.

La, E. C., & Fig, L. (n.d.). Erosion Corrosion - Cavitacion. *Corrosion*, (2), 1–15.

Lee, S. S., & Kim, Y. H. (2005). *Validation of Protocol for Corrosion and Deposits determination in small diameter pipes by radiography.* Seoul, Republic of Korea.

University of Ghana http://ugspace.ug.edu.gh

Lee, S., & Kim, Y. H. (1999). *Determination of pipe thickness using tangential radiography and film density-thickness correlation.* Seoul, Republic of Korea.

Munoz, J. C., & M.Vargas, C. (2005). *Validation of protocols for corrosion and deposit determination in pipes by radiography*. Costa Rica.

Onel, Y., Ewert, U., & Willems, P. (2000). "Radiography Wall Thickness Measurements using a New Tomographic Algorithm". *Proceedings of the 15th WCNDT*, (p. IDN 369). Roma.

Quinn, R. A., & Sigl, C. C. (1980). Radiography in Modern Industry. *Eastman Kodak Company*, *4Th Editio*, 1–212.

Radiography, I. (2011). *U.s.nrc*. (March).

Rastkhah, N. E., Kermani, K., Seiedi, A., Movafeghi, M., Shirzadian, A., & A. (2004, March 8- 12). *Internal Report of second RCM of the CRP: Corrosion and Deposit Evaluation in Large Diameter Pipes by Rdiography.* Istanbul, Turkey:

IAEA.Agency, I. A. E. (2005). Development of protocols for corrosion and deposits evaluation in pipes by radiography. *Atomic Energy*, (April), 1–114.

Roberge, P. R., & Pierre, R. (1999). *Handbook of Corrosion Engineering Library of Congress Cataloging-in-Publication Data*. https://doi.org/10.1016/S0026-0576(00)83445-5

Tennakoom, T. M. (2005). *Validation of protocols for corrosion and Deposit Determination in pipes by Radiography "CORDEP".* Sri Lanka.

Vaidya, P. R., Atomic, B., Atomic, T., & Authority, E. (2006). Radiographic Evaluation

University of Ghana http://ugspace.ug.edu.gh

of Corrosion and Deposits in Pipelines : Results of an IAEA Co-ordinated Research Programme. *Atomic Energy*, (June 2014), 1–14.

Up Front. (1992). Material Perfomance. 31:3.

Vaidya, P. R., Atomic, B., Atomic, T., & Authority, E. (2006). Radiographic Evaluation of Corrosion and Deposits in Pipelines : Results of an IAEA Co-ordinated Research Programme. *Atomic Energy*, (June 2014), 1–14.

Zirnhelt, J., Einav, I., Atomic, I., Agency, E., Box, P. O., & Infanzón, S. (2003). *Radiographic Evaluation of Corrosion and Deposits : An IAEA Co-ordinated Research Project*.

Zscherpel, U., Bellon, C., & Nimtz, R. (1998). Wall thickness estimated from digitized radiographs. *Proceedings of 7th ECNDT*, (pp. 2819-2825). Copenhagen.

Zscherpel, U., Onel, Y., & Ewert, U. (2000). New Concepts for Corrosion Inspection of Pipelines by digital Industrial Radiology. *Proceedings of 15th WCNDT*, (p. IDN 325). Roma.

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APPENDIX

Table A1: Parameter of Interiorly Machined Pipe using Tangential Radiographic Technique.

STEPS	MEAN MEASURED WALL THICKNESS FROM FILM (w') mm	CALCULATED TRUE WALL THICKNESS (w) mm	ULTRASONIC THICKNESS GAUGE mm	STANDARD DEVIATION	STANDARD ERROR
STEP 1	15.86	12.96	13.00	0.0479	0.0239
STEP 2	12.00	9.80	10.00	0.0816	0.0408
STEP 3	9.46	7.73	8.00	0.0479	0.0239
STEP 4	8.51	6.95	7.00	0.0854	0.0427
STEP 5	7.26	5.93	6.00	0.0479	0.0239
STEP 6	6.08	4.97	5.00	0.0645	0.0323

Table A2: Parameter of Externally Machined Pipe using Tangential Radiographic Technique.

STEPS	MEAN MEASURED WALL THICKNESS FROM FILM (w') mm	CALCULATED TRUE WALL THICKNESS (w) mm	ULTRASONIC THICKNESS GAUGE mm	STANDARD DEVIATION	STANDARD ERROR
STEP 1	25.53	12.78	13.00	0.0957	0.0479
STEP 2	24.00	12.00	12.00	0.1414	0.0707
STEP 3	19.95	9.98	10.00	0.1291	0.0645
STEP 4	15.5	7.75	8.00	0.0861	0.0408
STEP 5	12.00	6.00	6.00	0.1414	0.0707
STEP 6	10.05	5.05	5.00	0.0577	0.0289
STEP 7	7.48	3.74	4.00	0.0957	0.0479