Non-Destructive Evaluation Of Corrosion On Insulated Pipe Using Tangential Radiographic Technique

Alexander Boateng, Dr. K.A. Danso, Dr. C.P.K. Dagadu

Abstract: Tangential Radiographic Technique (TRT) principle was explored for evaluating deposits and corrosion attacks across the inner and outer walls of an insulated steel pipe using Iridium-192.The research was performed on a designed test piece to simulate corrosion attacks and deposits on industrial pipes. Pitting corrosion measurements based on TRT were more sophisticated, and therefore magnification factor and correction were used to establish the estimated pit depth on the film. From the relationship curve drawn between the radiographic film density and the thickness of the pipe, the attenuation coefficient of the insulating material was negligible compared to the concrete deposit. The TRT method overestimated the degree of penetrated corrosion attack in the tangential position in the neighbourhood of 9% and was within an accuracy of ± 0.37 mm. This tolerance limit is 5% less than the wall thickness of the pipe. From the results obtained, effective corrosion monitoring of insulated pipes can reliably be executed by the TRT without the costly removal of insulation material.

Keywords: Tangential Radiographic Technique, Pitting Corrosion, Insulated Pipe, Ir-192, Attenuation Coefficient, Wall Thickness

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INTRODUCTION

The reliability and the safety of industrial equipment in the processing industries are substantially influenced by degradation processes such as corrosion, erosion, deposits and blocking of pipes. Corrosion can trigger serious failures, which lead to large economic loss, sometimes combined with environmental pollution, or risk of personnel injuries, unpredictable and costly shutdowns of industrial facilities due to repair and replacement.This is as a results degradation of material or its properties because of its reaction with the environment; it is electrochemical in nature that is, it involves transfer of electrons and also requires an anode, cathode and electrolyte [1]. Corrosion often renders pipes useless and eventually may have to be scrapped. Several estimations have arrived at the conclusion that the total annual corrosion costs in some industrialized countries amount to about 4.6% of gross national product [2]. Erosion-corrosion is caused by a complicated interplay of a number of parameters. A large body of experimental work has identified several key variables that influence the rate of attack. These variables are fluid velocity, fluid pH level, fluid oxygen content, fluid temperature, component geometry and the presence of alloying components such as chromium, copper and molybdenum, these parametersimpact greatly on material loss [3].

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Ultrasonic, Eddy current, liquid penetrant, Magnetic particle and Acoustic emission are all Non-Destructive Testing (NDT) methods that have the ability to detect crack-like defects in industrial components. A major inspection challenge facing the factory process industries is how to examine insulated piping for corrosion. These pipes are usually covered by thick insulation materials, such as asbestos, nylon cloth, concreteor fibre wool and these make the above NDT methods not applicable in both the accessible and non-accessible surfaces of the components. The International Atomic Energy Agency (IAEA) is promoting industrial applications of Non-Destructive Testing (NDT) and other related methods, to assure safety and reliability of operating industrial facilities. One of the most significant parameters to be monitored and measured in the piping or pipeline industry is the wall thickness. Among the NDT methods, radiography has the advantage, because in the process of inspection it eliminates the need for the costly removal of the pipe insulation and also the added benefit that it can be carried out in high temperature environments [4]. Monitoring, assessment, and the evaluation of the working conditions of industrial laid pipes for corrosion and deposits have become very challenging, especially in situations of insulated pipes or pipes operating at high temperatures. The most critical steps in order to hinder or reduce the magnitude of such failures are early detection, proper diagnosis and effective prevention measures. While certain inevitable factors have contributed high corrosion rates; it remains clear that the service life of most piping systems could be prolonged by giving more serious consideration to corrosion control. This research seeks to explore the Tangential Radiographic Technique (TRT)using Ir-192 for evaluation of corrosion attack across the inner and outer walls of insulated steel pipes (mild steel) with diameter greater than 150 mm, a vital need for many industrial installations. It is only periodic inspection for the integrity of pipes and equipment can mitigate the risk in connection with failures associated with corrosion activities. It is therefore imperative to evaluate inner wall corrosion and deposit in large diameter pipes by radiography to address the challenges confronting processing industries.

THEORETICAL ANALYSIS

The film density (D) is the major parameter characterizing the quality of the radiographic film and is derived from the Beer Lambert law. Practically speaking, a condition of good geometry is difficult to attain and this is because of the effect the primary and the scattered radiations do have on the exposed film [5]. A multiplier called the build-up factor (B) is introduced in the equation to represent the distribution of scattered radiations. For this geometric set-up, the concept of an effective attenuation coefficient (μ_{eff}) is used for all the attenuations offered by the insulator, pipe and the deposit.

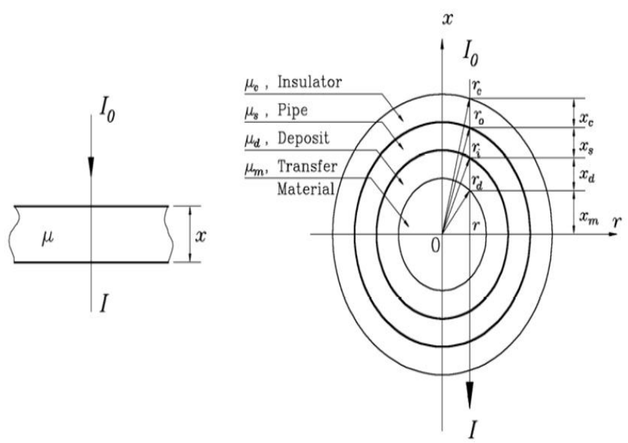

Figure1. Attenuation coefficients for different layers in a typical pipe with deposit on the internal diameter and insulation on the outer diameter [6].

Using beer's law for a pipe

$$I = BI_0 e^{-2\mu x} \quad (1)$$

$$I = BI_0 e^{-2(\mu_c X_c + \mu_s X_s + \mu_d X_d + \mu_m X_m)} \quad (2)$$

Forinsulatedemptypipewithdeposit ($X_m = 0$):

$$I = BI_0 e^{-2(\mu_c X_c + \mu_s X_s + \mu_d X_d)} \quad (3)$$

$$I = BI_0 e^{-\mu_{\text{eff}}\, x} \quad (4)$$

$$log_{10}\frac{I_0}{I} = log_{10}\frac{1}{B} e^{\mu_{\text{eff}}\, x} \quad (5)$$

$$D = log_{10}\frac{1}{B} e^{\mu_{\text{eff}}\, x} \quad (6)$$

Where I_0 is the intensity of the incident radiation, I is the intensity of the transmitted radiation, μ_c, μ_s, μ_d and μ_m are the attenuation coefficient of concrete, steel, deposit and transported material respectively. X_c, X_s, X_d and X_m represents thickness of concrete, steel, deposit and transported material respectively. The exposure angle (α) is a function of the Source Film Distance (SFD) and the Outer Diameter (OD). By changing the SFD, the tube position can be rearranged to project suspected defects on to the film with optimum resolution and contrast parameters. The relationship that determines the radiation exposure angle (α)is as shown in figure 2.

$$\alpha = \frac{\cos^{-1}(0.5\, OD)}{SFD - 0.5\, OD} \quad (7)$$

The technique does not provide any direct or linear correspondence between the actual pit depth on the pipe and the measured pit depth on the radiographic film; this is so because of the short source film distance. Magnification factor and correction helps to ascertain this linear or direct relationship between the actual and the measured parameter of the pipe.

$$\text{Magnification Factor} = \frac{\text{Average Measuerd Pit Depth}}{\text{Actual Pit Depth}} \quad (8)$$

$$\text{Magnification Correction} = \text{Actual Pit Depth} - \text{Average Measured Pit depth} \quad (9)$$

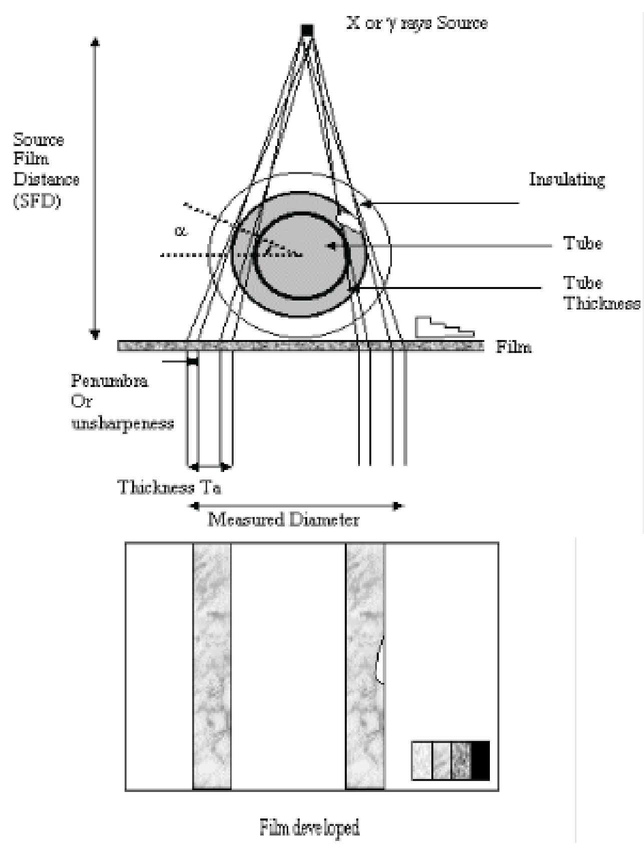

Figure 2: Tangential radiography set-up [2].

EXPERIMENTAL WORK

The experimental work includes the fabrication of the test blocks or specimen, the conduction of the tangential radiographic technique, the processing and the development of the exposed radiographic and finally analysing the film.

Preparation of Test Blocks

The test pipes present generalized corrosion both inner and outer surface of the pipe, with wear between 1000µm to 1300µm (39.4 mil – 51.2 mil); levels of pit penetration of the various segments ranges between 0.50 mm to 3.00 mm and diameters between 3.00 mm to 7.00 mm were created using drill bits during the fabrication process.

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.
- Hole diameter equal to remaining wall thickness, minimum of 3.00 mm.
- Hole depths 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% [6].

Table 1: Parameters of Interiorly Fabricated (machined) Pipe.

INTERIOR MACHINED PIPE				LENGTH OF PIPE = 302.00 n		
Step	Step Block Thickness (mm)	Pits (Drill) Diameter (mm)	Pits Depth (mm)	Outer Diameter (mm)	Inner Diameter (mm)	Step Bl Leng (mm
Step 1	4.50	3.00	0.50	163.00	154.00	49.0
Step 2	6.40	3.20	0.80	163.00	150.20	49.0
Step 3	7.50	4.00	1.20	163.00	148.00	49.0
Step 4	8.50	4.50	1.60	163.00	146.00	49.0
Step 5	9.40	5.00	2.00	163.00	144.20	49.0
Step 6	10.50	6.00	2.50	163.00	142.00	57.0

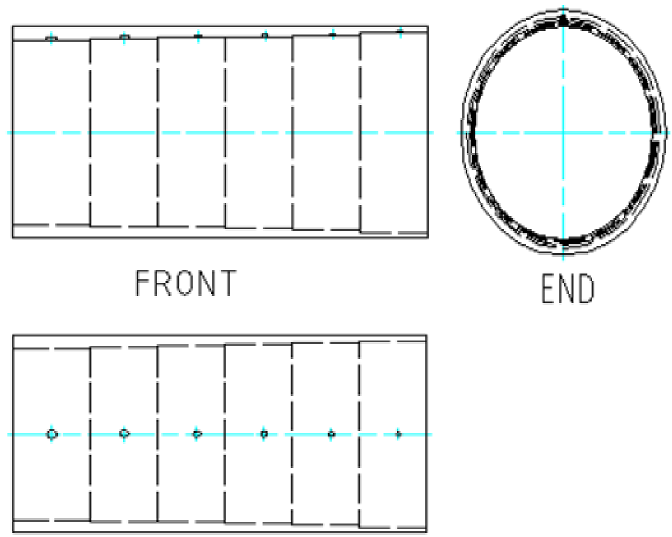

Figure3. Orthographic views of the interiorly machined pipe.

Figure4. Interiorly machined pipe (test pipes).

Table 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

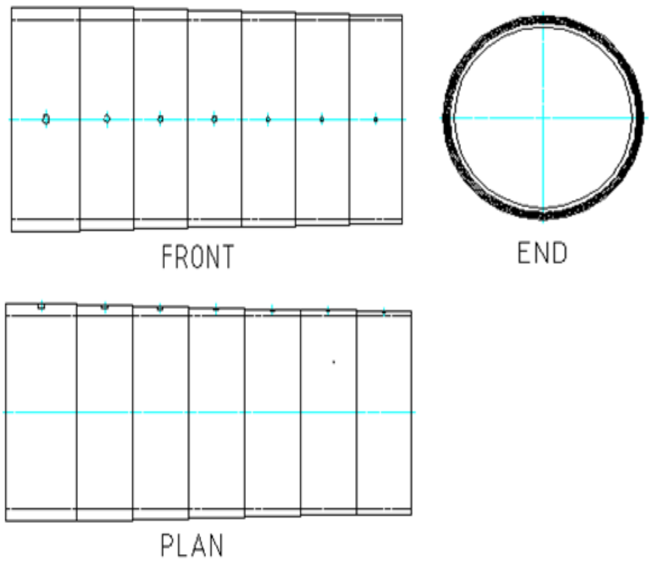

Figure5. Orthographic views of the exteriorly machined pipe.

Figure6. Exteriorly machined pipe (test pipes).

Insulation and Deposit Material

The material used to simulate the deposit attack in the experiment is concrete with uniform thickness of 40 mm withinthe internal diameter of the pipe and a fibre wool insulator of 30.00 mm thickness was used to insulate the pipe.

Figure 7. Fibre wool insulating material

Figure 8. Gamma Ray Source (Ir-192)

Gamma-Ray Source (GAMMAVOLT – SU50)

RADIOAKTIV

Type B(U) D/DB-0009B

Weight 16kg/ U(depleted) 12.1kg

Activity 3700 GBq (100 Ci), Ir-192

Film Kodak industrex AA-400, with a lead screen.

Tangential Radiographic Technique

The tangential radiography set-up for the pipe is presented in the figure 9. The source was positioned tangential to the wall of the pipe, because of the large nature of the diameter. The source had to be collimated to prevent backscatter and also to focus the beam to the target area of interest, its activity at the time of conducting the test was 45 curies (Ci). The source-film-distance (SFD) 1485.00 mm was maintained both for insulated and non-insulated pipe but with exposure times of 45, 50, 55, 80 and 90 seconds. The exposure angle between the source, the tangential position and the central axis of the pipe was 87 degrees and this was determined using equation 7. The radiographic film was plated around the circumference of the pipe. The remaining wall thickness and the depths of the pits were projected on the film by orienting both the pipe and source. The method was able to measure wall thickness on two sides of the pipe in the same exposure. The radiation source was placed above the pipe being radiographed tangentially rather than at centre of the pipe. Shading of the tangential radiograph between the two sides allows observation of local corrosion, erosion, deposits and pitting. The tangential paths of radiation within the pipe walls projected the edge location, and the pipe thickness to be evaluated. Thinning on the bottom of the pipe, process material deposit in the bottom of the pipe, and other defects related to corrosion and deposits were made possible to be viewed [2].

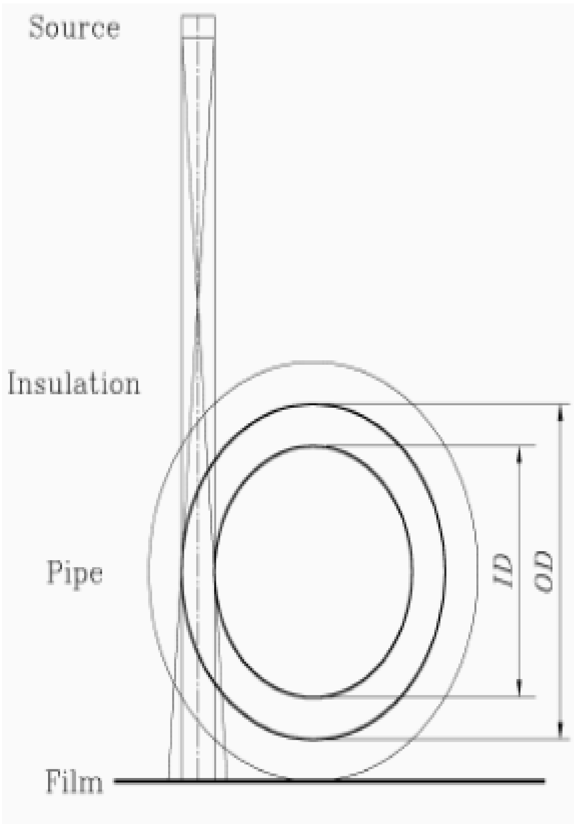

Figure 9. Test arrangement for Tangential Radiography [3].

Figure10. Reading of Radiographic film (Radiograph) in the dark room.

RESULTS

The results of the experiment for the exterior composite pipe geometry, the interiorly machined pipe including insulationare shown in table 3 and 4 respectively. Table 5 shows the magnification factor and correction of the exterior composite pipe geometry. Figure 11, 12 and 13 are graphs of average film density and pit depth of exteriorly machined pipe and deposit, the exterior composite pipe geometry and the interiorly machined pipe and insulation respectively. Density variation against pit depth at different exposure conditions and comparison between actual and measured pit depths are shown in figure 14 and 15 respectively.

Table3. Parameter of Exteriorly Machined Pipe, Deposit and Insulation using Tangential Radiographic Technique.

EXTERIOR + DEPOSIT + INSULATION — TIME OF EXPOSURE: 90 sec.
SOURCE FILM DISTANCE (SFD) : 1485 mm — TANGENTIAL METHOD

Step	Actual Pit Depth (mm)	Mean Density of Pit Depth	Standard Deviation	Standard Error	Relative Percentage Error	Mean Density Values
Step 1	0.50	1.51	0.033	0.01	0.83	1.51 ± 0.060
Step2	0.80	1.65	0.024	0.01	0.55	1.65 ± 0.055
Step3	1.20	1.92	0.071	0.03	1.40	1.92 ± 0.110
Step4	1.60	2.31	0.126	0.05	2.06	2.31 ± 0.280
Step5	2.00	2.65	0.112	0.04	1.60	2.65 ± 0.225
Step6	2.50	3.26	0.116	0.04	1.94	3.26 ± 0.300
Step7	3.00	3.94	0.038	0.01	0.36	3.94 ± 0.490

Table4. Parameter of Interiorly Machined Pipe and Insulation using Tangential Radiographic Technique.

INTERIOR + INSULATION — TIME OF EXPOSURE: 55 sec.
SOURCE FILM DISTANCE (SFD) : 1485 mm — TANGENTIAL METHOD

Step	Actual Pit Depth (mm)	Mean Density of Pit Depth	Standard Deviation	Standard Error	Relative Percentage Error	Mean Density Values
Step 1	0.50	2.08	0.108	0.04	1.96	2.08 ± 0.165
Step 2	0.80	2.18	0.114	0.04	1.98	2.18 ± 0.205
Step 3	1.20	2.38	0.081	0.03	1.29	2.38 ± 0.165
Step 4	1.60	2.59	0.055	0.02	0.80	2.59 ± 0.125
Step 5	2.00	2.91	0.053	0.02	0.69	2.91 ± 0.115
Step 6	2.50	3.24	0.098	0.04	1.15	3.23 ± 0.220

Table5. Parameter of Exteriorly Machined Pipe, Deposit and Insulation with Magnification Factor and Correction using Tangential Radiographic Technique.

EXTERIOR + DEPOSIT + INSULATION — EXPOSURE TIME: 90 Sec.
SOURCE FILM DISTANCE: 1485 mm — TANGENTIAL METHOD

Step	Actual Pit Depth (mm)	Average Measured Pit Depth (mm)	Standard Deviation	Magnification Factor	Magnification Correction
Step 1	0.50	0.54	0.044	1.08	-0.04
Step 2	0.80	0.87	0.039	1.08	-0.07
Step 3	1.20	1.30	0.043	1.08	-0.11
Step 4	1.60	1.73	0.054	1.08	-0.15
Step 5	2.00	2.17	0.087	1.09	-0.19
Step 6	2.50	2.72	0.067	1.09	-0.24
Step 7	3.00	3.27	0.045	1.09	-0.30

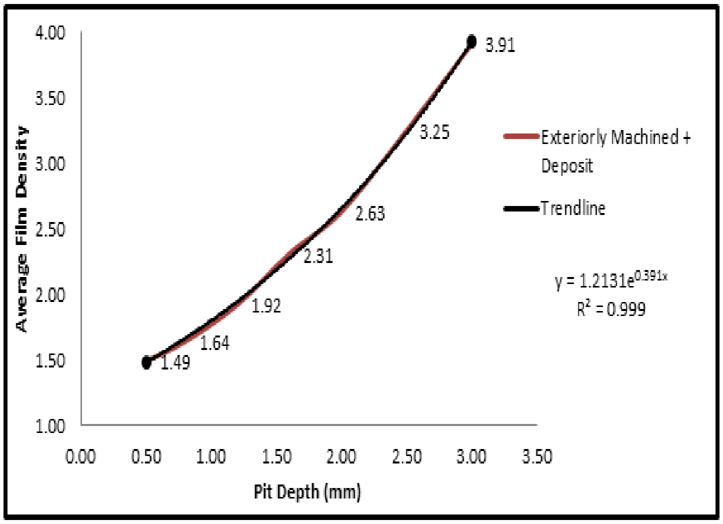

Figure11. Exteriorly Machined Pipe and Deposit Using the Tangential Radiographic Technique.

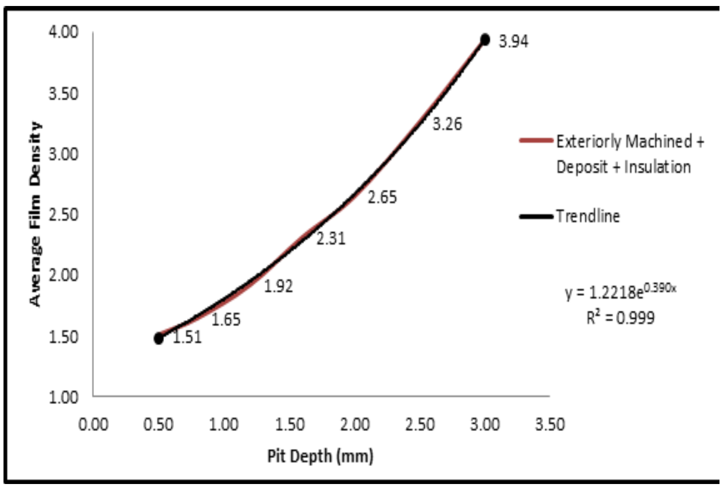

Figure12. Exteriorly Machined Pipe, Deposit and Insulation Using the Tangential Radiographic Technique.

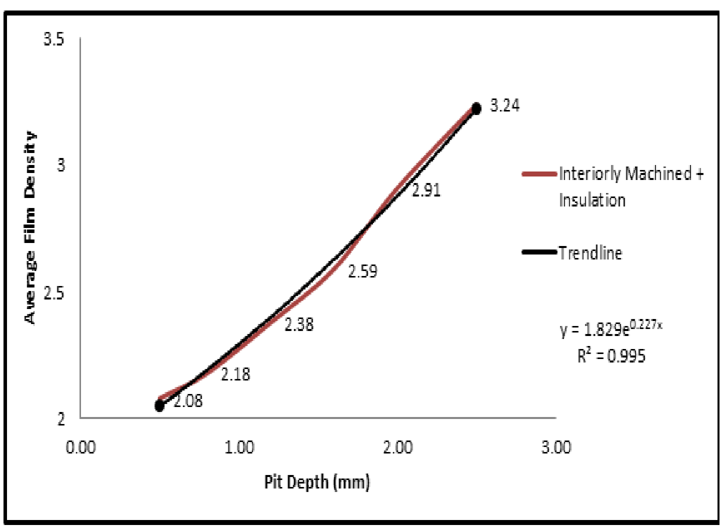

Figure13. Interiorly Machined Pipe and Insulation Using Tangential Radiographic Technique.

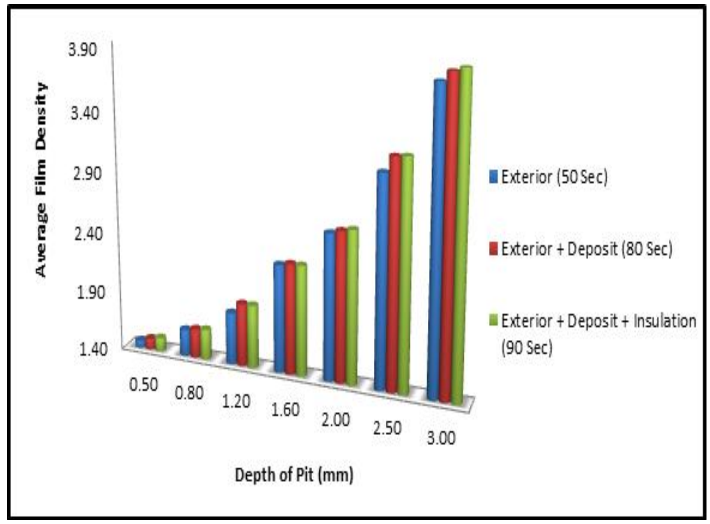

Figure14. Density variation versus Pit depth at different Exposure Conditions by Tangential Radiographic Technique.

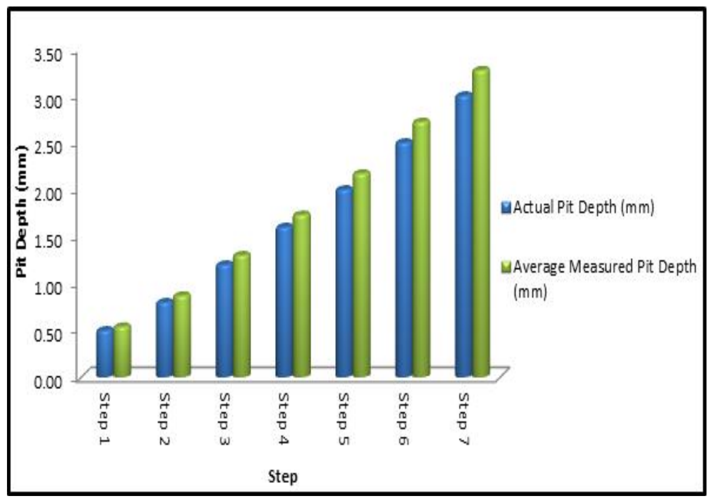

Figure15. Comparison between Actual and Measured Pit Depth by Tangential Radiographic Technique.

DISCUSSION

Insulation on pipe is most often used to preserve the thermodynamic properties of the flowing media and also protect the pipe surface from environmental attack. The presence of insulating material on the pipe makes other non-destructive methods impossible to access the internal profile of the pipe. From the experimental results, the insulating material insignificantly interfered with the radiographic exercise; this is exemplifiedin the closeness of the average density values in figure 11 and 12. From the exponential equations of both graphs ($y = 1.2131e^{0.391x}$, $y = 1.2218e^{0.390x}$), the attenuation coefficient of both the insulated and non-insulatedpipe was near to zero difference. This is indicative of the fact that the insulating material had negligible attenuation coefficient on the incident radiation. Variation with the build-up factor (1.2131 and 1.2218) isas results of the differences in thickness of the material. The plot in figure 14 depicts a characteristic nature between density and the degree of penetration of pit in the pipe. The deeper the depth of the pit the more gamma radiation is transmitted leading to higher radiographic density. It was also evident that, the more exposure time, the higher the density values, therefore it is imperative the exposure time be carefully managed in order not to over or under expose the test piece. This might generate pseudo radiographic density values which willgive untrue representation of the test piece (pipe). The degree of the exposure angle greatly determines the time to expose the pipe that is the tangential area of pipe required much more exposure time compared with film density - thickness relation method. The three different exposure conditions depicted how the radiographic film density varied with thickness of material. This confirmed the linear relationship that attenuation or absorption coefficient had with thickness. From the measured pit depth on the radiographic film, the estimated pit readings were close to the actual pit diameter on the pipe with magnification factor ranging between 1.08 – 1.09.). The over estimation of pit depth by the tangential radiographic technique was due to the magnification factor. This can be used to predict accurately the actual pit depth if the magnification factor and correction are applied to the estimated pit depth read on the radiograph. In a complex pipe system it is particularly important to obtain information regarding the ability of a corroded pipe to accommodate the axial stress. Further deterioration or internal metal loss may result in the pipe wall being unable to carry these axial loads. With reference to figure 13, the extent of pit propagation (pit depth) can be determined from the reference curve whenever the radiographic density is known. Knowledge of the degree pit propagation will aid in the establishment of the design safety-factor load to be sustained by the pipe.

CONCLUSIONS

The main objective of this paper is to explore the radiographic technique (TRT) using Ir-192 for evaluation of corrosion attack across the inner and the outer walls of an insulated steel pipe with diameter greater than 150 mm (large diameter pipe). Specific conclusions are as follows: On the whole the TRT overestimated the penetrated wall thickness of corrosion attack in the tangential position in the neighbourhood of 9% and was within an accuracy of ± 0.37 mm. The tangential configuration leads to greater material thickness which requires more exposure time. The magnification correction in this research work is very significant to account for high accuracy in the radiographic readings because of the relatively short source film distance. The TRT had difficulty in identifying some localised form of corrosion in the internal surface area of the pipe whilst the outer local area corrosion was better detected; this is so because with the TRT prior knowledge of defect location is necessary before effective evaluation can be conducted. The results from this research work asserts to the fact that periodic inspection of the internal corrosion of large diameter pipes will enable industries to predict the life time of pipes and to save unreasonable maintenance costs by shorter inspection time.

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