Chemistry and Materials Research
ISSN 2224- 3224 (Print) ISSN 2225- 0956 (Online)
Vol.3 No.4, 2013 www.iiste.org

Non-Destructive Evaluation of Corrosion on Insulated Pipe using Double Wall Radiographic Technique

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Abstract
The research explored the Double Wall Radiographic inspection technique using Ir-192 for evaluating deposits and corrosion attacks across the inner and outer walls of an insulated steel pipe .The experiment was performed on a designed test piece to simulate corrosion attacks and deposits on industrial pipes. 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 Double Wall Technique (DWT) had a maximum underestimation of 1.3% of the corroded surface area of the pipe and was within an accuracy of ± 0.29. 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 DWT without the costly removal of insulation material.
Keywords: Double Wall Radiography, Corrosion, Insulated Pipe, Ir-192, Attenuation Coefficient.

1. 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 (Bardal & Drugli. 2004)

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 (Recommended practice. 2000). 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 parameters impact greatly on material loss (Callister. 2000). 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, concrete or 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 (Fengqi. 2005).

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 Double Wall radiographic technique 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.

2. 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 (Technical Document. 2000). 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.

Using beer's law for a pipe

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

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

For insulated empty pipe with deposit ($X_m = 0$):

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

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

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

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

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.

3. Experimental Procedure

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

3.1. 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% (Final Report. 2008).

3.2. Insulation and Deposit Material

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

3.3. 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.

3.4. Double Wall Technique

The double wall radiographic technique set-up for the pipe had source positioned perpendicular with respect to the pipe axis projecting the double wall of the pipe on the radiographic film. Here the steps on the pipe (erosion corrosion) and the size of the pits diameter are captured on the film (Final Report. 2008). A source-film-distance of 1450.00 mm was used with exposure times of 32, 38, 43, 68 and 78 seconds. The density transmission applied in the double wall technique configuration was the classical density measurement radiography where the gamma rays penetrate through two walls of the pipe tube placed between source and film. On the side of the pipe, the steps were kept for comparison of density with the defect density.

4. Results

The results of the experiment for the exterior composite pipe geometry and that of the interiorly machined pipe including insulation are shown in table 3 and 4 respectively. Table 5 shows the comparison between the actual pit diameter and measured mean diameter. Figure 10 and 11 compare the average film density with the various exposure conditions of the exteriorly and interiorly machined pipes respectively. Variation of film density against thickness at different exposure conditions is shown in figure 12.

4.1. Discussion

Insulation on pipes 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. The density readings for the non-insulated pipe with deposit for the traversed thickness of 28.00 mm, 34.60 mm, 36.80 mm and 41.20 mm were analogous to the case of insulated pipes with deposit of traversed thickness 58.00 mm, 64.60 mm, 66.80 mm and 71.20 mm. This is also seen from the closeness of density values recorded for the interiorly machined pipe with the various exposure conditions. From the trend line equations of both the exteriorly machined pipe $(y = 15.257e^{-0.054x}, y = 72.374e^{-0.053x})$ and that of the interiorly machined type $(y = 5.517e^{-0.056x}, y = 31.149e^{-0.055x})$, from the exponential equations, the attenuation coefficient of both the insulated and non-insulated pipe for the two types of machining were near to zero difference. This is indicative of the fact that the insulating material had negligible attenuation coefficient on the incident radiation. Variations with the build-up factors (15.257, 72.374, 5.517 and 31.149) are as results of the differences in thickness of the material. DWT is useable where the radiation absorption of the insulating material is less than the absorption by the pipe (Kulkami et al. 2005).

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. The density (mass per unit volume) of concrete was much higher than the insulating material (fibre wool) hence attenuate much better than the insulator. This was what informed the increase in much higher exposure time for the concrete deposit in order to have a good radiographic record on the film for interpretation.

The DWT slightly underestimated the radiographic readings with 1.3% being the maximum underestimated corroded surface area of the pipe, this marginal underestimation of the corroded surface is as a result of the horizontal projection and the finite dimension of the radioactive source and these lead to an appearance of a penumbra or unsharpness on the film. The extension in the exposure time for the various exposure conditions were based on combination of absorption or attenuation coefficient of the concrete deposit, insulating material and the thickness of the pipe (relaxation length).

5. Conclusion

The main objective of this paper is to explore the radiographic technique (DWT) 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:

The double wall technique was successful in evaluating corrosion attack across both the inner and the outer surfaces of the insulated pipe. This means pipes can always be insulated when the need arises and will never interfere with the technique in accessing its interior and exterior profile. The marginal underestimation (1.3%) of the corroded will not in any way undermine the usefulness of DWT in evaluating corrosion in pipes. 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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Table 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

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

Table 3. Parameter of Exteriorly Machined Pipe, Deposit and Insulation using Double Wall Technique.

EXTERIOR + DEPOSIT + INSULATION TIME OF EXPOSURE: 78 sec.
SOURCE FILM DISTANCE (SFD): 1450 mm DOUBLE WALL METHOD

Step	Thickness Traversed (mm)	Mean Density of Step Block	Standard Deviation	Standard Error	Relative Percentage Error	Mean Density Values
Step 1	58.00	3.50	0.132	0.05	1.43	3.50 ± 0.285
Step 2	60.10	2.83	0.066	0.02	0.88	2.83 ± 0.145
Step 3	62.50	2.59	0.099	0.04	1.44	2.59± 0.185
Step 4	64.60	2.29	0.210	0.08	3.47	2.29 ± 0.211
Step 5	66.80	2.04	0.096	0.04	1.78	2.04 ± 0.225
Step 6	68.90	1.85	0.093	0.04	1.90	1.85 ± 0.180
Step 7	71.20	1.69	0.076	0.03	1.70	1.69 ± 0.140

Table 4. Parameter of Interiorly Machined Pipe and Insulation using Double Wall Technique.

EXTERIOR + DEPOSIT + INSULATION TIME OF EXPOSURE: 78 sec.
SOURCE FILM DISTANCE (SFD): 1450 mm DOUBLE WALL METHOD

Step	Thickness Traversed (mm)	Mean Density of Step Block	Standard Deviation	Standard Error	Relative Percentage Error	Mean Density Values
Step 1	58.00	3.50	0.132	0.05	1.43	3.50 ± 0.285
Step 2	60.10	2.83	0.066	0.02	0.88	2.83 ± 0.145
Step 3	62.50	2.59	0.099	0.04	1.44	2.59± 0.185
Step 4	64.60	2.29	0.210	0.08	3.47	2.29 ± 0.211
Step 5	66.80	2.04	0.096	0.04	1.78	2.04 ± 0.225
Step 6	68.90	1.85	0.093	0.04	1.90	1.85 ± 0.180
Step 7	71.20	1.69	0.076	0.03	1.70	1.69 ± 0.140

Table 5. Parameter of Exteriorly Machined Pipe, Deposit and Insulation with comparison between Actual Pit Diameter and Measured Mean Diameter using Double Wall Technique.

EXTERIOR + DEPOSIT + INSULATION EXPOSURE TIME: 78 Sec.
SOURCE FILM DISTANCE: 1450 mm DOUBLE WALL METHOD

Step	Actual Pit Diameter (mm)	Measured Mean Pit Diameter (mm)	Standard Deviation	Standard Error
Step 1	3.00	2.86	0.089	0.03
Step 2	3.20	3.16	0.072	0.03
Step 3	4.00	4.02	0.047	0.02
Step 4	4.50	4.44	0.065	0.02
Step 5	5.00	4.98	0.048	0.02
Step 6	6.00	5.92	0.034	0.01
Step 7	7.00	6.98	0.062	0.02

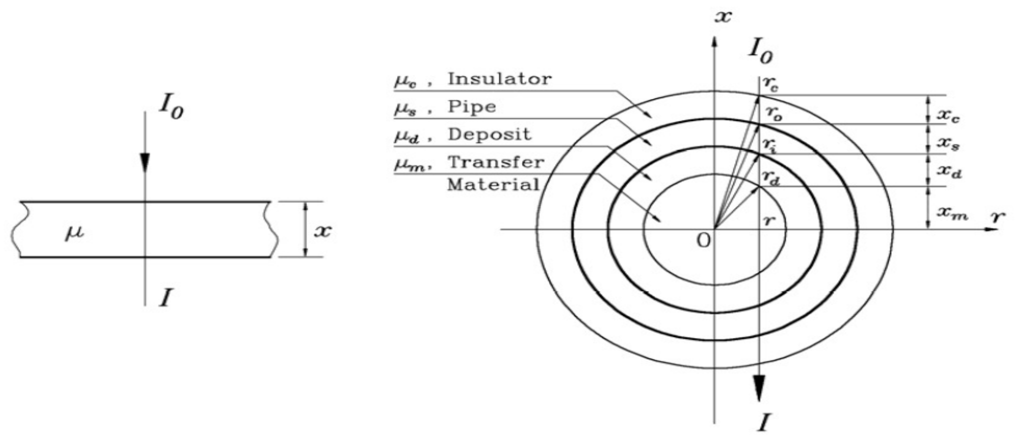

Figure 1. Attenuation coefficients for different layers in a typical pipe with deposit on the internal diameter and insulation on the outer diameter.

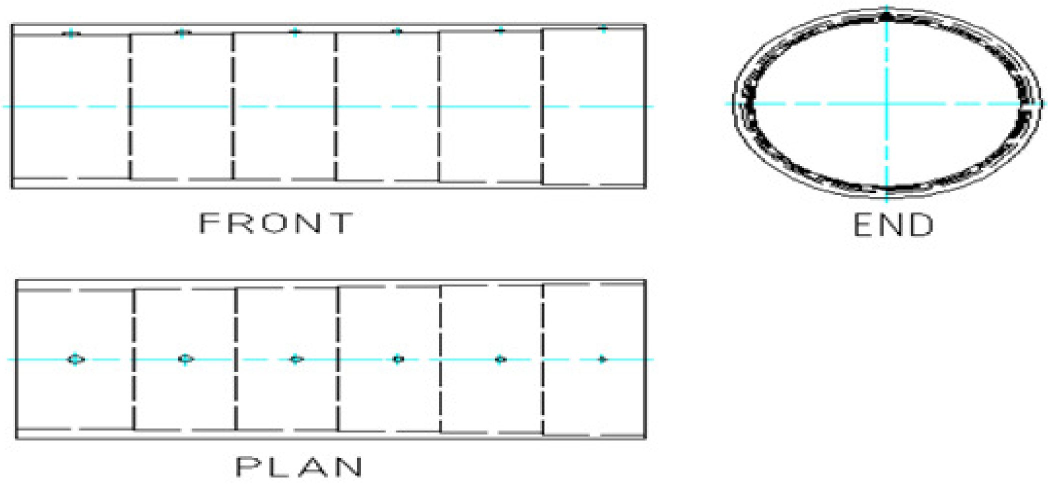

Figure 2. Orthographic views of the interiorly machined pipe

Figure 3. Interiorly machined pipe (test pipes)

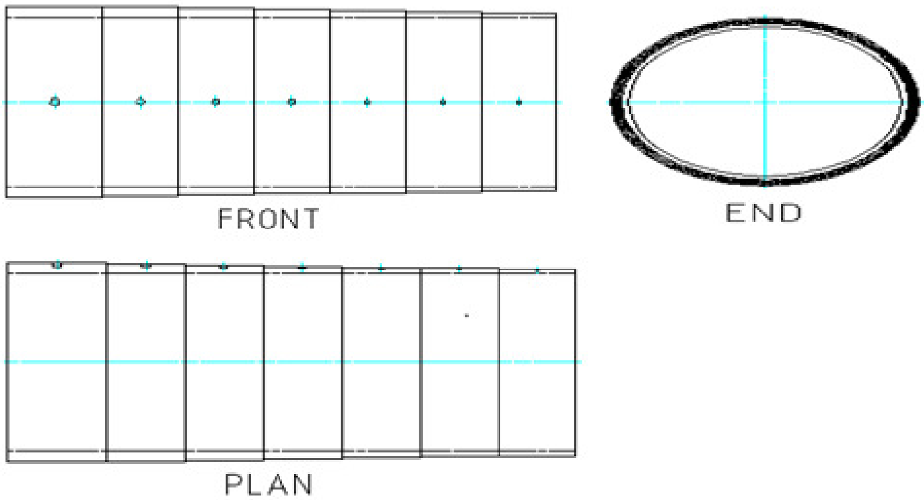

Figure 4. Orthographic views of the exteriorly machined pipe

Figure 5. Exteriorly machined pipe (test pipes).

Figure 6. Fibre wool insulating material

Figure 7. Gamma Ray Source (Ir-192)

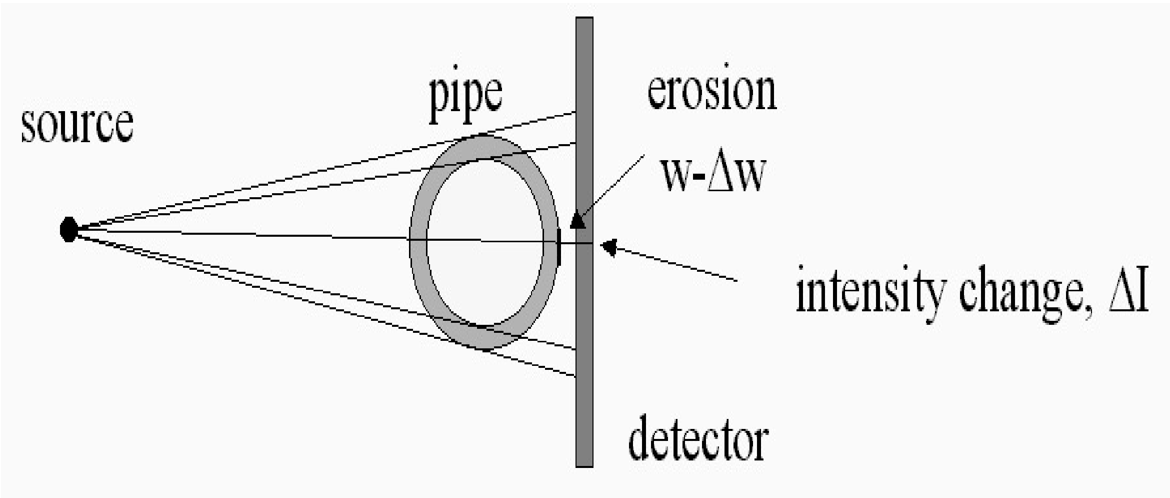

Figure 8. Density Evaluation in the Double Wall Technique.

Figure 9. Reading of Radiographic film (Radiograph) in the dark room.

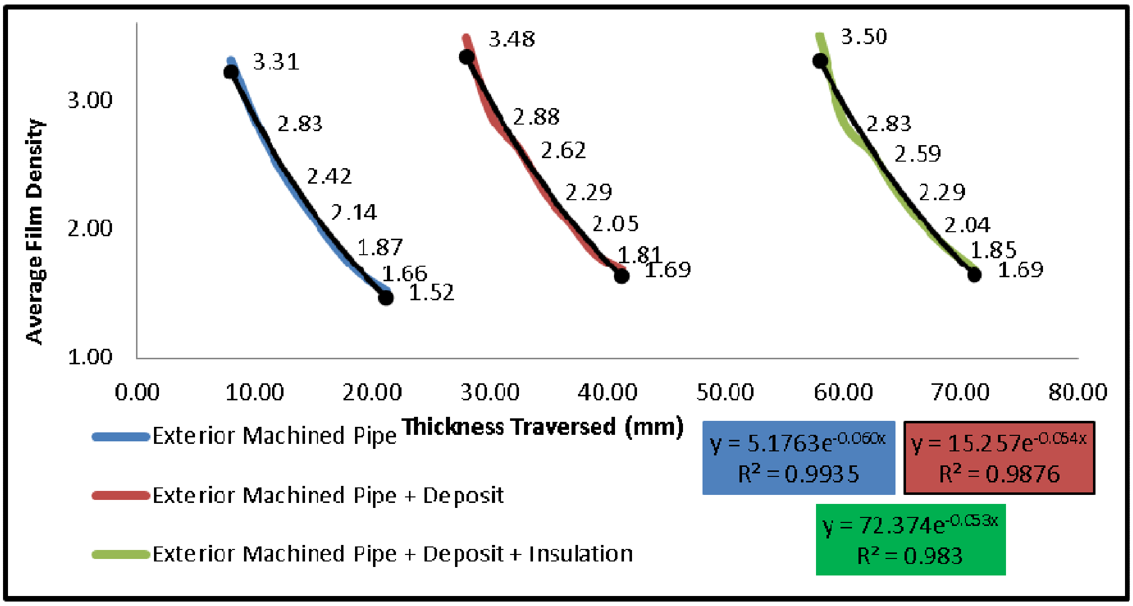

Figure 10. Exteriorly Machined Pipe (Step Block) with various Exposure Conditions.

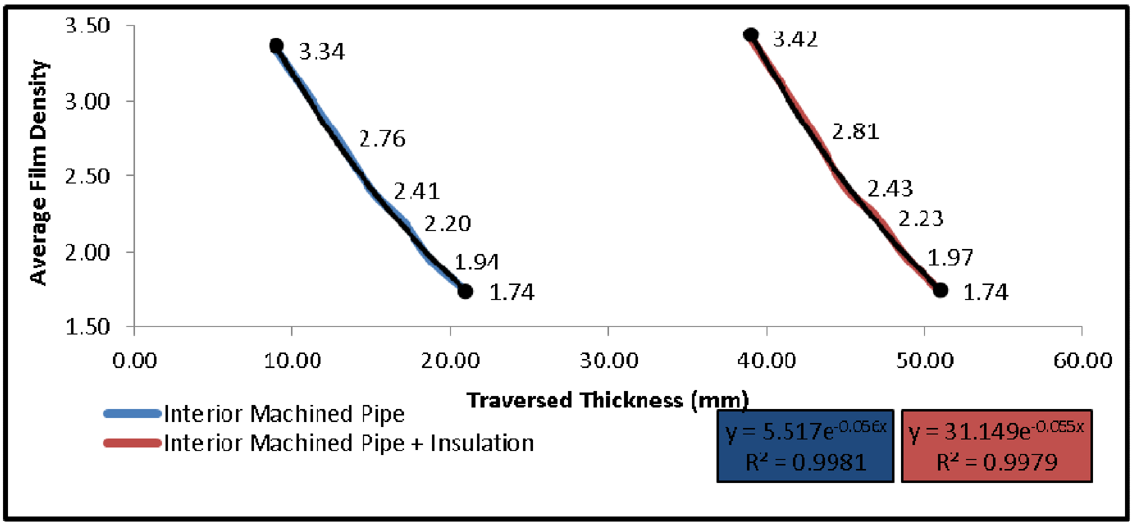

Figure 11. Interiorly Machined Pipe (Step Block) with various Exposure Conditions.

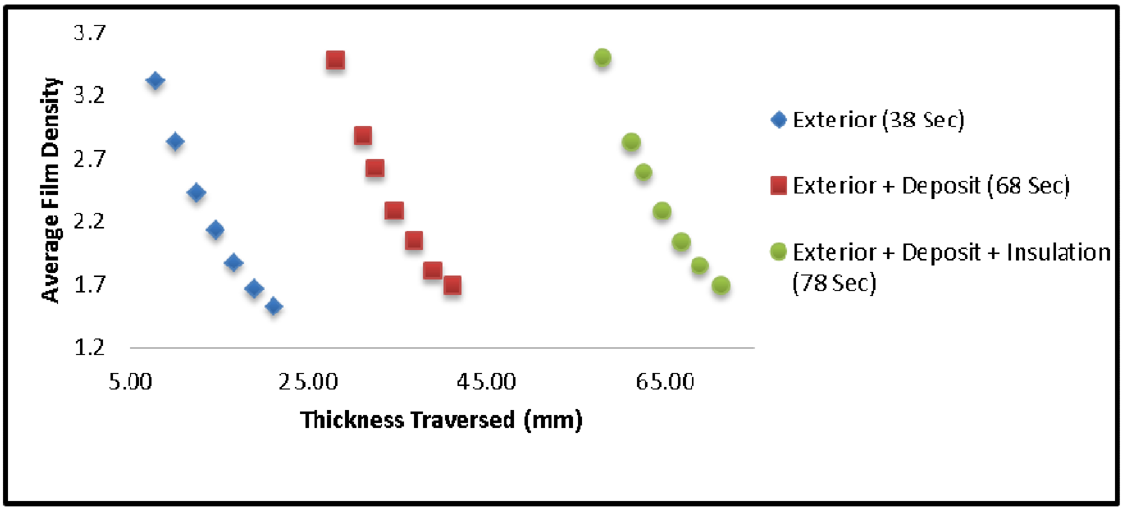

Figure 12. Density variation against Thickness at different Exposure Conditions by DWT

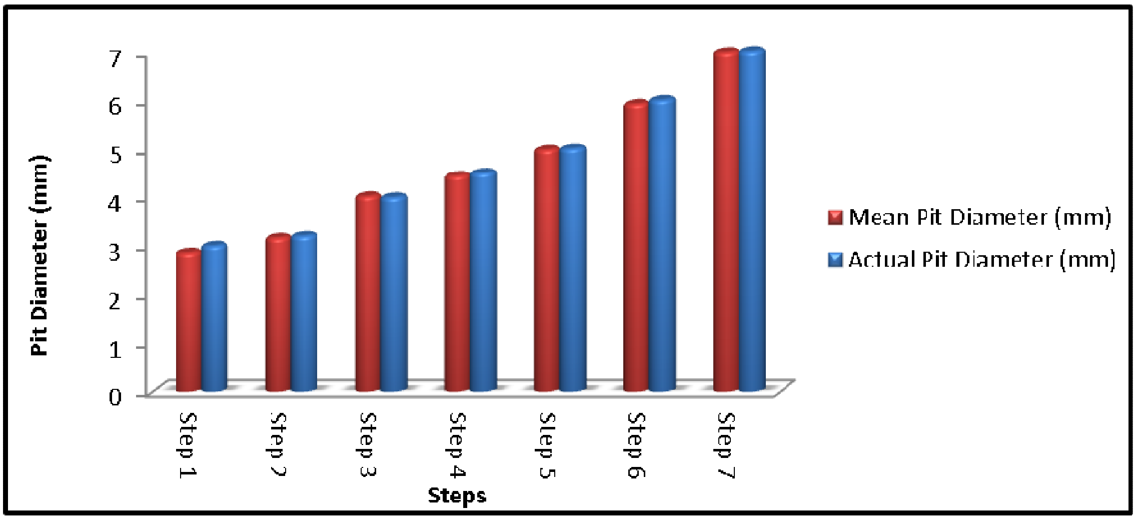

Figure 13. Comparison between Actual and Mean Pit Diameter by DWT.

Acknowledgement

1. Mr. Isaac Lawson
2. Mr. Edward Kumi Diawuo
3. Mr. Jerry Kwaku Ashong
4. Mr. Psalmiel Nana Kwabena Nti Agyei
5. Mr. Daniel Kwesi Awuvey

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