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Study of Corrosion Rate of Low and Medium Carbon Steel Pressure Vessel in Nigeria Oil and Gas Industry Using Ultrasonic Testing (UT) and Phase Array Ultrasonic Testing (PAUT) Method

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Abstract

This investigation was conducted on two on-stream test separators that were exposed to similar damage mechanisms. The test separators were constructed with low and medium carbon steel BS 1501-224-490BLT50 and SA 516 Gr 70 materials respectively. Thirteen and twelve years respectively of thinning and diminution of the test separators wall thickness data was collected to establish their corrosion rates (both short and long term) and their remaining life using manual contact ultrasonic test. Low and medium carbon steel test separators corrosion rates were evaluated using UT and PAUT. From the results obtained, the short-term corrosion rate for both low and medium carbon steel test separators was observed to be higher than the long-term corrosion rate. The estimated corrosion rates of the inspected vessels are in excess of 0.125mm/year prescribed by API 510 code. These high corrosion rates can be attributed to the aggressive working conditions of the vessels. The results of the study showed that the remaining life of the test separators can be safely and accurately predicted with the short-term corrosion rate.

1. Introduction

Pressure vessels are containers designed to hold gases or liquids at pressure substantially different from ambient pressure [1]. Pressure vessel components are designed for long service life under continuous use; however, premature failure may occur. Hence material degradation, corrosion, erosion, fatigue, operational and maintenance errors are common factor for engineering components failure [2]. Therefore, selection of materials and manufacturing processes are important activities that are essential for pressure vessel design [3]. A material resistance to corrosion is probably the most important factor that influences its selection for a specific application. The most common method that is used to address corrosion in pressure vessels is to specify a corrosion allowance level [2]. Corrosion allowance is a supplementary metal thickness that is added to the minimum thickness that is required to resist the applied loads. This added thickness compensates for thinning (i.e., corrosion) that will take place during service [4]. Predicting the remaining operating life of test separators that has been in oil and gas service for many years is a problem faced by many companies [5]. The problem is especially severe for those companies whose plants have been in service for 20 to 30 years or more and are approaching their design life expectancy [6]. The materials used in pressure vessels in oil and gas industries are carbon steels, low alloy steel and stainless steel. Carbon is the most common alloying element in steel. It is inexpensive and has a strong influence on hardness and strength. It is the basic and essential alloying element in all plain-carbon, low-alloy, and tool steels [5]. Hence the amount of carbon content in the steels used for the construction of the Test Separator form the basis for the comparison of the corrosion rates of the materials in order to ascertain which of the plates has long remaining life while subjected under similar condition of service.

2. Methodology

2.1 Materials

The pressure vessel separators for this project were three-phase test separators used to separate gas, oil and water to a level and provide accurate measurement of each the product phase. The material used for this study is made up of carbon (low and medium) steel pressure vessel located in Oil and Gas offshore facilities in Nigeria and the chemical composition of the pressure vessel is as shown in Table 1 and the equipment used for this research work were: Parametric 37DL Ultrasonic Testing Meter, SonatestSitescan D10+ Ultrasonic Testing Meter, Olympus MVX Phase Array Ultrasonic Testing (PAUT) machine, Thermo Fisher PMI (Positive Material Identification) machine, Corrosion Coupon, Couplants (grease, magnaflux and water), Laptop with Tomoview software capability.

2.2 Method

2.2.1 Sample Preparation.

The mechanical design of the two test pressure vessels separators was cylindrical shell with a size of 914.4 mm by 6,096mm in diameter and length respectively for vessel made of medium carbon steel (SA 516 Gr 70) and 2,007 mm by 7,620mm in diameter and length respectively for vessel made of low carbon (BS 1501-224-490BLT50) steel. The detailed reliability parameters of the two test separators are given in Table 2. Pressure vessel steels were constructed of steel plate of positive dimensional tolerances. The test separators remaining wall thickness data reading in Table 3, starting from 1993 to 2005 was collected as raw data while from 2007 to 2014, I participated in the data collection on the two pressure vessels. From 2015 to 2017, Phase Array Ultrasonic Testing was employed in the data acquisition.

2.2.1 Data Collection

Thinning and diminution of the wall thickness of the two pressure vessels separators were being monitored after their placement in-service in a space of thirteen years (for separator A) and twelve years (for separator B) to establish their corrosion rates (both short term and long term) and their remaining life. These parameters were considered as part of the prediction and rejection criteria used to ascertain the life span and usage worthiness of the two pressure vessels used during corrosion data gathering in order to get complementary data. The data collected using conventional method was done using two different ultrasonic testing equipment i.e Olympus 37D and Sitescan D10+ manufacture by Olympus and Sonatest respectively. The contact and normal beam techniques were employed during the data collection. Calibration of equipment was ensured before taken to the field for data collection. During data collection, CML points were selected on the vessel and the couplant (grease) applied at those points. The probe was then pressed gently on the couplant on the vessel to scan the area and the lowest reading on the display unit recorded as the thickness of the material of the vessel at that point.

2.2.2 Direct Thickness Measurement Determination Using Conventional UT Method

Data collection was done using two different ultrasonic testing equipment; Olympus 37D and SonatestSitescan D10+ respectively. For consistency of data collection, as per API 510 requirement for pressure vessel thickness monitoring a Condition Monitoring Locations (CML) measuring

152mm X 254mm were marked on the vessel and thickness measurement was taken on the same CML consistently. The pressure vessel was monitored by performing a representative number of examinations at CMLs to satisfy the requirements for an internal or on-stream inspection [1]. The thickness for pressure vessel shell plates were measured and recorded Corrosion rates, the remaining life and next inspection intervals were calculated to determine the limiting components. Pressure vessels with high potential consequences of failure, those subjected to higher corrosion rates, localized corrosion and high rate of damage from other mechanism of corrosion had more CMLs and were monitored frequently. The rate of corrosion damage was determined from successive measurements and the next inspection interval appropriately established. The thinnest reading or average of several measurement readings was taken within the area of the examination point, recorded and used to calculate the corrosion rates. CMLs and examination points were permanently recorded (i.e. marks on the inspection drawings and on the pressure vessel) to allow for repetitive measurements on the same CMLs. Repeated measurements at the same location improves the accuracy of the calculated damage rate. While using 37D and Sitescan D10+ for thickness gauging on vessel shell, couplant (grease) was applied covering the entire CML prior to placement of transducer for thickness data acquisition. The use of couplant was to eliminate air at the transducer and vessel plate interface. The probe was then pressed gently on the couplant and the CMLs were scanned with 10% overlap of the transducer footprint. The minimum reading in each CMLs that was displayed on the UT meter screen were recorded as the remaining thickness of the pressure vessel. Thickness was measured in echo-to-echo (without the thickness of external coating) at that point. The bottom sides of the vessels were noted to show reduction in thicknesses, hence the spot that shows lower thickness reading at the bottom sides of the two test separators were considered for this analysis.

2.2.3 Direct Thickness Measurement Determination Using Phase Array Ultrasonic Testing (PAUT) Method

Data collection was done using an advance ultrasonic corrosion mapping tool known as Phase Array Ultrasonic Testing (PAUT) equipment manufactured by Olympus to scan the bottom section of the vessel and enhance data accuracy by accurately locating the point of lowest thickness and to monitor corrosion propagation in the vessel plate and also to map out the extent of internal corrosion in the vessels as that was area susceptible to relevant damage mechanism. The vessel shells were gridded at spacing of 50mm along the vessel shell length (from one head of the vessel to the other) and circumferential length of 610mm for Separator A and 1220mm for Separator B. The variation in grid circumferential length was as a result of variation in diameter of the two separators. The 50mm grids were numbered from 0 to 6096mm for Separator A and 0 to 7874mm for Separator B. The PAUT Encoder (transducer) was coupled to the separator shell plate using eight magnet wheels starting from 0 datum of the grids marked on the separators shell plate. A continuous stream of water was supplied to the encoder via 4mm internal diameter rubber hose as couplant and was rolled along the 50mm grids circumferentially with 10mm overlap between each scam for proper coverage. The data acquired by the PAUT transducer as its being rolled circumferentially was displayed on the screen on of Ominiscan MVX in the form of three display (A-scan, B-Scan and C-Scan). PAUT technique uses color code to represent variation of plate thickness. The data is downloaded from the Ominiscan MVX unto a Laptop for analysis using a 'Tomoview' software for determination of area of the vessel with lowest remaining wall thickness which was then used for determining of the separator remaining life. After the analysis with Tomoview software, the scanned images were merged together to represent internal condition of the scanned area of the separator bottom section as shown in Plate 1and 2. The blue area on Plate 1 and 2 represent areas of the plate with higher thickness, while low thickness (corrosion) area is represented by colors other than blue (e.g. cyan, viridian, yellow, red etc.). Areas with the lowest thickness on each Test Separator plates were represented in yellow color. The thickness readings from 2014 to 2017 on Table 3 was obatined using this technique. All equipment aforementioned employed during the data collection are volumetric methods using normal beam pulse-echo ultrasonic techniques.

3. Results and Discussion

3.1 Results

Table 1: Chemical analysis of the Pressure Vessels Material

Chemical Composition	**Test Separator A (Medium Carbon Steel Test Separator)**		**Test Separator B (low Carbon Steel Test Separator)**	
Alloy Elements	Vessel Manufacturer	PMI Reading	Vessel Manufacturer	PMI Reading
C	0.28%	_	0.22%	_
Si	0.15-0.40%	0.390%	0.10-0.40%	0.370
Mn	0.85–1.20%	1.180%	0.90 – 1.60%	1.580
P	0.035 %	0.035%	0.030 max	0.028
S	0.035 %	0.034%	0.030 max	0.027
Al	-		0.015 min	0.018
Cr	-		0.25 max	0.023
Cu	-		[5] 0.30 max	0.029
Mo	-		[5] 0.10 max	0.099
Ni	-		[5] 0.75 max	0.730

Table 2: Detailed Reliability Parameters of the Two Test Separators

Reliability Data	**Test Separator A** **(Medium Carbon Steel Test Separator)**	**Test Separator B** **(low Carbon Steel Test Separator)**
Material of construction	SA 516 Gr 70	BS 1501-224-490BLT50
MAWT	343°C	100°C
Diameter	914.1 mm (36'')	2,006.6mm (79'')
Length/Height	6,096 mm	7,620mm
MAWP	27.579 bar (400psi)	10.48 bar (152psi)
MDMT	0°C	20 °C
MDMT Press	34.474 bar	10.48 bar
Operating Press	8.963 bar	3.45bar
Stress value	1296.214bar (18800psi)	1282.424 bar (18600psi)
Operating Temp	32°C	29.44 °C
Original Test Press	51.711 bar	15.72 bar
Year Built	1968	1993
Radiographic examination of weld joint	RT2	Full
E (Joint Efficiency value)	0.85	1.00
Shell plate thickness	29.00 mm	13 mm
Corrosion Allowance	3.175 mm	3 mm
Carbon Dioxide (CO)	1.43 mole %	0.62mole %
Hydrogen Sulphide (H_2S)	4.00 ppm	2.00 ppm
Dissolve Oxygen Present	Yes (max Allowable 10ppb)	Yes (max Allowable 10ppb)
pH	7.5	7.4
Presence of Bacterial	Sulphur reducing bacterial (SRB)	Sulphur reducing bacterial (SRB)
Presence of Anode	NA	NA
Internally coated	NA	NA
Water Cut	40%	32%
Service Consideration	Clean/sweet	Clean/sweet

Table 3: Inspection year and wall thickness survey for Test Separators A and B using UT

Inspection Year	Test Separator "A" Thickness in Millimeter (Medium carbon Steel)	Test Separator "B" Thickness in Millimeter (Low Carbon Steel)
1968	29.00	-
1993	25.72	13.00
1997	25.20	12.79
2000	23.55	12.58
2001	23.00	12.32
2005	20.20	11.28
2007	18.80	11.00
2010	17.87	10.58
2012	16.98	10.26
2014	16.12	9.93
2015	15.67	9.36
2016	15.47	8.80
2017	15.27	8.53

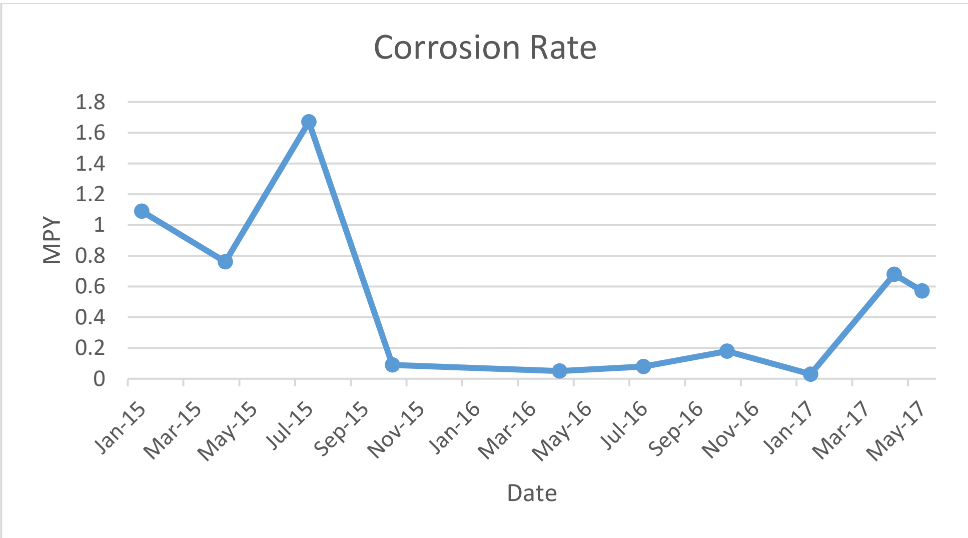


Figure 1: Corrosion Rate against the Date on Test Separator A (Medium Carbon Steel)
Shows gradual and fairly uniform weight loss over a period of time.

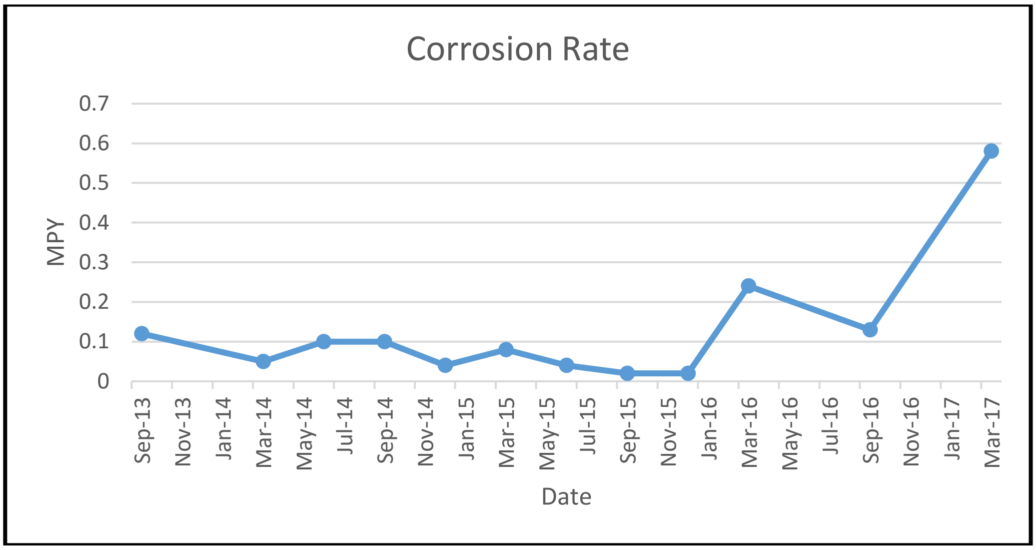


Figure 2: Corrosion Rate against the Date on Test Separator B (Low Carbon Steel)

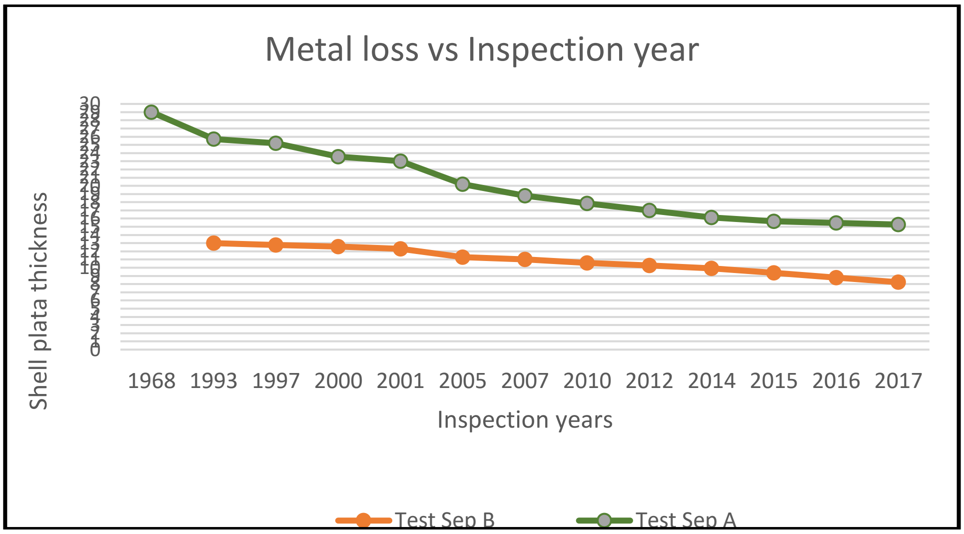
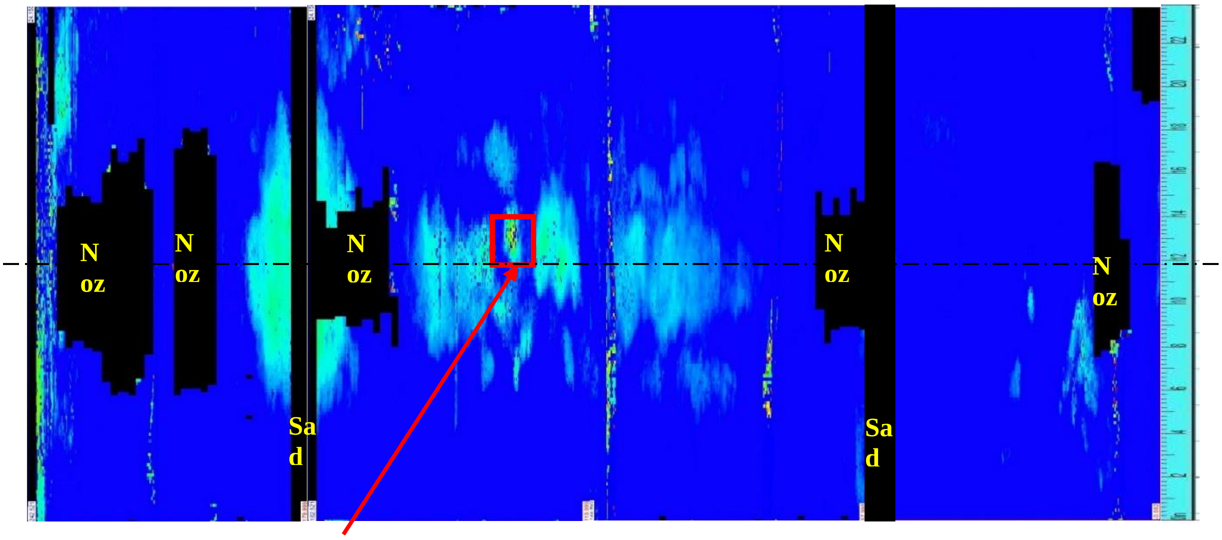
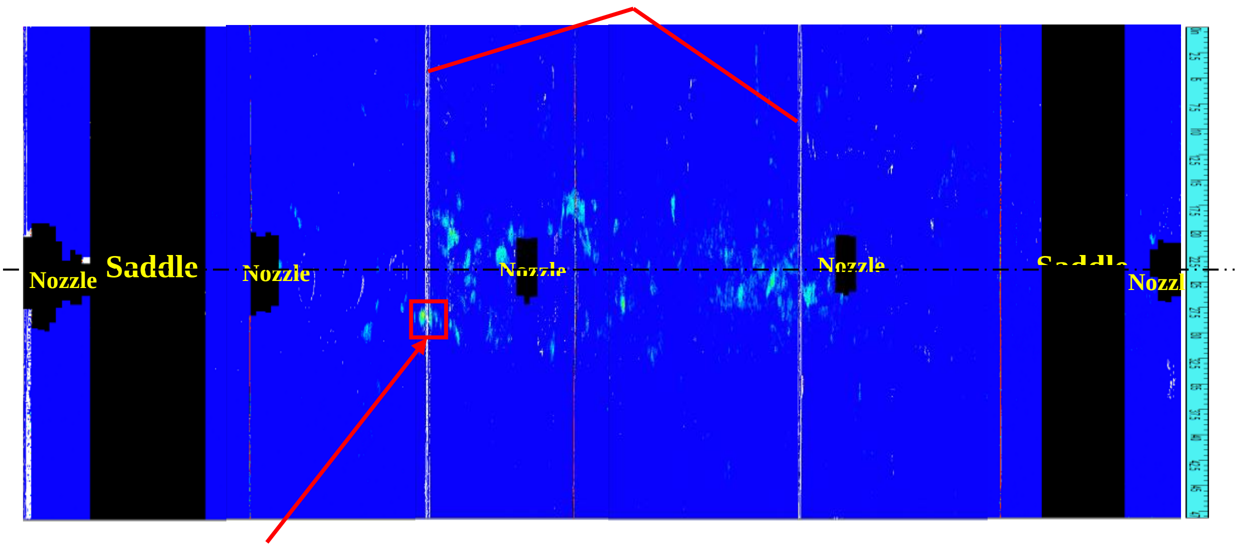


Figure 3: Graph of thickness survey results of Test Separators A and B



Lowest thickness area. 15.180mm

Plate 1. Internal condition of the bottom side of Test Separator A with lowest thickness of 15.180 mm as examined with PAUT



Lowest thickness area at circumferential seam. 8.230mm

Showing scattered spots of pitting corrosion as revealed by PAUT scan on bottom

Plate 2 Internal condition of the bottom side Test Separator B with lowest thickness of 8.230mm as examine with PAUT.

3.2 Discussion

The result shown in Table 3 and in Figure 3 show that in oil and gas service medium carbon steel plate (test separator A) appeared to corrodes faster than low carbon steel plate (test separator B). This was possibly due to higher water cut which tend to hydrolyze other minerals particularly chlorides and thus forms acidic environment and the presence of H^+ which further accelerate corrosion, hence this translate to higher long-term corrosion rate for medium carbon steel Test

Separator than for low carbon steel Test Separator, the presence of silicon, copper and nickel as the constituent chemical composition of the low carbon steel test separator material in-turn made the material more corrosion resistance than the medium carbon steel Test Separator [6]. Toward the 2014 to 2017, the rate of corrosion for medium carbon steel Test Separator became steadier than that of low carbon steel Test Separator which therefore implies lower short-term corrosion for medium carbon and higher for low carbon steel Test Separator. This is in agreement with [1], who stated that, the long-term corrosion rate cannot be relied on in predicting accurately the remaining life of the test separators pressure vessels [1]. The most common method that is used to address corrosion in pressure vessels is to specify the corrosion allowance as stated by [3]. This allowance is supplemental metal thickness that is added to the minimum thickness that is required to resist the applied loads. This added thickness compensates for thinning (corrosion) that will take place during service. It is this allowance (added thickness) that helps in predicting the service life of a vessel in a particular working or environmental conditions [8]. The corrosion rate calculated assumes uniform corrosion across the coupon. Corrosion coupon results shown in Figure 1 and Figure 2 indicate gradual and fairly uniform weight loss over a period of time. This further confirm steady rate of corrosion in the separators indicated in Figure 3. Sharp changes in Figure 1 and Figure 2 could have been caused by faulty injection pump, considerable morphology of flow and change in process fluid chemistry. The image in Plate 1 and 2 represent internal condition of the bottom side of the test separators. For better probability of detection of defect, PAUT machine presents data, acquired in a fully color coded automatic real time regular A scan (time vs amplitude), B scan (side view), C scan (planar view) and D scan (end view). In C Scan image presentation in Plate 1 and 2, the blue area here, represents area of the vessel shell plate with higher thickness (no significant internal corrosion); whereas the areas with cyan color indicates area of decreasing thickness (area of internal corrosion). However, spots of lowest thicknesses are indicated by orange color in both Plate 1 and 2. PAUT corrosion mapping images in Plate 1 and 2 revealed that the reduction in thickness extremely occurred at the bottom sections of both test separators. Also, from Plate 1 and 2, it can be deduced that medium carbon steel plate is susceptible to general corrosion attack than low carbon steel. This was also confirmed by the research work carried out by [8] which stated that the corrosion degradation of low carbon steel occurs largely by pitting corrosion attack.

4. Conclusion

This paper shows that pressure vessels used in oil and gas services, composed of medium carbon steel plate appeared to corrodes faster than Low carbon steel plate (Test separator B). This was possibly due to higher water content which tend to hydrolyze other minerals particularly chlorides and thus forms acidic environment and the presence of H^+ which further accelerate corrosion; hence this translate to higher long-term corrosion rate for medium carbon steel Test Separator than for low carbon steel Test Separator. The results obtained indicated that in general, based on short term and long-term corrosion rate, the wall thickness of the test separators was decreasing fairly uniformly, which is an indication that uniform corrosion had occurred on the internal surface of the two separators but higher in test separator A. PAUT corrosion mapping images in Plate 1 and 2 revealed that the reduction in thickness extremely occurred at the bottom sections of both test separators. Also, from Plate 1 and 2, it can be deduced that medium carbon steel plate is susceptible to general corrosion attack than low carbon steel.

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