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DETERMINATION OF CORROSION RATE AND REMAINING LIFE OF PRESSURE VESSEL USING ULTRASONIC THICKNESS TESTING TECHNIQUE

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Abstract

Pressure vessels suffer a loss of mass and strength when corrosion occurs. Sound integrity of these vessels is a major factor in the oil and gas industry and Corrosion is one key component that affects the durability of such equipment.Ultrasonic thickness measuring instrument is used to accurately obtain the thickness measurement of these vessels to establish its corrosion rate and remaining life. These parameters are considered as part of the prediction and rejection criteria used to ascertain the life span and usage worthiness of LPG vessels. The outcome of the research work suggests that, the remaining life of LPG vessel cannot be safely and accurately be predicted with the short-term corrosion rate unless its year on year corrosion rate is uniform.

Keywords: *Pressure Vessel, Corrosion, Remaining Life, Ultrasonic Thickness Testing*.

1.0 Introduction

Structural failures in pipelines, reactors and pressure vessels can be observed in the everyday world. Failures such as these can be costly to the industry and most importantly, potentially dangerous and life threatening to people working in that environment. All these failures are subject to one common factor: Corrosion. Corrosion, especially rust, is one of the leading causes of failure in metal structures and objects.

Corrosion is an electrochemical reaction between a metal and its environment; it involves transfer of electrons and also requires an anode, cathode and an electrolyte. Materials suffer a loss of mass and strength when corrosion occurs. Sound integrity of equipment is a major factor in the oil and gas industry and Corrosion is one key component that affects the durability of this equipment (Boateng et al, 2013(a)). Rust is most commonly found in metallic objects in refineries, processing plants and oil fields and this is what is commonly seen after an object has corroded. For many industries, corrosion has become a constant evaluated cost that is assumed to happen and always factored into production costs. The total annual cost of corrosion in the oil and gas production industry is estimated to be $1.372 billion (CPV, 2014). While corrosion is considered a purely chemical process, it is of critical importance to any engineer designing components or structures that use metals.

A material's 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. 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 (Carucci, 1999).

Corrosion may cause a uniform loss (a general, relatively even metal loss of a surface area) or may cause a pitted appearance (an obvious, irregular surface metal loss). Uniform corrosion may be difficult to detect visually, and thickness measurements may be necessary to determine its extent. Pitted surfaces may be thinner than they appear visually, and when there is uncertainty about the original surface location, thickness determinations may also be necessary. Any suitable NDE technique, such as ultrasonic or profile radiographic examination, may be used as long as it will provide minimum thickness determinations (Boateng et al, 2013(b)). The depth of corrosion may be determined by gauging from the uncorroded surfaces within the vessel when such surfaces are in the vicinity of the corroded area. Ultrasonic thickness measuring instruments usually are the most accurate means for obtaining thickness measurements.

Figure. 1. Condition of a Corroded Pressure Vessel.

2.0 Theoretical Analysis

2.1 Corrosion Rate Determination

2.1.1 Existing Pressure Vessels

Corrosion rate for thinning damage mechanisms is determined by the difference between two thickness readings divided by the time interval between the readings. The determination of corrosion rate may include thickness data collected at more than two different times. Suitable use of short-term versus long-term corrosion rates is determined by the inspector. Short-term corrosion rates are typically determined by the two most recent thickness readings whereas long-term rates use the most recent reading and one taken earlier in the life of the equipment. These different rates help identify recent corrosion mechanisms from those acting over the long-term.

Condition monitoring locations (CMLs) are designated areas on pressure vessels where periodic examinations are conducted to monitor the presence and rate of damage. The type of CML selected and placement of CMLs includes the potential for localized corrosion and service-specific damage. Some of the CMLs include locations for thickness measurement, locations for stress cracking examinations, and locations for high temperature hydrogen attack examinations (API 510, 2006).

The long-term (LT) corrosion rate of the vessel was determined within the period of five years and was calculated from the following formula:

$$Corrosion\ rate\ (LT) = \frac{t_{initial} - t_{actual}}{\text{time between } t_{initial} \text{ and } t_{actual}\ (years)}$$

The short-term (ST) corrosion rate was evaluated within one year and was calculated from the following formula:

$$Corrosion\ rate\ (ST) = \frac{t_{previous} - t_{actual}}{\text{time between } t_{previous} \text{ and } t_{actual}\ (years)}$$

Where

$t_{initial}$ = The initial thickness at the same Condition Monitoring Location (CML)as t_{actual}. It’s either the first thickness measurement at this CML or thickness at the start of a new corrosion rate environment, in (mm).

t_{actual} = The actual thickness of a CML, in (mm), measured during the most recent inspection.

$t_{previous}$ = The previous thickness measured during the prior inspection. It is at the same location as t_{actual} measured during a previous inspection, in (mm).

2.1.2 Newly Installed Pressure Vessels or Change in Service

For new vessel or for a vessel for which service conditions are being changed, the remaining life calculation methods is used to determine the vessel’s probable corrosion rate. The remaining life and can be estimated from this rate.

2.1.2.1 Remaining Life Calculation

The remaining life of the vessel (in years) was evaluated from the following formula:

$$Remaining\ Life = \frac{t_{actual} - t_{required}}{\text{Corrosion rate}}$$

$where$

t_{actual} = The actual thickness of a CML, in (mm), measured during the most recent inspection.

$t_{required}$ = The required thickness at the same (CML) or component, in (mm), as the t_{actual} measurement. It is computed by the design formula (e.g., pressure and structural) and does not include corrosion allowance or manufacturer's tolerances.

3.0 Data Analysis

Data collection was done using DM4E ultrasonic testing equipment manufactured by Krautkramer. The contact and normal beam techniques were employed during the data collection. Calibration of equipment is always ensured before taken to the field for data collection. Fig. 2 and 3 show the calibration and the data collection processes respectively. During data collection, points were randomly selected on the vessel and the couplant (grease) applied at those points. The probe was then pressed gently on the couplant on the vessel and the reading on the display unit recorded as the thickness of the material of the vessel at that point.

3.1Condition Monitoring Location (CML)

The pressure vessel is monitored by performing a representative number of examinations at CMLs to satisfy the requirements for an internal or on-stream inspection. For example, the thickness for all major components (shells and heads) and a representative sample of vessel nozzles is measured and recorded. Corrosion rates, the remaining life and next inspection intervals are calculated to determine the limiting component.

Pressure vessels with high potential consequences if failure should occur, and those subject to higher corrosion rates, localized corrosion, and high rates of damage from other mechanisms, will normally have more CMLs and be monitored more frequently. The rate of corrosion/damage shall be determined from successive measurements and the next inspection interval appropriately established.

The thinnest reading or an average of several measurement readings taken within the area of an examination point are recorded and used to calculate the corrosion rates. CMLs and examination points are permanently recorded, (e.g. marked on inspection drawings and/or on the equipment) to allow repetitive measurements at the same CMLs. Repeating measurements at the same location improves accuracy of the calculated damage rate.

Figure. 2 Calibration of ultrasonic thickness gauge.

Figure. 3 Data collection by personnel

4.0 Results

Thinning and diminution of the wall thickness of four different LPG vessels were monitored in a space of five years to establish their corrosion rate (both short term and long term) and the remaining life. These parameters are considered as part of the prediction and rejection criteria used to ascertain the life span and usage worthiness of LPG vessels. The above stated parameters computed were based on the API 510, ninth edition (2006), the Pressure Vessel Inspection Code.

Table 1. Maximum and Minimum Thickness Readings of all the Investigated Pressure Vessels in the year 2006.

Pressure Vessel #	**Minimum Thickness (mm)**		**Maximum Thickness (mm)**	
	Head	Shell	Head	Shell
1	8.800	8.400	9.200	9.400
2	17.200	8.000	18.600	10.500
3	6.400	8.100	6.900	9.100
4	9.100	10.600	11.000	14.900

Sample calculations of parameters done on Pressure Vessel 1

$$Corrosion\ rate\ (ST) = \frac{8.400\ \text{mm} - 8.290\ mm}{2007\ \text{yr} - 2006\ \text{yr}} = 0.110\ mm/yr$$

$$Corrosion\ rate\ (LT) = \frac{8.400\ \text{mm} - 7.670\ mm}{2011\ \text{yr} - 2006\ yr} = 0.146\ mm/yr$$

$$Remaining\ Life = \frac{7.670\ \text{mm} - 6.030\ mm}{0.146\ \text{mm/yr}} = 11.2\ yrs$$

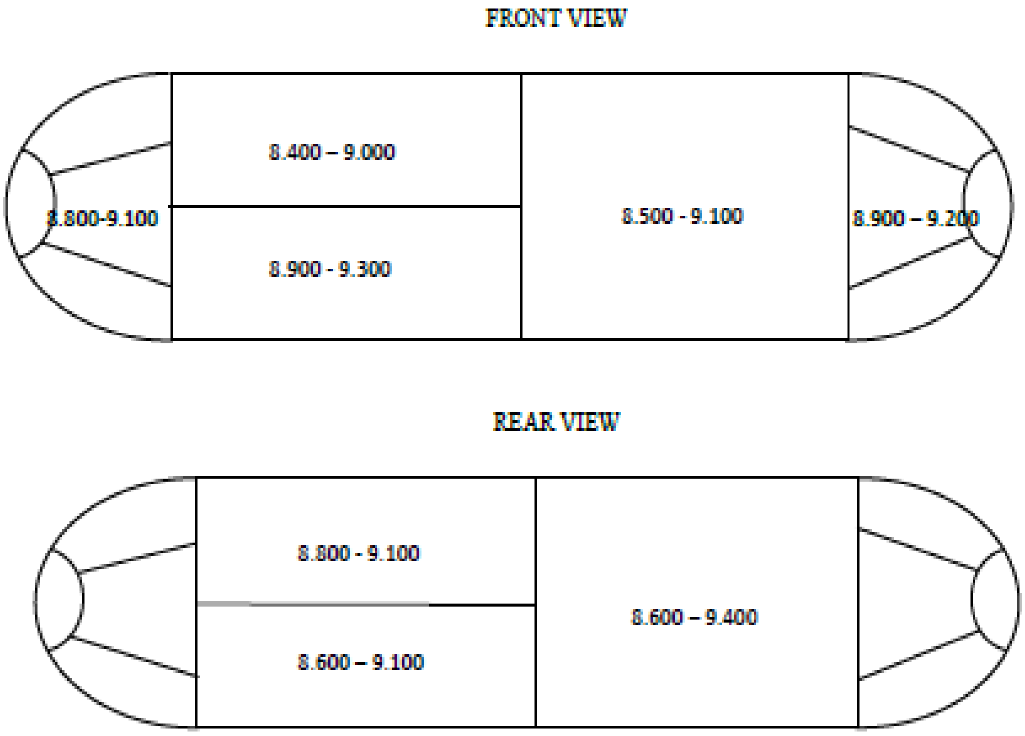

Figure 4. Schematic View of Pressure Vessel One

Vessel Parameter

- Serial #: 553-99
- Capacity # : 7570 litres
- Year Built : 1999
- Length : 6200 mm
- Circumference : 3850 mm
- Temperature : 115°F = 46.11°C
- Thickness of plate without corrosion allowance/tolerance = 6.030 mm

Table 2. Calculated Parameters of Pressure Vessel one

Pressure Vessel 1				
Year	**CML Shell/(mm)**	**Corrosion rate (mm/yr)**		**Remaining Life (yrs)**
		ST	**LT**	
2006	8.400	0.110	0.146	11.2
2007	8.290			
2008	8.130			
2009	7.940			
2010	7.790			
2011	7.670			

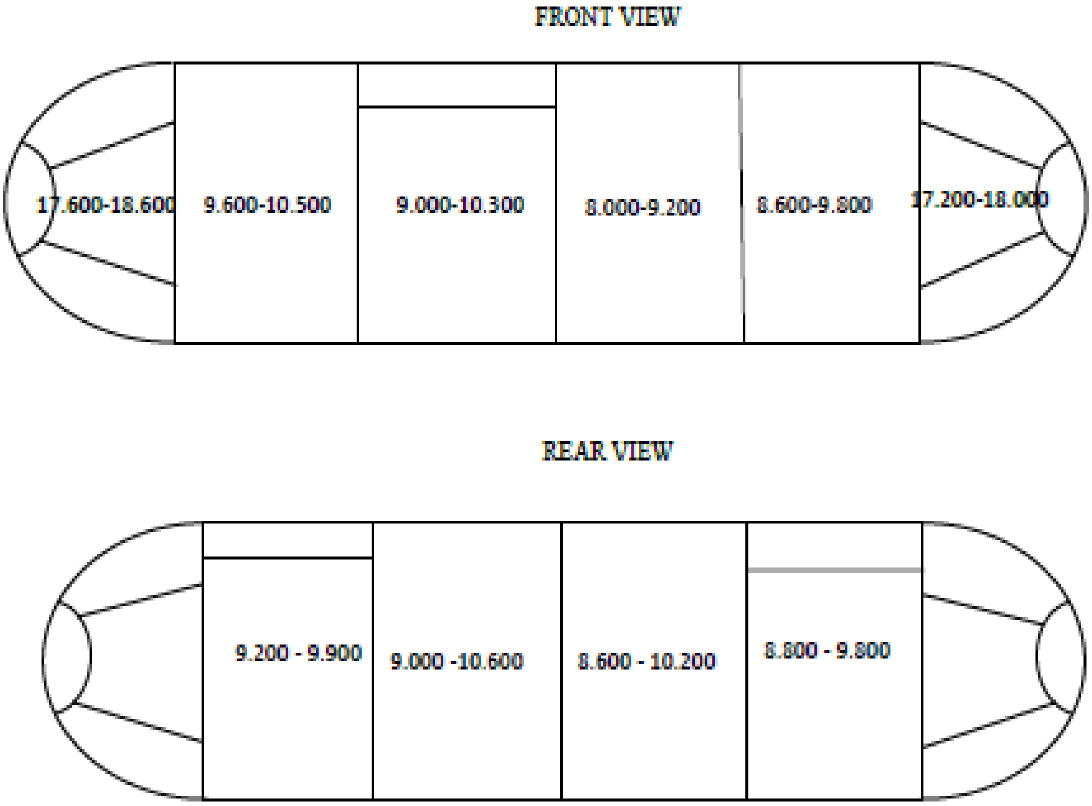

Figure 5.Schematic View of Pressure Vessel Two

Vessel Parameter

- Serial #: 64392
- Year Built : 1991
- Length : 9100 mm
- Circumference : 5050 mm
- Temperature : 110°F = 43.33°C
- Thickness of plate without corrosion allowance/tolerance = 7.090 mm

Table 3. Calculated Parameters of Pressure Vessel Two

Pressure Vessel 2				
Year	**CML Shell/(mm)**	**Corrosion rate (mm/yr)**		**Remaining Life (yrs)**
		ST	**LT**	
2006	8.000	0.100	0.108	3.4
2007	7.900			
2008	7.820			
2009	7.770			
2010	7.710			
2011	7.460			

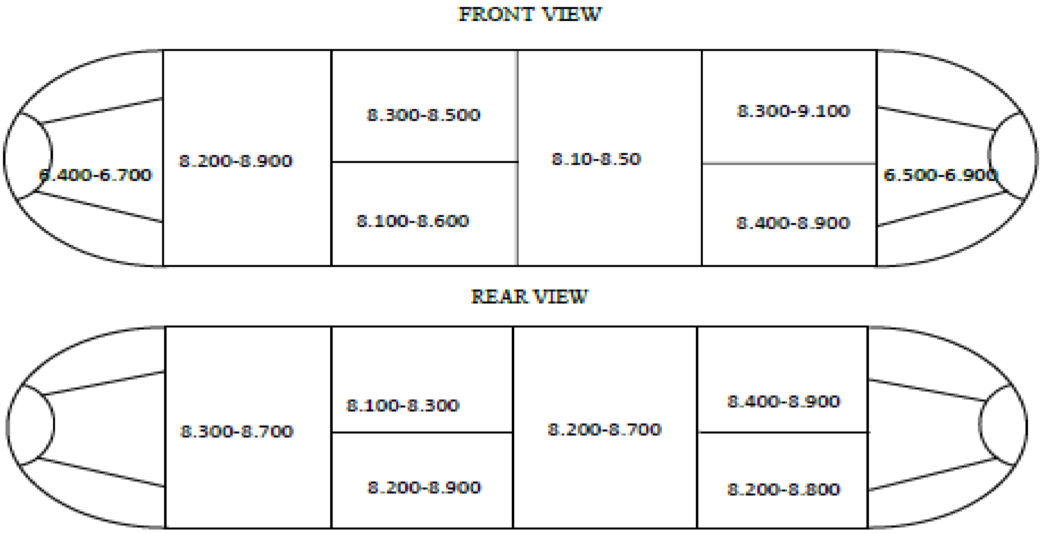

Figure 6.Schematic View of Pressure Vessel Three

Vessel Parameter

- Serial #: 567-99
- Capacity # : 3785 litres
- Year Built : 1997
- Length : 3900 mm
- Circumference : 3290 mm
- Temperature : 120^{o}F = 48.89^{o}C
- Thickness of plate without corrosion allowance/tolerance = 5.623 mm

Table 4. Calculated Parameters of Pressure Vessel Three.

Pressure Vessel 3				
Year	**CML Head/(mm)**	**Corrosion rate (mm/yr)**		**Remaining Life (yrs)**
		ST	**LT**	
2006	6.400	0.135	0.134	0.8
2007	6.265			
2008	6.190			
2009	6.090			
2010	5.980			
2011	5.730			

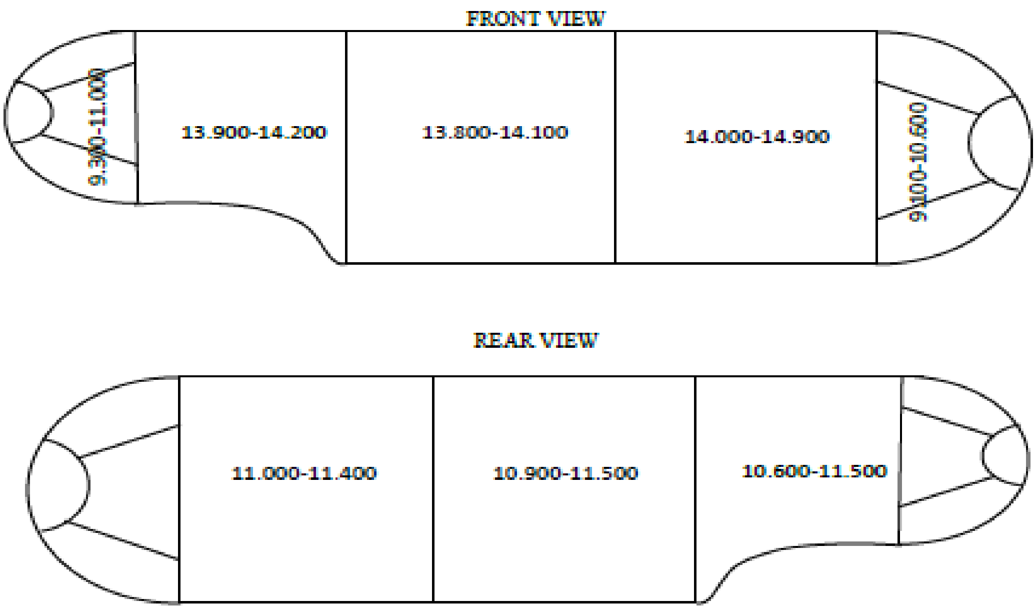

Figure 7. Schematic View of Pressure Vessel Four

Vessel Parameter

- Serial #: 49-98
- Capacity # : 37854 litres
- Year Built : 1998
- Length : 3900 mm
- Circumference : 6440 mm
- Temperature : 120^{o}F = 48.89^{o}C
- Thickness of plate without corrosion allowance/tolerance = 7.490 mm

Table 5. Calculated Parameters of Pressure Vessel Four.

Pressure Vessel 4				
Year	**CML Head/(mm)**	**Corrosion rate (mm/yr)**		**Remaining Life (yrs)**
		ST	**LT**	
2006	9.100	0.140	0.144	6.2
2007	8.960			
2008	8.840			
2009	8.710			
2010	8.580			
2011	8.380			

5.0 Discussion

The designated areas on the pressure vessels where periodic examinations were conducted to monitor the presence and rate of damage were the shell for vessel one and two and the head for vessel three and four. These CMLs become the critical areas on the vessels where failure (localized corrosion and service-specific damage) becomes probable. The corrosion mechanisms of all the inspected vessels with exception of vessel three had its long-term corrosion rate greater than the short-term corrosion rate. This implies that, the short term corrosion rate cannot be relied on in predicting accurately the remaining life of the vessels (1, 2 and 4). Vessel three had its year on year corrosion rate uniform (the closeness of short-term and long-term corrosion rates); hence one can use the short-term corrosion rate of such vessel to predict its remaining life.

The most common method that is used to address corrosion in pressure vessels is to specify the corrosion allowance. 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 of this allowance (added thickness) that helps in predicting the service life of a vessel in a particular working or environmental conditions. For example, in the year 2011, pressure vessel one, had its minimum wall thickness at CML to be $7.670\ mm$; based on long-term corrosion rate of $0.146\ mm/yr$, the remaining service life of the vessel is estimated as $11.2yrs$. This means, it will take $11.2yrs$ for the thickness of $7.670\ mm$ to be thinned to $6.030\ mm$ (thickness of plate without allowance / tolerance) at a corrosion rate of $0.146\ mm/yr$ when all other conditions remain constant.

Based on the API 510, ninth edition (2006), the corrosion rate of an on-stream inspection of a pressure vessel should be less than $0.125\ mm/yr$. The estimated annual corrosion rates of the inspected vessels (1, 3 and 4) are in excess of what is prescribed by the code. These high corrosion rates can be attributed to the aggressive working conditions (situated close to the coastal regions) of the vessels.

6.0 Conclusion

The remaining life and the diminution rate (both long-term and short-term) of the wall thickness of the four investigated LPG vessels were successfully monitored. The outcome of the research work suggests that, the remaining life of LPG vessel cannot be safely and accurately be predicted with the short-term corrosion rate unless its year on year corrosion rate is uniform. The estimated annual corrosion rates of the inspected vessels one, two, three and four are $0.146\ mm/yr$, $0.108\ mm/yr$,$0.134\ mm/yr$ and $0.144\ mm/yr$ respectively with corresponding remaining life of $11.2\ yrs$, $3.4\ yrs$, $0.8\ yrs$ and $6.2\ yrs$. The statistical analysis prescribed by the API 510 code is appropriate for corrosion rate and remaining life determination of pressure vessels, care must also be taken to ensure that the statistical treatment of data results reflects the actual condition of the vessel section especially those subject to localized corrosion. The analysis may not be applicable to vessels with random but significant localized corrosion and those vessels that have no nameplate and minimal or no design and construction documentation.

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8.0 References

A, Boateng, K.A, Danso and C.P.K, Dagadu (2013) (a), Non-Destructive Evaluation of Corrosion on Insulated Pipe using Double Wall Radiographic Technique. Retrieved from http://www.iiste.org .Accessed 15th December, 2013.

A, Boateng, K.A, Danso and C.P.K, Dagadu (2013) (b), Non-Destructive Evaluation of Corrosion on Insulated Pipe using Tangential Radiographic Technique. Retrieved from http://www.ijstr.org .Accessed 9th January 2014.

API 510 (2006), Pressure Vessel Inspection Code, 9th Edition.

Corrosion pressure vessels. Retrieved from *http://www.wikispaces.com*. Accessed 27th March 2014.

Vincent A. Carucci (1999), Overview of Pressure Vessel Design, Carmagen Engineering, Inc