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Remaining Life Determination of Cylindrical Oil Pressure Vessel Using UT Technique: Case Study

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Abstract

Pressurized pressure vessels utilized in the upstream sector of the oil and gas industry commonly experience in-service deterioration caused by factors such as corrosion and process-related issues. Most current research has emphasized the significance of calculating remaining lifetime (RLT) but with a little concentration on the Ultrasonic test (UT) for remaining life assessment. In this work, a case study of the pressure vessel unit (20-v-200) belonging to Basra Oil Company (BOC) at Hammar Mishrif Degassing Station (HM-DGS) is conducted. A nondestructive test (NDT) by UT technique was employed over the suspected area of the pressure vessel. Where it was identified the condition monitoring locations (CMLs) around the shell and heads of the pressure vessel, were marked twenty-one locations to obtain their wall thickness measurement. The results of the remaining lifetime showed that for shell and head were computed as 52.9 years and 56.8 years, respectively. Therefore, based on the present result, it can be deduced that the pressure vessel can remain in operation or continue to be in service for the next 52.9 years under the same process conditions. This assessment considers the existing condition of the vessel and indicates that it can meet the required safety and operational standards for an extended duration. However, as per the guidelines outlined in API 510, it is recommended that thickness measurement inspections should be conducted within a timeframe that does not exceed either half of the vessel's remaining life or a maximum of 10 years. This recommendation ensures that regular assessments are performed to monitor the thickness and condition of the vessel. By adhering to this practice, timely maintenance and necessary repairs can be identified and carried out, contributing to the continued integrity and safety of the vessel throughout its operational lifespan.

Keywords: Pressure Vessel, Remaining Life, Corrosion Rate, Ultrasonic Test, CMLs.

تحديد العمر المتبقي لأوعية الضغط الأسطوانية باستخدام تقنية الفحص بالموجات فوق الصوتية: دراسة حالة

الخلاصة:

تتعرض أوعية الضغط المستخدمة في قطاع الاستخراج لصناعة النفط والغاز عادةً للتدهور أثناء الخدمة بسبب عوامل مثل التآكل والمشاكل المتعلقة بالعمليات الانتاجية. وقد ركزت معظم الأبحاث الحالية على أهمية حساب العمر المتبقي (RLT) ولكن مع تركيز قليل على استخدام الفحص بالموجات فوق الصوتية (UT) لتقييم العمر المتبقي. في هذا العمل، تم إجراء دراسة حالة لوحدة وعاء الضغط (v-200-20) التابعة لشركة نفط البصرة (BOC) في محطة فصل الغازات في حقل الحمّار (HM-DGS). تم استخدام اختبار غير مدمر (NDT) بتقنية الموجات فوق الصوتية على المنطقة المشتبه بها من وعاء الضغط. حيث تم تحديد مواقع مراقبة الحالة (CMLs) حول غلاف ورؤوس وعاء الضغط، وتم تحديد 21 نقطة للحصول على قياس سمك الجدار الخاص بها. أظهرت نتائج العمر المتبقي للغلاف والرؤوس الذي تم حسابه بقيمة 52.9 عامًا و 56.8 عامًا على التوالي. لذلك، بناءً على هذه النتائج، يمكن الاستنتاج أن الوعاء يمكن أن يستمر في الخدمة لمدة 52.9 عامًا قادمة تحت نفس الظروف العملية. تأخذ هذه التقييمات في الاعتبار الحالة الحالية للوعاء وتدل على أنه يمكن أن يستوفي معايير السلامة والتشغيل المطلوبة لفترة طويلة. ومع ذلك، وفقًا للإرشادات المحددة في API 510، يُوصى بإجراء فحوصات قياس السماكة في إطار زمني لا يتجاوز نصف عمر الوعاء المتبقي أو بحد أقصى 10 سنوات. تضمن هذه التوصية إجراء التقييمات الدورية لرصد سمك وحالة الوعاء. من خلال الالتزام بهذه الممارسة، يمكن تحديد الصيانة في الوقت المناسب والإصلاحات الضرورية وتنفيذها، مما يساهم في استمرارية سلامة الوعاء طوال عمره التشغيلي.

1. Introduction:

In the oil and gas industry, the sound integrity of pressure vessels is crucial. Pressures vessels are specialized containers specifically designed to contain gases or liquids at pressures significantly higher or lower than the surrounding atmospheric pressure [1]. They can be described as a separator or enclosure that experiences varying pressures between their external and internal environments [2]. In general, the internal pressure of a pressure vessel tends to exceed the external pressure, except in specific isolated scenarios [3]. Popularly, pressure vessels are typically shaped either cylindrical or spherical. Thus, they play a significant role in various industrial processes for instance; coal, nuclear power plants, the chemical industry and the oil and gas industry [4]. In addition, pressure vessels can be considered the heart of the oil and gas processing industry due to their critical importance. Typically, pressure vessels are designed to enclose the flow of fluids that involve a simultaneous presence of both high pressure and temperature, and in certain circumstances, they may handle flammable fluids of highly radioactive substances. Due to the potential hazards involved, it is crucial for the design of pressure vessels to ensure absolute prevention of any leakage [5]. Additionally, these vessels must be considerably designed to withstand the specific demands of operating conditions, including temperature and pressure considerations. The materials utilized for pressure vessels can vary, ranging from potentially brittle options like cast iron to more ductile alternatives like mild steel [6]. Therefore, pressure vessels are carefully constructed to ensure their integrity, as a rupture can result in an explosion that poses a significant risk for both life and property.

Pressurized equipment, such as a large horizontal vessel commonly found in gas plants, is susceptible to damage during operation [7]. The condition of the vessel can deteriorate due to multiple factors, including mechanical issues, process-related challenges, and corrosion problems. Localized corrosion has emerged as a significant and concerning factor in the oil and gas industry, being one of the primary causes of pressure vessel failures [8], and experience a decline in both mass and strength, which can have detrimental effects on their overall performance and reliability [9]. Also, its presence poses a major threat to the integrity and reliability of pressure vessels in this industry [10]. Thereby, pressure vessel failure caused by corrosion and other factors can be severe, including production losses, unintentional releases, damage to nearby structures, and the potential for catastrophic explosions and fires that can result in fatalities and injuries to both the public and workers [11]. Therefore, it is imperative to prioritize measures to prevent and mitigate the factors mentioned earlier to avoid these detrimental consequences.

The issue of estimating the remaining operational lifespan of test separators in the oil and gas sector is significant for many companies, Particularly for plants that have been in service for 20 to 30 years or more and are approaching their intended design life expectancy [12]. Shafiee et al. [13] stated that it is crucial for decision-makers involved in life extension initiatives to accurately assess the remaining life of equipment, this assessment is instrumental in enabling stakeholders to reach accurate conclusion during the decision-making process related to life extension. Furthermore, according to Liao et al. [14], it has been recommended that in the event of detecting ageing degradation, it is significant to reassess the reaming life to facilitate prompt maintenance decisions and prevent potential failures. Therefore, utilising different techniques to calculate the remaining life of assets is enabled decision-makers to make well-informed choices regarding adjustments to integrity maintenance and avoiding expensive premature repairs or early retirement.

According to[15], [4], [16] studied the remaining life and corrosion rate of pressure vessel by using ultrasonic (UT) technique. Thus, nondestructive testing was conducted using an ultrasonic thickness gauge to obtain thickness measurements of the damaged pressure vessel's wall. Based on the findings of the study [15], it has been demonstrated that the remaining life of test separators can be reliable and precisely predicted using the short-term corrosion rate.

While, the research outcomes [16] suggest that unless there is a consistent year-on-year corrosion rate, it is not possible to accurately and reliably predict the remaining life of a vessel using the short-term corrosion rate. As for research results [4], by utilizing the corrosion rate, the remaining life of the vessel can be estimated, ultimately enhancing the overall reliability of the vessel’s operational assessment.

According to [17] conducted research to determine the remaining operational life of a hypothetical pressure vessel that contained a defect and was exposed to thermal shock. Using finite element modelling (FEM) analysis, they analyzed involved twelve different cases of thermal shock loads with varying degrees of severity. These cases were characterized by dimensionless parameters, specifically the Biot (B) and Fourier (F) numbers. The results provide quantitative evidence on the impact of thermal shock on crack growth rate. They reveal that more severe shocks accelerate crack propagation, while less severe shocks can result in slower growth or even the cessation of cracks.

According to [2] investigated a study on the Fitness for Service (FFS) methodology as per API 579. The analysis focused on an ageing pressure vessel, utilising Leve 1 and Level 2 assessments. The evaluation results indicated that the external localized corrosion defect fell within an acceptable range. This implied that the pressurized vessel was deemed fit to continue operating and still had a remaining lifespan of 40 years, considering the evaluated external corrosion defect.

The authors in [11] has presented a thorough overview of the technique for evaluating the remaining lifetime of oil equipment through vibration diagnostic. Experimental evidence has validated the importance of vibration diagnostics as a highly versatile parameter that provides accurate information about the equipment’s condition. This method enables the assessment of the equipment’s technical state during operation and facilitates reliable prediction of its future reliability.

Although previous research has emphasized the significance of calculating remaining lifetime (RLT) in various applications and conditions, there have been limited studies on the utilization of nondestructive tests (NDT) by the ultrasonic scheme (UT) for remaining life assessment, to the best knowledge of the authors.Where UT was utilised to inspect a horizontal pressure vessel. The automated ultrasonic testing machine (Elcometer device, model: MTG6DL) was employed to perform continuous scanning over suspected areas of corrosion thinning. This approach facilitated a thorough and efficient assessment of the pressure vessel for any corrosion-related issues. Therefore, the use of a nondestructive test (NDT) by ultrasonic technique (UT) to calculate the remaining lifetime of the pressure vessel is a significant factor to consider in this paper. The analysis of remaining life assessment is invaluable in maximizing the utilization of a potentially damaged asset. It empowers informed decision-making regarding adjustments to integrity maintenance, scheduling inspection frequencies, and avoiding costly premature repairs or retirement. In what follows, the method used for the quantitative analysis is presented in section 2, the data analysis of the case study is described in section 3, the results of the studied case are demonstrated in section 4, the research is concluded in section 5.

2. Methods

In the present paper, an Ultrasonic Thickness measurement (UT) Elcometer device (model: MTG6DL) was utilized to evaluate the physical state and determine the wall thickness of the pressure vessel that is thinned due to corrosion and erosion. Thickness gauging involves the application of technical methods to measure the thickness of materials or components without compromising their future usefulness and adherence to specifications. Calibration is crucial before taking measurements, and the surface being examined must be clean, smooth and free from any impurities. These precautions ensure accurate and reliable thickness measurements. Therefore, this section mainly presents the Corrosion Rate (CR) and Remaining Life Time (RLT), thus it includes the main equations utilized to calculate them. Furthermore, it describes the case study of the research.

2.1 Corrosion Rate Determination

The corrosion rate is determined for thinning damage mechanisms by comparing two thickness readings and dividing the difference by the time interval between them. The assessment of corrosion rate may involve collecting thickness data at multiple time points. The decision to use short-term or long-term corrosion rates is typically identified by the inspector based on the current conditions of the equipment [19]. Short-term rates are calculated based on the two most recent thickness readings, while long-term rates consider the most recent reading along with an earlier reading taken during the equipment’s lifespan. These distinct rates help differentiate between recent corrosion mechanisms and those that have been present over a longer duration.

Condition Monitoring Locations (CMLs) are specific areas designated on pressure vessels where regular inspections are performed to monitor the occurrence and progression of damage. The selection and placement of CMLs take into consideration the likelihood of corrosion and damage specific to the vessel's service conditions. These CMLs may include locations for measuring thickness, examining stress cracking, and evaluating high-temperature hydrogen attacks [19]. The corrosion rate is typically divided into two categories: short-term (ST) corrosion rate and long-term (LT) corrosion rate. The short-term (ST) and long-term (LT) corrosion rates are presented by equations 1 and 2, respectively [19].

$$\text{Short-term (ST) corrosion rate} = \frac{t_{previous}-t_{actual}}{time\ between\ previous\ and\ actual\ (years)} \tag{1}$$

$$\text{Long-term (LT) corrosionrate} = \frac{t_{initial}-t_{actual}}{time\ between\ intitial\ and\ actual\ (years)} \tag{2}$$

Where:

$t_{initial}$ = either the first thickness or thicknesses at the beginnings of a substitute corrosion rate setting, in inches or mm.

$t_{previous}$ = the last thicknesses reading recorded during the previous inspection in inches or mm.

4.1 Remaining Life Time Calculation (RLT)

Remaining life assessment refers to the process of measuring and estimating the remaining lifespan of equipment, like a pressure vessel in oil and gas treatment units. By determining or estimating the remaining life, field engineers can effectively plan maintenance activities and schedule equipment replacement when needed. This proactive approach enables efficient maintenance management and ensures uninterrupted operation of the oil and gas treatment units. Remaining life can be calculated by utilizing equation 3 [19], as shown below.

$$\text{Remaining Life} = \frac{t_{actual}-t_{required}}{corrosion\ rate} \tag{3}$$

Where, t_{actual} and $t_{required}$ are the actual thickness and required thickness in inch (mm), respectively.

The minimum required thickness for pressure vessels can be calculated by relying on ASME section (8) division 1 for shell and head [4].

- Shell

The minimum required thickness is presented by equation 4 for a pressure vessel that experiences circumferential stress in its longitudinal joints, if $t < 0.5\, R \text{ and } P < 0.385\, SE$.

$$t_{required} = \frac{P.R}{SE-0.6P} \tag{4}$$

While,

The minimum required thickness is presented by equation 5 for a pressure vessel that experiences longitudinal stress in its circumferential joints, if $t < 0.5\, R \text{ and } P < 1.25\, SE$.

$$t_{required} = \frac{P.R}{2SE-0.4P} \tag{5}$$

- Head

The minimum required thickness for the ellipsoidal head of the pressure vessel can be determined as shown in Equation 6.

$$t_{required} = \frac{P.D}{2SE-0.2P} \tag{6}$$

Where:

P = design pressure

R = internal radius

S = Maximum allowable stress

E = joint efficiency

D = inner diameter

2.3 Case Study

A horizontal pressure vessel number (20-V-200) was conducted as shown in Figure (1), it is owned by Basra Oil Company (BOC) at Hammar Mishrif degassing station (HM-DGS) in Iraq-Basra. This large vessel, constructed from steel plate, was commissioned in 1988 to separate three-phase streams that contained significant quantities of crude oil, gas and water. The technical data of pressure vessels are presented in Table (1).

Fig. (1): 1st stage test separator (20-V-100) at Hammar Mishrif station, Zubair oil field

Table (1) Stage Test Separator (20-V-100) Technical data

Pressure vessel specification		**Shell and Heads properties**	
Vessel Name	1st stage test separator	Material	SA 516 (GR.70)
Design Temperature (℃)	77	Shell Nominal Thickness (mm)	41
Design Pressure ($Kg/cm2$)	48.7	Head Nominal Thickness (mm)	44
Test Pressure ($Kg/cm2$)	73.1	Corrosion Allowance (mm)	3.18
Radiography	Full	Length (mm)	6096
Weld Joint Efficiency (E)	1	Internal Diameter (mm)	1829
Head Type	Elliptical	Radius (mm)	914.5
Installation Date	1988	Post Weld Heat Treatment	Yes

3. Data Analysis

A nondestructive test (NDT) using an ultrasonic thickness measurement (UT) Elcometer device was conducted in 2018 to inspect the horizontal pressure vessel. Ultrasonic thickness measurement is taken over the suspected area of the shell and heads. Twenty-one (21) Condition Monitoring Locations (CMLs) were marked and tested to monitor the occurrence and progression of damage, as shown in Figure (2). In addition, the thickness measurements at each grid point were recorded and are presented in Table (2) for reference. Analysis of the scanning revealed that the condition of the shell and heads was properly well, however, some areas had corrosion at the bottom of the vessel (5-7 o'clock). Therefore, it had been selected the lowest reading of measurement at spots C5 and D5 to calculate the corrosion rate (CR) and RLT of the pressure vessel.

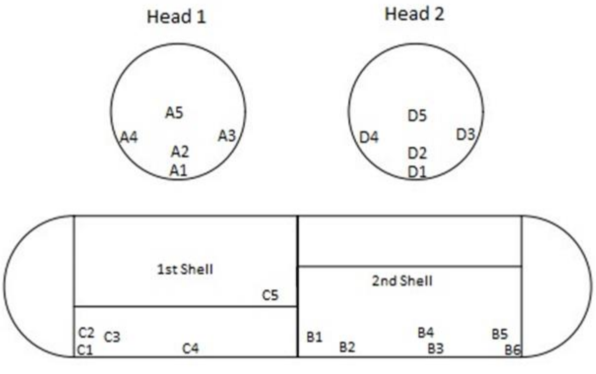

Fig. (2): Identify the Condition Monitoring Locations (CMLs) for pressure vessel

Table (2) Thickness measurements at each grid point

Section	**Spot**	**Thickness (mm) at point**				
		1	2	3	4	5
Head (A)	A1	47.3	47.35	47.5	47.8	47.4
	A2	47.5	47.4	47.3	47.5	47.35
	A3	48.6	48.7	4.1	48.9	49
	A4	48.7	48.8	48.7	48.9	48.7
	A5	47.9	48.1	47.6	47.5	47.3
1st shell (B)	B1	42.5	42.6	42.7	42.35	42.7
	B2	42.4	42.5	42.6	42.4	42.5
	B3	42.27	42.35	42.42	42.27	42.35
	B4	42.72	42.79	42.64	42.49	42.68
	B5	43.23	42.52	42.42	42.72	42.49
	B6	42.27	41.9	41.57	41.98	42.2
2nd shell (C)	C1	42.7	42.6	42.5	42.4	42.35
	C2	42.27	42.12	41.9	41.83	42.12
	C3	42.49	42.57	42.46	42.57	42.57
	C4	42.34	42.57	42.49	42.52	42.57
	C5	42.57	42.42	42.35	39.76	42.35
Head (D)	D1	49.2	49.3	49.6	48.8	49.1
	D2	48.7	48.8	49	49.32	49.15
	D3	48.1	48.35	48.48	48.27	48.12
	D4	48.4	48.6	48.5	48.7	48.4
	D5	42.75	42.42	42.35	39.76	42.57

4. Results and Discussions

By estimating the life span of the pressure vessel number (20-V-200), field engineers can effectively plan maintenance activities and schedule equipment replacement when needed. Thus, the remaining lifetime, the corrosion rate and the minimum required thickness of the pressure vessel are necessary to determine the lifespan. Therefore, by using equations 2, 3, 4 and 6, the results have been presented, as follows:

4.1 Minimum Required Thickness

For the pressure shell, the minimum required thickness is calculated by using equation 4 relying on ASME section 8 division 1 [20]. The maximum allowable stress (S) value is the relationship between the material and the design temperature, according to ASME *II* Part D, table 1A [20].

$$t_{required} = \frac{692.676*36}{20015*1-(0.6*692.676)}$$

$$t_{required} = 1.272\ inch$$

$$t_{required} = 32.3\ mm$$

For the pressure head, the minimum required thickness is calculated by using equation 6 depending on ASME section 8 division 1, as shown below.

$$t_{required} = \frac{692.676*72}{2(20015*1)-(0.2*692.676)}$$

$$t_{required} = 1.25\ inch$$

$$t_{required} = 31.75\ mm$$

4.2 Corrosion Rate

The data of Corrosion Rate (CR) is essential to calculate the remaining lifetime of the pressure vessel, thus by using equation 2 the result of CR is presented as follows.

Long-term (LT) corrosion rate = $\frac{44-39.76}{30\ (years)}$

Long-term (LT) corrosion rate = 0.141 mm/year

4.3 Remaining Life Time (RLT)

The remaining Lifetime for the shell and head of the pressure vessel can be calculated by using Equation 3, as shown below.

- For shell

Remaining Life = $\frac{39.76-32.3}{0.141}$

RLT = 52.9 years

- For head

Remaining Life = $\frac{39.76-31.75}{0.141}$

RLT = 56.8 years

In earlier calculation methods and data analysis, every significant component was assigned a finite original design life relying on its expected load history. Once the component Reaches the end of its design life it does not automatically require to be taken out of service. Instead, it serves as a “warning point” indicating the need for an evaluation of the component’s actual condition and structural integrity. This assessment takes into consideration factors such as the load history, accumulation of damage, and other relevant considerations. The objective is to make informed decisions regarding the component’s continued use or the necessary actions to be taken based on its current state. Thus, based on existing corrosion, the remaining life of the pressure vessel (20-V-200) for the shell and head were computed as 52.9 years and 56.8 years, respectively. Therefore, based on the present result, it can be deduced that the pressure vessel can remain in operation or continue to be in service for the next 52.9 years. This assessment considers the existing condition of the vessel and indicates that it can meet the required safety and operational standards for an extended duration. However, in line with industry best practices, it is advisable to limit thickness measurement inspections to either half of the remaining life of the vessel or a maximum of 10 years, according to API 510 [19]. This approach ensures that regular assessments are conducted to monitor the thickness and overall condition of the vessel, enabling timely maintenance and necessary repairs. By adhering to this guideline, the vessel’s integrity and safety can be effectively maintained throughout its operational lifespan. As a result, a long-term corrosion rate has been employed in the calculation of the remaining life instead of a short-term rate due to the presence of a uniform year-on-year corrosion rate. This emphasizes the significance of considering the consistency of the corrosion rate over time to ensure reliable predictions.

5. Conclusions

Remaining Life Time (RLT) calculations and Corrosion Rate (RT) were conducted to assess the actual condition and structural integrity of pressure vessel number (20-v-200). By utilizing the Nondestructive test (NDT) with the Ultrasonic Thickness measurement (UT) technique, twenty-one (21) Conditions Monitoring Locations (CML) were identified and inspected to observe the current state of the pressure vessel. The outcome of the marked area by CMLs revealed that the pressure vessel remained healthy and permitted to continue in service. Thereby, the remaining life of the pressure vessel based on the corrosion rate and minimum required thickness analysis was computed as 52.9 years. Based on the result of RLT the pressure vessel is considerably capable of remaining in operation and still safe to operate on the same process conditions. Whereas, periodic inspection and evaluation for pressure vessels are significant to ensure integrity and address any potential risk that may arise over time. Thus, it is recommended to conduct thickness measurement inspections within the confines of either half of the vessel's remaining life or a maximum period of 10 years, according to API 510.

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