International Journal of Engineering Materials and Manufacture (2024) 9(4) 130-135
https://doi.org/10.26776/ijemm.09.04.2024.01

Analysis of the Remaining Life Assessment of Fb-8701c Spherical Tank based on Thickness Measurement Data with Ultrasonic Testing Method

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Received: 18 September 2024
Accepted: 20 October 2024
Published: 30 October 2024
Publisher: Deer Hill Publications

ABSTRACT

This remaining life assessment assessed the thickness and corrosion rate characteristics of A516 Grade 70 carbon steel, a material widely used in the fabrication of pressure vessels and boilers, including spherical tanks. The material was evaluated through ultrasonic non-destructive testing, with the aim of determining the minimum thickness and corrosion rate, based on field data collected by the inspector. The data was then analysed to determine the minimum allowable thickness and estimate the remaining life of the pressure vessel based on API 510 standard. The study results showed that all components examined were within safe limits for use, above the required thickness (actual thickness > required thickness). The calculation of the highest corrosion rate is on the Top Head Plate 7 component, which is 0.067 mm/year, so this component has the shortest remaining life, which is 54.06 years. This study also calculates the maximum allowable working pressure (MAWP) value which is a reference to ensure the safety of pressure vessels when operated. The working pressure when operated must not exceed the calculated MAWP value. The calculated MAWP value is in the range of 48194.35 to 55985.43 Pa.

Keywords: Corrosion rate, remaining life assessment, spherical tank.

1 INTRODUCTION

Pressure vessels are one of the important components in the industry, especially petrochemicals, which function to store fluids with varying pressures between the inside and outside of the vessel [1], [2]. These pressure vessels are available in various shapes, including cylindrical and spherical, depending on the desired application [3], [4]. Spherical tanks, which are also a type of pressure vessel, are often used to store large amounts of fluid, especially in contexts involving the storage and transportation of liquefied natural gas (LNG) [3], [5]. This spherical shape is considered to have high efficiency because it can distribute pressure evenly throughout the tank, thereby increasing resistance to high internal pressure [2], [6].

The manufacture of these pressure vessels must comply with strict regulations designed to ensure safety control and monitoring throughout their operational life. This is essential to ensure reliable performance and prevent potential damage that could be fatal [7]. One of the main threats to the integrity of pressure vessels, especially spherical tanks, is corrosion [8]. Corrosion can occur both internally and externally, especially in areas exposed to aggressive external environments, such as corrosive chemicals, high humidity, or extreme temperatures [9].

To ensure the safety and integrity of the pressure vessel, the condition of the tank must be periodically evaluated through various inspection and testing methods [3]. One of the most frequently used methods is non-destructive testing (NDT), which allows inspection without damaging the physical structure or its function [9], [10]. One of the non-destructive testing methods is measuring the tank wall thickness using ultrasonic thickness gauging. By measuring the actual wall thickness and comparing it with previous wall thickness data, the corrosion rate can be determined [11], [12].

The non-destructive test data is then analyzed to calculate the minimum permissible thickness and corrosion rate according to the established standards [13]. Furthermore, calculating the remaining service life of the tank, which helps determine whether the tank has exceeded its operational design life or shows signs of aging that could compromise its structural integrity. This method allows operators to identify potential problems at an early stage, making it easier to implement preventive measures to prevent system failures that could compromise operational safety [13].

Proper monitoring and maintenance of pressure vessels, especially spherical tanks, are essential to ensure the safe and efficient operation, while extending their service life and reducing repair costs due to unforeseen damage [14].

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Reference: Faiqotul, H., Dharmaputra D. S. D., Ismail. (2024). Analysis of the Remaining Life Assessment of FB-8701C Spherical Tank based on Thickness Measurement Data with Ultrasonic Testing Method. *International Journal of Engineering Materials and Manufacture*, 9(4), 130-135.

Based on this background, this study was conducted to measure the remaining service life of A516 grade 70 spherical carbon steel tanks based on minimum thickness, corrosion rate, and maximum allowable working pressure.

2 MATERIALS, EQUIPMENT AND SAMPLES PREPARATION

2.1 Materials and Equipment

The Carbon Steel code A516 Grade 70 is a type of carbon steel that is frequently utilized in the fabrication of pressure vessels and boilers. This material is in compliance with the specifications set forth by ASME Section II, which establishes standards for materials utilized in pressure equipment. In accordance with the 2019 edition of ASME II, A516 Gr 70 exhibits an optimal combination of mechanical strength, weldability, and toughness, rendering it an ideal material for high-temperature and high-pressure environments, such as those encountered in the oil, gas, and petrochemical industries [15]. Table 1 sets forth the chemical requirements for determining the grade of test specimen FB-8701C.

Table 1: Chemical Requirement [15]

Elements	Composition, %			
	Grade 55 [Grade 380]	Grade 60 [Grade 415]	Grade 65 [Grade 450]	Grade 70 [Grade 485]
Carbon max:[A,B]				
½ in. [12.5 mm] and under	0.18	0.21	0.24	0.27
Over ½ in. to 2 in. [12.5 to 50 mm], incl	0.20	0.23	0.26	0.28
Over 2 in. to 4 in. [50 to 100 mm], incl	0.22	0.25	0.28	0.30
Over 4 to 8 in. [100 to 200 mm], incl	0.24	0.27	0.29	0.31
Over 8 in. [200 mm]	0.26	0.27	0.29	0.31
Manganese: B				
½ in. [12.5 mm] and under:				
Heat analysis	0.60-0.90	0.60-0.90[C]	0.85-1.20	0.85-1.20
Product analysis	0.55-0.98	0.55-0.98[C]	0.79-1.30	0.79-1.30
Over ½ in. [12.5 mm]:				
Heat analysis	0.60-1.20	0.85-1.20	0.85-1.20	0.85-1.20
Product analysis	0.55-1.30	0.79-1.30	0.79-1.30	0.79-1.30
Phosphorus, maxA	0.025	0.025	0.025	0.025
Sulphur, maxA	0.025	0.025	0.025	0.025
Silicon:				
Heat analysis	0.15-0.40	0.15-0.40	0.15-0.40	0.15-0.40
Product analysis	0.13-0.45	0.13-0.45	0.13-0.45	0.13-0.45

[A] Applies to both heat and product analyses.

[B] for each reduction of 0.01 percentage point below the specified maximum for carbon, an increase of 0.06 percentage point above the specified maximum for manganese is permitted, up to a maximum of 1.50% by heat analysis and 1.60% by product analysis.

[C] Grade 60 plates ½ in. [12.5 mm] and under in thickness may have 0.85-1.20 % manganese on heat analysis, and 0.79-1.30 % manganese on product analysis.

Table 2: Tensile Requirement [15]

Elements	Grade			
	55 [380]	60 [415]	65 [450]	70 [485]
Tensile strength, ksi [MPa]	55-75 [380-515]	60-80 [415-550]	65-85 [450-585]	70-90 [485-620]
Yield strength, min,[A] ksi MPa]	30 [205]	32 [220]	35 [240]	38 [260]
Elongation in 8 in. [200mm], min, %[B]	23	21	19	17
Elongation in 2 in. [50 mm], min, %[B]	27	25	23	21

[A] Determined by either the 0,2% offset method or the 0,5% extension-under-load method.

[B] See Specification A20/A20M for elongation adjustment.

The material in question exhibits a tensile strength that ranges from 485 to 620 MPa, thereby demonstrating the capacity to withstand mechanical stress and deformation. The minimum yield strength of the material is 260 MPa, which indicates that it is capable of withstanding high levels of stress before undergoing permanent deformation. The chemical composition of this steel is strictly regulated to maintain its mechanical properties. The composition of the material includes carbon (up to 0.24%), manganese (1-1.6%), phosphorus (up to 0.035%), and sulphur (up to 0.035%). This material offers an ideal combination of strength and toughness while ensuring high-quality welds. The heat treatment process typically involves normalization, which enhances the material's mechanical properties by refining the grain structure, leading to consistent hardness and strength throughout. It is commonly utilized in the production of pressure vessels, boilers, and welded structures that function at moderate or low temperatures. Moreover, this material is employed in the construction of storage tanks, pipes, and other essential equipment that must endure prolonged pressure and maintain durability in varying pressure and temperature conditions.

2.2 Samples Preparation

A spherical tank is a type of pressure container intended for storing high-pressure liquids or gases. The design of a spherical tank is based on its effectiveness in managing internal pressure, which is achieved through its spherical symmetry. Within structural mechanics, the spherical shape allows for even distribution of pressure across the entire surface of the tank's walls, reducing the risk of localized stress, deformation, or structural failure.

The spherical shape of the tank allows for a large storage capacity with a relatively small surface area, resulting in minimal material requirements while maintaining structural integrity. This is especially crucial for cost-effectiveness and material efficiency in large-scale industrial uses. Furthermore, spherical tanks are equipped with safety mechanisms such as safety relief valves for releasing excess pressure and leak detection systems for identifying pressure changes or the presence of hazardous gases. These safety features are essential due to the often flammable or toxic nature of the stored gases, requiring the minimization of potential hazards. The internal pressure of test specimen FB-8701C is outlined in Table 3.

Table 3: Internal Pressure

DATA				Plate 1A	Plate 2A	Plate 3A	Plate 4A	Plate 5A	Plate 6A	Plate 7A	Plate 8A
Design Press.	kg/cm²	(P)	=	6	6	6	6	6	6	6	6
Design Temp.	°C		=	65	65	65	65	65	65	65	65
Operating Press.	kg/cm²		=	0.715	0.715	0.715	0.715	0.715	0.715	0.715	0.715
Operating Temp.	°C		=	10	10	10	10	10	10	10	10
Static Head	kg/cm²	(SH)	=	0.886	0.881	0.838	0.756	0.284	0	0	0
Inside Diameter	mm	(D)	=	19600	19600	19600	19600	19600	19600	19600	19600
Inside Radius	mm	(R)	=	9800	9800	9800	9800	9800	9800	9800	9800
Allow. Stress Shell	kg/cm²	(S)	=	1407	1407	1407	1407	1407	1407	1407	1407
Joint Eff. Shell		(E)	=	1	1	1	1	1	1	1	1
Actual Thickness Shell	mm	(t_{act})	=	28.41	28.21	28.12	27.59	26.42	24.53	24.36	24.93
Nominal Thickness Shell	mm	(t_{nom})	=	28	28	28	27.8	26.8	25	25	25

2.3 Minimum Thickness

The calculation of the minimum required thickness for a pressure vessel aims to guarantee its ability to endure the applied operational pressure throughout its lifespan, preventing any structural failures. This calculation considers the pressure exerted on the vessel, both from the inside and the outside, to ensure it can resist the stress without undergoing deformation or damage. Additionally, the calculation considers the material's tensile and yield strengths to ensure the vessel's material is strong enough to handle the stress caused by the pressure. A safety factor is also included in the calculation to provide a margin of safety that accounts for possible variations in material properties, operational conditions, or unnoticed defects. By evaluating all these elements, the determined minimum thickness ensures the safe and reliable operation of the pressure vessel. The formula for calculating the required thickness is shown in Eqn 1 [16].

$$T_{req} = \frac{(P + SH)R}{2SE - 0.2(P + SH)} \tag{1}$$

2.4 Corrosion Rate

The rate of corrosion refers to the speed at which a material, usually metal, loses its thickness due to corrosion activities. This rate is measured by the American Petroleum Institute (API) following its API 510 2022 standard [16]. Corrosion monitoring activities are conducted on a systematic basis at specific locations, designated as "Corrosion Monitoring Locations."

The corrosion rate is calculated by subtracting the thickness measurement of the second reading from that of the first and dividing the result by the time interval between the readings. The determination of corrosion rates may encompass data collected at more than two distinct points in time. It is the responsibility of the inspector to determine whether the corrosion rate is short-term or long-term. The short-term corrosion rate is typically calculated using the two most recent thickness readings, while the long-term corrosion rate uses the latest reading compared to an earlier one taken during the equipment's lifetime. The use of different rates allows for the identification of recent corrosion mechanisms versus those acting over a longer period. In this instance, the long-term corrosion rate is used for remaining life assessment and determining the next inspection interval. Corrosion rate can be determined using Eqn 2 [16].

$$CR = \frac{t_{nom} - t_{act}}{year_{act} - year_{nom}} \tag{2}$$

In evaluating corrosion rates, it is essential to consider several factors as below.

1. The mechanism of corrosion is as follows: The evaluation of corrosion must consider whether it is general or localized. Localized corrosion may occur in areas affected by fluid impingement, erosive liquids, or specific corrosive conditions.
2. Determining the accurate onset time of corrosion is crucial for calculating precisely measured wall degradation and for selecting the optimal periods for corrosion rate evaluation. Should corrosion not have initiated at the start of the operational phase, it becomes vital to accurately gauge its actual starting point.
3. It is crucial to identify potential process points where corrosion could occur, such as water exposure, chloride penetration, or decreased pH levels.

2.5 Remaining Life Assessment

The methodical approach used to determine and predict the remaining operational lifetime of equipment is the Remaining Life Assessment (RLA). This assessment aims to determine the remaining operational lifetime of machinery thereby enabling the design of necessary repairs or replacements. This specific study used a Level 2 Remaining Life Assessment approach including metallographic analyses and wall thickness measurements. But since the related company did not ask for them, metallurgical inspection techniques including failure analysis or creep iso-stress testing were not carried out.

The efficiency and effectiveness of the maintenance and inspection systems depend much on the estimate of remaining life. Validation of data on corrosion rates and wall thickness is quite vital; however, these figures are quite important in deciding the suitable scheduling for next inspections. Unanticipated equipment failures or early shutdowns brought on by inaccurate data could raise operational risks and expenses by themselves. Optimizing asset lifetime and guaranteeing dependability so depend on proper data collecting. For this case, Remaining Life (RL) can be calculated using Eqn 3 [16].

$$RL = \frac{t_{act} - t_{req}}{CR} \tag{3}$$

2.6 Maximum Allowable Working Pressure

The highest pressure a pressure vessel is allowed to resist during operation is known as Maximum Allowable Working Pressure (MAWP). Considering the several extra loads the vessel could incur during its operational lifetime, it shows the highest internal or external pressure the vessel can safely withstand. Finding the MAWP is absolutely critical if one wants to ensure vessel's dependability and safety. Beyond this point structural collapse or dangerous leaks could follow. MAWP can be calculated using Eqn 4 [16].

Considering all pertinent elements, including operational pressure, temperature variations, and vessel material qualities, the computation of MAWP has to be done with the highest accuracy in line with set criteria and laws. Moreover, with a deduction of twice the expected corrosion loss before the next planned inspection, the thickness used in this computation should represent the real measured wall thickness. This guarantees that the pressure vessel stays structurally sound and keeps running within reasonable limits over time.

$$MAWP = \frac{2SEt_{act}}{(R + 0.2t_{act})} \tag{4}$$

3 RESULTS AND DISCUSSION

3.1 Material and Data

In ASME Section II 2019, A516 Gr 70's listed materials satisfy the strict criteria for pressure vessel materials, therefore guaranteeing their fit for important service purposes. This criterion ensures the performance of the material at low to moderate temperatures, when the resistance to stress corrosion and hydrogen-induced cracking is of critical relevance.

Because of its combination of strength, ductile behaviour, weldability, and temperature resistance, A516 Gr 70 is a high-performance carbon steel grade fit for pressure tanks and boilers. Field data—that which is gathered by qualified inspectors—helps one ascertain the substance in issue's thickness. The procedure involves choosing the lowest value observed at every measuring site. The smallest values are then further refined by means of the minimum value among them, hence determining the smallest thickness or minimal thickness. This approach ensures structural integrity and guarantees that the last thickness value is the most conservative measurement considering any fluctuations. The thickness, corrosion rate, and remaining life assessment of test specimen FB-8701C are shown in Table 4-5.

Table 4: Thickness of Point Location

Point Location	Original Thickness	Thickness Measurement (mm)				Actual Minimum Thickness (mm)
		A	B	C	D	
Bottom Head Plate 1	28.4	28.36	28.32	28.30	28.36	28.30
Bottom Head Plate 2	28.4	28.25	28.21	28.34	28.45	28.21
Bottom Head Plate 3	28.4	28.54	28.12	28.5	28.44	28.12
Shell 4/4P	28.2	27.59	28.04	28.18	28.12	27.59
Shell 5	27	26.86	26.82	26.42	26.63	26.42
Top Head Plate 6	25	24.53	24.6	24.84	24.88	24.53
Top Head Plate 7	25	24.7	24.36	25.02	24.75	24.36
Top Head Plate 8	25	25.44	24.93	25.51	25.61	24.93

Table 5: Corrosion Rate and Remaining Life

Point Location	Original Thickness (mm)	Actual Minimum Thickness (mm)	T_{Req} (mm)	CR (mm / year)	RLA (year)	MAWP (Pa)
Bottom Head Plate 1	28.4	28.30	23.99	0.01	431	55985.42
Bottom Head Plate 2	28.4	28.21	23.97	0.019	222.63	55778.58
Bottom Head Plate 3	28.4	28.12	23.83	0.028	153.21	55571.74
Shell 4/4P	28.2	27.59	23.54	0.061	66.39	54537.53
Shell 5	27	26.42	21.89	0.058	78.10	52262.26
Top Head Plate 6	25	24.53	20.90	0.047	77.23	48539.09
Top Head Plate 7	25	24.36	20.90	0.064	54.06	48194.35
Top Head Plate 8	25	24.93	20.90	0.007	575.71	49297.51

3.2 Original Thickness and Actual Minimum Thickness

Key markers in clarifying the process of material degradation over time are both the original and actual minimum thickness. For example, Bottom Head Plate 1's original thickness was 28.4 mm; the current minimum thickness was noted to be 28.30 mm. This suggests a very low corrosion rate—0.01 mm year. With a T-required (minimum required thickness for safe operation) of 23.99 mm, this component is quite well within safe limits for ongoing usage.

By contrast, Shell 5, which had a 27 mm thickness at first, now has an actual minimum thickness of 26.42 mm, almost nearing its mandated minimum thickness of 21.89 mm. This suggests that Shell 5 has experienced a more noticeable degree of thinning, so structural integrity must be constantly watched.

3.3 Corrosion Rate

With values ranging from 0.007 mm/year for Top Head Plate 8 to 0.064 mm/year for Top Head Plate 7, the corrosion rate across the several components shows quite great diversity. Top Head Plate 7's high corrosion rate points to a faster rate of material degradation, so inspection and possible maintenance should take top importance. According to the data, the remaining lifetime of every vessel component depends in major part on the corrosion rate.

3.4 Remaining Life Assessment

The Remaining Life Assessment (RLA) is determined by the corrosion rate and the difference between the actual minimum thickness and the required thickness. Top Head Plate 8 demonstrates the greatest remaining longevity, estimated at 575.71 years. This is because to its negligible corrosion rate, estimated at 0.007 mm annually. Conversely, the Shell 4/4P demonstrates the least remaining lifespan, at 66.39 years, attributable to a heightened corrosion rate of 0.061 mm/year and a reduced real minimum thickness. The observed variance in RLA underscores the need for customized maintenance plans particularly designed for the deterioration rate of each component.

3.5 Maximum Allowable Working Pressure

The MAWP shows the highest internal pressure the vessel can safely sustain. The values are from 48194.35 Pa for Top Head Plate 7 to 55985.43 Pa for Bottom Head Plate 1. As seen by Bottom Head Plate 1, there is a positive link between MAWP values and components showing both reduced corrosion rates and greater actual thicknesses. By contrast, Top Head Plate 7 shows a lower MAWP despite significant thinning and a higher corrosion rate. This emphasizes the need of keeping pressure inside acceptable operating limits, especially for parts with lower MAWP, to avoid catastrophic failure.

4 CONCLUSIONS

This study shows that: 1) The actual thickness measurement results on all components are still greater than the required thickness, so they are still safe to use. 2) The lowest corrosion rate is 0.01 mm/year on the Bottom Head Plate 1 component and the highest is 0.067 mm/year on the Top Head Plate 7 component. 3) The remaining life assessment calculation shows that the lowest service life is the Top Head Plate 7 component, which is 54.06 years due to its highest corrosion rate. Therefore, periodic monitoring is needed to ensure safety. 4) The MAWP calculation is carried out to determine the maximum operational pressure limit on each component so that it is not allowed to be operated at a pressure exceeding the MAWP value to ensure safety.

In general, it is very important to carry out periodic inspections and thickness measurements, to ensure safe and sustainable system operation. It is critical to accurately determine corrosion rate values and validate thickness measurements to maintain the structural integrity and operational safety of pressure vessels over time.

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