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Service Life Assessment and Safety Inspection of Pressure Vessels: A Comprehensive Analysis of Structural Integrity and Performance

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Abstract: Pressure vessel is a container used to store fluids and is very necessary for various industrial activities. Fluids stored in pressure vessels are fluids that have special characteristics and treatment, such as fluids at low or high temperatures, pressurized fluids and so on. In general, a pressure vessel is a container made of metal. Materials that contain metal will definitely experience corrosion. Corrosion can occur, one of the reasons is because there is a chemical reaction on the metal surface caused by the low pH of the water and humid air, so that the metal becomes thinner over time. This will affect the strength of the metal to withstand pressure. The thinner the metal, the less pressure it can withstand. With corrosion, the pressure vessel's ability to withstand pressure will decrease. If the pressure held is higher than the capacity of the pressure vessel, it can cause work accidents. This research will analyze the service life of pressure vessels using inspection procedures based on Minister of Manpower Regulation Number 37 of 2016 concerning Occupational Safety and Health of Pressure Vessels and Storage Tanks. To calculate the effect of thickness on the pressure of the pressure vessel, it will be based on the formula obtained from ASME sec VIII, div.1 regarding boilers and pressure vessels. The pressure vessel that will be tested is of the Jiangsu Ashun brand at PT. Setia Gas Jaya. From the results of analysis and testing, it shows that the pressure vessels at PT. Setia Gas Jaya has the point that experiences the most corrosion, namely at the bottom-head, which was originally 6.8 mm to 6.62 mm after 2 years and 3 months of operation. The results of the analysis also show that with a working pressure of 3.3 MPa, the pressure vessel can be operational for 13 years 3 months 13 days, or its remaining useful life is 11 years 13 days starting from June 2023.

INTRODUCTION

A pressure vessel is a container used for fluid storage and is very necessary for various industrial activities. Fluids stored in pressure vessels are fluids that have special characteristics and treatment, such as fluids at low or high temperatures, pressurized fluids and so on. In general, a pressure vessel is a container made of metal. Materials that contain metal will definitely experience corrosion. Corrosion can occur, one of the reasons is because there is a chemical reaction on the metal surface caused by the low pH of the water and humid air, so that the metal becomes thinner over time. This will affect the strength of the metal to withstand pressure. The thinner the metal, the less pressure it can withstand. With corrosion, the pressure vessel's ability to withstand pressure will decrease. If the pressure held is higher than the capacity of the pressure vessel, it can cause work accidents. An example of a work accident that can occur in a pressure vessel is a crack that can cause an explosion. In May 2009, a pressure vessel exploded, destroying nearby buildings and throwing material debris around the site. After investigation, the pressure vessel explosion occurred due to inspections that did not comply with standards and lack of maintenance on the pressure vessel.

Figure 1. Pressure Vessel Operational Failure
Source: www.aiche.org

From this description, it is necessary to carry out tests/inspections according to standards and regular maintenance on pressure vessels to ensure that pressure vessels can work under normal conditions and avoid work accidents. International standards commonly used in inspecting pressure vessels use standards from the American Society of Mechanical Engineering (ASME) section VIII which discusses boilers and pressure vessels. Meanwhile, national regulations for carrying out pressure vessel tests have also been regulated in Minister of Manpower Regulation Number 37 of 2016 concerning Occupational Safety and Health of Pressure Vessels and Storage Tanks. This research will more specifically discuss test checks on Jiangsu Ashun pressure vessels at PT. Setia Gas Jaya, with the aim of finding out the parts of pressure vessels that experience the most corrosion and getting the service life of Jiangshu Ashun pressure vessels at PT. Setia Gas Jaya when operated according to its working pressure.

METHOD

This study was conducted to analyze the service life and inspection process (riksa uji) of pressure vessels through a series of systematic experimental procedures. The initial phase began with a literature review using references from journals, books, and scientific articles to understand inspection standards, testing methods, and factors influencing the service life of pressure vessels. Subsequently, a testing plan was developed, outlining the data collection procedures and analytical methods to be employed. During the preparation phase, actual data on the pressure vessel was gathered through direct measurements of key parameters such as wall thickness, overall dimensions, and current operational conditions. A thorough inspection of pressure vessel components was also performed, including visual assessments of surface conditions, welded joints, and supporting structures to detect any signs of defects or damage. Additional data was obtained from the Manufacturer Data Report (MDR) to acquire technical specifications, including the vessel's initial material properties, design pressure, and operational history. Once all the data had been collected, data analysis was conducted, beginning with the calculation of the minimum allowable wall thickness (t_min) and the Maximum Allowable Working Pressure (MAWP). If the results indicated that the wall thickness remained within safe limits, the testing proceeded as planned. However, if the calculated values did not meet safety standards, mitigation measures were implemented by reducing the operating pressure to ensure structural integrity. Subsequently, safety tests were conducted, including safety valve testing and hydrostatic testing, to verify that the pressure vessel could still operate safely under the designated working pressure. After completing the tests, the vessel's service life was evaluated based on the rate of wall thickness reduction due to corrosion or other degradation factors. The test results were then analyzed and discussed to assess the performance of the pressure vessel and determine whether it remained fit for use or required repairs and component replacements. Finally, the study was concluded based on the obtained findings, providing recommendations for the maintenance and operation of the pressure vessel to ensure compliance with industrial safety standards and extend its service life optimally.

The pressure vessel testing planning process refers to Minister of Manpower Regulation Number 37 of 2016 concerning Occupational Safety and Health of Pressure Vessels and Storage Tanks. To carry out pressure vessel testing, it is necessary first

First, take the pressure vessel parameter data from the Manufacturing Data Record (MDR). Followed by checking the pressure vessel components, and measuring actual data in the field using a wall thickness gauge.

The pressure vessel that will be tested is a Jiangsu Ashun brand pressure vessel at PT. Setia Gas Jaya. Data taken from MDR are:

1. Pressure vessel specifications Pressure vessel specifications consist of Design Pressure (Pd), Hydrostatic Pressure (Ph), and Type of Material used by the pressure vessel.
2. Pressure vessel dimensions. The dimensions of a pressure vessel consist of the diameter of the pressure vessel (D), the height of the pressure vessel (T), the volume (V), the initial thickness of the shell body, the initial thickness of the head and the head radius.

The wall thickness gauge used to measure the thickness of pressure vessel plates is of the Check-line brand with model TI-25M (Fig. 2).

Figure 2. Image of Wall Thickness Gauge.

The steps for measuring the thickness of a pressure vessel plate using a check-line brand wall thickness gauge are as follows:

1. Turn on the wall thickness gauge by pressing the power button
2. Attach the probe cable to the probe receptacles on the top of the gauge
3. Put a little grease on the surface where the measurement will be taken.
4. Take the probe, then stick the probe on the greased surface, apply a little pressure so that the thickness of the plate can be read by the wall thickness gauge.
5. The measurement results in the form of the thickness of the plate will be displayed on the screen.
6. Repeat steps 3-5 to take thickness measurements at other points.

Thickness measurements on the shell body were carried out at 6 different points. Taking measurement points is based on points on the pressure vessel that are close to the welding area. In this area there is an oxidation process caused by the welding process so it rusts more easily compared to other areas. These points are shown in the following image.

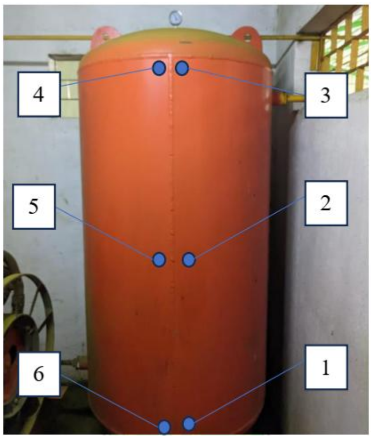

Figure 3. Measurement Points for Pressure Vessel Shell Body Parts.

Meanwhile, to measure the thickness of the pressure vessel plate at the head, 2 measurement points are taken, namely at the bottom and top of the pressure vessel for vertical pressure vessels.

RESULT AND DISCUSSION

Pressure Vessel Data from MDR

Jiangsu Ashun Pressure Vessel MDR (Manufacturing Data Report) at PT. Setia Gas Jaya is shown in Figure. 4, Jiangsu Ashun pressure vessel specification data is shown in Table.1 below.

Figure 4. Jiangsu Ashun Pressure Vessel MDR.

Table 1. Press Vessel Specification Data

NO	Technical data	Specification		Information
1.	Factory name	Jiangsu Ashun Manufacture CO., LTD		
	year of manufacture	2020		
	design pressure	3,3 MPa		
	hydrostatic pressure	4,13 MPa		
	volume series no	20-6373		
	volume	0,125 m^3		
	welding way	Single-welded butt joint with backing strip		
2.	Body Shell	Material	Q345R	
		Inner diameter	450 mm	
		height	566 mm	
3.	Head/Lid	Inner diameter	6,8 mm	
		Type of shape	Spherically	
		material	Q345R	
		initial thickness	6,8 mm	

The components in the pressure vessel are also available in good condition, the drawback lies in the lack of a manhole or handhole to check the inside of the pressure vessel, so checking can only be done from the outside. However, it is still possible to check the inside of the pressure vessel using an inspection camera via the pressure vessel pipeline.

Actual Data Measurement Results

The actual measured data is the pressure vessel thickness data on the shell and head. Thickness measurements use a Check-line brand wall thickness gauge model TI-25M. The results of the measurements are shown in Table. 2.

Figure 5. An example of measuring the actual thickness of a pressure vessel.

Point to-	Actual thickness	Information
1	6,68	
2	6,67	
3	6,72	
4	6,70	
5	6,69	
6	6,71	
Head-Top	6,78	
Head-Bottom	6,62	Minimal Thickness

Table 2. Actual Thickness Measurement Results.

Calculation of Minimum Thickness of Pressure Vessel Walls and MAWP

Before carrying out calculations, it is known that the data from the test planning results are as follows:

Working Pressure (Pd) = 3.3 MPa
Inner diameter (D) = 450 mm
Radius in Shell (R) = 225 mm

For Q345R Material specifications, see ASME II Part D, Table 1A, Page 22 Line 32, The following data was obtained:

Tensile Strength (SB) = 510 MPa — = 510 MPa
Yield Strength (SV) = 345 MPa — = 345 MPa
Maximum Temperature (T_{maks}) = 427° C — = 427 °C
Permissible stress at 150° C (S) = 146 MPa — = 146 MPa

From ASME VIII, Table UW-12, *Joint Efficiency* (E) for welding methods:
single-welded butt joint with *backing strip* — = 0,9

The results of calculating the minimum plate thickness to withstand longitudinal stress are as follows:

$$t_{min} = \frac{P_d \ x \ R}{2SE + 0,4 \ P_d}$$

$$t_{min} = \frac{3,3 \ MPa \ x \ 225 \ mm}{2 \ x \ 146 \ MPa \ x \ 0,9 + 0,4 \ x \ 3,3 \ MPa}$$

t_{min} = *5,74 mm*

Then the results of calculating the minimum plate thickness to withstand the circumferential stress are as follows:

$$t_{min} = \frac{P_d \ x \ R}{SE - 0,6 \ P_d}$$

$$t_{min} = \frac{3,3 \ MPa \ x \ 225 \ mm}{146 \ MPa \ x \ 0,9 - 0,6 \ x \ 3,3 \ MPa}$$

t_{min} = *2,53 mm*

Next, calculate the minimum thickness of the pressure vessel head because the Jiangsu Ashun pressure vessel head is an ellipsoidal head type.

$$t_{min} = \frac{PD}{2SE - 0,2 \ P}$$

$$t_{min} = \frac{3,3 \ MPa \ x \ 450 \ mm}{2 \ x \ 146 \ MPa \ x \ 0,9 - 0,2 \ x \ 3,3 \ MPa}$$

t_{min} = *5,09 mm*

From the calculation of these three equations, it can be seen that longitudinal stress has the largest minimum thickness provisions, so that by using the same formula and substitution, the MAWP is obtained as follows:

$$MAWP = \frac{S \ x \ E \ x \ t_{akt}}{R \ + \ (0,6 \ x \ t_{akt})}$$

$$MAWP = \frac{146 \ MPa \ x \ 0,9 \ x \ 6,62 \ mm}{225 \ mm \ + \ (0,6 \ x \ 6,62 \ mm)}$$

$$MAWP = 3,7990 \ MPa$$

By looking at the MAWP value, the Jiangsu Ashun Pressure Vessel at PT. Setia Gas Jaya can still be operated with a working pressure of up to 3,799 MPa.

When actual thickness measurements were carried out, of the 8 points tested, namely 6 points on the shell and 2 points on the head, the bottom head of the pressure vessel had the lowest actual thickness, thought to be due to the presence of deposits or fluid buildup at the bottom of the pressure vessel thereby increasing The corrosion rate at that point is compared with other points. The minimum wall thickness of a pressure vessel is 5.74 mm, the current actual thickness is 6.62 mm. This thickness difference is needed to anticipate corrosion occurring in pressure vessels. The corrosion rate is not always stagnant, depending on the maintenance of the pressure vessels at the company, an example of maintenance is opening the drain valve every day for pressure vessels that are operated every day.

The cause of an explosion in a pressure vessel does not always occur because the thickness of the pressure vessel plate has thinned, but there are other supporting factors such as a pressure gauge or pressure sensor whose pressure indication is no longer appropriate, a safety valve that does not function because there are deposits in the pressure vessel that create a channel. The safety valve is blocked and fluid cannot come out when excess pressure occurs. Therefore, it is important to carry out routine checks or maintenance so that the pressure vessel can operate normally and undesirable things do not happen.

Safety Valve Testing

The test is carried out by increasing the working pressure beyond the pressure set on the safety valve. Because the safety valve is set at 3.24 MPa, the safety valve test is carried out at a pressure 5% higher than the working pressure, namely 3.45 MPa. By seeing that the MAWP value is higher than the pressure value to test the safety valve, safety valve testing can be carried out.

Figure 6. Image of Jiangsu Ashun Pressure Vessel Safety Valve.

Safety valve testing shows that the safety valve is functioning and in good condition, but hydrostatic testing cannot be carried out because the safety valve is sealed and the pressure cannot be adjusted. If the test continues, the wind fluid will come out of the safety valve so that the pressure cannot be increased to the hydrostatic test pressure.

Remaining Service Life Analysis

From the results of the minimum thickness calculation, it is found that the minimum thickness in the longitudinal stress section has the highest minimum thickness requirement compared to the circumferential stress and the stress that occurs at the head. For a design pressure of 3.3 MPa a minimum thickness of 5.74 mm is required.

Jiangsu Ashun pressure vessel at PT. Setia Gas Jaya has been operating since March 2021, so as of the date of testing (June 2023), the pressure vessel has been operating for 2 years and 3 months. With the initial thickness of the pressure vessel being 6.8 mm, as of June 2023 the thickness has been reduced to the thinnest, namely 6.62 mm. From this description, the remaining life can be calculated with the following calculation:
Initial Thickness (tawal) = 6.8 mm
Actual Thickness (takt) = 6.62 mm
Minimum Thickness (tmin) = 5.74 mm
Operational Time of Pressure Vessels (n) = 2 years 3 months = 2 + (3/12) = 2.25 years.

$$Umur\ Pakai\ Bejana\ Tekan = \frac{t_{awal} - t_{min}}{t_{awal} - t_{akt}}\ x\ n$$

$$Umur\ Pakai\ Bejana\ Tekan = \frac{6{,}8\ mm - 5{,}74\ mm}{6{,}8\ mm - 6{,}62\ mm}\ x\ 2{,}25\ tahun$$

$$Umur\ Pakai\ Bejana\ Tekan = 13{,}28\ tahun = 13\ tahun\ 3\ bulan\ 13\ hari$$

So the remaining useful life of this pressure vessel can be calculated by subtracting the operating time of the pressure vessel.

$$Sisa\ Umur\ Pakai\ Bejana\ Tekan = 13{,}28\ tahun - 2{,}25\ tahun$$

$$Sisa\ Umur\ Pakai\ Bejana\ Tekan = 11{,}04\ tahun\ = 11\ tahun\ 13\ hari$$

If put into a graph, it looks as shown in Figure. 7 as follows:

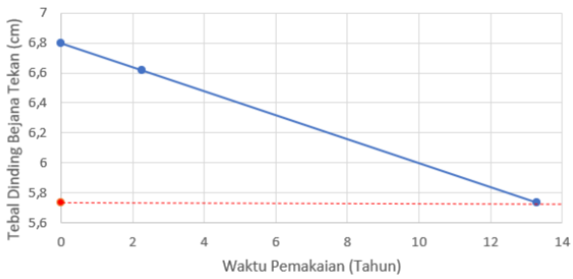

Figure 7. Pressure Vessel Lifetime Graph.

From a series of tests that have been carried out, the Jiangsu Ashun pressure vessel at PT. Setia Gas Jaya is still suitable for use. With the current rate of corrosion and maintenance, the pressure vessel can still be used for at least 11 years and 13 days with a design pressure of 3.3 MPa. The pressure vessel can also be used for longer if the design pressure is lowered.

CONCLUSION

1. Jiangsu Ashun Pressure Vessel at PT. Setia Gas Jaya has the most points experienced corrosion at the bottom-head, which was originally 6.8 mm to 6.62 mm after 2 years and 3 months of operation.
2. With a working pressure of 3.3 MPa, the Jiangsu Ashun Pressure Vessel at PT. Setia Gas Jaya has a useful life of 13 years 3 months 13 days. Because the pressure vessel has been in operation for 2 years and 3 months starting from June 2023, the pressure vessel has a remaining useful life of 11 years and 13 days.

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