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Technical Notes

Ultrasonic thickness gauging as a means of evaluating integrity of liquefied petroleum gas vessels

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ABSTRACT

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Wall thickness monitoring is very critical of the process pipes and transporting storage vessels in the power and the petrochemical industries. This is to assess their corrosion and erosion rate since failure of such equipment is very catastrophic. In this study, the wall thickness of liquefied petroleum gas (LPG) storage vessels were measured by means of ultrasonic thickness gauge and the operating pressure (OP) of each vessel evaluated. The purpose is for routine monitoring and safety assessment to ascertain the integrity of storage and transporting vessels. The OP of each vessel was compared with the vapor pressure of tropical LPG and the integrity of each vessel inferred. The minimum and the maximum margins are 0.4 bar (0.04 MPa) and 5.6 bar (0.56 MPa) respectively. The safety implications of the results are also discussed for each vessel tested. The result shows that all the vessels are safe and fit for use.

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I. Introduction

Vessels, tanks and pipelines that carry, store or receive fluids are called pressure vessels because of the pressure differential between inside and outside of the container. Pressure vessels often have a combination of high pressures together with high temperatures, and in some cases flammable fluids or highly radioactive materials. Because of such hazards, it is imperative that the design be such that no leakage can occur. In addition, these vessels have to be designed carefully to cope with the operating temperature and pressure. It should be borne in mind that the rupture of a pressure vessel has a potential to cause extensive physical injury and property damage. Plant safety and integrity are of fundamental concern in pressure vessel design and these of course depend on the adequacy of design codes (Somnath, 2014). Pressure vessels are generally designed to operate safely at a specific pressure and temperature, referred to as the "Design Pressure" and "Design Temperature" (Thakkar et al., 2012).

Maximum allowable operating pressure (MAOP) refers to the wall strength of a pressurized cylinder such as a pipeline or storage tank and how much pressure the walls may safely hold in normal operation (MAOP, 2015). If MAOP is determined by the highest safe pressure, the vessel must have overpressure protective devices installed on the segment in a manner that will prevent the maximum allowable operating pressure from being exceeded. The maximum safe pressure is the pressure determined by the operator to be the maximum safe pressure after considering the history of the segment, particularly known corrosion and the actual operating pressure (MAOP, 2015). MAOP is less than the MAWP (maximum allowable working pressure). MAWP being the maximum pressure based on the design codes that the weakest component of a pressure vessel can handle. The MAWP should be clearly stated for vessels or piping to figure out what pressures the system can withstand. Note that the MAWP does not remain constant throughout the life of the system and will reduce due to corrosion (carbon steel), wear and fatigue (Equipment Pressure Vessel, 2015).

Commonly standard wall thickness components are used in fabricating pressurized equipment and hence are able to withstand pressures above their design pressure. Design pressure is the maximum pressure a pressurized item can be exposed to, due to the availability of standard wall thickness materials, many components will have a MAWP higher than the required design pressure. Relief valves are set at the design pressure of the pressurized item and sized to prevent the pressurized item being over pressured. Depending on the design code that the pressurized item is designed, an overpressure allowance can be used when sizing the relief valve (MAWP, 2015).

II. Materials and Methods

Ultrasonic testing equipment: Ultrasonic testing equipment is a non-destructive evaluation tool used to measure the wall thickness of vessels to ascertain the diminution rate and the operating pressure. The equipment uses the principles of sound propagation to detect, locate and evaluate defects such as cracks, porosity, deterioration, corrosion, and foreign inclusions found in materials. It is also used for thickness gauging, to measure the physical thickness of the test object by measuring transmission and attenuation properties. The ultrasonic testing equipment can also be used as aid to determine certain physical and metallurgical characteristics of the material under test (NDT International Inc., 2011).

The equipment consists of a probe connected to a display unit, this allows for in situ visual display of data. The probe essentially contains a piezoelectric crystal which convert electrical pulse into mechanical vibration and vice versa. This vibration generates ultrasonic pulse which is introduced into the test piece during the inspection process. The probe of this equipment could be made of a single or two piezoelectric crystal materials. In the case of a single piezoelectric crystal material, the same crystal serves as the transmitter and the receiver. In order to improve the resolution when measuring thickness of thin materials, a delay mechanism is incorporated into the probe to give sufficient time lapse between the incident sound and the reflected one. The problem of good resolution is taken care of by using two different piezoelectric crystals in the same probe. In this case, one crystal serves as the transmitter and the other as the receiver so that the receiver does not need to perform any transmission function before listening for echoes (Hong Kong NDT, 2013).

Principle of operation: The probe is first calibrated by feeding into it the velocity of sound in that material which is to be inspected. It is then tested on standard calibration block to verify and ascertain the accuracy of its readings. In its operation, the probe generates ultrasonic waves by means of piezoelectric effect. The waves are sent through the test object in a beam of short bursts. The wave travel in a straight line and at a constant speed through the material until it enters a medium of different optical properties created by a defect in the material or by the backside of the material. Any discontinuity in the path of the ultrasonic beam, as well as the back side of the test object, reflects the ultrasound wave back to the probe. The time taken by the wave to travel through the material and subsequently return as echo is measured and this provides information on the distance that the sound has traveled through the material. Fig. 1 depicts the calibration process (ASNDT, 2009).

Figure 01. Calibration of ultrasonic thickness gauge using the test block

When the ultrasound makes a round trip through the material and back to the probe with time of flight, *t*, the velocity of sound in the material *v*. The thickness, *d* of the material is calculated by the probe according to Equation 01.

$$d = \frac{vt}{2} \quad \text{..} \quad (01)$$

The pressure that a pressure vessel such as LPG vessel can withstand (OP) is evaluated from the minimum thickness of the wall of the vessel by using various codes. The code that is used in this study is the ASME code. This is because this code is more conservative as compared to the others. The ASME code formula for cylindrical vessels is stated by Equation 02 (Vincent, 2005),

$$\text{OP} = \frac{SEt}{r + 0.6t} \quad \text{……………………………………….(02)}$$

Where,

S = allowable stress for the temperature range within which data was collected.
E = Longitudinal weld joint efficiency = unity for the vessels inspected
r = internal radius of the vessel
t = minimum thickness of the vessel

Data collection: The data was collected using DM4E ultrasonic testing equipment manufactured by Krautkramer. The contact and normal beam techniques were employed in the data collection and the equipment always calibrated both in the lab and on the field each time it was used in data collection. Figure 01 and 22 show the calibration and the data collection processes respectively. During data collection, points were randomly selected on the vessel (condition monitoring location) and the couplant 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.

Figure 02. Data collection on LPG vessel

III. Results and Discussion

The integrity of one vessel is not dependent on the other. This is because there is no relationship between the parameters of any two or more vessels. As such the discussion of the result does not relate one vessel to the other but each vessel is dealt with in isolation. Table 01 shows the raw data and the processed data of this experiment.

Table 01. Data collected on the inspected vessels

Vessel No.	Min thickness/mm		Max thickness/mm		OP/bar	DWP/bar	Margin/bar (OP-8.0)
	Head	Shell	Head	Shell			
1	10.8	10.3	11.7	11.2	8.8	13.8	0.8
2	11.3	11.7	13.3	13.0	8.7	16.7	0.7
3	15.0	12.4	16.8	13.9	9.4	15.6	1.4
4	17.2	8.0	18.6	10.7	9.5	14.0	1.5
5	8.7	8.4	9.1	9.3	13.1	17.2	5.1
6	5.1	6.8	5.7	8.0	9.3	17.2	1.3
7	5.1	7.1	5.9	8.0	9.3	17.2	1.3
8	8.2	9.6	8.9	10.2	12.8	17.2	4.8
9	5.6	8.3	6.1	9.0	10.2	17.2	2.2
10	5.7	8.2	6.6	9.0	10.4	17.2	2.4
11	8.1	12.7	10.0	13.3	9.6	17.2	1.6
12	14.2	12.2	15.8	14.0	9.3	16.7	1.3
13	8.7	9.7	9.3	10.2	13.6	17.2	5.6
14	6.3	8.7	6.8	9.3	11.6	17.2	3.6
15	9.6	9.9	10.2	10.7	8.4	16.6	0.4
16	7.1	8.5	8.4	9.6	12.3	16.6	4.3
17	8.5	8.0	9.5	8.7	13.0	15.6	5.0
18	6.9	6.7	7.4	7.5	10.3	17.7	2.3
19	10.2	9.0	11.1	9.8	8.9	14.7	5.8
20	8.5	10.0	9.4	11.4	9.3	16.7	1.3

The point where the minimum thickness of the vessel is taken is the weakest point of the vessel and that point is the point of interest. Should the vessel fail under load, it is the weakest point of the vessel that will give way first. Vessel No. 1 has its weakest point at the shell. The OP evaluated from the weakest point of this vessel shows that the vessel has deteriorated considerably and cannot survive when loaded to its design working pressure (DWP). However, the vessel could still be used since its OP shows that it could very well withstand the pressure from tropical LPG. When tolerance and safety factors are taken into consideration, the maximum vapour pressure expected to be exerted by tropical LPG should not exceed 8.0 bar. This means that the OP of any LPG vessel in the tropics should be at least 8.0 bar. Vessel No. 1 has passed this criterion but it needs annual assessment to establish its thinning rate to ensure safety.

The weakest point of Vessel No. 2 is found at its head, the OP of this vessel is also quite low hence its marginal point difference of 0.7 bar. This vessel can be in use for some time but needs frequent monitoring so that necessary safety measures can be taken. The same can be said of vessel No.1 and Vessel No. 15 whose weakest points are at the shell. The following vessels No. 4, 6, 7, 11, 12 and 20 have quite high OP and could withstand high pressures. Vessels No. 5, 8, 13, 17 and 19 have high OP and margin. This indicates that these vessels are very strong and can withstand high pressure but not as much as its DWP. Vessel Nos. 9, 10 and 18 also show a considerable strength because of their OP and margin values.

IV. Conclusion

The principle of using ultrasonic thickness gauge in measuring the physical thickness of a material was successfully applied in measuring the thickness of 20 randomly selected LPG storage vessels. All the vessels tested were fit and safe for storage of LPG, however, three of the vessels were quite weak and needs close monitoring.

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