INSPECTION AND EVALUATION OF DAMAGE MECHANISMS IN TWO-PHASES VERTICAL SEPARATOR

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ABSTRACT

Pressure vessels are critical components in various industries that store or transport fluids under pressure. Ensuring their mechanical integrity prevents catastrophic failures and maintains safe and reliable operations, regular inspections are necessary to identify potential defects and damages that can compromise the vessel's integrity. However, practical guidelines for pressure vessel inspection are often not readily available in educational institutions and require specialized certification courses or on-field experience. This article aims to provide a comprehensive and practical approach to inspecting a two-phase vertical separator commonly used in oil and gas based on industry standards and codes, specifically targeting mechanical engineers, engineering students, and professionals entering the inspection field. It demonstrates the application of a standardized methodology for inspecting a pressure vessel and analyzing its damage mechanisms. The inspection standards applied in this study include API-510, API-571, API-572, API-579, and API-580. The inspection process encompasses both external and internal evaluations. External inspections focus on identifying conditions that may affect the mechanical integrity of the vessel, such as support structures, corrosion, or external damage. Internal inspections utilize visual and non-destructive testing (NDT) techniques to detect damage or discontinuities within the vessel. It includes inspection planning, component selection, thickness measurements, and NDT techniques. The external inspection findings include thickness measurements of the shell, nozzle, and coupling areas. The identified material loss percentages are compared to design limits, enabling the determination of remaining structural integrity and the need for repairs or further evaluations.

Keywords: vessel inspection, pressure vessels evaluation, damage mechanisms.

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1. INTRODUCTION

Currently, pressure vessels are used in most industrial plants in the oil and gas sector and are designed to transport or store liquids or gases for a required process. A pressure vessel is a closed container subjected to internal or external pressure capable of storing a fluid. This pressure exerts from a direct or indirect source or an internal or external source [1]. Pressure vessels contain pressurized fluids or gases [2], and any failure can result in catastrophic consequences. Therefore, it is essential to perform regular inspections to identify potential defects or damage that can compromise the vessel's mechanical integrity, which must be evaluated to ensure safe and reliable operation [3].

Also, vessels walls are subjected to pressure gradients on their inner side by the fluids they contain, which are typically composed of chemicals that mildly react with the material they are constructed with, and on their outer side, they corrode due to external agents in the environment, leading to significant corrosion on both surfaces over time [4]. Due to the corrosiveness of some fluids for carrying out specific processes, pressure vessels' structural integrity must be periodically evaluated to determine their continuous performance during service [5]. This article aims to provide mechanical engineers or related fields, starting in the inspection area, or engineering students, with a practical approach to inspect this pressure vessel according to standards and codes. This information is not commonly found in universities and is generally only available in specialized certification courses or through on-field learning by junior engineers. We present a case study where a methodology under the standard is applied to define how to inspect a pressure vessel and analyze its damage mechanisms.

1.1 Inspection Types

An inspection is the external or internal evaluation of a pressure vessel's mechanical condition [6].

1.1.1 External inspection

This type of inspection is performed on the exterior of a component to check for conditions that could affect the mechanical integrity of the equipment. This inspection is most commonly done on support structures such as ladders, platforms, and equipment, whether in operation or out of service.

1.1.2 Internal inspection

Internal inspection is performed inside a pressure vessel using visual testing (VT) and/or non-destructive testing to search for damage or discontinuities that external inspections throughout the internal surface of the equipment cannot identify. This inspection must be performed with the vessel out of service to allow inspection personnel entry. In equipment not designed for personnel entry, inspection ports must be opened to examine internal surfaces and visual inspection techniques can be used to examine them.

There are pressure vessels with removable internal parts. However, removing them entirely for inspection is unnecessary unless there is reasonable assurance that no damage will be generated to the equipment. These parts can be examined using the inspection method defined by the certified API inspector.

1.2 Non-Destructive Testing

Non-destructive testing (NDT) allows for determining the internal integrity of pressure vessel components without modifying their properties. Thus, once their condition has been verified, according to what is found, the vessel may be deemed suitable for use, requiring repair or, in the worst-case scenario, replacement. The main objective of this type of test is to detect different internal damages that modify the material's physical properties and can affect the equipment's service life. Inspection prevents significant economic losses in industries [7]. Several techniques are available for evaluating the mechanical integrity of pressure vessels, including visual, ultrasonic, radiography, magnetic particle, and eddy current testing. Each method has advantages and limitations, and the choice of technique depends on various factors such as the vessel's material, size, shape, and location.

Visual testing (VT) is a primary method involving visual examining the external and internal vessel surfaces. This method is suitable for detecting surface defects such as cracks, corrosion, and deformation. However, it may not be effective in detecting defects that are not visible to the naked eye.

Ultrasonic testing (UT) is a widely used method that uses high-frequency sound waves to detect defects in the material. This method can detect both surface and subsurface defects and is suitable for a wide range of materials. However, it requires specialized equipment and trained personnel to perform the testing.

Radiography testing (RT) is another method that uses X-rays or gamma rays to detect defects in the material. This method detects internal defects such as cracks, voids, and inclusions. However, it involves ionizing radiation, which can be hazardous to personnel and requires strict safety precautions.

Magnetic particle testing (MT) and eddy current testing (ET) are non-destructive testing methods used to detect surface defects. Magnetic particle inspection involves magnetizing the material and applying iron particles to the surface, which are attracted to areas of magnetic flux leakage caused by surface defects. Eddy current testing uses an electromagnetic field to induce currents in the material, which are detected by sensors to identify defects.

1.3 Inspection Standard Applied

The API-510 standard [6] specifies the necessary inspections to ensure the proper operation to preserve their mechanical integrity and thus achieve the defined service life in the design. By fully performing the required inspections, the physical and mechanical properties of vessels, and the safety of the workplaces in the companies are preserved.

The API-571 standard [8] guides the fundamental mechanisms of different types of damage that can occur in equipment used in the refining and chemical process industries. It covers damage mechanisms such as corrosion, hydrogen-induced cracking, sulfide stress cracking, and fatigue and provides information on how to evaluate and manage these issues to ensure the safe operation of equipment.

The API-572 standard [9] is a recommended practice that complements API 510, as it provides pressure vessel inspectors with sufficient information to improve their skills and increase their basic knowledge of inspection practices. This practice describes in detail the inspection planning and evaluation processes and the repair methods that must be considered for the various types of pressure vessels used in petroleum refineries and chemical plants.

API-579 is a recommended practice for the fitness-for-service (FFS) assessment of equipment used in the oil and gas industry [10]. It provides a methodology to evaluate the equipment's structural integrity that has sustained damage or degradation during operation. The FFS assessment determines if the equipment can continue to operate safely until the next scheduled inspection or if it needs to be taken out of service for repair or replacement.

API 580 is a recommended practice [11] that guides the development and implementation of a risk-based inspection (RBI) program for fixed equipment and piping in the refining and petrochemical industries. The standard outlines the principles and best practices for assessing and managing risk and determining the appropriate inspection frequency and methods based on the likelihood and consequence of potential failures [12]. API 580 RBI methodology is widely used to improve safety, reliability, and cost-effectiveness by focusing inspection resources on the most critical equipment and areas.

1.4 Damage Mechanismus in Codes

According to API 572 standard [9], any damage or defect that can alter the equipment's mechanical integrity used in the chemical and refining process industry, such as corrosion, cracking, erosion, dents, and other mechanical, physical or chemical impacts, is defined as a damage mechanism [13]. Common damage mechanisms are grouped into five parts according to API 571 standard [8], its provides an in-depth look at nearly 70 different damage mechanisms that can occur to process equipment in refineries. Below are listed in brackets the possible ones on the pressure vessel inspected:

- Mechanical or metallurgical failure mechanisms (Erosion)
- Uniform or localized loss of thickness (CO_2 Corrosion, Corrosion under isolation CUI, Atmospheric corrosion)
- High-temperature corrosion
- Environment-Assisted cracking
- Other mechanisms

Table-1. Damage mechanismus for API 579.

Damage Mechanismus	Section Number
Brittle fracture	3
General metal loss	4
Local metal loss	5
Pitting corrosion	6
HIC/SOHIC damage blisters	7
Weld misalignment and wall distortion	8
Defects such as cracks	9
High-temperature operation and creep	10
Fire damage	11
Dents, scratches, and combinations	12
Laminations	13

API 579 covers various types of damage mechanisms in this section (Table-1), including corrosion, cracking, and deformation, and provides guidelines for using non-destructive examination (NDE) techniques to assess the extent and severity of the damage [14].

2. MATERIALS AND METHODS

2.1 Two-Phase Vertical Separator

The inspected equipment was a two-phases separator with an ASME manufacturing certification. The ASME plate was located on the side of the shell. However, this plate does not specify some data, such as material fabrication; therefore, it was assumed under the manufacturing materials defined by the API-510 standard. The equipment specifications are described in detail in Table-2.

Table-2. Specification of the vessel in the ASME identification plate.

Identification	Specifications
Manufacturer	NAT'L. BD
Certified by	PEERLESS MFG. CO.
Service	GAS
ASME Stampe	Yes
Shell Material	SA-283 Gr C (Assumed)
Material cap's	SA-283 Gr C (Assumed)
Corrosion allowance [CA]	0,063 in
Diameter	20 in
Shell Length	102,20 in
Design Pressure	270 Psi
Test Pressure	Not specified
Operating Temperature	Not specified
Design Temperature	150°F
Capacity	Not specified
Construction year	February 1985
Radiography RX	RT-3
Stress Relief	Not specified
Nominal Shell Thickness	0,375 in (Assumed)
Thickness Nominal Head	0,375 in (Assumed)

Figure-1. Vertical two-phase separator inspected.

2.2 Planning Inspection

The inspection procedure defined in the API 572 standard was applied to the two-phase separator's caps, nozzles, and body. Likewise, the classification of damage mechanisms according to API-571 standard and the evaluation of minimum thicknesses required by API-510 and ASME Section VIII Division I standard [1] were also thoughtful.

In addition, before the inspection was considered some previous documents or technical information, such as short- and long-term recommendations performed on prior inspection results and the mechanical integrity of the equipment. Inspection planning includes component parts, thickness measurement, NDT technique, and internal or external procedures. VT was evaluated in this order:

a) Locations for condition monitoring (CML) were identified. CML are specific areas designated in the pressure vessels with high potential for corrosion, where periodic tests are performed to monitor the presence and rate of equipment damage following the API 510 inspection recommendations and identified by certified inspectors.
b) The measure of thicknesses using UT Scan A on main parts such as shell, heads, and nozzles - were recorded to verify the minimum thicknesses required according to API 510 standard.
c) Detecting defects adversely affecting the performance or structural integrity of the separator's shell, heads, and nozzles.
d) Measure the thickness in different parts of the vessel, especially if there is a higher likelihood of damage.

Table-3 indicates the two-phase vertical separator parts to be inspected, the expected failure type, the NDT employees, the inspection extent, and the possible damage mechanisms that may occur.

Table-3. Two-phase vertical separator parts inspection, NDT, covering, and damage mechanism.

Parts & Inspection type		Observation	NDT	Covering	Damage Mechanism
Vessel - External inspection	Shell and Exterior caps	Porous layer precipitation Formation of corrosion layers Severe localized attacks	UT-Scan A VT	8 axes	Carbon dioxide corrosion (CO_2). Atmospheric corrosion. Corrosion under isolation (CUI).
		Caps thickness loss	VT	8 axes – Knuckle, crown center	
	Welds	Cracks	VT	100%	Atmospheric corrosion.
Vessel – Internal inspection	Shell and interior caps	Porous layer precipitation Formation of corrosion layers Severe localized attacks Material removal for fluid flow	VT	100% of shell and caps	Carbon dioxide corrosion (CO_2). Erosion.
	Seats and couplings	Formation of corrosion layers Severe localized attacks	VT	100% of bases and anchors	Atmospheric corrosion. Corrosion under isolation (CUI).
	Nozzles	Formation of corrosion layers Severe localized attacks	UT-Scan A VT	6 axes x 1 ring	Carbon dioxide corrosion (CO_2). Atmospheric corrosion Corrosion under isolation (CUI)

3. RESULTS AND DISCUSSIONS

3.1 External Inspection

A visual inspection of all external parts of the separator was carried out, including accessories such as access ladders, chairs, anchoring, ground connection, and welds. Thickness measurement was also performed using UT Scan A, considering API-572 standards and the criteria of the certified API inspector leading the inspection to define the inspection areas. Data was recorded during the thickness measurements, and the lowest value was considered the minimum one (tmin). Once tmin was identified, it was compared to the design or nominal thickness (tnom).

3.1.1 Shell inspection

For the thickness measurement, the shell was segmented into 26 rings of 4 [in]; and each ring was divided circumferentially into 45°, resulting in eight (8) inspection areas (Figure-2).

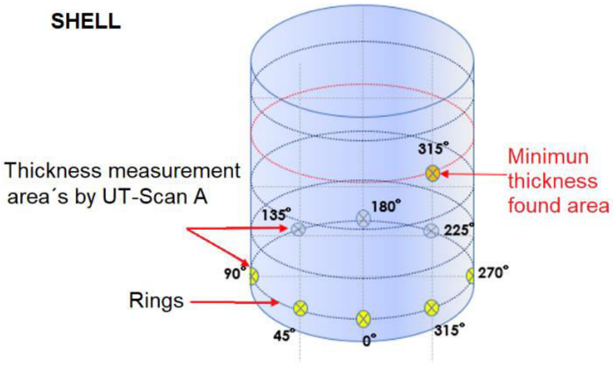

Figure-2. Diagram of rings and areas of the shell for thickness measurement.

The corresponding measurements were analyzed and the minimum thickness was determined, resulting in a tmin = 0.322 [in] located in ring 4, at the bottom of the shell. Design thickness at this point was tnom=0.375 [in] according to the plans.

$$\%Material\ Loss = \frac{t_{nom} - t_{min}}{t_{nom}} * 100 \qquad \text{(Eq. 1)}$$

Using equation 1, a material loss was 14%, a value considered significant by the API inspector because the bottom area of the shell is where the liquid phase of the system is collected. As a result, a more detailed segmentation was carried out in that area to perform thickness measurements and determine if there were higher loss percentages. A grid was drawn on the shell at a distance of one inch [1 in], with 25 axes numbered from 1 to 25 and 9 points per axis denoted alphabetically (Figure-3).

Figure-3. Verify minimum thickness in the lower zone of the separator's shell.

The procedure to determine the minimum thickness was the same as mentioned above, and a tmin = 0.219 [in] was obtained at axis 12, ring G, with a severe material loss of 42%. The data obtained for this and the other sections forward were used to determine the corrosion rate and remaining equipment life in the mechanical integrity assessment according to API 510 standards and ASME Section VIII Division 1 calculation, which will be shown in another paper.

3.1.2 Nozzle inspection

3.1.2.1 Elbow Nozzle

A single 90° elbow nozzle was found, connecting at the upper end to the lower cap of the equipment's cap, and one nipple located at the other end of the elbow, connecting to the flange. To determine the minimum thickness (tmin) using UT scan A, the elbow nozzle was divided into 18 areas, resulting from dividing it into 4 rings (4 areas per ring) and 2 pinpoint areas as shown in Figure-4. Ring 1 was located on the lower cap (near the elbow) to verify the weld condition and identify possible damage mechanisms in the equipment's helmet. Ring 2 was diagrammed at the centre of the elbow (curved zone), and the two pinpoint areas were located at the ends of the elbow. Rings 3 and 4 were traced on the nipple connecting to the flange. All rings were placed clockwise, and their measuring areas have intervals of 90° (Figure-4).

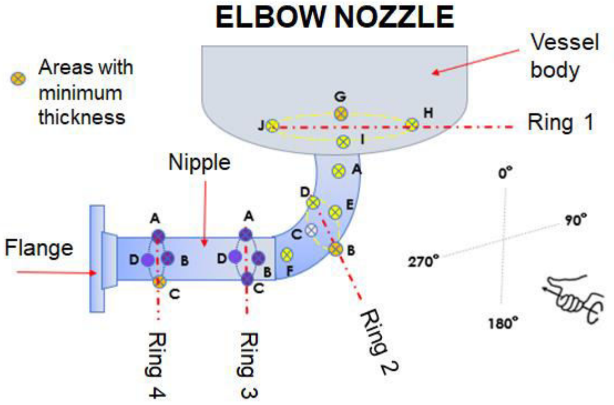

Figure-4. Division of elbow nozzle in rings and areas for thickness measurement.

Table-4 shows the minimum thicknesses (tmin) obtained using ultrasonic Scan A in the different rings and their respective nominal minimum thicknesses by design (tnom).

Table-4. Minimum thicknesses for the elbow nozzle.

	Shell R1	Elbow 90° R2	Nipple R3	Nipple R4
Tnom [in]	0,375	0,344	0,344	0,344
Tmin [in]	0,270	0,265	0,316	0,258
% Loss	28%	23%	8%	25%

In Table-4 and Figure-4 highlighted in orange, it can be observed that the highest percentages of material loss were found in the center of the elbow with a 23% material loss in ring 2, area B; in the helmet with a 28% material loss in ring 1, area G; and in the nipple connecting to the flange with a 25% material loss in ring 4, area C.

3.1.2.2 Straight nozzles

For the thickness measurement of the straight nozzles using UT Scan A, each of them was divided into two (2) clockwise rings. The first ring (ring 1) was performed on the neck of each nozzle with six (6) measuring areas, identified as letters A to F, at intervals of 60°, as shown in yellow in Figure-5. The second ring (ring 2) was done around the straight nozzle in the equipment's helmet, with four (4) measuring areas at intervals of 90°, identified as letters G to J, as shown in green in Figure-5. It is worth noting that the location and intervals of the last four areas used to segment the nozzles were defined by the certified API inspector leading the equipment inspection in the field.

After performing the segmentation above procedure on each of the straight nozzles of the separator, the measurement with UT Scan A was carried out in all specified areas and rings, and the minimum thickness of each was obtained.

Table-10 displays the values of minimum thicknesses (tmin) obtained using ultrasonic Scan A for each of the straight nozzles in the neck and equipment's helmet, along with their respective nominal minimum thicknesses by design (tnom), which were used to calculate the percentage of loss in each component.

Table-5. Minimum thicknesses for the straight nozzles.

Straight Nozzles	Ø [in]	Neck			Shell		
		tnom [in]	tmin [in]	% Loss	tnom [in]	tmin [in]	% Loss
N2	4	0,337	0,312	7%	0,375	0,386	0%
N3	4	0,337	0,283	16%	0,375	0,369	2%
N4	8	0,322	0,29	10%	0,375	0,384	0%
N5	8	0,322	0,301	7%	0,375	0,385	0%

Table-5 shows that the highest percentage of material loss occurred in the neck of nozzle 3 (N3) with 16%, tmin= 0.283" in ring 1, area D, as illustrated in Figure-5 in orange. The percentages of losses obtained in the helmet measurements were negligible, ranging from 0% to 2% as shown in Table-10.

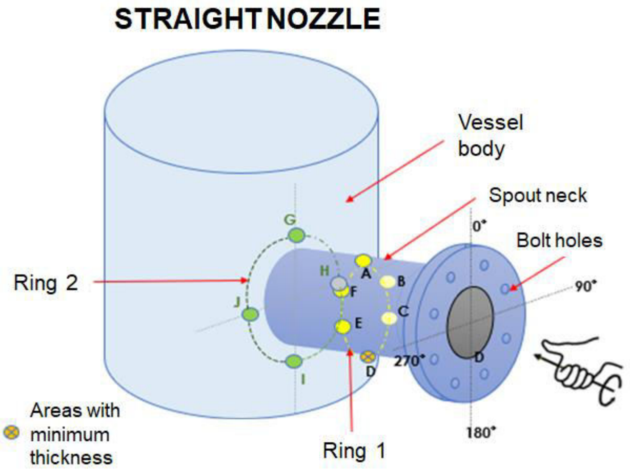

Figure-5. Area with minimum thickness found in the straight nozzle of the separator.

3.1.3 Separator couplings inspection

To perform thickness measurement of the separator couplings, each of them was divided into two (2) rings with 4 measuring areas at an approximate 90° interval. The first ring was performed in the central part of the coupling, and the second ring was done in the equipment's helmet, around each (Figure-6).

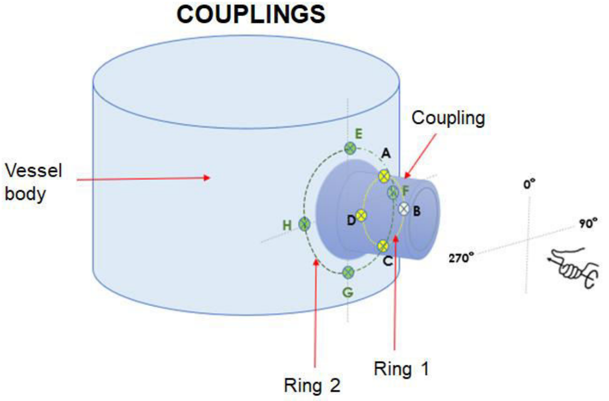

Figure-6. Diagram of rings and areas performed in the field for thickness measurement in the separator couplings.

The minimum thickness was determined similarly as in the previous sections. Table-6 presents the values of minimum thicknesses (tmin) for each of the couplings in the neck and equipment's helmet, their respective nominal minimum thicknesses by design (tnom), and the percentage of loss in each component.

Table-6. Minimum thicknesses for the couplings.

Coupling	Ø [in]	Neck			Shell		
		tnom [in]	tmin [in]	% Loss	tnom [in]	tmin [in]	% Loss
C1	0,75	0,154	0,133	14%	0,375	0,323	14%
C2	2	Plug			0,375	0,35	7%
C3	0,75	0,154	0,142	8%	0,375	0,358	5%
C4	0,5	0,147	0,14	5%	0,375	0,371	1%
C5	0,5	0,147	0,135	8%	0,375	0,397	0%
C6	2	Plug			0,375	0,372	1%
C7	0,75	0,113	0,11	3%	0,375	1,753	0%

In Table-6, it can be observed that the coupling with the highest percentage of thickness loss is coupling 1 (C1), located in the lower cap of the equipment, with a 14% loss in the neck (tmin= 0.133 inches) in ring 1, area B, and also a 14% material loss in the separator's helmet (tmin=0.323 inches) in ring 2, area G, as illustrated in Figure-7 in orange.

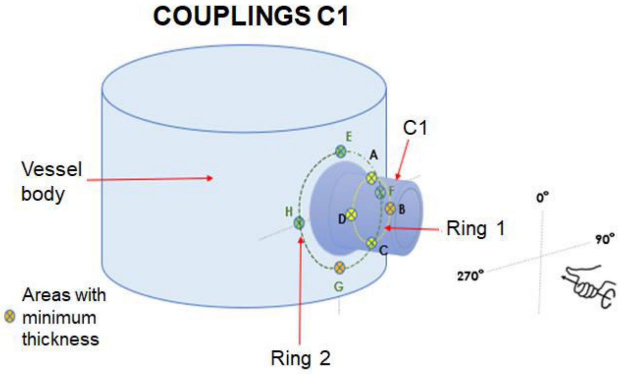

Figure-7. Minimum thickness found in coupling 1.

3.1.4 Separator caps inspection

3.1.4.1 Lower cap

The thickness measurement of the separator's lower cap using ultrasonic Scan A was performed by segmenting it into 6 rings, separated at a distance of approximately 3 inches, with 8 measuring areas at intervals of 45° in a clockwise direction. Two (2) rings were made on the knuckles of the cap, near the equipment's helmet joint. The other four (4) rings were made on the crown, as indicated in Figure-8.

After performing the segmentation as mentioned above procedure on the lower cap, the measurement with UT Scan A was carried out in all specified areas and rings, and the minimum wall thickness was determined. Table-12 presents the values of minimum thicknesses (tmin) obtained using ultrasonic Scan A in the lower cap, along with their respective nominal minimum thicknesses by design (tnom), which were used to calculate the percentage of material loss in the mentioned component.

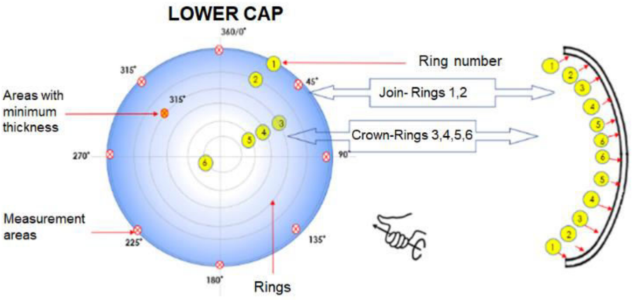

Figure-8. Diagram of rings and areas performed in the field for thickness measurement A in the lower cap of the separator.

Table-7. Minimum thicknesses for the lower cap.

Rings	tnom [in]	tmin [in]	% Loss
1	0,317	0,375	15%
2	0,317	0,375	15%
3	0,254	0,375	32%
4	0,271	0,375	28%
5	0,258	0,375	31%
6	0,258	0,375	31%

It can be observed in Table-7 that the crown of the lower cap has significant percentage losses, but the highest percentage was found in ring 3, area 8 (315°) with tmin=0.254 inches, as illustrated in Figure-9.

Due to this finding, the API inspector decided to perform a thickness verification in the area with the highest material loss to assess the mechanical condition of the initially uninspected parts in the crown of the lower cap. For this reason, measurements were retaken using UT Scan A, creating 4 rings in a clockwise direction around the affected area, with a distance of 1 inch between each ring, and 8 measuring areas at a 45° interval. Two rings were made in the upper part, and the other two were made in the lower part of the area with the highest loss percentage.

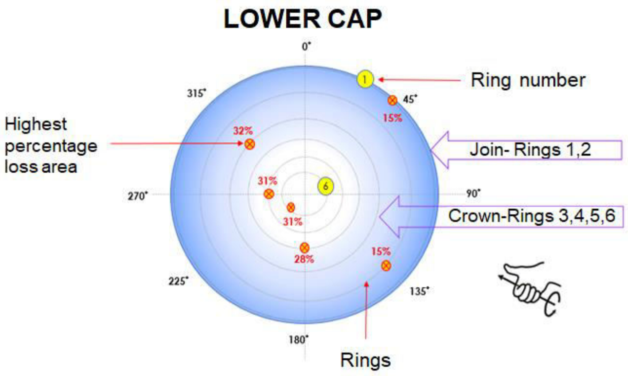

Figure-9. Percentage of material loss in the lower cap.

The procedure for determining the minimum thickness (tmin) in the thickness verification of the material in the crown of the lower cap was the same as the one used for the general tmin measurement conducted earlier. The data from the UT Scan A were recorded, and the lowest value among them was considered the tmin for the crown of the lower cap. Subsequently, the percentage of material loss was calculated using tmin and tnom to assess the mechanical integrity of the cap's crown. It was found that the highest percentage of material loss was 62% in ring 3, area 3 (90°), with a tmin of 0.141 inches, as described in Table-8 which presents the nominal thickness by design (tnom) for the lower cap, which was used to calculate the percentage of loss.

Table-8. Thickness verification is used for the crown of the lower cap.

Rings	tnom [in]	tmin [in]	% Loss
1	0,218	0,375	0,42
2	0,186	0,375	0,5
3	0,141	0,375	0,62
4	0,226	0,375	0,4

The value of tmin found in the lower cap was used to determine the corrosion rate and remaining equipment life in assessing mechanical integrity according to API 510 standard and the calculations of ASME Section VIII Division I in section 5.7 of this document, specifically for the lower cap.

3.1.4.2 Upper cap

For thickness measurement using UT Scan A in the upper cap of the separator, it was segmented into one (1) ring and one (1) pinpoint the area. The ring was created on the knuckles of the cap, with 8 measuring areas at approximately 45° intervals in a clockwise direction. The pinpoint measurement area was located on the cap's crown, as shown in Figure-10.

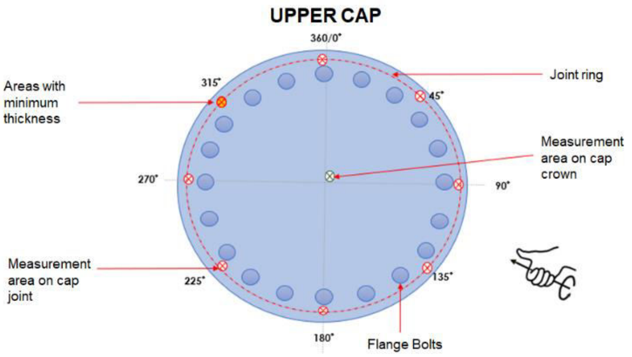

Figure-10. Thickness verification in the upper cap using UT Scan A.

After performing the mentioned segmentation procedure on the upper cap, thickness measurements were taken using UT Scan A in all the specified areas and the ring shown in Figure-10, resulting in the determination of the minimum wall thickness.

Table-9 presents the values of minimum thickness (tmin) obtained with UT Scan A in the upper cap, along with their respective nominal minimum thicknesses by design (tnom), which were used to calculate the percentage of material loss for the component in question.

Table-9. Minimum thicknesses in the upper cap.

Joint			
Ring	**tnom [in]**	**tmin [in]**	**% Loss**
1	1,51	1,62	7%
Crown			
Area	tnom [in]	tmin [in]	% Loss
1	1,6	1,62	1%

The upper cap crown does not exhibit significant material loss percentages, as seen in Table-14. The UT Scan A revealed a tmin of 1.51 inches with a 7% loss in the cap's knuckles in Area 8 (315°), as shown in Figure 10. Additionally, a 1% material loss was found in the crown, as indicated in Table-**9**.

3.2 Internal Inspection

The internal inspection of the separator was conducted using visual inspection and following the inspection procedure outlined in API 572. For this inspection, a shutdown of the equipment was planned, and as a result, it was completely disassembled and cut at the circumferentially welded joint connecting the shell to the lower cap, as depicted in Figure-11.

Figure-11. Disassembled TEA vertical two-phase separator for internal inspection.

Internally, a deficient cleaning was observed (which should have been entirely carried out during the previous inspection), with product deposits that hindered proper inspection. However, the damage mechanisms in the equipment's internal components were successfully identified, including the mist extractor box, the associated condensate pipe, the impact tray of the separator, and the surfaces of the vessel, caps, and nozzles. Following the internal inspection, the opportunity was taken to replace the lower cap per the previous year's inspection recommendations. Finally, with the collected data, a general diagnosis of the equipment's condition was conducted under the existing regulations - ASME Section VIII Division I Code and API-510.

3.3 Determination of Damage Mechanisms and Defectology

The damage mechanisms present in the equipment were identified through external inspection using the ultrasonic scan A technique and internal inspection through visual inspection (VT) to subsequently determine the mechanical integrity of the separator using the wall thicknesses found in its various components. The API 571 standard was used for defect identification, classification of damage mechanisms, and the contingency plan to mitigate the identified damages.

3.3.1 Damage mechanisms present in the external part of the separator

During the VT external inspection, it was observed that the equipment's shell was in good mechanical condition, without distortions, scratches, dents, protrusions, or significant undercutting. There was no significant material loss due to generalized or localized external corrosion (pitting). Furthermore, no weld mat repairs, lap patches, or butt-weld inserts were observed on the shell or nozzles. The circumferential welds and nozzle welds were coated and showed no indications of significant material loss. The equipment's coating was functional, with slight detachment observed at the upper flanged joint. During the UT Scan A external inspection, it was determined that the shell, lower shell head, Nozzle 3, and Coupling C1 exhibited the highest thickness losses in the equipment (42%, 62%, 16%, and 14%, respectively). It is important to clarify that although no discontinuities associated with a specific damage mechanism were observed on the external parts of the separator components during VT, the minimum wall thicknesses indicated damage mechanisms such as CO_2 corrosion and/or pitting corrosion in their interior zones.

Tabla-10. Damage mechanisms in the internal part of the separator.

Part of separator		Damage mechanism	Observations	Contingency Plan
Shell	Mist extractor (1)	CO_2 corrosion	Severe corrosion and loss were relevant to the material in the fins of the mist extractor.	Change
	Extractor condensate pipe (2)	CO_2 corrosion	Moderate uniform general corrosion throughout the condensate piping.	Carry out a CO_2 elimination process through hydrogen plants. Use aerators and injection of inhibitors.
	Shell surface in the intermediate zone (3)	CO_2 corrosion	Rough orange peel-like surface, mild to moderate uniform corrosion occurred.	
	Shell surface in the lower zone (4)	CO_2 corrosion	Moderate uniform corrosion on the lower surface of the shell.	
Lower cap (5)		CO_2 corrosion	Moderate-severe corrosion	Change
Nozzle (6)		CO_2 corrosion	Moderate-severe corrosion	
Coupling (7)		CO_2 corrosion	Not present active threads for threading.	

Figure-12. Photos of damage mechanisms in the internal part of the separator.

3.3.2 Damage Mechanisms present in the internal part of the separator

During the VT internal inspection, material thinning was found in the lower zone of the shell, along with moderate to severe corrosion in the lower shell head, confirming the findings from the previous inspection and the results obtained from the UT Scan An external inspection regarding the significant material loss in this area of the equipment. In the intermediate zone of the shell, mild to moderate uniform general corrosion was observed, with a rough orange-peel-like surface and no internal coating.

The locations where evidence of damage mechanisms was found during the VT internal inspection corresponded to the areas of the equipment that exhibited minimum wall thicknesses in the external UT Scan An inspection. Additionally, internally, the mist extractor box showed severe corrosion and material loss in the fins, while the condensate pipe of the mist extractor exhibited moderate uniform general corrosion. Table-14 provides an overview of the damage mechanisms identified in the separator through the VT internal inspection, the components where they were observed, and the proposed contingency plan to mitigate them, which involves repair or replacement recommendations based on the mechanical condition encountered.

As observed in Table-14 and Figure-12, only CO_2 corrosion was identified as the damage mechanism in the equipment's internal components, resulting from the gas condensation occurring within the separator in the liquid phase

4. CONCLUSIONS

The visual inspection and thickness measurements using UT Scan A revealed a material loss in various separator components, including the shell, elbow nozzle, straight nozzles, separator couplings, and lower and upper caps. The identified minimum thickness values (tmin) were compared to the design thickness (tnom) to determine the percentage of material loss.

The elbow nozzle and straight nozzles were inspected separately. Significant material loss percentages were found in the elbow's centre, the elbow nozzle's cap, and the nipple connecting to the flange. The straight nozzles showed material loss, primarily in the neck area.
The thickness measurement of the separator couplings revealed a material loss in both the neck and the equipment's shell. Coupling 1 exhibited the highest percentage of thickness loss in both areas.

The lower cap exhibited a significant material loss in the crown, particularly in ring 3, and area 8. Further thickness verification was conducted in the affected area, confirming a high percentage of material loss. The upper cap showed negligible material loss percentages.

The internal inspection of the separator identified deficient cleaning and damage mechanisms, such as CO2 corrosion in the lower zone of the shell, lower shell head, mist extractor box, and condensate pipe. The damage mechanisms correlated with the areas that exhibited minimum wall thickness in the external inspection.

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