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Analysis of Connected Pipeline Loads on Nozzles Welded To Air Receiver Drum Using WRC Method

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Abstract: Nozzles welded to air receiver drums for fluid inlet and outlet, subjected to complex loads from connected pipelines, require robust design to prevent structural failure. These nozzles, reinforced with additional plates to compensate for metal loss from hole punching, face primary and secondary stresses at the junctions. The WRC method is employed to analyze these stresses, ensuring they remain within allowable limits to maintain safety. This study utilizes WRC 107 and WRC 297 guidelines for detailed stress analysis under various loading conditions, aiming to identify critical stress points and evaluate the structural integrity of nozzle connections, thereby enhancing the reliability of air receiver drums in industrial applications.

Index Terms **– Pipe line loads, Nozzles, Air receive drum, WRC method, stress analysis, Reinforcement plates, Structural integrity, Primary stresses, Secondary stresses, Design optimization.**

I. INTRODUCTION

Stress analysis of nozzles welded to pressure vessels is a critical aspect of pressure vessel design, ensuring safety and integrity under various operating conditions. The methods for accurately predicting and analyzing these stresses have evolved significantly over the years. One prominent method is the Welding Research Council (WRC) method, which has been extensively studied for its effectiveness and limitations. Researchers have demonstrated the practical application of the WRC method in analyzing stresses on nozzles welded to air receiver drums, highlighting its accuracy in real-world scenarios (1). The challenges in predicting stress concentrations around nozzles in pressure vessels have been a significant focus, emphasizing the need for precise modeling techniques to prevent potential failures (2). The validation of WRC method results using finite element analysis (FEA) has been a critical step in understanding the strengths and weaknesses of both approaches (3). An overview of various stress analysis methods for pressure vessels, including the WRC method, provides insights into their respective advantages and limitations in different contexts (4).

Comparative studies have shown the relative accuracy and reliability of WRC 107, WRC 297, and FEA for nozzle stress analysis under various loading conditions (5). The limitations of the WRC method in nozzle stress analysis and the complementary role of FEA in providing a more comprehensive evaluation have been thoroughly examined (6). The integration of thermal and mechanical load analyses using both WRC and FEA methods demonstrates how these approaches can be combined for a more robust stress analysis (7). The application of WRC 297 in complex loading conditions for pressure vessel nozzles has been explored, showcasing its effectiveness and adaptability in challenging scenarios (8). Case studies on the utilization of WRC 107 for stress analysis in cylindrical shell nozzles highlight its practical benefits and applications (9).

Further research has delved into nozzle load stress analysis using both WRC 107 and WRC 297, providing a comparative perspective on the strengths and weaknesses of each method (10). Investigations into the stresses and interaction effects of nozzle-cylinder intersections when subjected to multiple external loads offer a comprehensive understanding of the complexities involved in real-world applications (11). Studies on load checking of in-service pressure vessel nozzles address critical aspects of maintenance and reliability, emphasizing the importance of ongoing assessment in operational environments (12).

Beyond these specific studies, the WRC method's impact on the field of pressure vessel design cannot be understated. It has provided engineers with a practical tool for initial design and evaluation, which can be supplemented with more detailed analyses such as FEA when necessary. This layered approach allows for both efficient preliminary assessments and detailed, high-fidelity investigations of stress distributions. The ongoing advancements in computational methods, including improvements in FEA software and hardware capabilities, continue to enhance the precision and applicability of stress analysis techniques.

Moreover, the industry standards and guidelines that incorporate methods like WRC and FEA are continuously updated to reflect new research findings and technological advancements. This dynamic field requires engineers to stay informed about the latest developments and methodologies to ensure the safety and reliability of pressure vessel designs. As research progresses, the integration of advanced materials, novel manufacturing techniques, and improved computational tools will likely drive further innovations in the stress analysis of pressure vessel nozzles, enhancing their performance and safety in increasingly demanding applications.

Overall, the extensive body of research and ongoing developments in this field underscore the critical importance of accurate stress analysis in maintaining the structural integrity and operational safety of pressure vessels. By combining traditional methods with modern computational techniques, engineers can better predict and mitigate the stresses experienced by nozzles and other critical components, ensuring the continued reliability and safety of these essential systems.

II. EXPERIMENTAL PROCEDURE

2.1 WRC Method:

The analysis of the air receiver drum and nozzles requires the collection of several critical parameters. Firstly, the geometric details of the components need to be gathered, including the diameter, thickness, and specific dimensions of the nozzles. These parameters are essential for understanding the physical configuration and potential stress concentrations within the system. Additionally, material properties must be collected, such as Young's modulus, Poisson's ratio, and yield strength. These properties define how the material will respond to the various loads and stresses it will encounter during operation. Furthermore, the operational loading conditions must be clearly defined. This includes the internal pressure within the drum, the external pipeline loads, which consist of forces and moments acting on the structure, and any thermal loads that may be present due to temperature variations. Collectively, these details form the basis for a comprehensive analysis, ensuring the air receiver drum and nozzles can be evaluated accurately for safety and performance under all anticipated operating conditions.

To ensure the structural integrity of the air receiver drum and its nozzles, a detailed stress analysis is performed using procedures outlined in WRC Bulletin 107. This involves calculating the local stresses in the cylindrical shell due to external loadings on the nozzles. The process begins with determining the force and moment components acting on the nozzle. These components are then used in conjunction with the charts and equations provided in WRC 107 to find the stress concentration factors. By applying these factors, the resulting stresses in the shell and nozzle junction can be accurately calculated. For more complex loading scenarios and geometries, the analysis is extended using WRC Bulletin 297. This bulletin allows for the incorporation of additional factors such as pressure loads and spherical shell considerations. The extended charts and equations in WRC 297 refine the stress calculations, providing a more comprehensive understanding of the stresses involved. Together, these methodologies ensure a thorough evaluation of the stress distribution, contributing to the safe and efficient design of the air receiver drum and its components.

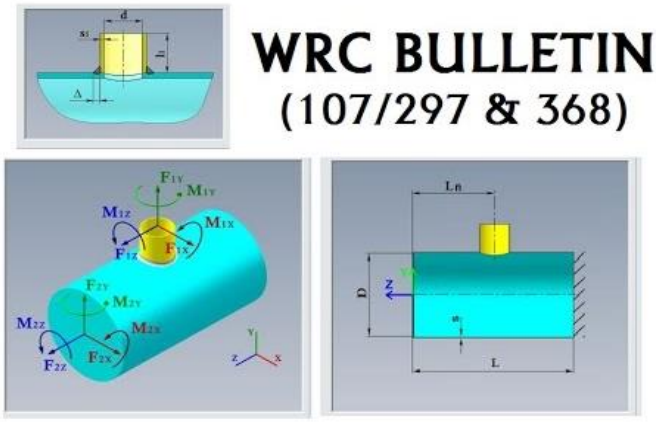

Fig 1: WRC Analysis

2.2 Sensitive analysis

To comprehensively study the stress distribution in the air receiver drum and nozzles, various parameters are systematically varied. Load variation involves changing the magnitude and direction of the external pipeline loads to observe their impact on the stress distribution within the structure. This helps in understanding how different loading conditions influence the stresses experienced by the drum and nozzles. Geometric variation includes modifications to the nozzle size, position, and orientation. By adjusting these geometric parameters, the study aims to identify how they affect stress concentrations and overall stress distribution. Material variation involves exploring the effects of different material properties, such as Young's modulus, Poisson's ratio, and yield strength, on the stress results. This analysis helps in determining how changes in material characteristics influence the structural behavior under various loading conditions.

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III. RESULTS & DISCUSSIONS

3.1 Software incorporated - PV ELITE SOFTWARE

PV Elite is a comprehensive software package designed by Intergraph for pressure vessel and heat exchanger design, analysis, and evaluation. It caters to the needs of engineers involved in the design and maintenance of these critical components in various industries, including oil and gas, chemical, power, and more.

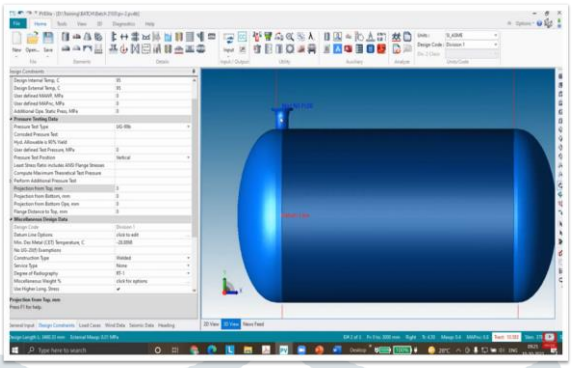

Fig 2: PV ELITE SOFTWARE Interface

3.2 RESULT (FAILED)

3.2.1 Input, Nozzle Disc: N1 From: 10

Parameters	Symbols	Value in Units
Pressure for Reinforcement	P	6.895 bars
Temperature for Internal Presssure	Temp	75 °C
Design External Pressure	Pext	1.03 bars
Temperature for External Pressure	Tempex	75 °C
Parent Material	SA-516 70	
Parent Allowable Stress at Temperature	Sv	137.90 N./mm²
Parent Allowable Stress At Ambient	Sva	137.90 N./mm²
Inside Diameter of Cylindrical	D	1117.60 mm.
Design Length of Section	L	2286.2000 mm.
Shell Finished (Minimum) Thickness	t	8.0000 mm.
Shell Internal Corrosion Allowance	c	3.0000 mm.
Shell External Corrosion Allowance	co	0.0000 mm.
Distance from Bottom/Left Tangent		1500.00 mm.
User Entered Minimum Design Metal Temperature		-28.89 °C

Table 1: Input, Nozzle Disc: N1

The parameters for the vessel design are detailed as follows: The reinforcement pressure is specified at 6.895 bars, with the internal temperature maintained at 75°C. The design external pressure is set at 1.03 bars, with the external temperature also at 75°C. The vessel's parent material is SA-516 70, which has an allowable stress of 137.90 N./mm² at both the operating temperature and ambient conditions. The inside diameter of the cylindrical section measures 1117.60 mm, and the design length of the section is 2286.2000 mm. The shell is designed with a minimum finished thickness of 8.0000 mm, incorporating an internal corrosion allowance of 3.0000 mm, while there is no external corrosion allowance. The distance from the bottom or left tangent is 1500.00 mm. Additionally, the minimum design metal temperature is specified as -28.89°C. These parameters ensure that the vessel is designed to withstand both internal and external pressures, as well as corrosion and temperature variations, while maintaining structural integrity and operational safety under specified conditions.

3.2.2 Type of element connected to the parent : Nozzle

The material used for the air receiver drum is SA-106 B, with a UNS number of K03006, specified as seamless pipe. The allowable stress at both temperature and ambient conditions is 117.90 N/mm². The diameter basis for thickness calculations is taken from the outside, with a diameter of 6.0000 inches. The thickness is nominally rated at 80. The flange material is SA-105, specifically a weld neck flange.

For corrosion allowance, a value of 3.0000 mm is considered. The joint efficiency of the shell seam at the nozzle and the nozzle neck are both rated at 1.00. The outside projection measures 250.0000 mm, with a weld leg size of 10.0000 mm between the nozzle and the pad or shell, and a groove weld depth of 8.0000 mm between the nozzle and the vessel. The inside projection is 0.0000 mm, and the weld leg size for the inside element to the shell is also 0.0000 mm.

The pad material is SA-516 70, with allowable stress at temperature and ambient conditions being 137.90 N/mm². The diameter of the pad along the vessel surface is 200.0000 mm, and the thickness of the pad is 8.0000 mm. The weld leg size between the pad and shell is 8.0000 mm, with a groove weld depth of 8.0000 mm between the pad and nozzle. The reinforcing pad width is 15.8625 mm. The flange class is rated at 150, with a grade of GR 1.1.

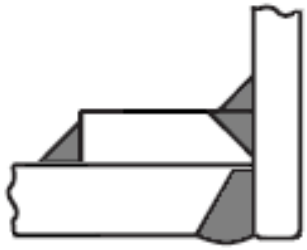

Fig 3: Nozzle design

3.2.3 External Forces and Moments in WRC 107/537 Convention:

Radial Load	(SUS)	P	100.0 Kgf
Longitudinal Shear	(SUS)	Vl	100.0 Kgf
Circumferential Shear	(SUS)	Vc	100.0 Kgf
Circumferential Moment	(SUS)	Mc	300.0 Kg-m.
Longitudinal Moment	(SUS)	Ml	200.0 Kg-m.
Torsional Moment	(SUS)	Mt	200.0 Kg-m.

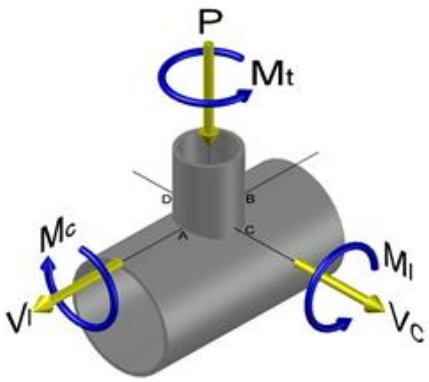

Fig 4: Dimensional Limitations of pad for 200mm

3.2.4 WRC 107/537 Stress Summations:

3.2.4.1Vessel Stress Summation at Attachment Junction (N./mm²)

Stress Intensity Values								
Type ofStressLoad |	Au	Al	Bu	Bl	Cu	Cl	Du	Dl|
Circ. Pm (SUS) |	29.5|	30.1|	29.5|	30.1|	29.5|	30.1|	29.5|	30.1|
Circ. Pl (SUS) |	-18.6|	-18.6|	16.7|	16.7|	-9.5|	-9.5|	8.0|	8.0|
Circ. Q (SUS) |	-37.8|	37.8|	33.4|	-33.4|	-128.0|	128.0|	121.3|	-121.3|
Long. Pm (SUS) |	14.7|	14.7|	14.7|	14.7|	14.7|	14.7|	14.7|	14.7|

Long. Pl (SUS)	-6.3	-6.3	4.8	4.8	-14.6	-14.6	12.7	12.7
Long. Q (SUS)	-57.5	57.5	50.5	-50.5	-67.4	67.4	63.0	-63.0
Shear Pm (SUS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shear Pl (SUS)	0.3	0.3	-0.3	-0.3	-0.3	-0.3	0.3	0.3
Shear Q (SUS)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Pm (SUS)	29.5	30.1	29.5	30.1	29.5	30.1	29.5	30.1
Pm+Pl (SUS)	10.9	11.6	46.2	46.9	19.9	20.6	37.5	38.2
Pm+Pl+Q (Total)	49.7	66.7	80.5	44.8	108.3	148.8	159.0	83.4

Table 2: Vessel Stress Summation - Attachment Junction

3.2.4.2Vessel Stress Summation Comparison (N./mm²):

Type of Stress Int.	Max. S.I.	S.I. Allowable	Result
Pm (SUS)	30.15	137.90	Passed
Pm+Pl (SUS)	46.85	206.85	Passed
Pm+Pl+Q (TOTAL)	159.01	413.70	Passed

The comparison of the vessel stress summation provides a thorough examination of the various stresses encountered by the vessel, expressed in Newtons per square millimeter (N./mm²). The stress criteria are met since the highest stress intensity of the primary membrane stress (Pm) under sustained conditions (SUS) is 30.15 N/mm², well under the permitted limit of 137.90 N/mm². Under sustained circumstances, the combined primary membrane and primary local stress (Pm+Pl) likewise passes, with a maximum stress intensity of 46.85 N/mm² compared to an acceptable limit of 206.85 N/mm².Lastly, all stress components combined show a maximum value of 159.01 N/mm² for the total stress intensity (Pm+Pl+Q), which is below the acceptable limit of 413.70 N/mm² and passes the evaluation. This thorough investigation shows that the vessel can sustain the stresses placed on it under different loading scenarios while maintaining structural integrity and operating safety.

3.2.5 WRC 107/537 Stress Summations:

3.2.5.1 Vessel Stress Summation at Reinforcing Pad Edge (N./mm²)

		Stress Intensity Values							
Type of Stress	Load	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
Circ. Pm (SUS)		77.1	77.8	77.1	77.8	77.1	77.8	77.1	77.8
Circ. Pl (SUS)		-82.6	-82.6	72.9	72.9	-53.2	-53.2	47.9	47.9
Circ. Q (SUS)		-98.2	98.2	86.1	-86.1	-542.2	542.2	510.5	-510.5
Long. Pm (SUS)		38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
Long. Pl (SUS)		-36.0	-36.0	30.8	30.8	-117.9	-117.9	108.2	108.2
Long. Q (SUS)		-130.5	130.5	105.1	-105.1	-244.1	244.1	226.7	-226.7
Shear Pm (SUS)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shear Pl (SUS)		0.6	0.6	-0.6	-0.6	-0.6	-0.6	0.6	0.6
Shear Q (SUS)		6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Pm (SUS)		77.1	77.8	77.1	77.8	77.1	77.8	77.1	77.8
Pm+Pl (SUS)		8.1	7.4	150.1	150.7	103.3	104.0	146.8	146.8
Pm+Pl+Q (Total)		129.7	134.2	236.7	101.0	518.4	567.0	635.7	384.9

Table 3: Vessel Stress Summation - Reinforcing Pad Edge

3.2.5.2 Vessel Stress Summation Comparison (N/mm²):

Type of Stress Int	Max. S.I.	S.I. Allowable	Result
Pm (SUS)	77.82	137.90	Passed
Pm+Pl (SUS)	150.74	206.85	Passed
Pm+Pl+Q (TOTAL)	635.73	413.70	Failed

The comparison of the vessel stress summation offers an understanding of the various stress intensities that the vessel has encountered, expressed in Newtons per square millimeter (N/mm²). The highest stress intensity of the primary membrane stress (Pm) under sustained conditions (SUS) is 77.82 N/mm², falling within the permissible limit of 137.90 N/mm². Consequently, the stress criteria are met. Under continuous circumstances, the combined primary membrane and primary local stress (Pm+Pl) likewise passes, with a maximum stress intensity of 150.74 N/mm2 against an admissible limit of 206.85 N/mm2. The sum of all stress components, or total stress intensity (Pm+Pl+Q), exceeds the allowable limit of 413.70 N/mm², reaching a maximum value of 635.73 N/mm², leading to a failure. The vessel breaks under the total stress intensity, despite the fact that it can withstand primary and combined primary-local stresses, according to this research. This suggests that the design needs to be reconsidered or reinforced in order to guarantee safety and integrity under all loading scenarios.

3.3 RESULT (PASSED)

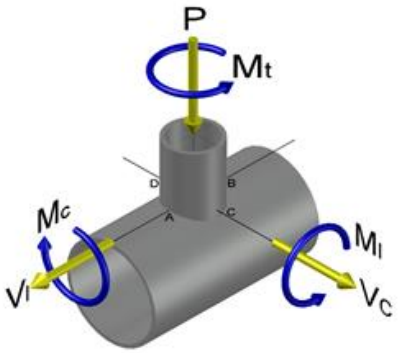

Fig 5: Dimensional Limitations of pad for 300mm

3.3.1 WRC 107/537 Stress Summations:

3.3.1.1Vessel Stress Summation at Attachment Junction (N./mm²)

	Stress Intensity Values							
Type of Stress Load	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
Circ. Pm (SUS)	29.5	30.1	29.5	30.1	29.5	30.1	29.5	30.1
Circ. Pl (SUS)	-18.6	-18.6	16.7	16.7	-9.5	-9.5	8.0	8.0
Circ. Q (SUS)	-37.8	37.8	33.4	-33.4	-128.0	128.0	121.3	-121.3
Long. Pm (SUS)	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
Long. Pl (SUS)	-6.3	-6.3	4.8	4.8	-14.6	-14.6	12.7	12.7
Long. Q (SUS)	-57.5	57.5	50.5	-50.5	-67.4	67.4	63.0	-63.0
Shear Pm (SUS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shear Pl (SUS)	0.3	0.3	-0.3	-0.3	-0.3	-0.3	0.3	0.3
Shear Q (SUS)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Pm (SUS)	29.5	30.1	29.5	30.1	29.5	30.1	29.5	30.1
Pm+Pl (SUS)	10.9	11.6	46.2	46.9	19.9	20.6	37.5	38.2
Pm+Pl+Q (Total)	49.7	66.7	80.5	44.8	108.3	148.8	159.0	83.4

Table 4: Vessel Stress Summation - Attachment Junction

3.3.1.2 Vessel Stress Summation Comparison (N./mm²):

Type of Stress Int.	Max. S.I.	S.I. Allowable	Result
Pm (SUS)	30.15	137.90	Passed
Pm+Pl (SUS)	46.85	206.85	Passed
Pm+Pl+Q (TOTAL)	159.01	413.70	Passed

The comparison of the vessel stress summation offers an understanding of the various stress intensities that the vessel has encountered, expressed in Newtons per square millimeter (N./mm²). With a maximum stress intensity of 30.15 N/mm², the primary membrane stress (Pm) under sustained conditions (SUS) passes the stress requirements because it is far within the permitted limit of 137.90 N/mm². Under sustained circumstances, the combined primary membrane and primary local stress (Pm+Pl) likewise passes, with a maximum stress intensity of 46.85 N/mm² compared to an acceptable limit of 206.85 N/mm². Ultimately, the evaluation is passed because the overall stress intensity (Pm+Pl+Q), which takes into account all stress components, reaches a maximum value of 159.01 N./mm² and stays below the allowable limit of 413.70 N./mm². This thorough analysis shows that the vessel can safely bear the stresses placed on it under different loading scenarios, guaranteeing both operational safety and structural integrity.

3.3.2 WRC 107/537 Stress Summations:

3.3.2.1 Vessel Stress Summation at Reinforcing Pad Edge (N./mm²)

Stress Intensity Values								
Type of Stress Load	Au	Al	Bu	Bl	Cu	Cl	Du	Dl
Circ. Pm (SUS)	77.1	77.8	77.1	77.8	77.1	77.8	77.1	77.8
Circ. Pl (SUS)	-39.0	-39.0	31.6	31.6	-25.8	-25.8	22.9	22.9
Circ. Q (SUS)	-31.6	31.6	26.1	-26.1	-305.4	305.4	273.7	-273.7
Long. Pm (SUS)	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6
Long. Pl (SUS)	-19.0	-19.0	16.1	16.1	-83.2	-83.2	75.8	75.8
Long. Q (SUS)	-46.4	46.4	31.8	-31.8	-126.9	126.9	109.5	-109.5
Shear Pm (SUS)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shear Pl (SUS)	0.4	0.4	-0.4	-0.4	-0.4	-0.4	0.4	0.4
Shear Q (SUS)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Pm (SUS)	77.1	77.8	77.1	77.8	77.1	77.8	77.1	77.8
Pm+Pl (SUS)	38.1	38.8	108.8	109.5	95.9	96.6	114.3	114.3

Pm+Pl+Q (Total)|	34.0|	72.1|	135.0|	83.4|	254.1|	357.4|	373.8|	177.8

3.3.2.2 Vessel Stress Summation Comparison (N/mm²):

Type of Stress Int.	Max. S.I.	S.I. Allowable	Result
Pm (SUS)	77.82	137.90	Passed
Pm+Pl (SUS)	114.35	206.85	Passed
Pm+Pl+Q (TOTAL)	373.81	413.70	Passed

The comparison of the vessel stress summation indicates the various stress intensities that the vessel has encountered, expressed in Newtons per square millimeter (N/mm²). The highest stress intensity of the primary membrane stress (Pm) under sustained conditions (SUS) is 77.82 N/mm², which is less than the permissible limit of 137.90 N/mm² and satisfies the stress criterion. With a maximum stress intensity of 114.35 N/mm2 against a permitted limit of 206.85 N/mm2, the combined primary membrane and primary local stress (Pm+Pl) likewise passes. Furthermore, the assessment is also passed because the overall stress intensity (Pm+Pl+Q), which includes all stress components, has a maximum value of 373.81 N/mm², which is below the allowable limit of 413.70 N/mm². This assessment ensures the structural integrity and operational safety of the vessel by confirming that it can safely withstand the stresses imposed under a range of loading circumstances.

IV. Conclusion

The analysis of connected pipeline loads on nozzles welded to an air receiver drum, conducted using the Welding Research Council (WRC) method, has provided valuable insights into the stress distribution and structural integrity of these critical connections. The study demonstrated that the WRC method, particularly the WRC 107 and WRC 297 guidelines, is highly effective for performing initial stress estimations. It successfully identifies key stress points at the nozzle-shell junction across a range of loading conditions, offering a fundamental understanding of where critical stresses may occur. However, the study also revealed that while the WRC method is useful for preliminary analysis, it often fails to capture the detailed and complex stress patterns that can emerge in practical scenarios. This highlights the necessity for numerical validation techniques, such as finite element analysis (FEA), to more accurately capture peak stress values and intricate interactions that the WRC method might overlook or underestimate.

The sensitivity analysis conducted as part of the study illustrated how various factors—including the magnitude and direction of loads, geometric variations, and material properties—affect stress distribution. These findings are crucial for guiding design optimizations aimed at reducing stress concentrations and enhancing overall structural integrity. To address the identified issues, the study recommends practical measures such as incorporating fillet welds, applying reinforcement pads, and choosing materials with higher yield strength. These modifications can significantly improve the durability and safety of the nozzle-shell junctions. For existing installations, the study underscores the importance of regular inspections and preventive maintenance practices to monitor areas susceptible to high stresses and to prevent potential failures. Overall, the insights gained from this study are instrumental in refining pressure vessel design and maintenance practices, thereby ensuring the safety and reliability of air receiver drums in various industrial applications.

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