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Analyzing Weld Quality in LPG Storage Tanks Using Statistical Process Control Tools

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ABSTRACT: This paper presents a comprehensive analysis of weld quality in Liquefied Petroleum Gas (LPG) storage tanks at Bajrawiya Oil & Gas Equipment Plant. Utilizing historical inspection data from 2016 to 2019, the study identifies common welding defects such as porosity, undercut, lack of fusion, and misalignment. Findings indicate that process variability, operator skill level, and equipment maintenance significantly impact weld integrity. Recommendations include enhancing training programs, standardizing welding procedures, and implementing continuous monitoring using SPC tools. This research contributes to improving quality assurance practices in the manufacturing of pressure vessels and ensuring compliance with international standards such as ASME, API, and ISO 5817.

Received: 22 June 2025
Accepted: 17 March 2026
DOI: https://doi.org/10.71107/gbdb3180

I. INTRODUCTION

Welding is an important and inseparable part of the development of technology and industrial development. Almost every industrial development that uses metal involves a welding process. Therefore, a good quality welding joint is needed. This has an impact on determining quality (Quality Assurance) and ensuring quality (Quality Control). The quality of products or goods is a very important factor and is a key factor in business success and business competitiveness, so that to increase the value of the company's products, it is required to improve quality[1].

The integrity of welded joints in Liquefied Petroleum Gas (LPG) storage tanks is critical for ensuring operational safety and compliance with international standards. Even when carefully controlled, welding processes produce defects, leading to its reputation as a process of uncertainty[2]. Given the flammable nature of LPG, even minor welding defects can lead to catastrophic failures[3,4]. The failure can result in lawsuits, stock loss, or bankruptcy[3,5]. Therefore, rigorous quality management practices, including the application of Statistical Process Control (SPC) tools, are essential during the manufacturing and maintenance stages[4]. Researchers implemented SPC tools in investigating weld defects causes and evaluating welding quality and trends and suggested improvement[6–9]. George E. et al.[10] describes a statistical weld process monitoring system using parameters such as voltage, current, wire feed speed, gas flow rate, travel speed, and elapsed arc time.

This study focuses on analyzing the welding quality of LPG storage tanks at Bajrawiya Oil & Gas Equipment Plant, utilizing historical inspection data from 2016 to 2019. It employs various statistical tools to identify key defect patterns and suggest improvements for welding processes.

II. MATERIALS AND METHODS

A. Data Collection

Data collection followed a systematic sampling approach to allow for extensive trend analysis related to welding quality. Due to the volume and complexity of the dataset, Minitab software was used for statistical analysis. This included descriptive statistics, hypothesis testing, regression analysis, and the creation of control charts to assess process stability.

The Bajrawiya plant specializes in the production of LPG tanks and applies stringent quality management practices to ensure product reliability and safety. The primary data used in this study were obtained from non-destructive testing (NDT) records and visual inspec-

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tions conducted between 2016 and 2019. These datasets document the types of weld defects detected in LPG tanks across multiple production batches. Various statistical tools including Pareto charts, cause-and-effect diagrams, and control charts were employed to analyze defect trends and determine root causes.

TABLE I: THE TEST LIST FOR THE NUMBER OF DEFECTS IN THE LPG PRODUCT DURING THE PERIOD FROM 2016 –2019 WHEN CONDUCTING THE PENETRANT LIQUID TEST

Defect	2016	2017	2018	2019	Total
Undercut	5	0	4	6	15
Lack of Fusion	3	0	3	5	11
Porosity	4	1	5	4	14
Other Defects	2	1	2	1	6
Total	14	2	14	16	46

TABLE II: THE TEST LIST FOR THE NUMBER OF DEFECTS IN THE LPG PRODUCT DURING THE PERIOD FROM 2016 –2019 WHEN CONDUCTING THE RADIOGRAPHIC TEST

Defect	2016	2017	2018	2019	Total
Lack of Fusion	2	2	2	4	10
Undercut	3	2	4	3	12
Misalignment	1	2	3	3	9
Other Defects	2	0	2	1	5
Total	8	6	11	11	36

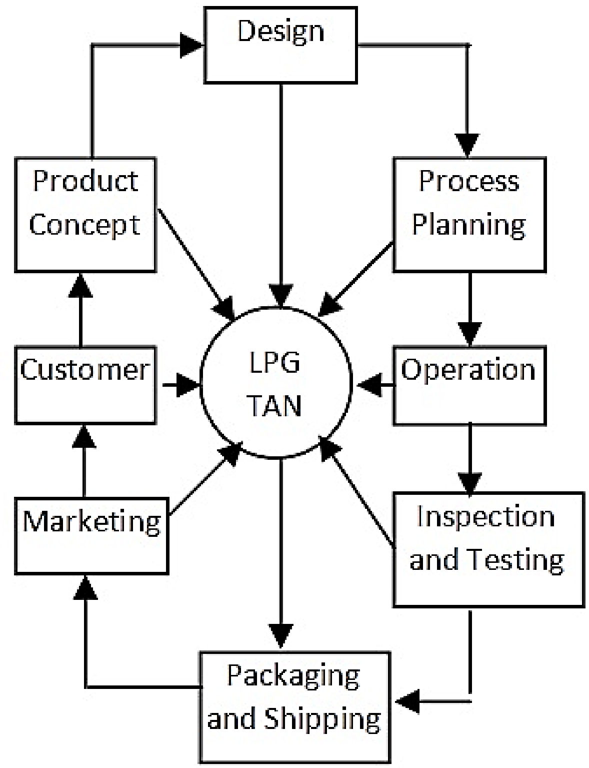

FIG. 1: LPG tank product lifecycle.

B. Tank Lifecycle

A comprehensive understanding of the LPG tank lifecycle is crucial to enhancing production quality and efficiency. The lifecycle encapsulates several critical stages that a product must undergo, starting from conceptualization and ending with customer delivery. As depicted in Figure 1, these stages encompass design, material sourcing, manufacturing processes, testing, and finally, distribution, each of which plays an integral role in ensuring the final product meets safety and operational standards.

C. Types of Weld Defects in LPG Storage Tanks

Porosity: Gas pockets or voids trapped in the weld metal. Causes include contaminated base metal, improper shielding gas, or high moisture levels. Effect: weakens the weld and can lead to failure under stress.

Undercuts: A groove melted into the base metal next to the weld toe but not filled with weld metal. Causes: excessive heat, improper technique, or incorrect electrode angle. Effect: reduces cross-sectional thickness and creates a stress riser.

Lack of Fusion: Failure of the weld metal to fuse completely with the base metal or previous weld bead. Causes: low heat input, improper cleaning, or poor technique. Effect: weakens the joint and may lead to cracking or failure.

Cracks: Fracture-like defects that can occur during or after welding. Types include hot cracks (during solidification), cold cracks (after cooling), and crater cracks. Effect: very serious; always considered unacceptable in structural welds.

Incomplete Penetration: The weld metal does not extend through the joint thickness. Causes: low heat input, incorrect joint preparation, or improper technique. Effect: significantly reduces joint strength, especially under tension.

D. 2.4 Quality Tools Applied:

Control Charts: Used to monitor process stability over time.

Pareto Analysis: Applied to prioritize defect types based on frequency.

Cause-and-Effect Diagrams: Employed to explore potential root causes of defects.

III. THEORY AND CALCULATIONS

A. Welding Defects Overview

Common weld defects in LPG storage tanks include porosity, undercuts, lack of fusion, cracks, and incomplete penetration. According to ISO 5817, these imperfections can severely reduce a weld's mechanical strength and must be strictly controlled[3].

B. Statistical Process Control (SPC)

Statistical Quality Control (SQC) is a system designed to maintain uniform production quality standards at minimum cost, while supporting the operational efficiency of the company. This method involves the use of statistical techniques to collect and analyze data to determine and monitor the quality of production results efficiently.

C. Pareto Principle Application

Following the 80/20 rule, Pareto analysis identifies the few defect types responsible for the majority of welding quality problems[11].

D. Cause-and-Effect Diagrams

Employed specifically to analyze the root causes of welding issues, these diagrams helped in understanding the underlying problems contributing to defects in tank integrity.

E. Control Charts

Statistical tools that enabled monitoring of process stability over time, these charts were vital in detecting variations, thus ensuring consistent quality. Specifically, p-charts (for defect rates) and U-charts (for defects per unit) are applied to determine if the welding processes are statistically under control[12].

The control limits are calculated using:

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}, \qquad LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}, \tag{1}$$

where $\bar{p}$ is the average proportion of defects and n is the sample size.

IV. RESULTS AND DISCUSSION

A. Defect Trend Analysis

During the analysis period from 2016 to 2019, porosity and lack of fusion emerged as the most frequently occurring weld defects, accounting for more than 65% of all reported imperfections. These findings highlight their significant impact on overall product quality. Furthermore, statistical monitoring using control charts revealed instances of process instability, particularly during late 2017 and early 2019, where defect rates exceeded the upper control limits (UCL). This indicates the presence of special causes affecting the welding process during these periods.

B. Pareto Analysis Results

The collected data from both penetrant liquid testing and radiographic testing was analyzed using Pareto charts to identify the most frequent types of welding defects. This method enabled prioritization based on defect frequency, allowing for efficient allocation of resources toward resolving the most impactful issues. As shown in Table III and Figure 2, undercut and porosity accounted for approximately 63% of all detected defects, confirming their dominance in the production process.

TABLE III: SHOWN BELOW PRESENTS THE RESULTS OBTAINED FROM THE PENETRANT LIQUID TEST

Defect	Frequency
Undercut	15
Porosity	14
Lack of Fusion	11
Other Defects	6

TABLE IV: THE RESULTS OBTAINED FROM THE RADIOGRAPHIC TEST

Defect	Frequency
Lack of Fusion	12
Undercut	10
Misalignment	9
Other Defects	5

The Pareto chart clearly identified porosity and undercut as the dominant defect types. Addressing these

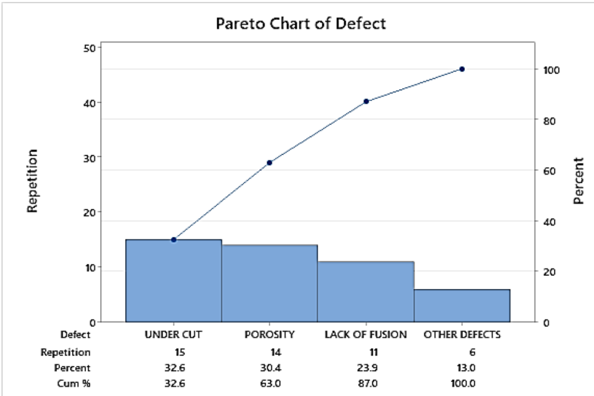

FIG. 2: The Pareto Chart of the Penetrant Liquid Test

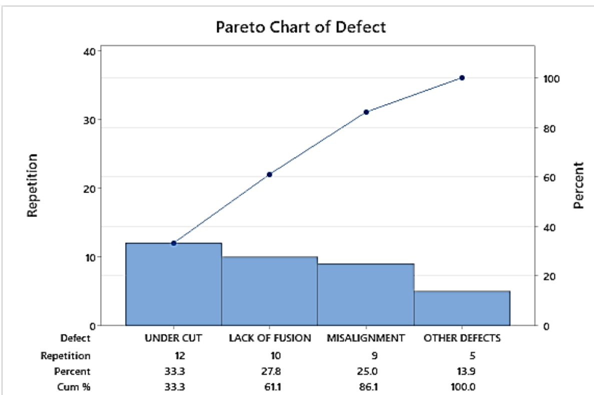

FIG. 3: Pareto chart of defects (Radiographic Test).

two issues would resolve approximately 63% of all quality problems. Operator technique and shielding gas issues were the major contributors to porosity, while improper travel angle was the main cause of undercuts.

C. Root Cause Analysis

A comprehensive root cause analysis was conducted using fishbone diagrams to identify the underlying factors contributing to the observed welding defects. The identified causes were systematically grouped into four main categories:

Man: Inadequate training and certification of welders led to inconsistent application of welding techniques.

Machine: Irregular maintenance schedules of welding equipment resulted in performance variability.

Material: Use of substandard or improperly stored filler metals negatively affected weld integrity.

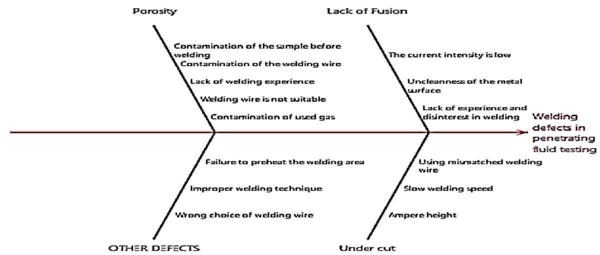

FIG. 4: Cause-and-effect diagram for Penetrant Liquid Test defects.

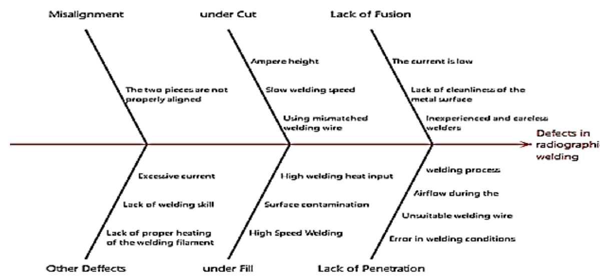

FIG. 5: Cause-and-effect diagram for Radiographic Test defects.

Method: Lack of adherence to standardized welding procedures (WPS) and inconsistent parameter settings contributed to process deviations.

This categorization facilitated a targeted approach toward addressing each factor and implementing corrective actions.

The Impact and Cause Map of Welding Defects in Window Fluid Testing and Radiographic Testing **Man:** Lack of welder skill certification and training gaps. **Machine:** Irregular maintenance of welding machines. **Material:** Use of substandard filler metals. **Method:** Inconsistent welding procedures and parameter settings.

D. Control Chart Observations

Attribute control charts (U-Chart and P-Chart) were used to monitor defect rates over time. While the overall process was generally stable, occasional spikes were observed during periods of increased production pressure or staff turnover.

U-Chart: Monitors the number of defects per unit. **P-Chart**: Tracks the proportion of defective items.

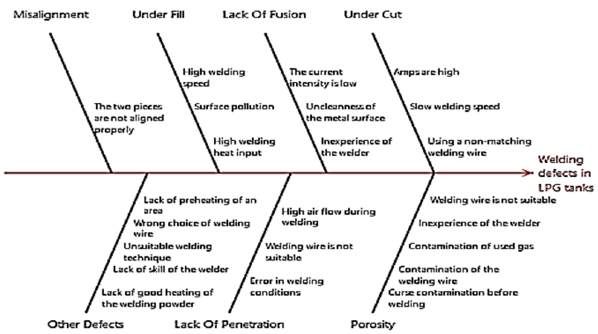

FIG. 6: The Effect and cause Map for Welding Defects in the Penetrating Fluid Test

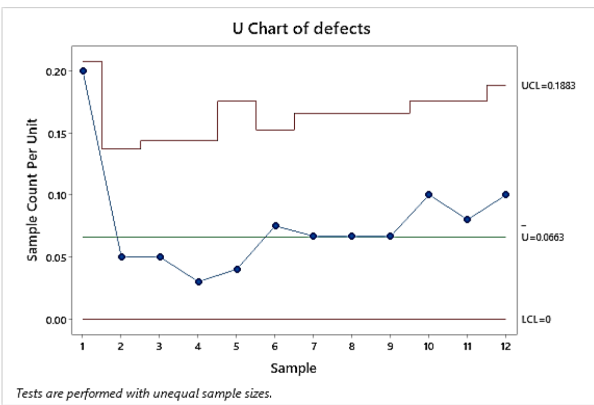

FIG. 7: U-chart: defects per unit over time.

TABLE V: THE NUMBER OF DEFECTS IN EACH TANK AND THE BATCH SIZE

Batch Size	Number of Defects
30	6
120	6
100	5
56	3
50	2
80	6
60	4
60	4
60	4
50	5
50	4
40	4
30	6
120	6
100	5
100	3

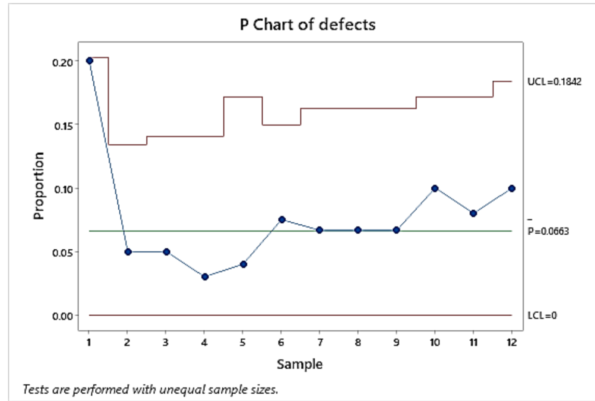

FIG. 8: P-chart: proportion of defective items.

Control charts for each year indicated that while the process was generally stable, there were occasional spikes in defect rates, particularly during periods of increased production pressure or staff turnover.

7 shows the control chart for 2018, where points above the UCL indicated special cause variation due to a shortage of certified welders.

E. Discussion

The analysis indicates that while welding operations at Bajrawiya Plant were generally compliant with industry standards, there were periods of diminished quality that correlated with process variability and human factors. Enhancing operator training programs, implementing stricter process monitoring, and enforcing standard welding procedure specifications (WPS) could significantly reduce defects.

V. CONCLUSION

The quality of welds in LPG storage tanks is critical for operational safety and regulatory compliance. Through the application of SPC tools and root cause analysis, key areas of improvement were identified at the Bajrawiya Oil & Gas Equipment Plant. The findings recommend:

- Mandatory periodic re-certification and advanced training for all welding operators.
- Implementation of a preventive maintenance schedule for all welding equipment.
- Adoption of real-time SPC monitoring systems to detect process deviations early.
- Standardization of Welding Procedure Specifications (WPS) across all production lines.

- Regular audits of material storage and handling practices to ensure filler metal quality.

Continuous application of statistical quality tools will ensure that weld integrity meets the stringent requirements of ASME, API, and ISO standards, ultimately safeguarding LPG storage operations.

DECLARATION OF COMPETING INTEREST

The authors have no conflicts to disclose.

ACKNOWLEDGMENTS

The authors acknowledge the support of Bajrawiya Oil & Gas Equipment Plant for providing access to inspection data.

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