International Journal of
Advanced Engineering and Technology

Journal homepage: https://ijaetech.org/index.php/ijaetech

Quality Control Analysis of the Carbonated Beverage Filling Process Using an Automated Filler Machine

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ABSTRACT

This study aims to analyze the implementation of quality control in the carbonated beverage filling process using an automated filler machine and to identify critical control points that influence product conformity and production efficiency. A descriptive quantitative approach was employed through production line observation, machine monitoring, and quality control documentation review. The study focused on the filling process of carbonated beverages packaged in 330 mL aluminum cans and the associated quality control activities throughout the production line. The findings show that the filling process is the key quality control stage, supported by the automated filler machine, Fill High Detector (FHD), seaming, temperature stabilization, and traceability systems to maintain product conformity. The study was limited to a descriptive evaluation of a single production line and did not include statistical process capability analysis or quantitative measurements of filling variation. Therefore, the findings primarily provide operational insights rather than statistical validation of process performance. The findings may assist beverage manufacturers in improving filling accuracy, strengthening inspection systems, and enhancing production reliability through effective quality control practices. This study provides a comprehensive overview of quality control implementation in an automated carbonated beverage filling system and highlights the integration of filling, inspection, and supporting production processes in maintaining product quality and operational efficiency.

ARTICLE INFO

Article History:
Submitted/Received 14 May 2026
First Revised 8 Jun 2026
Accepted 19 Jun 2026
First Available Online 21 Jun 2026
Publication Date 21 Jun 2026

Keyword:
Carbonated beverage, quality control, automated filler machine, filling process, Fill High Detector, beverage manufacturing

1. INTRODUCTION

The carbonated beverage industry continues to grow along with increasing consumer demand for practical, safe, and consistent ready-to-drink products. In beverage manufacturing, product quality is determined not only by formulation and packaging design, but also by the stability and reliability of the production process. Therefore, quality control has become an essential part of modern manufacturing systems, particularly in food and beverage production where product conformity, safety, and customer satisfaction are closely related to process performance (Lim et al., 2014; Mataragas et al., 2012).

One of the most critical stages in carbonated beverage production is the filling process. This stage determines whether the product meets the specified volume, maintains carbonation stability, and achieves proper package integrity. In 330 mL aluminum can production, filling errors such as underfilling and overfilling can lead to product rejection, material loss, production inefficiency, and customer complaints. Therefore, filling accuracy must be controlled through systematic monitoring and reliable inspection mechanisms (Dalgıç et al., 2011; Grigg & Daly, 1998).

Automated filler machines are widely used to improve filling consistency, reduce human error, and increase production efficiency. These machines control several important parameters, including filling pressure, flow rate, valve operation, and filling duration. However, automation does not fully eliminate quality variation. Deviations may still occur due to valve wear, pressure instability, machine calibration problems, operational disturbances, or changes in production conditions. For this reason, continuous quality monitoring remains necessary even in automated production systems (Filz et al., 2024; Lim et al., 2015).

Statistical process control and quality management approaches are important tools for evaluating process stability and identifying sources of variation. In food manufacturing, statistical quality control can support the detection of abnormal process behavior, reduce defects, and improve decision-making in quality assurance activities. These approaches are also increasingly connected with Industry 4.0 and Quality 4.0 concepts, where automation, data-driven monitoring, digital inspection, and real-time process evaluation are used to improve manufacturing performance (Antony et al., 2022; Chiarini, 2020; Liu et al., 2023; Maganga & Taifa, 2023).

In carbonated beverage production, automated inspection systems such as Fill High Detectors (FHD) are used to detect cans with abnormal fill levels before they continue to the next production stage. This inspection system helps prevent nonconforming products from reaching the packaging process and supports product conformity. Nevertheless, the effectiveness of such systems depends on proper machine operation, inspection accuracy, preventive maintenance, and consistent implementation of quality control procedures (Fonseca et al., 2021; Souza et al., 2022).

Based on these considerations, this study aims to analyze quality control practices in the carbonated beverage filling process using an automated filler machine. The study focuses on identifying critical control points in the filling process, describing the role of automated inspection systems, and evaluating potential sources of filling variation. The findings are expected to provide practical insights for improving filling accuracy, reducing product rejection, and strengthening quality assurance practices in automated beverage manufacturing systems.

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

Volume 2 Issue 1 May 2026 Page 1-12

2. METHODS

2.1 Research Design

This study employed a descriptive quantitative research design to evaluate quality control performance in the carbonated beverage filling process using an automated filler machine. The research focused on identifying critical quality control points, evaluating filling process consistency, and assessing the effectiveness of inspection systems in preventing nonconforming products from proceeding to subsequent production stages. A descriptive quantitative approach was selected because it allows systematic observation and evaluation of production parameters under actual manufacturing conditions while providing measurable information regarding process performance (Montgomery, 2020; Antony et al., 2022).

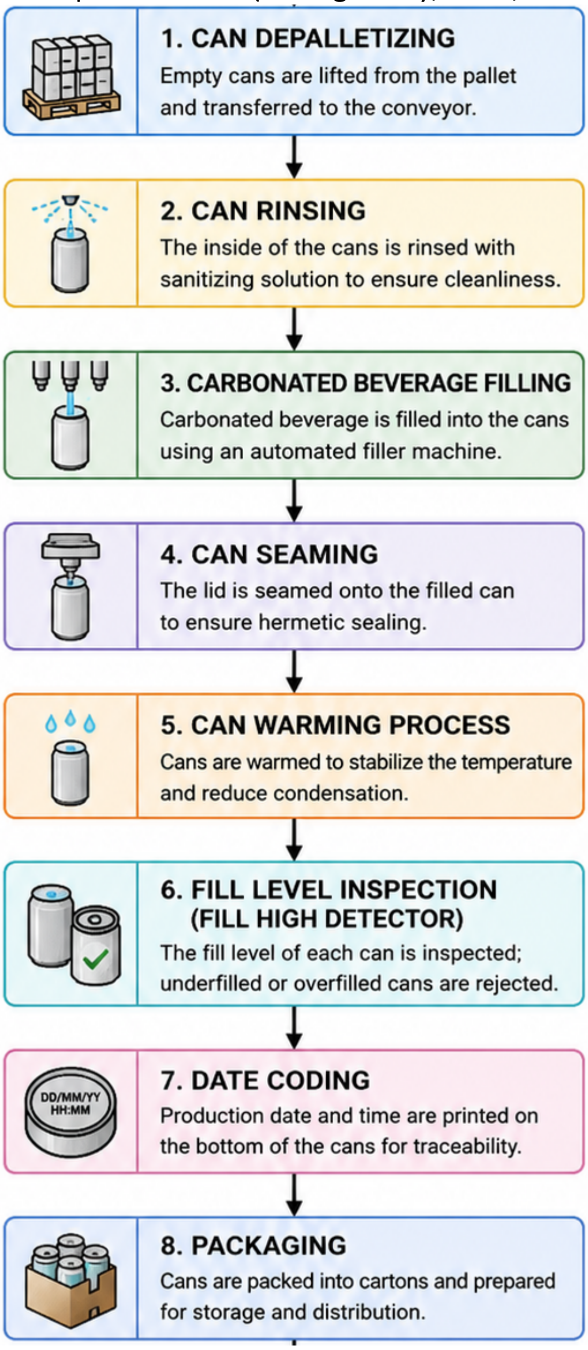

Figure 1. Flowchart of Carbonated Beverage Can Filling Process

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

2.2 Research Location and Object

The study was conducted on a carbonated beverage production line utilizing 330 mL aluminum cans as the primary packaging material. The object of the research was the automated filling process, including associated quality control activities implemented throughout the production line. Particular attention was given to the filler machine, seaming operation, Fill High Detector (FHD) inspection system, and supporting processes that directly influence product conformity.

The automated filling machine used in this study was a rotary filler equipped with 90 filling valves operating under pressurized conditions. The machine was designed to maintain carbonation stability while achieving the specified filling volume. The filling system operated at approximately 4.20 bar pressure during production.

2.3 Production Process Description

The carbonated beverage production process consisted of several sequential operations including depalletizing, rinsing, filling, seaming, warming, fill-level inspection, date coding, and packaging. Empty aluminum cans were initially transferred from pallets to the conveyor system using a depalletizer before passing through a rinsing unit for internal cleaning. Subsequently, cans entered the automated filler machine where beverages were dispensed under controlled pressure conditions.

After filling, cans were transferred to the seaming machine for lid attachment and sealing. The sealed products then passed through a warmer unit to stabilize product temperature and minimize external condensation. Product quality was subsequently verified using an automated Fill High Detector (FHD) system before date coding and packaging operations were completed.

2.4 Data Collection

Data were collected through direct observation, production monitoring, and documentation review. Direct observations were conducted throughout the production process to identify operational procedures, machine performance, and quality control activities. Production monitoring was performed to observe filling conditions, machine operating parameters, filling pressure stability, and inspection system performance.

Secondary data were obtained from machine specifications, standard operating procedures (SOPs), production records, and quality control documentation. These documents were used to verify process requirements and support the interpretation of operational observations.

2.5 Quality Control Parameters

The evaluation of quality control performance focused on four primary parameters:

a. **Filling Volume Accuracy**
   Filling volume accuracy refers to the conformity between the actual beverage volume and the nominal package volume of 330 mL. Variations in filling volume were considered indicators of process deviation and filling performance.

Volume 2 Issue 1 May 2026 Page 1-12

b. Filling Process Consistency

Filling consistency was assessed based on the ability of the automated filler machine to maintain uniform filling conditions throughout production. Consistent filling performance indicates stable machine operation and effective process control.

c. Reject Rate

Reject rate represents the percentage of products identified as nonconforming by the Fill High Detector (FHD) system. Products classified as underfilled or overfilled were automatically removed from the production line. The reject rate was calculated using Equation (1).

$$\text{Reject Rate} = \frac{\text{Number of Rejected Cans}}{\text{Total Number of Inspected Cans}} \times 100$$

where:
(N_r) = number of rejected cans
(N_t) = total number of inspected cans

d. Equipment Performance

Equipment performance was evaluated through observations of machine operating conditions, valve functionality, filling pressure stability, and production continuity. Any abnormal conditions that could potentially affect filling quality were identified and recorded.

2.6 Data Analysis

The collected data were analyzed using descriptive statistical techniques. The analysis included the evaluation of process conformity, identification of potential sources of variation, assessment of machine operational performance, and interpretation of inspection system effectiveness. Process observations were compared with established production specifications and quality control requirements.

The analysis focused on determining whether the automated filling system was capable of maintaining filling accuracy, minimizing product rejection, and supporting consistent product quality throughout the manufacturing process. The findings were subsequently used to identify opportunities for process improvement and enhanced quality assurance implementation within the production line.

3. RESULTS

3.1 Overview of the Carbonated Beverage Filling Process

The production process of carbonated beverages packaged in 330 mL aluminum cans consists of several sequential and integrated stages. Based on the production line observation, the process begins with depalletizing and continues through rinsing, filling, seaming, warming, fill-level inspection, date coding, and packaging. Each stage has a specific function in ensuring that the final product meets the required quality standards. The overall production flow is presented in Figure 1.

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

3.2 Depalletizing and Can Preparation Process

The production process begins with the depalletizing stage. In this stage, empty aluminum cans are transferred from pallets to the conveyor system. The depalletizer supports continuous production by ensuring that empty cans are supplied consistently to the next process without interrupting the filling line.

The depalletizer system consists of several main components, including the pallet loader, pallet lift, layer gripper, and raw pusher. These components work together to move empty cans automatically while minimizing handling errors and reducing the possibility of mechanical damage to the cans. The depalletizer system used in the production line is shown in Figure 2.

Figure 2. Depalletizer System

3.3 Automated Filling Process

The filling stage is the main process observed in this study because it directly determines product volume conformity. The automated filler machine used in the production line is equipped with 90 filling valves. The machine operates under controlled pressure conditions to maintain filling accuracy and carbonation stability.

The filling process consists of three main stages: air evacuation, beverage filling, and valve closing. First, air inside the can is removed to reduce pressure differences and support carbonation retention. Second, the carbonated beverage is filled into the can under a pressure of approximately 4.20 bar. Third, the filling valve closes automatically after the predetermined filling volume has been reached. The automated filler machine used in the production line is presented in Figure 3.

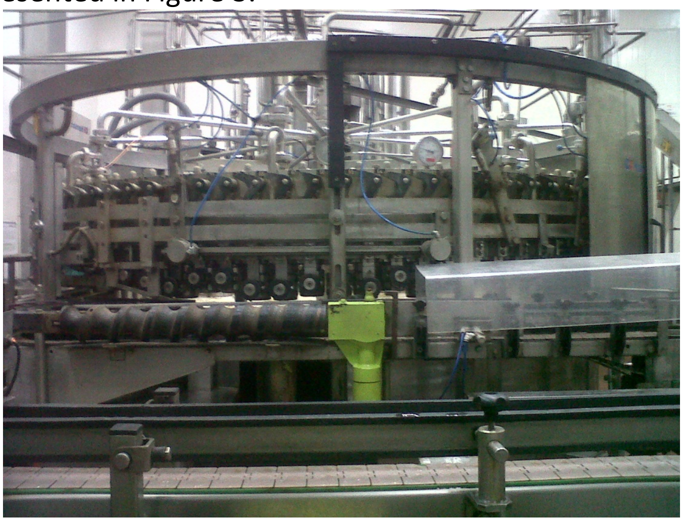

Figure 3. Automated Filler Machine

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

Volume 2 Issue 1 May 2026 Page 1-12

3.4 Seaming Process and Package Integrity

After the filling process is completed, the filled cans are transferred to the seaming machine for lid attachment and sealing. The seaming process is important because it determines package integrity and prevents leakage, carbonation loss, and contamination.

The seaming machine operates using a rotary mechanism that allows multiple cans to be sealed continuously. Proper seam formation is necessary to ensure that the product remains safe, stable, and suitable for distribution. The seaming machine is shown in Figure 4.

Figure 4. Seaming Machine

3.5 Temperature Stabilization Process

Following the seaming process, the filled cans pass through a warmer unit. This stage is carried out to stabilize product temperature and reduce condensation on the surface of the cans. Condensation control is important because excessive moisture may affect coding quality, packaging appearance, and carton strength during storage and distribution.

The warmer unit sprays heated water at approximately 45°C onto the cans while they move along the conveyor system. The warmer unit is shown in Figure 5.

Figure 5. Warmer Unit

3.6 Fill-Level Inspection

The fill-level inspection stage is performed using an automated Fill High Detector (FHD). This system functions as a quality control mechanism to detect cans with abnormal fill levels. Products identified as underfilled or overfilled are automatically rejected from the production line. The implementation of FHD helps ensure that only products meeting the established filling requirements continue to the next production stage. This system also reduces the risk

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

of nonconforming products reaching the packaging and distribution processes. The Fill High Detector system is presented in Figure 6.

Figure 6. Fill High Detector (FHD)

3.7 Date Coding and Packaging Process

Products that pass the fill-level inspection stage proceed to the date coding process. The coding system prints production information, expiration dates, and batch codes on the bottom of each can. This information supports product traceability in the event of quality complaints or product recall. After date coding, the products are transferred to the packaging machine. The packaging process arranges cans into cartons to support storage, transportation, and distribution efficiency. The automated date coding process and packaging machine are shown in Figure 7 and Figure 8.

Figure 7. Automated Date Coding Process

Figure 8. Packaging Machine

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

Volume 2 Issue 1 May 2026 Page 1-12

3.8 Critical Quality Control Points

Based on the production line observation, several critical quality control points were identified in the carbonated beverage filling process. These control points are related to can cleanliness, filling volume, seam quality, surface condition, fill-level conformity, and product traceability.

Table 1. Critical Quality Control Points in the Filling Process

Process Stage	Quality Parameter	Potential Defect	Control Method
Rinser	Can cleanliness	Contamination	Washing inspection
Filler	Filling volume	Underfill/Overfill	Pressure monitoring
Seamer	Seam integrity	Leakage	Seam inspection
Warmer	Surface condition	Condensation	Temperature control
FHD	Fill level	Volume deviation	Automatic rejection
Date Coding	Product traceability	Missing or unclear code	Visual inspection

4. DISCUSSION

The results show that the carbonated beverage filling process relies on several integrated production stages that collectively ensure product conformity and production efficiency. Among these stages, the filling operation represents the most critical control point because it directly influences filling volume accuracy, carbonation stability, and final product quality. According to Lim et al. (2014), process stability in food and beverage manufacturing is strongly associated with the effectiveness of quality control practices implemented throughout production. Therefore, maintaining consistency during the filling operation is essential to reducing process variation and ensuring compliance with product specifications.

The automated filler machine observed in this study operates using controlled pressure conditions and multiple filling valves to achieve consistent product filling. The use of automation supports production continuity and reduces human intervention, thereby minimizing the likelihood of operational errors. Similar findings were reported by Filz et al. (2024), who emphasized that automation and data-driven quality management systems contribute significantly to process consistency and manufacturing performance. Furthermore, Chiarini (2020) stated that automation technologies integrated with quality management practices can improve operational reliability and reduce quality deviations in modern manufacturing environments.

The filling process is also closely related to carbonation retention and product acceptance. Carbonated beverages require stable pressure conditions during filling to maintain dissolved carbon dioxide levels and prevent excessive foaming. Variations in pressure or filling valve performance may result in underfilled or overfilled cans, which can subsequently increase product rejection rates. Lim et al. (2015) reported that process variability in food manufacturing often originates from equipment conditions, calibration issues, and operational disturbances. Consequently, routine inspection and calibration of filling equipment are necessary to maintain process capability and quality consistency.

The findings further indicate that package integrity depends not only on filling accuracy but also on the effectiveness of downstream operations such as seaming and warming. Proper

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

seam formation prevents leakage, carbonation loss, and external contamination, while temperature stabilization reduces condensation that may affect coding quality and packaging performance. Similar observations were reported by Mataragas et al. (2012), who found that multiple production stages must be controlled simultaneously to achieve overall product quality and process reliability in food manufacturing systems.

The Fill High Detector (FHD) serves as an important quality assurance mechanism within the production line. By automatically identifying underfilled and overfilled cans, the system helps prevent nonconforming products from proceeding to packaging and distribution. Automated inspection technologies are widely recognized as effective tools for reducing defects and strengthening process control. According to Fonseca et al. (2021), Quality 4.0 principles encourage the integration of automated inspection systems and real-time monitoring technologies to improve manufacturing quality performance and support data-driven decision-making.

Despite the implementation of automated production equipment, several potential sources of variation remain. These include filling valve wear, pressure fluctuations, equipment calibration errors, and operational disturbances. Such factors may affect filling accuracy and overall process stability if not addressed through preventive maintenance activities. Antony et al. (2022) highlighted that continuous monitoring and improvement are fundamental requirements for maintaining process performance in modern manufacturing systems. Similarly, Maganga and Taifa (2023) emphasized that successful quality management depends on the integration of technology, maintenance practices, and organizational commitment to continuous improvement.

Overall, the findings demonstrate that quality control in carbonated beverage manufacturing extends beyond the filling operation itself. Effective quality assurance requires the integration of automated filling systems, inspection technologies, process monitoring, preventive maintenance, and operational discipline. Consistent implementation of these elements can reduce process variation, improve product conformity, and enhance manufacturing efficiency. These findings support previous studies that emphasize the importance of combining automation technologies with systematic quality management practices to achieve sustainable manufacturing performance (Liu et al., 2023; Souza et al., 2022).

5. CONCLUSION

This study analyzed the implementation of quality control in the carbonated beverage filling process using an automated filler machine. The results indicate that the production process consists of several interconnected stages, including depalletizing, rinsing, filling, seaming, warming, fill-level inspection, date coding, and packaging. Among these stages, the filling process represents the most critical quality control point because it directly influences filling volume accuracy, carbonation stability, and product conformity.

The implementation of automated production equipment, particularly the filler machine and Fill High Detector (FHD), contributes significantly to maintaining process consistency and preventing nonconforming products from reaching the packaging stage. In addition, supporting processes such as seaming, temperature stabilization, and product traceability strengthen the overall quality assurance system. The findings demonstrate that effective quality control in carbonated beverage manufacturing depends not only on automation technology but also on process monitoring, equipment maintenance, and adherence to standard operating procedures.

DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439

This study has several limitations that should be considered when interpreting the findings. First, the research was conducted using a descriptive observational approach and focused on a single production line. As a result, the findings primarily describe the implementation of quality control practices rather than providing statistical evidence of process capability or production performance. Second, the study did not include quantitative measurements such as process capability indices (Cp and Cpk), statistical process control charts, filling volume distributions, or detailed reject-rate analysis. Therefore, the ability to evaluate process performance quantitatively remains limited. Third, operational data related to production output, machine efficiency, and quality deviations were not available for analysis, which restricts the generalization of the findings to other manufacturing environments.

Future studies are recommended to incorporate quantitative quality control techniques such as Statistical Process Control (SPC), process capability analysis, control charts, and reject-rate evaluation to provide a more comprehensive assessment of filling process performance. Further research may also compare different filler machine configurations, investigate the impact of machine parameters on filling accuracy, and evaluate the effectiveness of predictive maintenance strategies in reducing process variation. The integration of Industry 4.0 technologies, including real-time monitoring systems and data analytics, may also provide valuable insights for enhancing quality control performance in beverage manufacturing industries.

6. AUTHORS' NOTE

The author declares that there is no conflict of interest regarding the publication of this article. The author confirms that the manuscript is original, has not been published elsewhere, and is free from plagiarism. All sources used in this study have been properly cited and acknowledged.

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DOI: https://doi.org/10.63956/ijaetech.v2i1.50
e-ISSN: 3089-767X; p-ISSN:3089-8439