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## Improving Production Quality in the Blow Molding Process for 600ml Bottles Using the Taguchi Method

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### Abstract

*This study addresses the challenge of optimizing the blow molding process for producing 600ml PET bottles, which is critical to ensuring consistent product quality and manufacturing efficiency amid increasing industry demands. The primary objective is to identify the optimal process parameters—air pressure, heating temperature, and stretching time—that minimize defect rates. Employing a quantitative experimental approach, the research utilizes the Taguchi method with an orthogonal array L9 (3<sup>3</sup>) design to systematically investigate the effects of these parameters. The population comprises PET bottles produced under varying process conditions at a manufacturing facility, with a sample size of 1,260 bottles across nine experimental treatments. Data collection involved defect counting and quality inspection, analyzed through Signal-to-Noise Ratio (SNR), Analysis of Mean (ANOM), and Analysis of Variance (ANOVA) techniques using specialized software. The results reveal that the optimal parameters are an air pressure of 33 bar, a heating temperature of 150°C, and a stretching time of 0.933 seconds, with air pressure being the most influential factor. The findings suggest that precise control of these parameters significantly reduces defects, enhances process stability, and improves product quality. However, limitations include the specific industrial setting and focus solely on defect count. Future research should explore additional quality metrics and broader process variables to further optimize blow molding processes for various bottle sizes and materials.*

**Keywords:** *Blow Molding, Optimization, PET Bottles, Taguchi Method, Quality Improvement*

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## INTRODUCTION

The global bottled beverage industry has experienced unprecedented growth, positioning itself as a cornerstone of modern lifestyle and consumer behavior across diverse markets worldwide. This rapid expansion has fundamentally transformed packaging demands, particularly in the production of polyethylene terephthalate (PET) bottles, which have become the preferred choice for beverage manufacturers due to their lightweight properties, recyclability, and cost-effectiveness (Chen et al., 2023; Lozano et al., 2022). The increasing consumer preference for convenience and portability has driven manufacturers to prioritize the development of high-quality, consistent packaging solutions that meet stringent safety and aesthetic standards while maintaining production efficiency.

Within the Indonesian market context, bottled drinking water (AMDK) represents a significant segment, defined as processed water packaged in sealed containers that meets specific physical, chemical, and microbiological standards without requiring additional treatment before consumption (Fitriani & Purwanto, 2022). The technological backbone supporting this industry growth is blow molding technology, which ranks as the third largest plastic processing method globally and is extensively utilized for manufacturing various plastic products, including PET bottles (Kamaruddin et al., 2016; Heidari-Rarani et al., 2022). This manufacturing technique has gained widespread adoption due to its capability to produce high-quality products with superior dimensional accuracy, surface finish, mechanical strength, and physical properties that meet increasingly demanding market specifications.

Despite the technological advancements in blow molding processes, significant challenges persist in maintaining consistent production quality, particularly in the formation of 600ml PET bottles through injection stretch blow molding (ISBM) methods. Production quality fluctuations frequently occur due to variations in critical process parameters, creating a complex optimization challenge that directly impacts

product quality, manufacturing efficiency, and economic viability (Amirullah & Yudistiro, 2019; Singh et al., 2022). These variations manifest in multiple forms of product defects, including dimensional inconsistencies, wall thickness variations, surface imperfections, and structural weaknesses that can compromise product integrity and consumer satisfaction.

The complexity of the blow molding process involves multiple interdependent parameters, including preform heating temperature, blowing pressure, stretching time, and mold configuration, each contributing to final product quality in different ways. Inaccurate parameter settings can result in cascading effects that lead to increased defect rates, reduced production efficiency, compromised product performance, and potential safety concerns (Pratama & Ramadhan, 2023). Furthermore, the traditional approach to process optimization often relies on trial-and-error methodologies or experience-based adjustments, which are not only time-consuming and resource-intensive but also lack the systematic rigor required for consistent quality improvement in modern manufacturing environments.

The increasing demand for sustainable and efficient manufacturing processes necessitates the adoption of robust statistical methods that can systematically identify, analyze, and optimize the key factors affecting product quality while minimizing experimental costs and production downtime. Contemporary manufacturing excellence requires the implementation of scientific approaches that can effectively bridge the gap between process inputs and quality outputs through systematic experimentation and data-driven decision-making (Hisam et al., 2024; Heidari-Rarani et al., 2022).

This research aims to enhance the production quality of 600ml PET bottles by implementing the Taguchi method as a robust experimental design technique to determine the optimal combination of critical process parameters in the blow molding process. The study seeks to systematically identify and quantify the influence of air pressure, heating temperature, and stretching time on product defect rates, thereby establishing a scientific foundation for process optimization that minimizes quality variations while maximizing production efficiency. The research addresses a critical gap in the existing literature by providing a comprehensive statistical analysis of parameter interactions specific to 600ml PET bottle production, offering practical insights that can be directly applied to industrial manufacturing settings. The urgency of this research stems from the growing market demands for consistent product quality, increasing production costs associated with defective products, and the need for sustainable manufacturing practices that optimize resource utilization. The novelty of this work lies in its systematic application of the Taguchi method with orthogonal array L9 (3<sup>3</sup>) design specifically tailored to 600ml PET bottle production, providing empirical evidence for optimal parameter combinations that can serve as industry benchmarks and contribute to the advancement of knowledge in plastic manufacturing optimization.

## RESEARCH METHODS

### Research Type and Method

This study employed a quantitative experimental research approach designed to systematically investigate the effects of process parameter variations on the production quality of 600ml PET bottles in the blow molding process. The experimental research methodology was selected as it provides the most appropriate framework for establishing causal relationships between independent variables (process parameters) and dependent variables (product defect rates) through controlled manipulation and systematic observation (Creswell & Creswell, 2023; Sugiyono, 2022). The research utilized a pre-experimental design with a one-group posttest-only approach, where multiple experimental conditions were applied to assess their individual and collective impacts on production outcomes. The Taguchi method was implemented as the core experimental design strategy, representing a robust statistical approach that enables efficient optimization through the systematic variation of multiple factors simultaneously while maintaining experimental validity and minimizing resource requirements (Hisam et al., 2024; Singh et al., 2022). This methodology aligns with the principles of Design of Experiments (DOE), providing a structured framework for understanding complex process interactions and identifying optimal parameter combinations for enhanced product quality.

### Experimental Design and Data Analysis Techniques

The experimental framework was constructed using an Orthogonal Array L9 (3<sup>3</sup>) design, strategically selected to accommodate three primary factors—air pressure, heating temperature, and stretching time—each examined at three distinct levels, resulting in nine experimental combinations that comprehensively represent the parameter space while maintaining statistical efficiency. The orthogonal

design ensures that each factor's effects can be analyzed independently, preventing confounding effects and enabling accurate assessment of individual factor contributions to overall process performance (Patel et al., 2021; Sudaryono, 2023). Data analysis employed multiple statistical techniques, including Signal-to-Noise Ratio (SNR) calculations using the "Smaller is Better" approach to emphasize defect minimization, Analysis of Mean (ANOM) to determine factor-level effects, and Analysis of Variance (ANOVA) to quantify the statistical significance and percentage contribution of each factor to the total variance. The SNR analysis served as the primary quality metric, converting defect count data into logarithmic ratios that facilitate direct comparison of experimental conditions and identification of optimal parameter combinations (Chen et al., 2023; Pratama & Ramadhan, 2023). Statistical computations were performed using specialized software to ensure accuracy and reliability of analytical results, with validation procedures implemented to confirm the robustness of findings.

### **Population and Sampling Strategy**

The target population for this research comprised 600ml PET bottles produced using the injection stretch blow molding process under varying parameter combinations at the designated manufacturing facility. The sampling approach employed a systematic experimental sampling method, where each of the nine experimental conditions generated a sample of 140 bottles, resulting in a total sample size of 1,260 bottles across all experimental runs (Emzir, 2024; Creswell & Creswell, 2023). This sample size was determined based on statistical power analysis considerations and practical manufacturing constraints, ensuring adequate representation of process variability while maintaining experimental feasibility. The sampling strategy incorporated randomization principles to minimize systematic bias and ensure representative coverage of production conditions within each experimental treatment. Quality assessment focused on defect identification and quantification, with trained personnel conducting standardized inspection procedures to maintain consistency in defect classification and counting protocols. The raw material population consisted of 600ml PET preforms manufactured from high-grade polyethylene terephthalate, with standardized specifications including an average weight of 12.6 grams per preform to ensure material consistency across all experimental conditions (Fitriani & Purwanto, 2022; Kamaruddin et al., 2016).

### **Research Procedure and Implementation**

The research implementation followed a systematic multi-stage procedure designed to ensure methodological rigor and result validity throughout the experimental process. The initial phase involved comprehensive problem identification through detailed observation of existing production processes, documentation of quality fluctuations, and establishment of baseline defect rates to provide comparative benchmarks for optimization assessment (Sugiyono, 2022; Ikhwan & Indrayana, 2020). Factor selection and level determination were conducted through preliminary analysis and consultation with production experts, resulting in the identification of air pressure (31, 32, 33 bar), heating temperature (130, 140, 150°C), and stretching time (0.866, 0.933, 1.000 seconds) as the critical control parameters. The experimental execution phase utilized a Techlong RJM14A Blow Molding machine, with systematic implementation of each L9 array combination under controlled conditions to minimize external variability and ensure consistent experimental environments. Data collection procedures incorporated standardized quality inspection protocols, with defective products systematically identified, classified, and quantified using predetermined quality criteria. Statistical analysis was conducted using established computational procedures, beginning with SNR calculations for each experimental condition, followed by ANOM analysis to determine optimal factor levels, and concluding with ANOVA analysis to establish factor significance and contribution percentages. The final validation phase involved confirmation testing using the identified optimal parameter combination to verify the effectiveness of the Taguchi optimization approach and ensure practical applicability of research findings (Sari & Nugroho, 2023; Hidayat & Permana, 2023). Throughout the research process, quality control measures were implemented to maintain data integrity, experimental consistency, and result reliability, with comprehensive documentation of all procedures and observations to support result interpretation and future research applications.

## RESULTS AND DISCUSSION

### Results

**Table 1. Optimal parameter settings**

Factor	Optimal Level	Value
A	Level 3	33 bar
B	Level 3	150 °C
C	Level 2	0.933 seconds

The combination based on the is an air pressure of

temperature of 150 °C, and a stretching time of 0.933 seconds. This combination was chosen because it produces the highest SNR value, which means it can minimize the number of defects in 600 ml PET bottles. With these optimal parameters, it is expected that the blow molding process will run more stably, product quality will improve, and the number of defective products can be minimized, thereby supporting the overall efficiency and effectiveness of the production process.

optimal parameter recommended highest SNR value 33 bar, a heating

### Discussion

#### Research Factors and Levels

In this study, there were three main factors examined, each with three levels of adjustment. The first factor was Air Pressure with levels of 31 bar, 32 bar, and 33 bar. The second factor is Heating Temperature, which is varied at levels of 130 °C, 140 °C, and 150 °C. The third factor is Stretching Time, with variations of 0.866 seconds, 0.933 seconds, and 1.000 seconds.

The determination of these factors and levels is shown in Table 2 below:

**Table 2. Factors tested**

Factor	Level 1	Level 2	Level 3
A: Air Pressure (bar)	31	32	33
B: Heating Temperature (°C)	130	140	150
C: Stretching Time (s)	0.866	0.933	1.00

### Experimental Results

The experiment was conducted by producing 600 ml PET bottles using various combinations of process parameters according to the L9 (3<sup>3</sup>) Orthogonal Array design. The L9 Orthogonal Array approach was used to design an experiment involving three main parameters, each at three levels, to determine the most optimal combination of parameters in the blow molding process in order to improve production quality and efficiency." (Sari, P. R., & Nugroho, H. (2023). Each combination was tested on 140 bottles, and the number of defects was counted for quality evaluation. The following are the levels tested according to Table 3 below:

**Table 3. Experimental Results of Parameter Combinations, Number of Defects, and SNR Values**

No	A (Pressure)	B (Temperature)	C (Time)	Number of Defects	SNR (dB)
1	31	130	0.866	25	-27.9588

No	A (Pressure)	B (Temperature)	C (Time)	Number of Defects	SNR (dB)
2	31	140	0.933	17	-24.6050
3	31	150	1,000	13	-22.2789
4	32	130	0.933	20	-26.0206
5	32	140	1,000	9	-19.0849
6	32	150	0.866	11	-20.8279
7	33	130	1,000	10	-20,000
8	33	140	0.866	5	-13.9794
9	33	150	0.933	3	-9.5424

The results of the study show variations in the number of defects in each combination of process parameters. The Signal to Noise Ratio (SNR) value is calculated using the Smaller is Better approach to emphasize the goal of minimizing the number of defects in the product. In this case, decibels (dB) are used in SNR calculations to express the ratio of signal to noise on a logarithmic scale, so that the higher the SNR value (approaching zero for Smaller is Better), the better the process quality because it indicates less variation in defects. The use of the Smaller is Better approach in Signal to Noise Ratio calculations allows for the identification of optimal conditions by effectively minimizing variation and the number of defects in the product. (Pratama, I. A., & Ramadhan, F. (2023) Experiment 9 showed the best results with only 3 defective bottles and the highest SNR value of -9.5424 dB, which means that the combination of parameters in this experiment was most effective in minimizing the number of defects in 600 ml PET bottles.

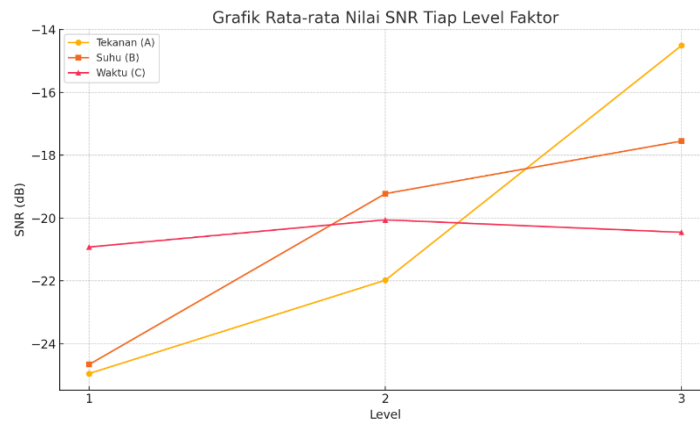
**Average SNR for Each Factor Level**

Based on the calculation of the average Signal to Noise Ratio (SNR) value at each factor level, the data is as shown in the following table. The range value (R) was calculated to determine the magnitude of each factor's influence on production quality.

**Table 4. Average SNR Values for Each Factor Level and Influence Range (R)**

Factor	Level 1 (SNR)	Level 2 (SNR)	Level 3 (SNR)	Range (R)
<b>A: Pressure (bar)</b>	-24.9476	-21.9778	-14.5073	<b>10.44</b>
<b>B: Temperature (°C)</b>	-24.6598	-19.2231	-17.5497	<b>7.11</b>
<b>C: Time (s)</b>	-20.9220	-20.0560	-20.4546	<b>0.87</b>

From the average SNR values for each factor, the data was then processed in the form of a graph in Figure 1 below:



**Figure 1. Graph of the average Signal to Noise Ratio (SNR) values for each factor**

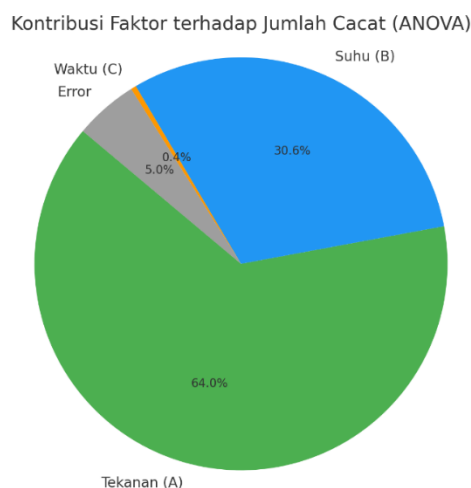
The graph of the average Signal to Noise Ratio (SNR) for each factor, namely air pressure, heating temperature, and stretching time, shows differences in the level of influence on the quality of PET bottle production. The air pressure factor (A) shows a sharp increase in SNR values from level 1 to level 3, indicating that changes in pressure have a significant impact on reducing the number of defects. Meanwhile, the heating temperature factor (B) shows a moderate change pattern, reflecting that although it has an effect, its impact is not as great as pressure. On the other hand, the stretching time factor (C) has a relatively flat graph, which means that variations in this parameter have very little effect on improving product quality. Therefore, it can be concluded that controlling air pressure is the most important aspect in minimizing the number of defects in the blow molding process. Therefore, adjusting the pressure parameter is the key to reducing production defects. (Susanto, R., & Wibowo, A. (2023).

### ANOVA Analysis

In addition to SNR analysis, an Analysis of Variance (ANOVA) was also conducted to reinforce the test results of each factor's contribution to product quality, with the aim of identifying the most statistically significant factors in the blow molding process (Hidayat & Permana, 2023).

**Table 5. ANOVA Calculation Results**

Source of Variation	DOF	SS	MS	Calculated F	Contribution (%)
<b>A: Pressure</b>	2	173,595	86.7975	12.90	64.04%
<b>B: Temperature</b>	2	82.938	41.469	6.17	30.60%
<b>C: Time</b>	2	1.127	0.5635	0.08	0.42
<b>Error</b>	2	13.45	6.725	-	4.96%
<b>Total</b>	8	<b>271.11</b>	-	-	100



**Figure 2. Circle Diagram Graph of Each Factor's Contribution to the Number of Defects**

The presentation of data on the contribution of each factor to the number of defects, which was previously presented in ANOVA table format, is now visualized in a pie chart to facilitate interpretation and comparison between factors. This visualization provides a more intuitive picture of the proportion of influence of each variable, namely air pressure, heating temperature, and stretching time, on the total number of defects produced during the production process. From the graph, it can be seen that the pressure factor (A) has the most dominant contribution of 64.0%, followed by temperature (B) at 30.6%. Meanwhile, stretching time (C) only contributes 0.4%, and the rest comes from the error factor of 5.0%. This visual presentation not only reinforces the results of the variance analysis calculations but also makes it easier to identify the most significant process parameter improvement priorities for product quality improvement.

### Factor Analysis

The average SNR calculation results show that air pressure has the most dominant influence on product quality with a contribution of 64.04%, followed by heating temperature with a contribution of 30.60%, while stretching time has the smallest contribution of only 0.42%. This finding indicates that controlling air pressure is a key factor in minimizing defects in 600 ml PET bottles. Based on the results of the highest SNR analysis, the recommended optimal parameter combination is an air pressure of 33 bar, a heating temperature of 150°C, and a stretching time of 0.933 seconds. The application of these parameters significantly contributes to reducing production defects, thereby improving process efficiency and maintaining product quality in a sustainable manner (Sari & Nugroho, 2023).

## CONCLUSION

This study demonstrated that the application of the Taguchi method effectively identified the optimal process parameters—specifically, an air pressure of 33 bar, a heating temperature of 150°C, and a stretching time of 0.933 seconds—that significantly minimize defects in the production of 600ml PET bottles through blow molding. The analysis revealed that air pressure is the most influential factor, contributing approximately 64% to the reduction of defects, followed by heating temperature with around 30%, while stretching time had minimal impact. These findings suggest that precise control of these key parameters can enhance process stability, improve product quality, and increase manufacturing efficiency, thereby providing valuable insights for industry practitioners aiming to optimize their production processes systematically.

However, the research has certain limitations, notably that it was conducted within a specific industrial setting with a limited scope of process variables, which may affect the generalizability of the results to other manufacturing environments or bottle sizes. Additionally, the study primarily focused on defect count as the quality metric, without exploring other important factors such as surface finish, mechanical strength, or long-term durability of the bottles. Future research could expand upon these

findings by incorporating a broader range of process parameters, exploring different bottle volumes, and utilizing additional quality assessment metrics. Moreover, implementing real-time monitoring and control strategies based on the identified optimal parameters could further enhance process robustness and sustainability in industrial applications.

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