
Analysis of the Effect of Energy Consumption on Can Size Variations in Tuna Canning

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Abstract

This study analyzes the effect of can size variations on energy consumption during the vacuum process in canned tuna production. The background for this research is the high energy intensity of the canning industry, driven by rising production costs and the need for greater environmental sustainability. The study's objective was to quantify the relationship between can size, headspace volume, and the energy required for vacuuming, a specific gap in existing literature. A quantitative experimental method was employed, with a population of canned tuna products from a single facility and a sample of three can sizes: 301×102 (70 g), 211×109 (95 g), and 307×112 (185 g). Data was collected using direct observation and operational records, with analysis performed via descriptive statistics and an ANOVA test. Results showed significant differences in energy consumption, with larger cans requiring higher steam pressure but demonstrating greater overall efficiency per gram of product. The 185 g can was found to be the most optimal choice, exhibiting the highest packaging efficiency and lowest coal consumption per gram, while also maintaining the best microbiological quality. The study concludes that can size is a critical factor for optimizing energy costs and product quality in mass production.

Keywords: Can Size, Canned Tuna, Energy Efficiency, Steam Consumption, Vacuum Process

INTRODUCTION

Energy efficiency is a critical concern in the canned tuna industry, as the production process, particularly stages like sterilization, filling, and seaming/vacuums, is highly energy-intensive (Putra et al., 2022). The massive energy consumption, often sourced from the combustion of fuels like coal to generate steam, not only inflates production costs but also contributes significantly to environmental impact (Elwardany et al., 2024). This issue is not unique to the tuna industry; it is a widespread challenge across the entire food processing sector, where rising energy costs and environmental regulations are driving a global push for more sustainable manufacturing practices (Kumar et al., 2021; O'Sullivan et al., 2022; Ghasemi et al., 2023). Therefore, optimizing energy usage is essential for both economic viability and environmental responsibility.

The type of packaging is a key factor influencing energy efficiency. Specifically, variations in can size directly impact the headspace volume, which in turn determines the amount of steam required for the vacuum process (Astaty & Gani, 2020). The vacuum process is a crucial step where steam is injected into the headspace to remove oxygen, thereby extending the product's shelf life and preserving its quality (Temdee et al., 2022). This process is highly sensitive to the internal volume of the can, with larger headspaces demanding greater steam consumption to achieve the required vacuum levels (Sutrisno et al., 2023). This relationship highlights a direct link between packaging selection and operational energy costs.

Despite its importance, the specific link between can size, headspace volume, and energy consumption during the vacuum process remains an underexplored area in the literature. Previous studies have primarily focused on the broader effects of vacuum packaging. For instance, Astaty and Gani (2020) and Milijašević et al. (2024) investigated how vacuum packaging affects the microbiological and chemical quality of various seafood products, confirming its effectiveness in maintaining quality and extending shelf life. Other research has addressed production efficiency from different angles, such as using Six Sigma to control quality and identify packaging defects in frozen fish (Sucipto et al., 2020) or analyzing energy consumption in canning processes in general (Sutrisno et al., 2023; Kumar et al., 2021).

Furthermore, while some studies have touched upon the impact of can size on product quality and production profitability (Wahyudi et al., 2022), they have not specifically quantified how these size variations influence energy use at the vacuuming stage. This gap is significant because even small differences in energy consumption per unit can accumulate into substantial costs at an industrial scale, affecting overall production efficiency and profitability (Pérez-López et al., 2021; Abeysekera et al., 2023; Sharma et al., 2024). The lack of specific data on this relationship makes it difficult for manufacturers to make informed decisions about optimal can sizes for both product quality and energy savings. Given this research gap, there is a clear need to conduct a focused study that systematically analyzes the effect of can size on energy consumption during the vacuum process. Such a study would provide critical insights into a key variable that has a direct impact on operational efficiency and cost management.

Therefore, the purpose of this study is to fill this gap by analyzing the influence of energy consumption on the different can sizes used in the canned tuna production process. The urgency of this research lies in its potential to provide practical insights for the canned tuna industry, helping producers to select the most energy-efficient and cost-effective packaging. This not only aids in reducing production costs but also aligns with the growing global emphasis on sustainable manufacturing and environmental conservation. The novelty of this research is its specific focus on quantifying the relationship between can volume, headspace, steam requirements, and the amount of coal consumed per production cycle. By providing a direct, data-driven link between these factors, this study offers new knowledge that can serve as a practical reference for improving production efficiency and profitability in a major food processing industry.

RESEARCH METHODS

This study employed a quantitative approach with an experimental method to systematically analyze the effect of can size on energy consumption during the tuna canning vacuum process. The selection of a quantitative experimental design was essential to establish a cause-and-effect relationship between the independent variable (can size) and the dependent variable (energy consumption), a core principle in engineering and industrial research (Sudaryono, 2021; Sugiyono, 2022). Three different can sizes were chosen for the experiment: 301x102 (70 grams), 211x109 (95 grams), and 307x112 (185 grams). These specific can sizes were selected because their varying headspace volumes were hypothesized to directly influence the amount of steam required for vacuuming, processing time, and, ultimately, the final product quality (Wahyudi et al., 2022; Kumar et al., 2021).

The research was conducted at the production facility of PT XYZ, utilizing a direct observation method and operational data recording over three consecutive days. This on-site, in-situ approach ensured that the data collected accurately reflected real-world production conditions (Emzir, 2023). Sample collection involved eight measurements per day, with four units for each can size, alongside one microbiological test per day to assess product quality. This structured sampling provided a robust dataset for subsequent statistical analysis. The research instruments included a Varin 41 seamer machine for vacuuming and sealing, a Tunipack filling machine for tuna meat, a digital scale, and a caliper to measure can dimensions. A laptop was used for data processing and analysis. The materials used in the experiment consisted of fresh tuna, supplementary media (oil and saline), the three aforementioned can sizes, coal as the primary fuel for the boiler, and clean water to produce steam (Putra et al., 2022; Sutrisno et al., 2023).

For data collection and analysis, the volume of each can was calculated using the formula $V = \pi \times (d/2)^2 \times t$, where d is the diameter and t is the height (Siregar, 2019). The fill volume was determined by dividing the total weight of the can's contents by the density of the mixture (Widodo & Haryono, 2020), while the headspace was calculated as the difference between the can's volume and the fill volume, or by adhering to the industry standard of approximately 6% of the can's total volume (Kumar et al., 2021). Energy consumption data was collected by measuring the mass of steam used in each vacuuming process. This mass was then converted into thermal energy based on the enthalpy of saturated steam (2700 kJ/kg). Subsequently, the required amount of coal was calculated by comparing the total thermal energy to the caloric value of coal (20,920 kJ/kg) and the boiler's efficiency (Sutrisno et al., 2023).

The collected data underwent both descriptive and statistical analysis. Descriptive analysis was used to present the average energy consumption for each can size, while an Analysis of Variance (ANOVA) was performed to determine if there were statistically significant differences between the

treatments (can sizes). Furthermore, an estimation of energy costs was calculated based on the price of coal for each can size, providing a comprehensive view of the relationship between can size, energy consumption, and production cost efficiency within the tuna canning industry. This multi-faceted approach, combining direct measurement, empirical calculation, and statistical validation, ensured the reliability and practical applicability of the research findings (Sutrisno et al., 2023; Kumar et al., 2021; Abeysekera et al., 2023).

RESULTS AND DISCUSSION

Result

Vacuum Process Pressure and Temperature

The observation results showed that the temperature parameters of the vacuum process were kept constant at $\pm 100^{\circ}\text{C}$ for all sizes of cans, to ensure that the sterilization process ran optimally. However, there are significant differences in *steam* pressure and engine speed for each can size.

As seen in the Table, the larger the size of the can, the higher *the steam* pressure required. A 301×102 (70g) can requires only a pressure of 0.3 kg/cm², while the largest can of 307×112 (185g) requires a pressure of up to 1.0 kg/cm². This increase in pressure is associated with a larger *volume of headspace*, so more steam is required to expel air and achieve the desired vacuum conditions.

In addition, the machine speed (*cycle per minute / cpm*) also adjusts to the size of the can. Small cans can be processed faster (190 cpm), while larger cans have lower speeds (145–150 cpm) to maintain process stability and quality of the final result.

Table of Pressure, Temperature, and Machine Speed in a Vacuum Process

Can Size	Steam Pressure (kg/cm ²)	Temperature(°C)	Machine Speed (cpm)
301×102 (70g)	0,3	±100	190
211×109 (95g)	0,8	±100	145
307×112 (185g)	1,0	±100	150

These findings are in line with the research of Kumar et al. (2021), which stated that increasing *the volume of headspace* requires greater pressure and *steam* mass to achieve optimal vacuum conditions. This difference in pressure and speed also has an impact on energy consumption, where large cans tend to require higher energy than small cans, even though the process temperature remains constant.

Can Volume and Headspace

Based on the results of the calculation of the volume of contents and headspace on the three sizes of cans, it can be seen that the larger the size of the can, the smaller the percentage of headspace formed. In a 301×102 (70 g) can, the average headspace obtained is 8.10%, being the highest compared to other sizes. Meanwhile, in a 211×109 (100 g) can, the average headspace drops to 6.09%, and in a 307×112 (185 g) can, the average headspace is only 5.11%. These results show a trend of decreasing headspace as the size of the cans increases.

This phenomenon indicates that the efficiency of space utilization in cans is increasing at a larger size. Too large a headspace can reduce packaging efficiency, as the space in the packaging is not optimally utilized. However, a certain amount of headspace is also still needed to maintain the stability of the product, especially as an expansion space. Therefore, a larger can size is considered more ideal because it can balance the volume of contents with the required headspace.

Table Of Average Headspace Percentages on All Three Can Sizes:

Can Size	Headspace Average (%)
301×102 (70 g)	8.10
211×109 (100 g)	6.09
307×112 (185 g)	5.11

The visualization also shows a clear difference between the volume of contents and the headspace of each can size. From this comparison, it can be concluded that larger capacity cans provide more efficient space utilization than small cans.

Packaging Efficiency

Packaging efficiency is calculated from the ratio between the volume of the contents and the volume of the can. The calculation results show that the larger the size of the can, the higher the packaging efficiency. In the 301×102 (70 g) can, the packaging efficiency was recorded at 92.10%, indicating a relatively larger headspace. Cans 211×109 (95 g) have an efficiency of 94.35%, while cans 307×112 (185 g) show the highest efficiency of 94.96%.

These findings confirm that larger cans are more optimal in utilizing their internal space, as the proportion of headspace to total volume is getting smaller. Thus, the selection of can size can have an effect on the packaging efficiency and stability of the product.

Packaging Efficiency Table

Can Size	Contents Volume (cm ³)	Can Volume (cm ³)	Packaging Efficiency (%)
301×102 (70 g)	120.1	130.6	92.10
211×109 (95 g)	133.6	142.5	94.35
307×112 (185 g)	247.0	260.4	94.96

Steam Exposure Length and Machine Speed

The length of exposure to steam in the canning process is determined by the engine speed (cpm) and the number of spindles. The results of the calculation show that the exposure time is very short, which only ranges from 0.315 – 0.414 seconds. A small 301×102 (70 g) can with the highest engine speed (190 cpm) gets the shortest exposure time of 0.315 seconds. In contrast, 211×109 (95 g) cans with lower engine speed (145 cpm) experienced the longest exposure of 0.414 seconds.

This shows that the faster the engine speed, the shorter the steam exposure time. Thus, setting cpm is an important factor to ensure that the sterilization process and product quality run optimally.

Steam Display Time Table

Can Size	cpm	Spindle	rpm	1 Revolution (seconds)	Steam Exposure (seconds)
301×102 (70 g)	190	4	47.5	1.26	0.315
211×109 (95 g)	145	4	36.25	1.655	0.414
307×112 (185 g)	150	4	37.5	1.60	0.400

Energy Steam

Steam energy calculations show that the energy requirement to heat cans is relatively small, only ranging from 2.55 – 3.35 kJ per can. The 95 g can requires the highest energy because it has a longer exposure time, while the 70 g can is the lowest. Although small individually, on the scale of mass production this energy will accumulate significantly.

Steam Energy Table per Can

Can Size	Steam Mass (kg)	Steam Energy (kJ)
301×102 (70g)	0.000945	2.55
211×109 (95g)	0.001242	3.35
307×112 (185g)	0.001200	3.24

Coal Consumption

The consumption of coal to produce steam is very small, which is between 0.000203 – 0.000282 kg/can. A 95 g can requires the highest coal consumption because the steam energy required is also greater.

Table of Coal Consumption per Can

Can Size	Steam Energy (kJ)	Coal Consumption (kg)
301×102 (70g)	2.55	0.000203
211×109 (95g)	3.35	0.000282
307×112 (185g)	3.24	0.000258

The accumulation of coal consumption increases linearly with the amount of production. For example, for 96,000 cans per day, coal needs reach 19,488 kg (70 g), 27,072 kg (95 g), and 24,768 kg (185 g).

Daily Coal Consumption Table by Production Amount

Can Production	Consumption 70g (kg)	Consumption 95g (kg)	Consumption 185g (kg)
24.000	4.872	6.768	6.192
33.600	6.821	9.475	8.668
48.000	9.744	13.536	12.384
72.000	14.616	20.304	18.576
96.000	19.488	27.072	24.768

Assuming production is carried out in 30 days, coal consumption increases along with production capacity. The cost is calculated at the price of coal Rp 2,000/kg. From the calculations, a 95 g can has the highest consumption and cost, while a 70 g can has the lowest.

Table of Coal Consumption and Cost in 1 Month

Daily Production	Monthly Production	70g (kg / Rp)	95g (kg / Rp)	185g (kg / Rp)
24.000 Can	720.000	146.16 / Rp292.320	203.04 / Rp406.080	185.76 / Rp371.520
33.600 Can	1.008.000	204.62 / Rp409.248	284.26 / Rp568.512	259.97 / Rp519.936
48.000 Can	1.440.000	292.32 / Rp584.640	406.08 / Rp812.160	371.52 / Rp743.040
72.000 Can	2.160.000	438.48 / Rp876.960	609.12 / Rp1.218.240	557.28 / Rp1.114.560
96.000 Can	2.880.000	584.64 / Rp1.169.280	812.16 / Rp1.624.320	743.04 / Rp1.486.080

Cost of Coal Consumption per Can

The calculation results show that the cost of coal consumption per can is very small, which is only around Rp 0.41 – Rp 0.56. The 95 g can has the highest cost because it requires the most steam energy.

Table of Coal Consumption Costs per Can

Can Size	Coal Consumption (kg)	Cost (Rp)
301×102 (70g)	0.000203	0.41

Can Size	Coal Consumption (kg)	Cost (Rp)
211×109 (95g)	0.000282	0.56
307×112 (185g)	0.000258	0.52

Although the cost per can is very small, on a mass production scale the cost increases linearly with the amount of production. For example, the production of 96,000 cans of 95 g per day costs around Rp 54,144 just for coal.

Table of Coal Consumption Costs by Production Quantity

Total Production	Cost 70g (Rp)	Cost 95g (Rp)	Cost 185g (Rp)
24.000 Can	9.744	13.536	12.384
33.600 Can	13.641,6	18.950,4	17.337,6
48.000 Can	19.488	27.072	24.768
72.000 Can	29.232	40.608	37.152
96.000 Can	38.976	54.144	49.536

This proves that although energy consumption per unit is small, on an industrial scale energy cost remains an important factor that must be managed for production efficiency.

ANOVA Statistical Analysis

To confirm the effect of Can Size on energy consumption, an ANOVA test was carried out. The results showed that there was a significant difference in energy consumption between Can Sizes (F count = 8509.53; p-value = $4.38e-11 < 0.05$).

ANOVA Test Results Table			
Variation Sources	df	F Hitung	p-value
Intergroup	2	8509.53	4.38e-11
In Groups	287	-	-

Thus, Can Size significantly affects energy consumption. This is natural, because the larger or longer the exposure to steam, the energy needs and coal costs also increase.

Coal Consumption per Gram of Product

The calculation results show that the larger the contents of the Can, the more efficient the coal consumption per gram of product. Can 185 g has the lowest consumption (1.39×10^{-6} kg/gr), while Can 95 g has the highest (2.97×10^{-6} kg/gr). This confirms that canning products with a larger capacity is more energy-efficient per unit of mass.

Table of Coal Consumption per Gram of Products

Can Size	Consumption Coal (kg)	Net weight(g)	Coal per Gram (kg/g)
301×102 (70g)	0.000203	70	2.90×10^{-6}
211×109 (95g)	0.000282	95	2.97×10^{-6}
307×112 (185g)	0.000258	185	1.39×10^{-6}

For this reason, the interpretation of Can 185 g is superior in energy efficiency compared to other measures.

Final Product Quality (Microbiology)

The results of the Total Plate Count (TPC) test showed that all Can Sizes had values below the maximum limit of 3.0 CFU logs/g. This proves that the canning process maintains the microbiological quality of the product. Interestingly, Can 185 g records the lowest TPC value, which can be attributed to a more even distribution of heat in large volumes.

TPC Average Table per Can Size

Can Size	TPC (log CFU/g)	Maximum Limit	Status
301×102 (70g)	2.1	3.0	Secure
211×109 (95g)	1.9	3.0	Secure
307×112 (185g)	1.8	3.0	Secure

Daily TPC tests on three consecutive days showed small variations between samples, but the overall values remained well below the 3.0 log CFU/g threshold.

Daily TPC Table per Can Size (Summary)

Can Size Rentang	TPC (log CFU/g)	Status
70 g	2.0 – 2.2	Secure
95 g	1.8 – 2.1	Secure
185 g	1.7 – 1.9	Secure

Untuk itu, Stabilitas mikrobiologi produk sangat baik. Can 185 g konsisten memiliki nilai TPC terendah, menunjukkan potensi keunggulan dalam kualitas penyimpanan.

Discussion

The vacuuming process in canning plays a crucial role in maintaining sterilization and product quality, with key parameters including temperature, pressure, and machine speed. While the process temperature was consistently maintained at approximately 100°C for all can sizes, we observed significant variations in the required steam pressure and machine speed. The smallest cans (70 g) required only a low pressure of 0.3 kg/cm² with a high machine speed of 190 cycles per minute (cpm), whereas the largest cans (185 g) required up to 1.0 kg/cm² of pressure at a slower speed of 150 cpm. This is directly related to the headspace volume, as larger headspaces demand a greater amount of steam to displace air and achieve the optimal vacuum condition. This finding is consistent with the research by Kumar et al. (2021), which highlights that increased headspace volume necessitates higher steam pressure and mass for optimal vacuuming.

From a headspace perspective, a notable trend was a decrease in the percentage of headspace as the can size increased. The 70 g can had the largest average headspace at 8.10%, while the 185 g can had the smallest at just 5.11%. This trend indicates that larger cans are more efficient in internal space utilization, as the proportion of empty space is smaller. Our calculations of packaging efficiency further support this: the 70 g can had an efficiency of only 92.10%, whereas the 185 g can achieved the highest efficiency at 94.96%. Consequently, larger cans are not only better at minimizing the headspace proportion but are also more effective at balancing the need for expansion space and overall product stability.

The steam exposure time during the process was found to be very brief, ranging from 0.315 to 0.414 seconds. The smaller 70 g cans, with their higher machine speed, had the shortest exposure time (0.315 seconds), while the 95 g cans, operating at a slower speed, had the longest exposure (0.414 seconds). As a result, the steam energy requirements varied: the 95 g can needed the most energy (3.35 kJ), and the 70 g can required the least (2.55 kJ). Although these differences are marginal per can, they

accumulate significantly on a mass production scale. Our analysis of coal consumption showed a similar pattern, with the 95 g can consistently having the highest energy and cost requirements. However, when calculated per gram of product, the 185 g can was the most efficient, consuming only 1.39×10^{-6} kg/g, making it far more energy-efficient than the other sizes.

Statistically, the ANOVA results confirmed that can size has a significant effect on energy consumption (F-statistic = 8509.53; $p < 0.05$). This finding has practical implications: choosing a can size is not just about product capacity but also directly impacts energy efficiency and production costs. This becomes particularly relevant when considering accumulated daily and monthly costs, where small consumption differences per unit become a significant factor at an industrial scale.

From a microbiological quality standpoint, all products were found to be safe, with Total Plate Count (TPC) values well below the maximum limit of 3.0 log CFU/g. Notably, the 185 g can consistently performed best, recording the lowest TPC values (1.7–1.9 log CFU/g). This can be attributed to a more even heat distribution within the larger volume, which more effectively inhibits microbial growth.

In summary, these findings demonstrate that larger-capacity cans excel not only in terms of space and energy efficiency but also tend to yield a more stable microbiological quality. Therefore, the use of the 185 g can size can be considered the most optimal choice in terms of technical, energy, economic, and final product quality aspects.

CONCLUSION

Based on the research findings, it can be concluded that can size significantly impacts energy consumption, packaging efficiency, and production costs in the tuna canning process. The larger can size (185 g) proved to be the most efficient, demonstrating a smaller headspace, lower coal consumption per gram of product, and more stable microbiological quality. Conversely, smaller cans (70 g and 95 g) were less energy-efficient per unit of mass, making them less economical for large-scale production. While the energy cost per can may seem negligible, its cumulative effect on a mass production scale is substantial, underscoring the importance of optimizing energy-saving strategies. This study, however, was limited to a specific type of tuna and a single production facility, which may affect the generalizability of the results to other types of canned fish or factories with different equipment and processes. Future research should explore a wider range of can sizes and different food products to validate these findings. Furthermore, it would be beneficial to conduct a more detailed thermodynamic analysis of the steam injection process and to investigate the potential of alternative, more sustainable energy sources to further enhance the efficiency and environmental responsibility of the canned food industry.

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