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Energy Consumption Analysis and Conservation Guidelines for the Pineapple Industry Supply Chain

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Abstract

This study investigates the overall energy consumption of the pineapple industry supply chain. Data were collected in Prachuap Khiri Khan Province, which has the largest share of pineapple plantations and processing plants. The study focuses on energy consumption in processing plants, as they are the most energy-intensive part of the supply chain. Energy consumption analysis was conducted at both the plant and product levels. The findings of this study can help improve the cost-effectiveness of policies aimed at enhancing energy efficiency and provide guidelines for energy conservation and reduction in canned pineapple production. These guidelines may also be applicable to industries with similar energy consumption patterns.

Keywords
Specific Energy Consumption, Energy Consumption and Canned Pineapple Industry.

1. Introduction
The pineapple industry is an industry that has expanded to meet the consumption demand, with approximately 80 percent of the products entering the processing plants. Prachuap Khiri Khan Province has the largest number of processing plants and planting areas, so it is a representative for collecting data. Currently, the canned pineapple industry tends to expand more (The Royal Irrigation Department 2024). Energy consumption is an important factor in the production process of canned pineapple factories. It was found that the trend of energy consumption has increased according to the advancement of production technology, whether it is electricity or heat energy used in the production process. Measuring energy consumption is an important factor in the production and processing of products. The factory does not indicate the level and points that need to be improved in energy consumption. However, the improvement to reduce the specific energy consumption index per unit of production (SEC) must be improved in each process. The factory has not yet assessed the energy consumption in each process to indicate the important parts that affect energy saving. In addition, the current environmental assessment of products must consider the acquisition of pineapple raw materials, which uses energy at the plantation and transportation in the supply chain. Therefore, it is important to study the approach to assess the energy consumption to increase the energy efficiency of the canned pineapple industry.

The canned pineapple industry supply chain is an industry that connects the agricultural and industrial sectors by processing fresh pineapples into canned pineapples until they become finished products for delivery to consumers. The structure of the pineapple industry consists of 3 parts: the upstream part is the agricultural sector, pineapple planting; the midstream part is the operators of fresh pineapple collection and purchasing stalls, and the canned pineapple processing industry, concentrated pineapple juice from industrial factories in the lower central provinces; and the downstream part is the domestic consumers and the export of products abroad. The activities of the canned pineapple industry supply chain are related to many parts, starting from farmers starting to grow pineapples. The harvested products will be sold to pineapple purchasing stall operators and pineapple processing factories. When they are processed into canned pineapple products, they will be consumed domestically and exported abroad, as shown in Figure 1.

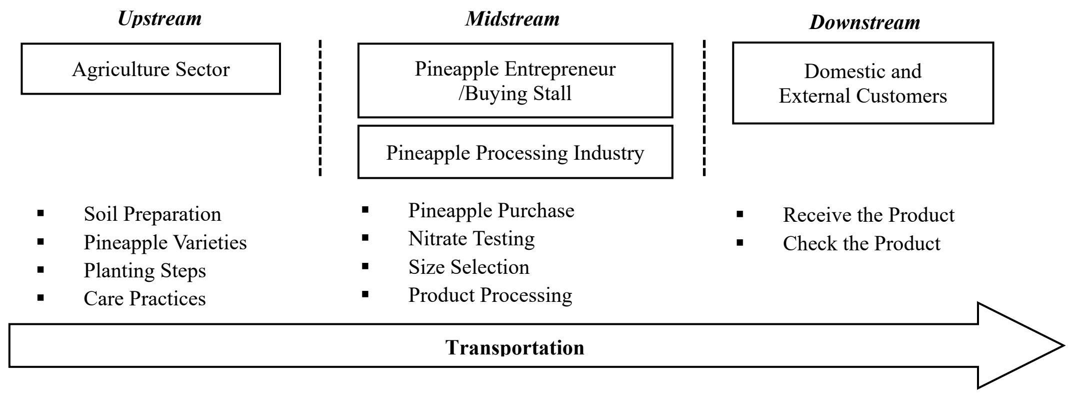


Figure 1. Supply chain structure of the canned pineapple industry

2. Literature Review

Research related to industrial supply chain management includes research that studies and analyzes supply chains in various industries, including forecasting the demand for pineapple cultivation in advance (Chareonchai et al. 2005), studying methods for reducing costs (Cheng et al., 2024) and increasing the efficiency of logistics systems (Valery et al., 2017), evaluating efficiency using models to plan raw material orders for the electronics industry (Ruxing et al. 2023) and creating models to adjust the transportation system and select routes for transporting goods (Qiankun and Haiyan 2025). However, there is no research presented on energy management of the canned pineapple industry supply chain. Therefore, this research will present an assessment of energy use in the industrial supply chain to determine measures and plan for improving energy use in the canned pineapple industry supply chain.

Literature reviews have explored renewable energy, energy storage, and energy use in industry. For example, Reducing energy consumption in a factory in sugar plant. Xiao (2021) colleagues investigated a risk management plan for a renewable energy system in a commercial complex in 2021. Jeong and Taelim (2024) investigate the relationship between regional characteristics and smart factory adoption in South Korea by analyzing smart factory data for reducing energy use (Park and Choi 2024) and response based industrial energy management with focus on consumption of renewable energy May et al. (2016)**.**

Considering the strategies used for energy-saving purposes, it is essential to clarify their suitability within the context of our study. Although these strategies are well known for their energy-saving potential, the way they were implemented and adapted to the specific characteristics of our factory underlines their relevance and effectiveness in achieving the objectives of our study. Our selection of these strategies considered not only their proven energy-saving benefits but also their compatibility with the factory's climatic conditions, use patterns, and structural considerations.

3. Overview of Activities of the Canned Pineapple Industry

The basic characteristics of the pineapple industry, explained from the overview of the canned pineapple industry, details of the canned pineapple production process in each step, including the management of data and information in the sector within the factory. To operate the canned pineapple industry, it is necessary to consist of 8 basic activities. Receiving a product order is an activity in which the customer specifies the details of the canned pineapple they want.

They must specify the details of the canned pineapple in 3 aspects: can size, syrup details, and pineapple slice pattern. In addition, the order quantity and the delivery date must be specified, which generally have a waiting period of about 3-6 months and the unit of order quantity is a container. Confirming the product order and delivery date activity is an activity in which the factory confirms the product order with the customer and the delivery date that it can be produced and the product can be delivered to the customer on the date and time specified by the customer. Raw material ordering activity is the ordering of raw materials consisting of a total of 5 types of raw materials: fresh pineapple, packaging, syrup ingredients, boxes, and labels. There are 2 ways to order pineapples: 1. Receiving pineapples from the pineapple plantation where a trade contract has been previously made. 2. Buying pineapple from a pineapple auction. The auction has a base price that is jointly set and adjusted according to the demand for fresh pineapples from each pineapple factory. If there is a high demand, the price of pineapples per kilogram will also be higher. Raw material import activity is the process of receiving raw materials from pineapple farmers, who transport the pineapples to the factory and deliver them to the factory themselves. and delivered by truck. Canned pineapple production is the process of processing fresh pineapple into canned pineapple according to the details of the purchaser. Product quality inspection is the process of taking canned pineapples that have been finished and not yet labeled and storing them for 2 weeks to check the quality. Canned pineapples that are not of good quality will swell from other cans. Product labeling is the application of trademarks according to customer needs, as the same type of product can have different trademarks Product delivery is the process of taking the labeled products to the port and delivering them to the customer in order as shown in Figure 2.

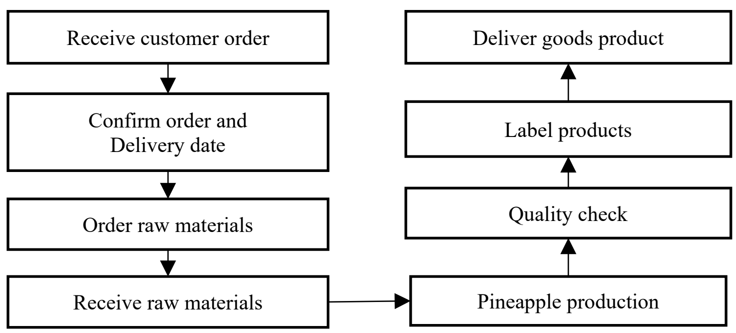


Figure 2. Diagram showing overall activities of the canned pineapple production

4. Methodology for Measuring and Analyzing Energy Consumption

The methods for measuring and analyzing energy consumption in the sample canned pineapple factory are considered at two levels: the overall level (Plant and Product Level) and the level of individual product processing. The data obtained will be used for analysis and management at each respective level.

4.1 Total Energy Use

The objective at this level is to determine the proportion of energy consumption in the production of canned pineapple, concentrated canned pineapple juice, supporting systems, and other non-related productions within the factory. This includes the specific energy consumption (SEC) for each product based on production units, as well as the production capacity utilization rate as Figure 3.

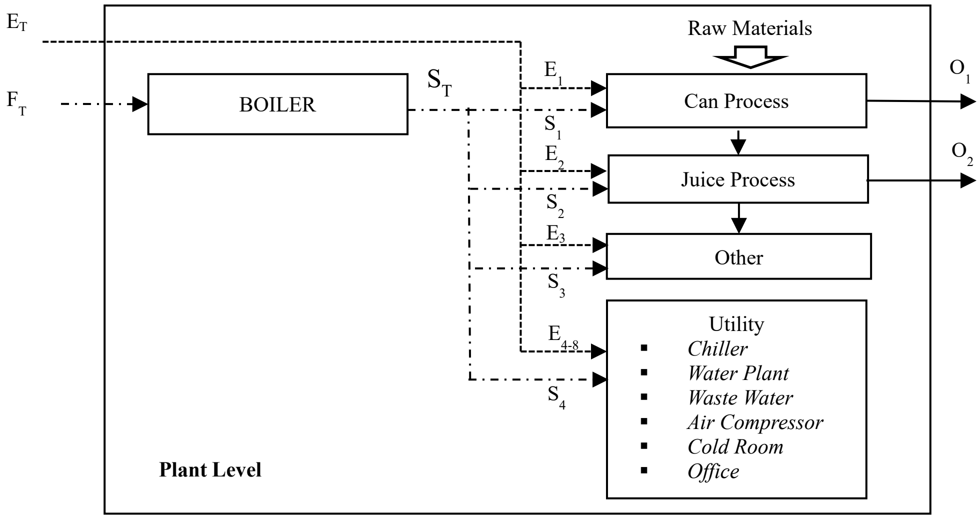


Figure 3. Energy measurement points at the plant level for the factory

Considering the energy use system of a pineapple factory, it can be classified into energy use for canned pineapple production, use for concentrated pineapple juice production, use for other unrelated products such as aloe Vera or dried fruit, and production support parts such as cold-water production, cold storage, tap water production, treatment systems, offices, and others. The measured data is shown in Table 1.

Table 1. Collecting data at the plant level

Measuring Point	Measured Data Values	Unit
E_T	Total daily electricity usage	kWh/day
E_1	Electricity consumption in canned pineapple production	
E_2	Electricity consumption in pineapple concentrate production	
E_3	Electricity consumption for production of other products	
E_4	Electricity consumption of water chiller	
E_5	Electricity consumption of cold storage	
E_6	Electricity consumption in water production systems	
E_7	Electricity consumption of wastewater treatment systems	
E_8	Electricity consumption of air compressor	
E_9	Electricity usage in offices and factories	
E_B	Electricity consumption of boiler system	
F_T	Daily fuel consumption	MJ/day
S_T	Amount of steam produced	Ton/day
S_1	Daily steam consumption for canned pineapple production	
S_2	Daily steam consumption for canned pineapple juice production	
S_3	Daily steam consumption for another products production	
S_4	Daily steam consumption for support systems (if any)	
RM	Amount of pineapple produced	
O1	Amount of canned pineapple produced per day	
O2	Amount of concentrated pineapple juice produced per day	

The recorded values are kept as daily data for management purposes. However, if the meters record electricity consumption on an hourly basis, it would provide insights into the daily energy usage patterns and wasted energy during non-production periods with greater detail. At the very least, cumulative daily data should be recorded, and if an overall monthly analysis is required, the results can be aggregated on a monthly basis.

4.2 Data Analysis

The main analysis of overall data to assess energy efficiency, production efficiency, energy consumption proportion of each major system and production capacity utilization is as equation follows in Figure 4:

Specific Energy Consumption (SEC) refers to the amount of energy consumed per unit of output produced. Examples include kWh/ton, MJ/kilogram, kWh/m³, etc., depending on the type of product as Eq. (1).

$$SEC = \frac{Quantity\ of\ Output}{Energy\ Consumption} \tag{1}$$

Energy Balance is widely used to assess systemic heat losses and establish optimal energy-saving strategies for industrial factory. Energy Balance; A condition in which two or more objects are in contact and no net heat transfer occurs between them. This happens when the objects reach the same temperature, causing the flow of thermal energy to cease, in accordance with the principle of energy conservation.

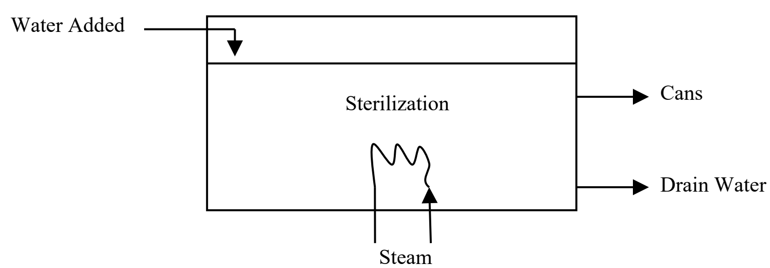


Figure 4. Thermal balance of sterilization

<u>*Where;*</u>

T_W	=	Water Temperature in the Sterilizer	$(^\circ C)$
T_{amb}	=	Ambient Temperature	$(^\circ C)$
T	=	Surface Temperature of the Sterilizer	$(^\circ C)$
A	=	Surface Area of the Sterilizer	(m^2)
h	=	Heat Transfer Coefficient of the Sterilizer Surface	$(W/m^2 \cdot {}^\circ C)$
C_{pc}	=	Heat Capacity of Canned Pineapple	(kJ/kg)
C_{pw}	=	Heat Capacity of Water	(kJ/kg)
ε	=	Emissivity Coefficient of the Sterilizer Surface	

- Amount of Heat Applied to the Cans. (MJ/day)

$$Q_{CAN} = m_c C_{pc}(T_W - T_{amb}) \tag{2}$$

- Amount of Heat Applied to the Water. (MJ/day)

$$Q_W = m_w C_{pw}(T_W - T_{amb}) \tag{3}$$

- Amount of Heat from Heat Transfer. (MJ/day)

$$Q_{loss} = hA(T_s - T_{amb}) + (5.67 \times 10^{-8}) \times \varepsilon A \left[(T_s + 273)^4 - \left(T_{amp} + 273\right)^4\right] \tag{4}$$

- Amount of heat used by steam. (MJ/day)

$$Q_s = Q_{CAN} + Q_W + Q_{loss} \tag{5}$$

5. Energy Use in the Canned Pineapple Production Process

The canned pineapple production process consists of 7 steps, starting from receiving raw pineapple for production, cutting, processing, packing, sterilizing, drying and storing every step. Electricity is used in every step and steam is used to produce hot water, remove air and sterilize as a Figure 5.

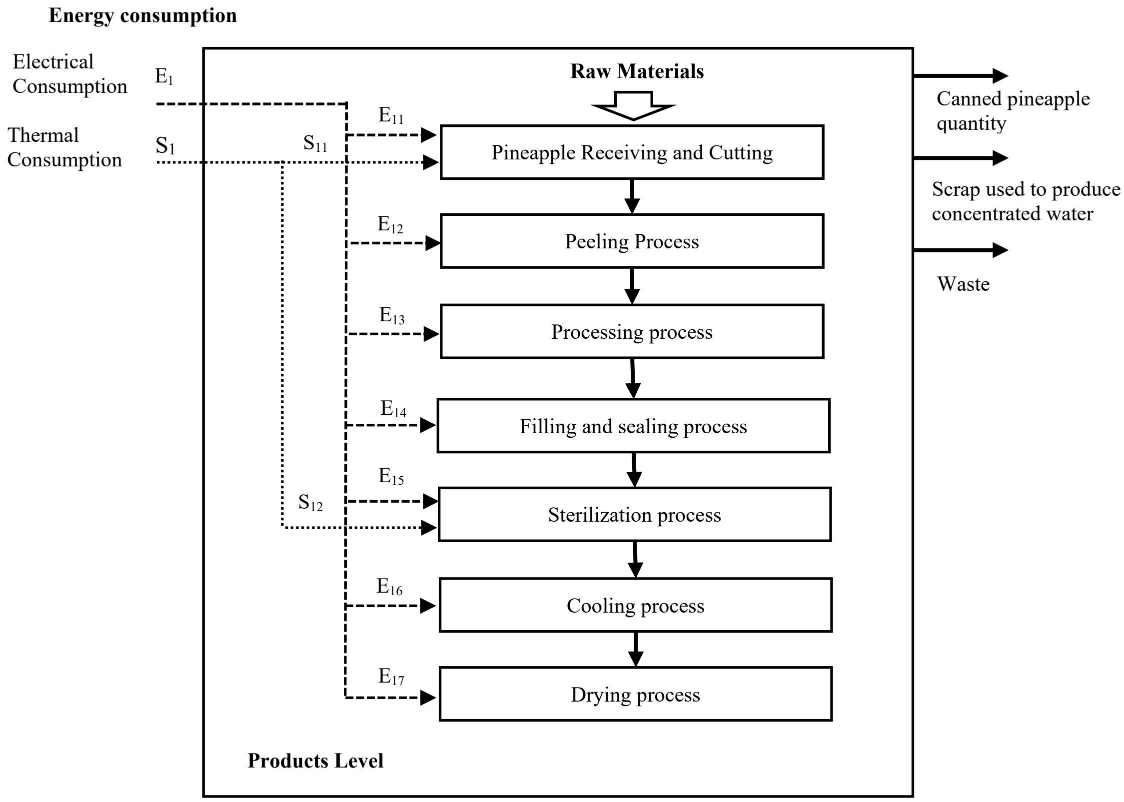


Figure 5. Energy measurement points of canned pineapple process

The researcher conducted a survey on energy consumption in sample canned pineapple production based on the process flow diagram. The measurement of electrical and thermal energy usage was carried out using a Chervin Arnov Model: CA8332 power logger, which continuously recorded data every hour and report data per days. The measured data is shown in Table 2.

Table 2. Collecting data at a product level

Measuring Point	Measured Data Values	Unit
E_1	Total Daily Electricity Usage in Canned Pineapple Process	*kWh/day*
E_{11}	Electricity consumption for pineapple receiving and cutting process	
E_{12}	Electricity consumption for peeling process	
E_{13}	Electricity consumption for processing process	
E_{14}	Electricity consumption for filling and sealing process	
E_{15}	Electricity consumption for sterilization process	
E_{16}	Electricity consumption for cooling process	
E_{17}	Electricity consumption for drying process	
S_1	Daily steam consumption for canned pineapple production	*MJ/day*
S_{11}	Daily steam consumption for pineapple receiving and cutting process	
S_{12}	Daily steam consumption for sterilization process	
RM	Amount of pineapple produced	*Ton/day*

6. Results

The researcher conducted a survey on energy consumption in sample canned pineapple production, based on the process flow diagram, at both the Plant Level and the Process Level. Measurements of electrical and thermal energy usage were taken using a Chervin Arnov model CA8332 power logger, which continuously recorded data over a 10-day period.

6.1 Data Energy Consumption

The recorded energy data were then analyzed to assess energy consumption at the Plant Level as shown in Table 3 and to evaluate the Specific Energy Consumption (SEC) index at the Product Level as show in Table 4, taking production volume into account. The findings are intended to support the development of measures to improve energy efficiency in production processes where energy losses occur.

Table 3. Daily electrical and thermal energy consumption

Date	Total electricity consumption (E_T)	Can Process (E_1)	Juice Process (E_2)	Other (E_3)	Chiller (E_4)	Water Plant (E_5)	Waste Water (E_6)	Air Compressor (E_7)	Office (E_7)	Fuel (F_T)	Steam Production (S_T)	Raw Material (RM)
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(MJ)	(Ton)	(Ton)
Day 1	26,011	3,126	3,085	13,656	363	1,774	1,073	648	562	1,952,113	293	286
Day 2	26,128	2,936	2,876	13,045	376	1,774	1,240	657	508	1,985,425	298	267
Day 3	24,063	3,182	2,619	10,944	401	1,774	1,243	614	650	1,998,750	300	308
Day 4	27,204	3,468	3,146	13,033	413	1,774	1,457	644	662	1,985,425	298	322
Day 5	26,595	3,486	3,222	12,572	414	1,774	1,178	694	627	1,998,750	300	333
Day 6	27,026	2,934	2,946	14,176	437	1,774	935	646	612	1,772,225	266	288
Day 7	26,848	3,161	2,914	13,763	406	1,774	924	666	609	1,812,200	272	297
Day 8	26,448	3,087	2,611	13,103	363	1,774	1,602	705	554	1,918,800	288	285
Day 9	22,556	3,189	2,695	9,844	399	1,774	745	674	544	1,672,288	251	295
Day 10	24,764	3,108	2,884	11,786	371	1,774	1,123	762	569	1,772,225	266	261
Total	**257,642**	**31,677**	**28,996**	**125,921**	**3,943**	**17,736**	**11,518**	**6,709**	**5,897**	**18,868,200**	**2,832**	**2,943**
Average	**46,844**	**5,759**	**5,272**	**22,895**	**717**	**3,225**	**2,094**	**1,220**	**1,072**	**3,430,582**	**515**	**535**

Table 4. Electrical and thermal consumption of canned pineapple factory

Process	Electrical Consumption		Thermal Consumption	
	Average Daily Consumption (kWh/day)	Percentage (%)	Average Daily Consumption (*MJ/day*)	Percentage (%)
Canned Pineapple Production	5,759.46	12.40	366,192.38	48.90
Juice Production	5,272.04	11.30	335,943.22	44.90
Chiller	716.97	1.50	-	-
Air Compressor	1,219.86	2.60	-	-
Water Plant	3,224.73	6.90	-	-
Waste Water	2,094.23	4.50	-	-
Cold Room	4,352.85	9.30	-	-
Office	1,072.11	2.30	-	-
Other	22,894.65	49.10	46,418.64	6.20
Total	**46,606.89**	**100.00**	**748,554.24**	**100.00**

Table 5. Canned pineapple energy consumption data

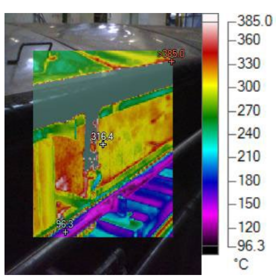
Energy Consumptions Detail	Data	Unit
Production Coordinates	200 - 250	Ton/Day
Electricity Consumption	2,977,280	kWh/Year
Fuel Consumption	19,717.45	Ton/Year
Canned Pineapple Production Volume	2,869.70	
Pineapple Juice Concentrate Production Volume	2,356.80	

According to Table 4 and Table 5, it was found that the sample canned pineapple factory uses about 50% of its electricity for canned pineapple production, while the remaining portion is for other products such as dried fruits. For canned pineapple and concentrated juice, electricity consumption is roughly similar, at about 10% each. The cold storage accounts for about 10%, while other supporting systems consume no more than 5% of total electricity usage. These supporting systems include the water supply system and the wastewater treatment system. In terms of thermal energy usage, the factory produces steam to supply three main production processes: canned pineapple production, concentrated pineapple juice production, and other processes such as dried fruit production.

Table 6. The specific energy consumption in the canned pineapple production process

Products	**Production Process**	**Production (Ton/day)**	**Electrical Consumption (kWh/day)**	**Thermal Consumption (MJ/day)**	**Specific Energy Consumption**		
					Electrical (kWh/ton)	**Thermal (MJ/ton)**	**Total (MJ/day)**
Canned Pineapple	Pineapple Receiving	294.29	114.32	32,917.50	0.39	111.85	113.25
	Peeling process	234.85	580.46	-	2.47	-	8.90
	Processing	176.89	22.24	-	0.13	-	0.45
	Filling and Sealing Process	38.30	200.15	93,942.24	5.23	2,452.91	2,471.73
	Sterilization process	38.30	2,034.02	183,835.95	53.11	4,800.11	4,991.31
	Cooling and Drying Process	38.30	50.00	-	1.31	-	4.70
Concentrated Pineapple Juice	Extraction Process	82.21	3,614.08	-	43.96	-	158.26
	Blending Process	82.21	145.94	-	1.78	-	6.39
	Evaporation	82.21	7,838.46	351,932.00	95.35	4,280.97	4,624.22

An examination of the energy consumption of the sample canned pineapple factory at the Plant Level revealed that thermal energy represented the highest share of usage, primarily in the production of canned pineapple and concentrated pineapple juice. Consequently, the researcher analyzed the data at the Process Level, incorporating raw material production volumes, and calculated the Specific Energy Consumption (SEC) for the sample factory. The SEC results are presented in Table 6 to identify potential approaches for energy conservation and reducing energy losses. Analysis of the electricity and thermal energy consumption data further showed that the sterilization process consumed the largest share of energy. As a result, an insulation measure was implemented for the canned pineapple sterilizer to reduce energy consumption during sterilization (Figure 6).

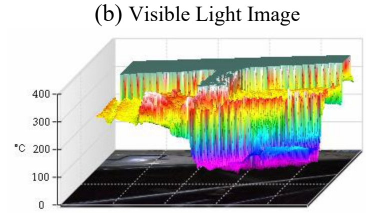


(a) IR002686.IS2

(b) Visible Light Image

Name	Temperature	Emissivity
Center Point	316.40 °C	0.10
Hot	>385.00 °C	0.10
Cold	96.30 °C	0.10

(c) Main Image Markers



(d) Graph 3D -TR™

Figure 6. Thermal image of evaporation oven of concentrated pineapple juice product

Figure 6 shows that in the evaporation process of concentrated pineapple juice, drying is a process that requires a large amount of heat. Therefore, energy-saving measures for the dryer are very important, as shown by the thermal imaging data in the evaporator oven in Figure 6. This leads to improvements through the installation of thermal insulation as part of energy conservation measures. The main sources of heat loss in the dryer are as follows:

1) Heat that is lost with the air exiting the drying chamber.
2) Heat loss due to conduction, convection, and radiation from the dryer.
3) Heat loss from hot air leaking through various gaps in the dryer.

Based on the electricity usage data from the canned pineapple factory in Table 6, the production processes for canned pineapple, concentrated pineapple juice, and the cold room are among the top three in terms of electricity consumption. Data on electricity reduction suggests that industrial factories should incorporate solar energy to help lower overall energy use. Solar energy offers several advantages for the industry: it is environmentally friendly, reduces greenhouse gas emissions, mitigates climate impacts, and lowers long-term costs. Although the initial investment may be relatively high, once the payback period is reached, the cost of electricity production decreases. Furthermore, solar energy is sustainable because the sun provides an inexhaustible and abundant source of power every day. Thus, alternative electricity sources in industry not only help produce clean, eco-friendly power but also represent a long-term investment that enables businesses to maintain stability and remain competitive in a global market increasingly oriented toward sustainability.

In the analysis of the heat balance of the factory's boiler, the parameter values are shown in Table 7.

Table 7. Parameters of the heat balance of the boiler in a sample canned pineapple factory

Detail	Para meter	Data	Unit	Detail	Para meter	Data	Unit
1. Capacity of the hot water boiler	T	12	Ton/hr	- Side surface (left side)	T_{SS1}	47.00	$^{\circ}C$
2. Fuel feeding rate	mf	9,500	kg / hr	- Side surface (right side)	T_{SS2}	43.00	$^{\circ}C$
3. Fuel heating value	H	6.57	MJ / kg	- Front surface	T_{sf}	168.00	$^{\circ}C$
4. Water feed rate	mw	11.42	Ton/hr	- Rear surface	T_{sr}	210.00	$^{\circ}C$
5. Produced water pressure	P	8	bar	9. Boiler diameter	D	3.00	m
6. Feed water temperature	T_w	30	$^{\circ}C$	10. Boiler length	L	7.80	m^2
7. Exhaust gas				11. Electrical conductivity			
- % Oxygen	O	10.20	%	- Soft Water	TDS_{sf}	200	μs
- CO	CO	3,837	ppm	- Blow Down	TDS_{bd}	3,500	μs
- Exhaust gas	T_{amb}	32.50	$^{\circ}C$	12. Enthalpy of Hot Water	hg	2.769	MJ / kg
- Exhaust gas temperature	T_{fl}	105.10	$^{\circ}C$	13. Enthalpy of Feedwater	hw	0.126	MJ / kg
8. Average boiler surface temperature							

Steps for Calculating Heat Balance

1. Amount of Heat Entering the Boiler $\left(Q_{in}\right)$ = $mf \times H$ = 9,500 x 6.57 = 62,415 MJ/h

2. Amount of Heat Exiting the Boiler $\left(Q_{out}\right)$ = $mw \times \left(hg - hw\right)$ = 11.42 x (2.769-0.126)

= 30,185.34 MJ/h

3. Heat Loss from Exhaust Gas

- Theoretical Air $\left(A_o\right)$ = $\left(\dfrac{1.10H}{1{,}000}\right) + 0.50 = \left(\dfrac{1.10 \times 6.57}{1{,}000}\right) + 0.50$

= 2.08 Nm^3/Nm^3

- Theoretical Flue Gas Volume (G_0) $= \left(\frac{0.89H}{1,000}\right)+1.65 = \left(\frac{0.89\times 6.57}{1,000}\right)+1.65$

  $= 3.05 \quad Nm^3/Nm^3$
- Excess Air Ratio (m) $= \frac{21}{21-O_2} = \frac{21}{21-10.20} = 1.94$
- Exhaust Gas (G) $= G_0 + (m-1)A_0$

  $= 3.05+(1.94-1)2.08 = 5.02 \quad Nm^3/Nm^3$
- Exhaust Gas Heat Capacity (C_{pfl}) $= 1.37 \quad kJ/Nm^3$

$\therefore$ Heat Loss (Q_{fl}) $= mf \times G \times C_{pfl} \times (T_{fl} - T_{amb})$

$= 9,500 \times 5.02 \times 1.37 \times (105.10 - 32.50) = 4,739.\ MJ/h$

4. Heat Loss through Boiler Surface

- Front Side $= \left[5.67A\times10^{-8}\times\left(T_{sf}{}^4 - Tamb^4\right)\right]+\left[1.31A\times\left(T_{sf}-Tamb\right)^{1.333}\right] = 48.45 \quad MJ/h$
- Side $= \left[5.67A\times10^{-8}\times\left(T_{sr}{}^4 - Tamb^4\right)\right]+\left[1.31A\times\left(T_{sr}-Tamb\right)^{1.333}\right] = 23.42 \quad MJ/h$

  Total Heat Loss $= 97.79 \quad MJ/h$

5. Heat Loss from Incomplete Combustion $= mf \times G \times CO \times (0.1281\times10^{-6}) = 23.42 \quad MJ/h$

6. Other Heat Losses (Q_{other}) $= Q_{in} - Q_{out} - Q_{fl} - Q_s - Q_{bd} = 27,392.85 \quad MJ/h$

From the data on electricity and heat consumption of the sample factory, it was found that the sterilization process has the highest energy usage. Therefore, an insulation measure was implemented for the pineapple can sterilization oven to reduce energy consumption in the sterilization process.

6.2 Insulation Measure for the Sterilization Oven

Details of heat-loss calculations before and after the improvement for the sterilization oven as Table 8.

Table 8. Dimension parameters for the heat balance of the boiler in a sample canned pineapple factory

Wide (m)	**Length (m)**	**Angle (Rad)**	**Angle (Dd)**	**Cos θ**	**δ (m)**	**A (m^2)**
0.41	22.76	0	0	1	0.20	9.33

In the process of measuring the surface temperature of the water, the temperature was measured at 10 points distributed around the water surface. The average of these values was then calculated for use in further computations, as shown in Table 9. The average surface temperature was 86.25 °C.

Table 9. Water temperature on the surface of the sterilization vessel

Temperature Measurement Point	**Water Temperature (°C)**
1	83.47
2	88.50
3	86.60
4	88.40
5	86.33
6	82.10
7	83.50
8	83.33
9	91.00
10	89.00
Average	86.25

- **Before Renovation;**

Average sterilization oven temperature		=	86.20	°C
Oven surface	Width	=	0.41	m
	Length	=	22.76	m
Machine hours		=	3,100	hr / y

$$Q_{Loss} = Q_{\text{Convection}} + Q_{\text{Radiation}}$$

$$Q_{Convection} = hA\left(T_s - T_{amb}\right) = 1.788 \times 9.33 \times \left(68.25 - 34.00\right) = 1,319.20 \quad W$$

$$Q_{\text{Radiation}} = \left(5.67 \times 10^{-8}\right) \times \varepsilon A\left[\left(T_s + 273\right)^4 - \left(T_{amp} + 273\right)^4\right]$$

$$= \left(5.67 \times 10^{-8}\right) \times 0.44 \times 9.33 \times \left[\left(68.25 + 273\right)^4 - \left(34 + 273\right)^4\right] = 257.05 \quad W$$

$$\therefore \quad Q_{Loss} = 1,319.20 + 1,809.91 = 3,129.11 \quad W$$

The heat loss at the oven surface. $= Q_{Loss} \times 0.0036 \times Machine\ hours$

$= 3,129.11 \times 0.0036 \times 3,100 = 34,920.90 \quad MJ / y$

Fuel consumption equivalent = Q loss /(7.53*0.4) = 11,593.92 kg / y

- **After Renovation;**

	Average sterilization oven surface temperature	=	45.00	°C
	The heat loss at the oven surface.	=	5,622.84	MJ / y
	Fuel consumption equivalent	=	1,866.81	kg / y
$\therefore$	Reduce heat energy loss	=	29,298.06	MJ / y
	Fuel consumption equivalent	=	9,727.11	kg / y

After applying insulation measures to the sterilization oven for canned pineapples, it was found that the temperature around the sides of the oven decreased by 41.20 °C. The calculated heat loss at the oven surface before improvement was 34,920.90 MJ/year, while after improvement it was reduced to 5,622.84 MJ/year. This resulted in a reduction of 29,298.06 MJ/year, equivalent to an 84% decrease.

Building on this, the researcher further examined the dryer's heat usage, as shown in Figure 6, by calculating the heat consumption and heat loss before and after improvement to clearly identify the differences. Insulation measures were then implemented for the dryer to reduce heat loss. However, these methods still present certain limitations. Fundamentally, the principles and methods for heat utilization should be structurally considered from the design stage, as outlined below:

- Electrical: In cases where a dewatering process is applied prior to drying, mechanical dewatering should be employed to reduce the moisture content as much as possible. Examples include centrifugation, filtration, and mechanical pressing. Although equipment costs may be high, operating expenses are significantly lower than those of drying.
- During the constant-rate drying period, raw materials remain at a low temperature, ensuring effective heat transfer. Therefore, powdered raw materials should be stirred or tumbled in hot air to disperse them, which helps lower the critical moisture content.
- Efforts should be made to maximize the heat transfer coefficient per unit volume or the overall heat transfer coefficient. Achieving this will allow the heat transfer medium to exit at a lower temperature, thereby improving thermal efficiency.
- In hot-air dryers, a portion of the steam released should be recirculated as much as the dryer's capacity allows to further enhance thermal efficiency.

In terms of production management, raw material feeding schedules should be carefully planned to align with the sterilizer's operation cycle, ensuring a continuous and efficient process. The schedule should be adjusted according to production volume and factory conditions to help reduce energy consumption. Data on raw material usage and sterilization outcomes should be monitored and recorded to evaluate process efficiency. Processes should then be refined and developed based on the collected data, ensuring that planning is accurate and better aligned with production needs. With effective planning at every stage, raw material delivery to the sterilizer can proceed smoothly, waste can be minimized, and product quality can be maintained in accordance with established standards.

7. Conclusion and Suggestions

In this study, the factory's energy consumption was analyzed and measured along with annual energy usage. Initially, efforts were made to select a more suitable system by considering the characteristics of the canned pineapple processing plant. Subsequently, opportunities to reduce energy consumption were examined. The study revealed that the sterilization process in canned pineapple production and the evaporation process in dried pineapple production consume large amounts of thermal energy. Therefore, energy conservation measures should be implemented by improving processes to minimize energy loss and by adopting production planning strategies to reduce energy consumption. Furthermore, if alternative energy sources derived from production byproducts, such as coconut shells and woods, are used to generate thermal energy, both energy costs and consumption can be reduced. However, this may result in increased carbon dioxide emissions. Nevertheless, it is still considered a clean energy source derived from nature.

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