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Specific Energy Consumption of Container and Tableware Glass Manufacture Industry

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Energy consumption of the nonmetallic sector is approximately 30.74 % of the industrial sector energy consumption in 2019, uppermost in the industrial sector of Thailand. The industry of container glass and tableware glass manufacture industry consumes the second-highest energy percentage after cement. Following that, the Ministry of Energy aims to reduce 30 % of energy intensity by 2036, followed by the Thai Energy Conservation Plan 2015 (EEP2015). Specific energy consumption (SEC) and Baseline energy consumption (BEC) are obtained to interest the relationship between relevant variables. Regression equations are developing to predict BEC and SEC baseline. These equations can be used as a powerful instrument for energy management to save energy. 14 of 15 containers glass and tableware glass plants in Thailand were audited and analyzed in this paper. The main product is a glass bottle, glassware, and other (handmade glass and industrial marble balls). Approximately 84% of the energy used in this sector is thermal energy. The BEC and SEC equations showed that total product quantity, molten glass volume from the glass-melting furnace, and glass melting furnace age ratio are affected by energy consumption. Therefore, entrepreneurs in this sector can apply developed BEC and SEC equations from this study as a guideline for establishing their energy performance indicator baseline.

1. Introduction

Final energy consumption in Thailand is continuously increasing every year. In 2019, the final energy consumption was 85,829 ktoe. The industrial sector consumed energy percentage is 36.4 of the energy uses in Thailand, second-highest after the transportation sector. The Energy Conservation Plan (2011-2030) has been improved and integrated into the Energy Efficiency Plan 2015-2036 (EEP2015) to determine strategies and methodologies to support and promote energy conservation. Decreasing energy intensity by 30 % in 2036 compared with 2010 is the primary goal of EEP2015, or equivalent to 56,142 ktoe of total final energy consumption. The Ministry of Energy, the main responsible for the EEP2015 target, implemented various measures in 4 economic groups that consume a massive amount of energy, including transportation, industrial, business, and residential sectors. The measures included both compulsory program voluntary program and complimentary program.

To meet the EEP2015 target to reduce energy consumption, the Department of Alternative Energy Development and Efficiency (DEDE) may enforce a compulsory program on the nonmetallic sector that consumes approximately 30.74 % of the industrial sector energy uses. According to the Energy Conservation Promotion Act B.E.2535, the designated factories may be the first group to be enforced to penalty charge measure. DEDE will charge the penalty based on standard indicators established under Energy Performance Indicator (ENPI). Nevertheless, there is no current ENPI standard in Thailand; hence the standard aforementioned is needed to define. Under Asswamartbunlue and Luknongbu (2020), Asswamartbunlue et al. (2019), and Asswamartbunlue et al. (2018), investigated ENPI in 3 industries; Cement, Sugar cane mill, and Native Starch industry. This paper presents the investigation of ENPI in the containers glass and tableware glass manufacture industry. This industry consumes the second highest energy consumption after cementing in the nonmetallic sector.

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1.1 Industrial Background

Thailand Standard Industrial Classification (TSIC 2009) classifies the container glass and tableware glass industry as a nonmetallic sector by TSIC-ID as 23102. There are 15 container glass and tableware glass manufacture factories in Thailand (2017). This sector's products can be dividing into four groups in this research, i.e., glass bottles, glassware, handmade glass, and industrial marble balls. Most energy usage is thermal energy, approximately 84 % of the total energy, where the glass melting process consumes the highest point. The production process of all 4 product groups has similar characteristics, starting from preparation and raw material mixing, then feeding the ingredients mixed into the glass melting furnace. Next, the melting glass will pass to the conditioning process to reduce the temperature before forming a circle; after that, the product will bring into the annealing process to reduce product stress and then through the quality inspection process and packing. The production processes flow diagram is depicted in Figure 1.

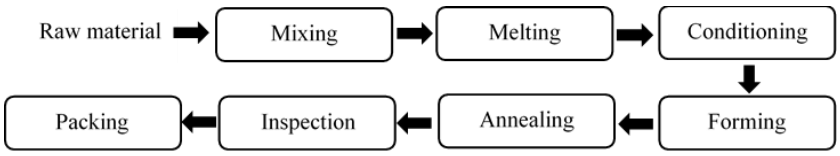

Figure 1: Glass production processes

1.2 Energy Performance Indicator concept

Energy Performance Indicator (ENPI) is a number used to indicate the energy efficiency of processes or activities that consume energy. The definition of ENPI can be divided into four categories: Thermodynamic, Physical-thermodynamic, Economic-thermodynamic, and Economic. This research investigated Physical-thermodynamic indicators based on plant performance. Typical indicators used to compare energy efficiency between their factory and other factories (in the same industry) are Baseline Energy Consumption (BEC) and Specific Energy Consumption (SEC). BEC and SEC are usually presented as a single number because of their simplicity and less data requirement.

Schmitz et al. (2011) studied the energy consumption of the EU glass industry in 2007. It was found that the average fuel intensity energy consumption is about 7.8 GJ/t of saleable products. Container glass production has fuel intensity between 6.1 - 7.1 GJ/t while total SEC between 4.7 - 8.5 GJ/t.

Beerkens et al. (2004) investigated the energy use in 131 glass melting furnaces to produce container glass and SEC ranking by normalizing cullet use at 50 %. The result shows that 10% of the ranking level reported SEC at 4.285 GJ/t of molten glass, while the average SEC is approximately 5 GJ/t of molten glass.

Revitasari and Susanto (2018) compiled world maximum benchmarking of SEC standards in the flat glass industry. The report shows that Indonesia has the sternest SEC standard at 6.7 GJ/ton (Indonesian Green Industry Standard 2016). China has three standard grades consist of China 1st, 2nd, and 3rd. China 1st standard grade defines the lowest SEC at 7.84 GJ/ton, then China 2nd and 3rd are 10.8 GJ/t and 11.52. European Union has tree case studies from the Publications Office of the European Union (2013); 8 GJ/t, Centre for European Policy Studies (2014); 9.2 GJ/t and Intergovernmental Panel on Climate Change; 8 GJ/t. In addition, agencies of the USA: The United States Environment Protection Agency (EPA) and the Department of Energy (DOE) reported SEC standard at 11.07 GJ/t.

The SEC can also be used to indicate the ability to reduce carbon emissions in the manufacturing process. Zier et al. (2021) study and review each technology's carbon reduction in the glass manufacturing industry using SEC as an analytical aid. Carbon emissions are related to SEC, and the electric fusion and hydrogen combustion technology or a combination of both is the most promising option for decarbonization.

2. Research approaches

The definition of BEC is the amount of base energy usage, and SEC is the ratio between energy input and production quantity at the same period. In order to increase the indicator's accuracy, the clarification of studying boundary is necessary to determine. This study defined the boundary of BEC and SEC as plant performance-based. The chosen independent variables investigated independence with dependent variables and determining the relationship between BEC and SEC. The development of BEC and SEC equations uses statistical methods and regression analysis. The best equation for selection is based on statistical values, including R-squared, adjusted R-squared, and p-value. The research step is as follows:

Consider and analyze the factory energy management report to investigate primary independent and dependent variables that affect energy consumption.

Define base year data. In this research, 2016 - 2017 audit and measurement data are used. Audit and analyze participating factories data both mass balance and energy balance concept. Then choosing independent variables that have effect on BEC and SEC. However, the variables ought to be accumulated regularly and able to be measured. Independent variables are shown in Table 1.

Table 1. Independent variables.

Variables	Description	Unit
x_1	Average quantity of product	t/month
x_2	Molten glass volume from glass melting furnace	t/month
x_3	Glass melting furnace age ratio (Specification age (month)/Actual age (month))	-
x_4	Working hour	h/mouth

The selection of independent variables should also consider the reasoning and collinearity between the dependent variables and the independent variables. Then an analysis of the relationship of variables is determined using the curve fitting technique, and the correlations between variables are verified according to the principles of Chuvenet's criterion. The Pearson's correlation coefficient is also taken into account. Figure 2 shows the relationship of the variables with energy consumption. There are two variables: the average quantity of the product and molten glass volume, linearly correlated with energy consumption with an R-square value greater than 0.9. However, the glass melting furnace age ratio and working hours may not have seen a trend concerning energy consumption as expected.

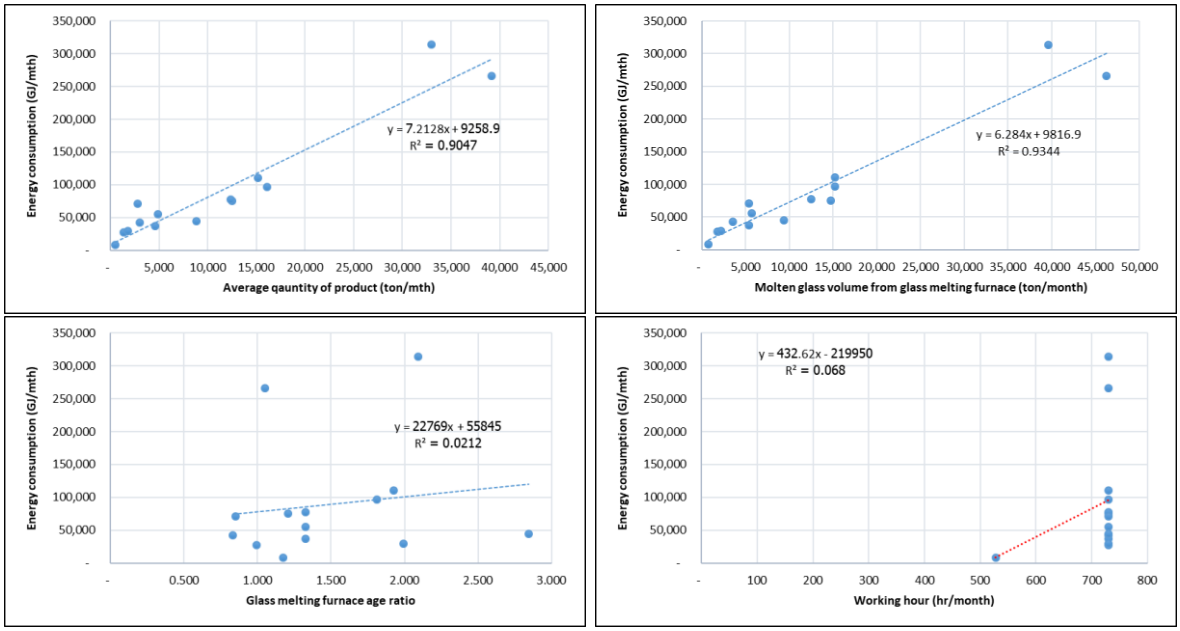

Figure 2: The relation of variables with energy consumption

Regression analysis is performed using statistical software to determine the relationship of variables in BEC and SEC that be either linear or nonlinear. The relations are chosen as simple as possible because they will be used by non-technical staff.

3. BEC and SEC correlation equations

There are three equations of the BEC relationship model consisting of electricity, thermal, and total energy. The electrical indicators show the efficiency of the entire plant's electricity consumption, and thermal indicators show the efficiency of thermal energy consumption. Finally, the total energy indicator shows the total energy efficiency of the whole plant. The second-order polynomial term obtains the best correlation for BEC of container and tableware glass manufacture industry as shown in Eq(1)

$$BEC = a_1(x_1) + a_2(x_2) + a_3(x_3) + a_4(x_1)(x_2)(x_3) + a_5(x_1^2) + a_6(x_2^2) + a_7(x_3^2) + a_8 \quad (1)$$

Where a is constants, as shown in Table 2.

Table 2. Constants for BEC equation.

Constants	Electric	Thermal	Total
a_1	-2.149	-17.206	-19.355
a_2	2.475	18.121	20.596
a_3	7,925.387	-2,221.222	5,704.190
a_4	7.564×10^{-5}	7.937×10^{-6}	8.358×10^{-5}
a_5	-6.008×10^{-5}	0.001	0.001
a_6	-2.059×10^{-5}	-0.001	-0.001
a_7	-3,657.015	-511.160	-4,168.180
a_8	-1,754.560	18,865.889	17,111.303
R^2	0.997	0.988	0.991

Similarly, the best correlations for SEC are in second-order polynomial terms, as shown in Eq(2)

$$SEC = b_1(x_1) + b_2(x_2) + b_3(x_3) + b_4(x_1)(x_2)(x_3) + b_5(x_1^2) + b_6(x_2^2) + b_7(x_3^2) + b_8 \quad (2)$$

Where b is constants, as shown in Table 3.

Table 3. Constants for SEC equation.

Constants	Electric	Thermal	Total
b_1	-1.336	-8.025	-9.361
b_2	1.146	5.711	6.856
b_3	-1,741.442	-2,812.881	-4,554.318
b_4	3.159×10^{-6}	7.824×10^{-6}	1.098×10^{-5}
b_5	3.861×10^{-5}	0.000	0.000
b_6	-3.105×10^{-5}	0.000	0.000
b_7	356.079	497.218	853.296
b_8	2,965.356	18,712.545	21,677.893
R^2	0.788	0.931	0.928

This research analyzed only 14 of 15 participating factories. The other factory that produced handmade glass containers has an entirely different energy usage pattern from the other plants. The data from this factory excluded from the analysis. The analysis used average monthly data in 2016-2017. The comparison between predicted and actual BEC of electric, thermal and total energy shows that most of them are in the range of ±10 %, as shown in Figure 3 (a-c). The prediction of SEC also gives a similar result as BEC, as shown in Figure 3 (d-f).

BEC can be further used to calculate the energy usage index (EUI) to compare the actual energy consumption (AEC) with the base year. The EUI is defined in Eq(3). If the EUI greater than 0, the energy consumption in the evaluation period has higher energy consumption than the base year or existing energy usage has less efficient. Thus, causes should be identified and solved. In contrast, if the EUI is negative, energy consumption is lower than the base year. The existing energy usage has more efficient.

$$EUI = \frac{AEC - BEC}{BEC} \quad (3)$$

Where AEC is the actual energy consumption from the meter, bill, or measurement.

Similarly, SEC can be used as benchmarks to compare the current energy consumption with the base year or among factories in the same industry. In addition, the factories can use it as a reference to reduce their energy consumption.

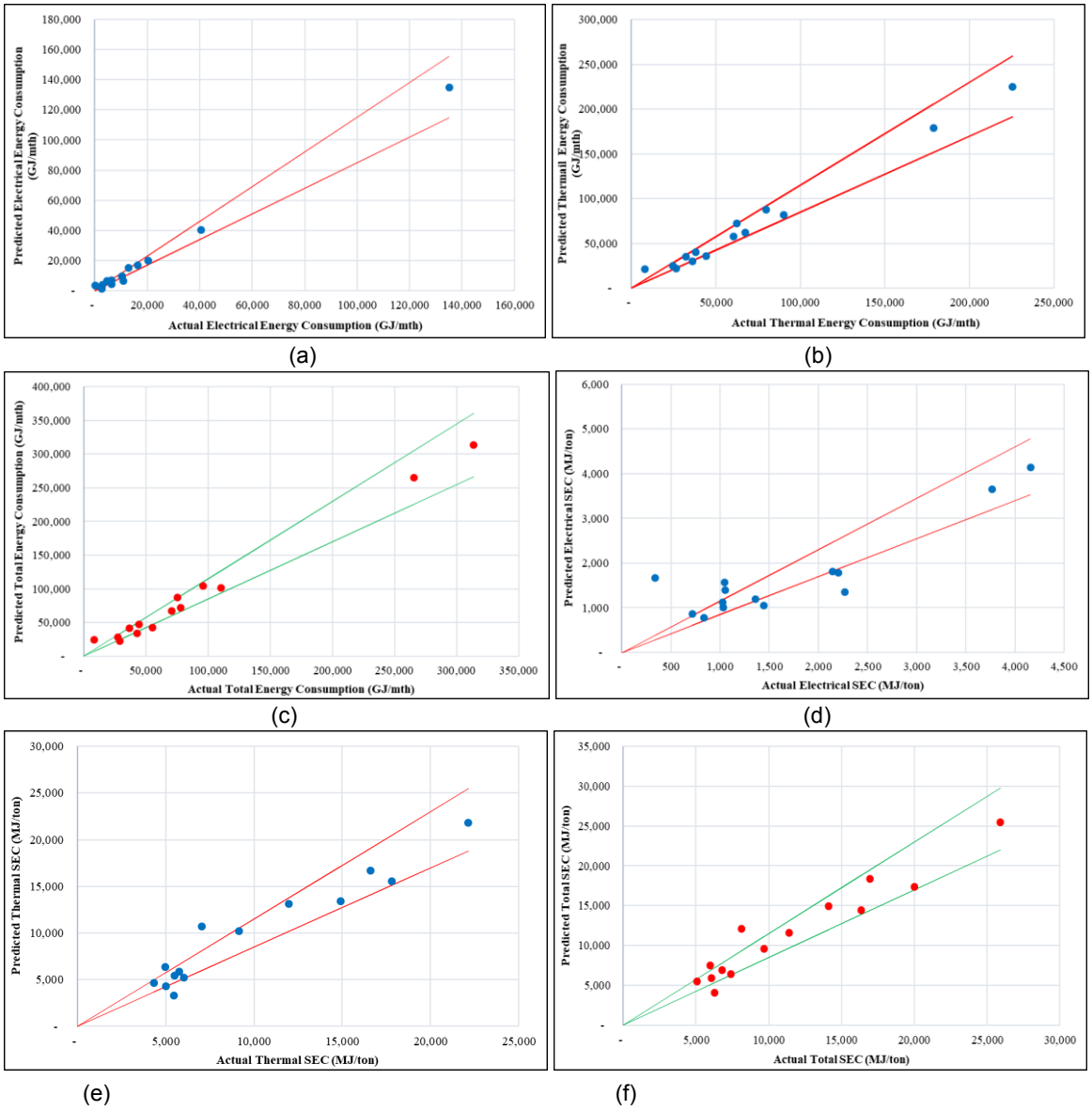

Figure 3: Comparisons of predicted and actual BEC and SEC equation.

4. Conclusions

The nonmetallic industry has the highest energy usage in the industrial sector. The manufacturing of container glass and tableware glass has the second highest energy consumption after cementing. Therefore, it is one of the target groups of the EEP2015 plan to implement penalty charge measures for reducing energy consumption. The penalty charge might be based on ENPI established as a standard of the industrial sector. BEC and SEC are one ENPI based on plant performance to define the industry energy standards. This paper presents the development of BEC and SEC regression equations to determine the relationship between relevant variables affecting energy consumption. The developed regression equations will predict BEC and SEC baseline that can be used to compare with current years. The research analyzed data from 14 of 15 participating factories. The main product types of this sector can be classified into four groups: glass bottles, glassware, handmade glass, and industrial marble balls. Approximately 84% of the energy used in this sector is thermal energy. The results of BEC and SEC regression equations shown that total product quantity, the volume of the molten glass, and glass melting furnace age ratio are affected by energy consumption.

Entrepreneurs can use either BEC or SEC to compare their energy consumption between before and after their implementation of energy conservation measures whether or not the measures are efficient. Although previous research used a similar approach to derive the relationship between BEC and the SEC, this study focused on total plant efficiency rather than equipment, systems, or product performance. The approach is more realistic

and be able to implement efficiently and conveniently by those involved. However, the amount of energy consumption tends to change over times. BEC and SEC baseline should also be adjusted accordingly.

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