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Article

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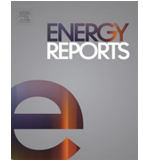
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Specific energy consumption of native starch industry in Thailand

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Abstract

According to the Thai Energy Efficiency Plan (EEP 2015), the government has set the target of 30% reduction in 2036 compared to the total energy consumption in 2010. The industry sector accounts for approximately 37% of the total energy consumption. Thai industries have been classified into 11 main sectors, in which food, beverage, and tobacco are the most energy-consumed sectors which consume about 35.7% of the total energy consumption. Among industries in the food, beverage, and tobacco sector, the native starch industry is the second most energy-consumed industry. Thus, the rational amount of energy saving target will be assigned to the native starch industry. Their baseline energy consumption and their potential energy saving should be known to verify the actual amount of energy savings each year. In this paper, 18 of 67 native starch plants are carefully investigated and audited to determine baseline energy consumption (BEC) and specific energy consumption (SEC) based on plant performance. Factors that effect on BEC and SEC are identified. Equations for predicting baseline BEC and SEC are developed using statistic regression approaches. It is found that SEC and BEC of the native starch industry depend on annual production quantity and annual production hours. The regression equations for predicting baseline BEC and SEC are developed and are in $\pm 10\%$ error range of observed data.

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Keywords: Native starch; Cassava; Energy performance index; Specific energy consumption; Baseline energy consumption

1. Introduction

Thai Integrated Energy Blueprint (TIEB) composes of 5 energy master plans including (1) Thailand Power development Plan: PDP, (2) Energy Efficiency Development Plan: EEDP, (3) Alternative Energy Development Plan: AEDP, (4) Natural Gas Supply Plan, and (5) Petroleum Management Plan. Energy Efficiency Plan (EEP 2015) is a part of EEDP. The goal is to reduce energy intensity by 30% in 2036, compared to 2010, or equal to 56,142 ktoe of final energy consumption. Government agencies will issue energy conservation measures to enforce, promote and support the industries to achieve the target. Currently, 5285 high energy intensive factories consume approximately 21,430 ktoe of final energy consumption and expectedly increase to 11,300 factories with 41,600 ktoe in 2036 [1].

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This goal is then rationally distributed to designated industrial sectors. The high energy intensive factories will be enforced to meet stringent energy standards. The penalty will be charged to those who do not achieve the target. The native starch industry is one of the designated industries.

There must be an indicator to verify actual savings, not caused by reduced production volume or fewer working days. This indicator should be able to respond to changes in production conditions that affect the amount of energy consumption, such as production quantity, number of the working day. This indicator of the designated industries will be annually evaluated and then compare with one of a baseline period to determine the actual savings. One of EEP 2015 missions is to develop a baseline energy performance indicator for each industry sector.

Baseline Energy Consumption (BEC) and Specific Energy Consumption (SEC) are commonly used as energy performance indicators. However, the existing BEC or SEC for an industry sector is usually represented as an average or constant value, which is not fair to use as a baseline for industries with different production capacities and technologies. The relationship between the BEC or SEC and corresponding factors should be developed to obtain a rational value with the actual production conditions and technologies instead of using a constant or average value. This paper aims to develop such energy performance indicators for the native starch industry sector using 2018–2019 as base-year data. The approach purposed by Assawamartbunlue et al. [2] and Assawamartbunlue et al. [3] is adapted to determine BEC and SEC correlations.

2. Industrial background and basic concepts

Based on Thailand Energy Situation Jan.-Nov.2018, which is conducted by the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy has reported the energy consumption in the industry sector for approximately 36% of the total final commercial energy consumption. Thailand industries have been classified into 11 main sectors, food, and beverages, textiles, wood, and furniture, paper, chemical, non-metallic, basic metal, fabricated metal, stone and mining, power plant and others (unclassified). The food, beverage, and tobacco sector is the most energy-consumed sector, approximately 35.7% of industry sector consumption. The native starch industry is the second most energy-consumed industry subsector that consumes almost 6.2% of such sector or $13,201.7 \times 10^6$ MJ/y.

2.1. Production and energy consumption of native starch plants

Native starch is a carbohydrate ingredient with fine white powder with neutral odor and taste, generally used for texturizing in the feed industry. It is obtained from cereals and tubers by physical extraction, purification, and drying of starch milk. Products of a native cassava starch plant under investigation include native starch (standard and extra dry) and modified starch. The native starch plant demands a huge amount of energy for production, especially heat. Heat is a primary energy source that is mostly used for the drying process. Other processes are normally used electric energy such as desanding, washing, rasping, extraction, separation. Currently, there are 67 plants in Thailand, according to the report of the DEDE. Based on the observed data. The proportion of energy is divided into two parts: electricity 12.8% and thermal energy 78.2%. In this paper, 18 of 67 plants are carefully investigated and audited to determine BEC and SEC based on plant performance [4]. Their productions and total energy consumptions are between 20,000 to 210,000 ton/y and 15,000 to 310,000 GJ/y respectively.

Fig. 1 shows starch production processes based on site survey. Cassava roots are first desanded using sieve plate and then washing. After that, they are rasped, cut, and grinded into a pulp before adding water. The separator is used to extract the lignocellulosic fibers from the free starch, so-called starch slurry. The hydrocyclones are used to remove contaminants from the starch slurry. The starch slurry is then dewatering to become wet starch. The wet starch is heated using hot air at 180–200 °C to remove remaining water to become dry starch. Three types of heater are normally used; hot oil heater, steam heater, and hot combustion air. The hot dry starch is next cooled down and refined before packaging to customers.

International Starch Institute reported energy consumption of a typical Danish starch factory that processes 300,000 ton of cassava a year or equivalent to 60,000 ton of native starch [5]. The factory consumed approximately 1.5 million cubic meter of natural gas and 10 million kWh of electricity. Thus, the specific energy consumptions were roughly 1500.52 MJ/ton, based on 3.6 MJ/kWh and 36.02 MJ/m³ of gas.

Tran et al. [6] compared the energy use of cassava starch production in Thailand, Vietnam and Colombia. One large-scale factory and two small-scale factories were investigated. They found that a large-scale factory consumed

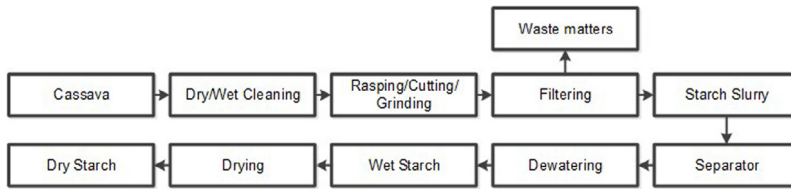


Fig. 1. Cassava starch production processes.

approximately 2527 MJ/ton both thermal and electrical energy. A small-scale factory consumed 212 MJ/ton for electrical energy. The drying processes in the small-scale factory mostly relied on solar energy, which was estimated to 1361 MJ/ton.

3. Research approach

BEC is the amount of energy that is consumed during the baseline period. SEC is the ratio between the amount of energy and production quantity during the baseline period, which indicates the amount of energy required to produce one unit of product. In addition, the evaluation boundary is also important. In this case, both BEC and SEC are based on plant performance. They will be developed in the form of correlation equations with influenced factors instead of using an average or constant value. There are steps to be taken as follows:

- Define baseline referring to the system, time period, or conditions that provide a reference to which later performance of BEC and SEC can be compared. In this study, the year of 2018–2019 was chosen as a baseline period. Based on the participating factories, there is only one product from the plants which is native starch.
- Identify static factors which are those characteristics affecting energy consumption. They are not expected to change and are therefore not included as independent variables, for example, operating set points of machines. If they change, adjustments need to be performed to account for these changes. However, the methodology of these non-routine adjustments is not in the scope of this paper.
- Analyze factory and measured data in the baseline period using the concept of mass and energy balance to indicate potential independent variables that affect BEC and SEC. The independent variables should be ones that are regularly collected and are expected to change routinely and have a measurable impact on BEC and SEC.
- Determine independent and dependent variables. In this case, the SEC and BEC are dependent variables. Potential independent variables are first identified, and correlation analysis is then used to examine the correlation among variables by which independent variables are truly independent and not collinearity or multi-collinearity among them. Selected independent variables are shown in Table 1.
- Determine the relationship between independent and dependent variables that could be either linear or nonlinear. Curve fitting technique is adopted in regression analysis to specify the model that provides the best fit between variables. In this study, the polynomial terms are proposed in the model.
- Use a commercial statistical software to determine the parameters in proposed BEC and SEC models. The polynomial terms in the model are selected based on adjusted R-squared, predicted R-squared, and P-values.

Table 1. Independent variables.

Variable	Description	Unit
x_1	Annual quantity of production	ton/y
x_2	Annual operating hours	h/y

4. BEC and SEC correlations

Second-order polynomial terms of selected independent variables are proposed in regression models to enhance the accuracy of the models. Each BEC and SEC includes three regression equations for thermal, electrical, and total energy. The best correlations for BEC of native starch are in the form of

$$BEC = C_1x_1^2x_2^2 + C_2x_1^2x_2 + C_3x_1x_2^2 + C_4x_1^2 + C_5x_2^2 + C_6x_1x_2 + C_7x_1 + C_8x_2 + C_9 \tag{1}$$

Table 2. Constants for BEC and SEC equation.

Constants	BEC Eq. (1)			SEC Eq. (2)		
	Thermal	Electric	Total	Thermal	Electric	Total
C_1	-42.255×10^{-9}	-5.563×10^{-9}	-42.403×10^{-9}	-886.540×10^{-15}	-10.927×10^{-15}	-836.805×10^{-15}
C_2	515.293×10^{-6}	57.798×10^{-6}	512.000×10^{-6}	10.966×10^{-9}	-7.149×10^{-12}	10.275×10^{-9}
C_3	3.160×10^{-3}	564.105×10^{-6}	3.086×10^{-3}	62.544×10^{-9}	601.225×10^{-12}	56.003×10^{-9}
C_4	-1.551	-0.140	-1.521	-33.470×10^{-6}	528.863×10^{-9}	-31.042×10^{-6}
C_5	-31.791	-8.413	-24.195	-476.757×10^{-6}	98.717×10^{-6}	-198.713×10^{-6}
C_6	-39.783	-5.543	-38.547	-812.419×10^{-6}	9.459×10^{-6}	-727.023×10^{-6}
C_7	123,840.346	12,782.655	119,036.814	2.571	-0.091	2.283
C_8	480,707.402	80,633.299	396,790.013	8.532	-1.316	5.373
C_9	-1.672×10^9	-158.817×10^6	-1.421×10^9	-31,202.366	5389.420	-21,221.738
R^2	0.949	0.982	0.979	0.755	0.889	0.727

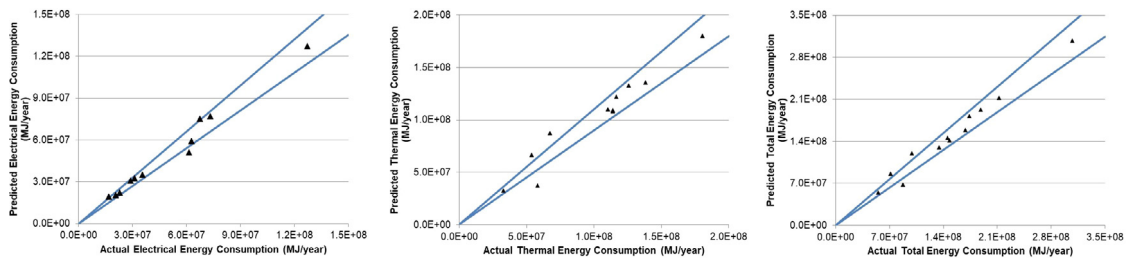
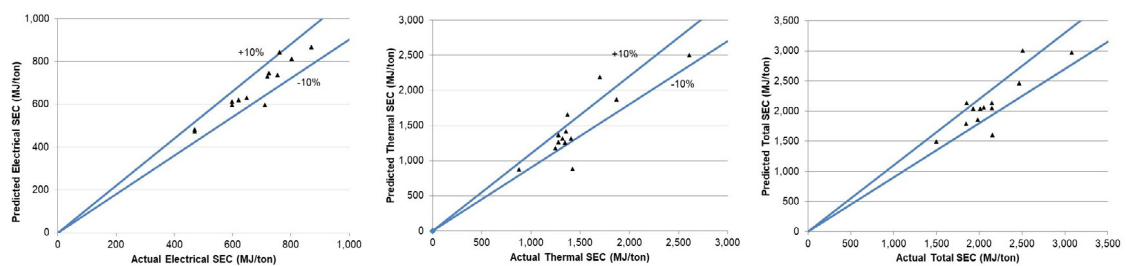
where C is constant, as shown in Table 2.

Similarly, the best correlations for SEC are in the form of

$$SEC = C_1x_1^2x_2^2 + C_2x_1^2x_2 + C_3x_1x_2^2 + C_4x_1^2 + C_5x_2^2 + C_6x_1x_2 + C_7x_1 + C_8x_2 + C_9 \quad (2)$$

where C is constant as shown in Table 2.

The comparisons between actual and predicted values are shown in Figs. 2 and 3. They are mostly within a range of $\pm 10\%$. Electrical BEC and SEC is well predicted compared to thermal and total BEC and SEC. This is because of the difficulty in accurately measuring the amount of fuel used, especially solid fuels. The properties of solid fuels are also uncertain. Thus, the total heat inputs are not accurate.

**Fig. 2.** Comparisons of actual and predicted BEC Eq. (1).**Fig. 3.** Comparisons of actual and predicted SEC Eq. (2).

5. Conclusions

The native starch industry is the second most energy-consuming industry subsector that consumes almost 6.2% of the food, beverage, and tobacco industrial sector. The native starch industry is one of the target subsectors to enforce the stringent energy standards to achieve the EEP 2015 target. The penalty will be charged to those who do not achieve the target. To be able to implement this measure, a rational indicator and its benchmark must be developed.

As it is obviously shown on the observed data of the participating factories, neither BEC nor SEC is constant. They vary more than two to three times of the average values. So that using a constant or average value as the benchmark to evaluate the achievement of factories does not reasonable, and not fair for designated factories. In this study, six regression models for calculating baseline BEC and SEC are developed to use as the energy benchmark for native starch plants in Thailand. The proposed correlations depend on two variables, including the annual quantity of a product and annual operating hours. Data for analysis and regression are gathered and measured from 18 of 67 plants in 2018–2019. The correlations can predict the BEC and SEC within acceptable tolerances or in the range of $\pm 10\%$ compared to the actual data.

For each year, production quantities and operating hours of a designated factory are gathered and substituted into the correlations to evaluate baseline BEC or SEC. This baseline represents the energy consumption or specific energy consumption if no energy conservation measures were implemented. They will be then compared with the actual one of the same year to determine whether the energy usage is more effective or not. Even though few studies were using the same approach to obtain the BEC/SEC correlations, this study focuses on the whole plant performance instead of equipment, systems or product performance. Hence, they can be easily implemented and convenient for those involved.

Acknowledgments

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