Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 156 (2019) 212–216

Energy Procedia

www.elsevier.com/locate/procedia

2018 5th International Conference on Power and Energy Systems Engineering, CPESE 2018, 19–21 September 2018, Nagoya, Japan

Specific energy consumption of cement in Thailand

Kriengkrai Assawamartbunlue[a,*], Prakob Surawattanawan[a], Wanwiwa Luknongbu[a]

[a]*Energy Technology Research Laboratory, Mechanical Engineering Department, Kasetsart University, Bangkok, Thailand*

Abstract

According to the 2015 Thai Energy Conservation Plan, the government aims to reduce energy consumption by 37% in 2036 compared to the final energy consumption in 2010. The industry sector consumes about 35.7% of total energy consumption. Non-metallic sector accounts for 30.74% of the energy consumption of the industry sector. The cement industry is one of the non-metallic sector that consumes up to 60.69% of the energy consumption of the non-metallic sector. Specific energy consumption (SEC) and Baseline energy consumption (BEC) are used as a tool to assign energy conservation target for each industry sector. This paper presents BEC and SEC for cement production. There are 12 of 21 participating cement plants that provide relevant information to be used for BEC and SEC analysis. According to the analysis, the BEC and SEC of cement production does not depend only on the quantity produced, but also ambient temperature and humidity. Therefore, setting a typical BEC and/or SEC target for reducing energy consumption is not appropriate and unfair to the factory. The BEC and SEC equations are developed using statistical approaches. The cement productions are classified into 2 categories; clinker and cement. Regression equations are developed to determine the relationship between BEC/SEC and relevant variables, including BEC/SEC for electrical energy, thermal energy and total energy.

Keywords: cement; clinker; energy performance index; specific energy consumption; baseline energy consumption

* Corresponding author. Tel.: +66-2-797-0999 ext.1866; fax: +66-2-561-4622.
E-mail address: fengkka@ku.ac.th

10.1016/j.egypro.2018.11.130

1. Introduction

Energy Efficiency Plan (EEP 2015) [1] is the energy master plan of Thai government. In 2036, the government sets the target of 30% reduction in energy intensity compared to 2010, or equal to 56,142 ktoe of final energy consumption. To achieve the EEP 2015 target, energy performance index for each industry sector is studied, i.e., Baseline Energy Consumption (BEC) and Specific Energy Consumption Index (SEC), to support the promotion and regulation of energy efficiency activities. Currently, 5,285 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]. The high energy intensive factories will be enforced to meet the stringent energy standards based on either BEC or SEC. The penalty will be charged to those who do not meet the standard.

The existing BEC and/or SEC for an industry sector is usually represented as a typical value which is unfair for industries with different production capacities and technologies. The relationship between the BEC and/or SEC and relevant factors should be developed to obtain a rational value with the actual production conditions and technologies instead of using a constant or average value. Thus, this paper presents BEC and SEC correlations for the cement industries based on statistic regression approaches.

1.1. Industrial background

Cement is a type of ceramic product that is currently research and development to be good quality and suitable for more use. Cement production process is shown in Fig. 1. The process consists of two main adjoining processes which are clinker production process and cement production process. Raw materials are first converted to clinkers, and then the clinkers are used to produce cement. The clinker process consumes 95% thermal energy and 5% electrical energy, meanwhile the cement process consumes 100% electrical energy. Most of the energy used is thermal energy which is used in kiln and precalciner. Major fuels include oil, coal and natural gas.

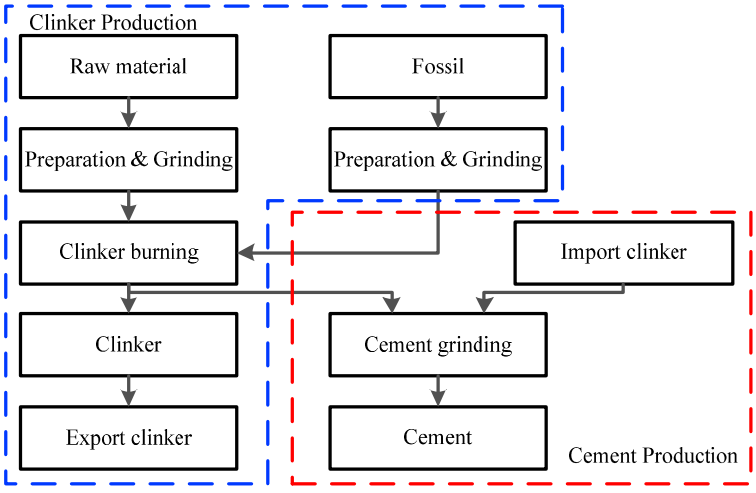

Fig. 1. Clinker and cement production process

1.2. Energy efficiency of cement production

ICF [2] studied energy efficiency and energy conservation in industries of 28 countries in the European Union (EU). The industries were divided into eight industrial sectors which consumed up to 98% of total final energy consumption in all industries in the EU. Energy efficiency as specific energy consumption (SEC) was one of the goals of the study. The SEC of the cement production was based on technologies, i.e., wet kiln is the highest SEC of 5.8-6.7 GJ/$t_{clinker}$ while dry kiln with six stages preheater and precalciner is the lowest SEC of 2.8-3.4 GJ/$t_{clinker}$.

Dodier [3] studied energy efficiency trends and energy policy in the industry. The program was supported by the Intelligence Energy Europe Program, with 32 members from 27 countries, including the government budget of each country. Energy consumption data and energy efficiency metrics were provided by the ODYSSEE and Enerdata databases. Energy policy data was from the MURE database. Energy efficiency was presented in terms of energy consumption. The SEC of cement production was between 2.93-4.18 GJ/t_{cement} depending on the ratio of clinker to cement production.

Rane [4] conducted a study on the energy use and energy conservation potential of 10 cement plants in India. The energy efficiency of the cement industry was presented in terms of specific energy consumption (SEC) with between 2.10-3.00 GJ/t_{cement}. Jayaraman [5] collected and disseminated six energy conservation measures for 12 cement plants in India. He reported the best SEC of 2.85 GJ/$t_{clinker}$ and 2.40 GJ/t_{cement}.

Kawase [6] studied the cement production process of the Japan Cement Factory and analyzed the energy and raw materials used in the production process. In the production of 1 ton of cement, 2.72 GJ of coal and 99 kWh of electricity was used. The SEC of total energy consumption was equal to 3.08 GJ/t_{cement}. Worrell [7] compiled data to compare the SEC of cement production. The SEC of 7.70 GJ/t_{cement} in 1970 was dropped to 4.75 GJ/t_{cement} in 2010.

2. Research approaches

Baseline Energy Consumption (BEC) is the amount of energy that should be consumed over the same period or same production volume. While, Specific Energy Consumption (SEC) is the ratio between the amount of energy and production quantity, 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.

Energy consumption of cement production is divided by two main products, i.e., clinker and cement. The energy consumption for clinker accounts from raw materials to clinker, including both thermal and electrical energy. Meanwhile the energy consumption for cement accounts from clinker to cement, including only electrical energy. There are steps to be taken as follows:

- Factory and measurement data are analyzed using concept of mass and energy balance to indicate potential independent variables that effects on BEC and SEC. Variables should be ones that are collected on a regular basis.
- Determine independent and dependent variables. In this case, SEC and BEC are dependent variables. Potential independent variables are first identified and then correlation analysis are 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.
- Using a static tool to determine appropriate BEC and SEC regression equations.

Table 1. Independent variables.

Variables	Description	unit
x_1	the quantity of production	t/month
x_2	yearly-averaged ambient temperature	C
x_3	yearly-averaged ambient humidity	%

3. BEC and SEC correlations

There are totally eight equations for BEC and SEC of clinker and cement products. There are three equations for clinker, including thermal, electrical and total energy. There is only one equation for cement, i.e., electrical or total energy, because there is no thermal energy for cement production process. The correlation for BEC of both clinker and cement are in the form of

$$BEC = C_0 + C_1x_1 + C_2x_2 + C_3x_3 \quad (1)$$

where C_0, C_1, C_2, and C_3 are constant as shown in Table 2.

Table 2. Constants for BEC equation (1).

Products	Clinker			Cement
Energy	Thermal	Electrical	Total	Electrical (Total)
C_0	-15,657,984,597.65	-66,728,343.99	-15,724,691,169.33	-197,439,634.69
C_1	3,796.56	202.007	3,998.57	203.065
C_2	53,858,644.81	-4,976,388.24	48,881,646.22	-7,312,033.96
C_3	191,455,876.41	3,038,656.17	194,494,473.07	5,776,071.26
R^2	0.989	0.996	0.990	0.997

The correlation for SEC of both clinker and cement are also in the form of

$$SEC = C_0 + C_1x_1 + C_2x_2 + C_3x_3 + C_4x_2^2 + C_5x_3^2 \quad (2)$$

where C_0, C_1, C_2, and C_3 are constant as shown in Table 3.

Table 3. Constants for SEC equation (1).

Products	Clinker			Cement
Energy	Thermal	Electrical	Total	Electrical (Total)
C_0	-992,928.962	126,207.428	2,735,338.591	-1,036,161.480
C_1	-0.00022717	-0.00002037	-0.00024754	-0.000002049
C_2	6,904.708	-6,460.641	-180,199.928	50,406.251
C_3	24,296.568	-967.165	-5,797.865	8,970.611
C_4	-114.236	114.671	3,204.215	-893.765
C_5	-164.986	6.668	41.989	-61.595
R^2	0.848	0.920	0.861	0.604

The comparisons between actual and predicted values are shown in Fig. 2 and Fig. 3. They are mostly within the range of ±10 %.

4. Conclusions

The cement industry is the most energy-consumed industry subsector which consumes almost 60.69% of non-metallic sector. The cement industry is one of target subsectors to promote and regulate energy efficiency measures to achieve the EEP 2015 target. Energy consumed are divided into two portions by products, i.e., one to produce clinker and the other to produce cement. Most of the energy are used to produce clinker by which both thermal and electrical energy are needed. For cement, only electrical energy are required.

Regression equations to determine BEC and SEC are developed for clinker and cement products in Thailand. They can be further used as benchmarks for energy consumption in this sector. Data for analysis and regression are gathered and measured from 12 of 25 cement plants. BEC and SEC equations are developed based on products, i.e., clinker and cement. The results show that the equation can predict the value within acceptable tolerances. BEC and SEC depend on three variables, i.e., quantity of product, yearly-averaged ambient temperature and yearly-averaged ambient humidity. For each particular year, data for each variable are gathered and substituted into the equations to calculate BEC and SEC that will be further used as benchmarking. They will be compared with the actual BEC and SEC of the same year to determine whether the energy usage is effective or not.

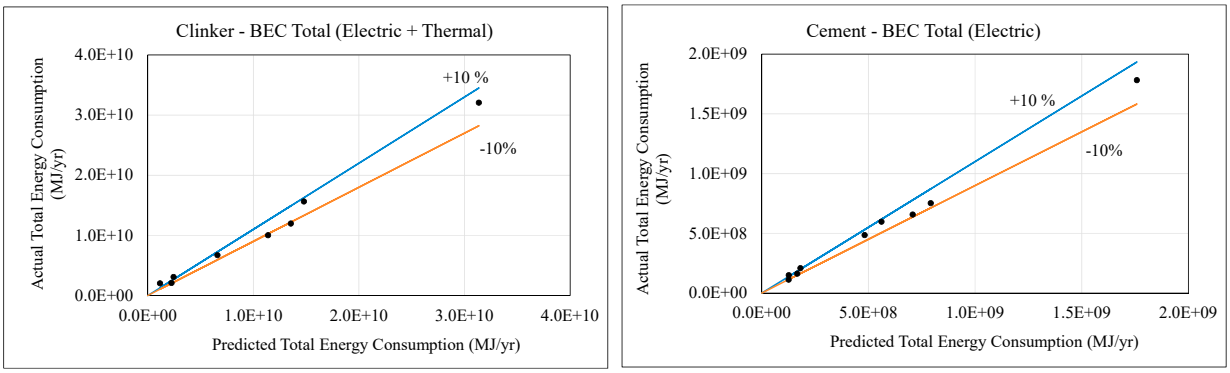

Fig. 2. Comparisons of actual and predicted BEC for clinker and cement products using equation (1).

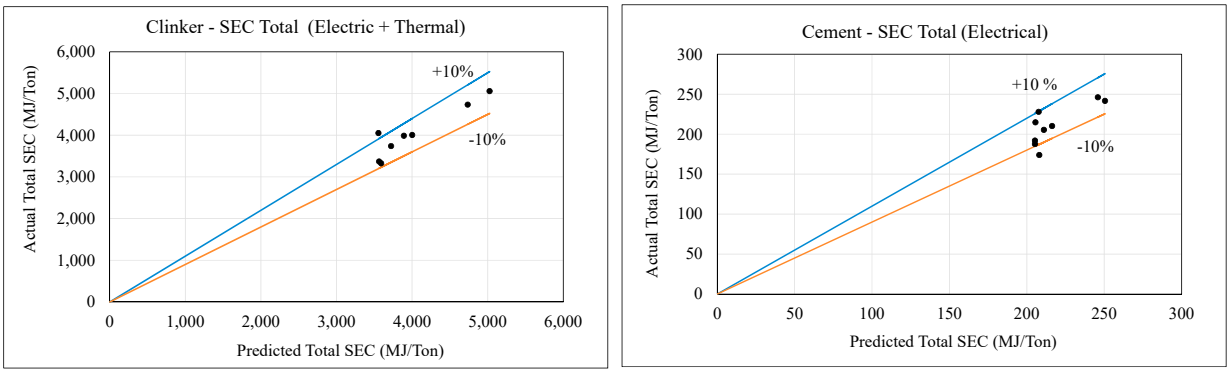

Fig. 3. Comparisons of actual and predicted SEC for clinker and cement products using equation (2).

Acknowledgements

Special thanks to the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, Thailand for financial supports and data related to this research.

References

[1] Energy Policy and Planning Office. *Energy efficiency plan (2015)*, Available at: www.eppo.go.th/index.php/en/policy-and-plan/en-tieb/tieb-eep; March 2017.
[2] Yeen Chan, and Ravi Kantamaneni. *Study on energy efficiency and energy saving potential in industry and on possible policy mechanism*, (2015) ICF Consulting Limited.
[3] Dodier Bosseboeuf. *Energy efficiency trends and policies in industry*, (2015).
[4] Rane, M. "Analysis of energy saving opportunities in cement sector." *Journal of Computer Engineering*, (2015): 7-13.
[5] Jayaraman, G. Case study booklet on energy efficiency technologies in cement industry. *Confederation of Indian Industry*, (2015).
[6] Kawase, T. *Cement Process & Energy Saving*, The Energy Conservation Center, (2006).
[7] Worrell, E., et.al. Energy Improvement and Cost Saving Opportunities for Cement Making. *An ENERGY STAR Guide for Plant Manager*, Berkeley National Laboratory, (2013).