

Optimization of milling performance of a sugar mill

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Abstract. Thailand is the sugar cane exporters in the world market. It is important for sugar factory to operate efficiently in milling against its competition. This study was conducted to find the optimization of milling performance of a sugar mill based on extraction (EXT), power requirements (POW), specific energy consumption (SEC), and specific extraction per energy consumption (SEE) that is important parameters for sugar factory. Testing was performed using a small milling machine. The compressed pressure and speed were adjusted from 2.7 to 10.0 x 10⁶ N/m² and 0.0844 m/s to 0.1631 m/s, respectively. After the test, the polarization meter was used to measure sugar in juice. The results showed that the maximum extraction (%) is earned at the intermediate compressed pressure and the lowest speed. The minimum power requirement (W) is earned at the lowest compressed pressure and the lowest speed. The minimum specific energy consumption (kWh/t) is earned at the lowest compressed pressure and the intermediate speed. The maximum specific extraction per energy consumption (%.t/kWh) is earned at the intermediate compressed pressure and the lowest speed. The method and results of this study can benefit for sugar factory to find performance and to make the decision on process operation.

1 Introduction

Sugar trade averages 56 million tons/year in the world with Brazil, Thailand and Australia accounting for 65% of the trade in 2014. The world's largest sugar producer and exporter is Brazil, accounting for 24.01 million tons. Thailand, the second largest, accounts for 7.97 million tons [1]. There are several processes in the sugar cane production such as sugar cane growing, sugar cane milling, credit banking, exportation, etc. [2] The sugar production comprises juice extraction, preheating, evaporation, crystallization, centrifugal and drying. The sugar refinery process is part of sugar cane crushing mills. Furthermore, raw sugar and refined sugar is produced by using sugar cane bagasse from milling as an energy source [3]. Currently, there are 55 sugar mills in Thailand with sugar cane crushing capacity about 93 million tons per year [4].

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A small scale sugar cane juice mill was developed for farmers who were involved in the processing of sugar, ethanol and other related products. The extraction efficiency ranged between 40 and 61% at operating speeds of 0.25 and 0.36 m/s and the output capacities were 10.50, 12.00 and 14.25 kg/h at operating speeds of 0.25, 0.3 and 0.36 m/s respectively [5]. Sugar cane milling is one step in sugar production. There are several machines in the sugar production such as sugar cane unloading, sugar cane knives, shredders, sugar cane milling, bagasse conveyor and so on [6]. Normally, there are two ways for juice extraction: 1) extraction by the mills and 2) extraction by the diffusers. The sugar cane milling was simulated by finite element algorithm. Energy dispersing during milling of sugar cane could be presented in terms of four components; juice flow, bulk plasticity, seepage induced plasticity and frictional sliding. In this simulation, constant crushing rate showed that higher roll speeds and thinner blankets reduced power requirements, frictional sliding, roll torque, roll load and increased extraction of juice slightly [7]. The variable speed of the drives and different speeds of the rolls presented almost constant torques on each roll. The results of the tandem mill as extraction, capacity and power consumption were very good [8]. The current sugar extraction process compared the sugar extraction efficiency and energy consumption with a similar process in a modern fuel alcohol distillery. Distilleries could use more soak water to increase juice extraction during crushing because the fermentation broth must be diluted. An analysis of the substitution process showed that if the steam consumption of evaporator did not rise significantly, the net revenue increased significantly [9]. There was a feed opening which resulted in the maximum throughput at the same speed for a particular mill configuration. However, the feed opening affected mill torque and the forces acting on the mill housing. The maximum throughput could be limited due to insufficient roller roughness causing slippage [10].

This paper investigated the optimization of milling performance of a sugar mill based on Extraction (EXT), Power requirements (POW), Specific energy consumption (SEC) and Specific extraction per energy consumption (SEC). It is very important to have some technique available in order to manage the standard milling operation that Thailand sugar factory never have it. The key objectives were to analyze the effect of compressed pressure and tandem mill speed on 1) the extraction of sugar from sugar cane, 2) power requirements in the mill, 3) specific energy consumption in the mill, 4) specific extraction per energy consumption in the mill.

2 Materials and methods

2.1 Equipment used in the test

Testing was performed using a small milling machine (Figure 1) with two tandem mills [11] with a diameter of 21.5 mm and a length of 43 mm. A 5 kW electric motor (Brand: Teco) was used as a power source. The compressed pressure was adjustable by using the hydraulic pressure compare with change in length of spring. During the test, the inverter (Brand: Yaskawa) was used to change the speed and monitor current, voltage for power requirement, specific energy consumption and specific extraction per energy consumption calculation. After the test, the polarization meter was used to measure sugar in juice for extraction calculation. The test was performed entirely in the laboratory of the studied sugar factory.



Fig. 1. A small milling machine.

2.2 Test method

Testing of each factor involved three replications, each using a ‘Khon Kaen 3’ sugar cane. The change in length of spring was used to monitor the compressed pressure and the inverter display was used to monitor the speed. Data were collected from the input sugar cane, the discharge of juice, and bagasse outlet weight. The power requirement for crushing was measured using the inverter display. The parameters obtained were used to calculate the power requirement, specific energy consumption and specific extraction per energy consumption. Moreover, the polarization meter (Brand: Anton Paar, Model: MCP 500 Sucromat, Austria) was used to analyze the extraction. The study has a schematic diagram of milling process shown in Figure 2.

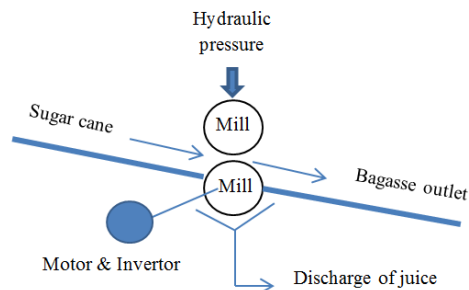


Fig. 2. A schematic diagram of milling process.

2.3 Indicator parameters

The indicating parameters in the test comprised of extraction, power requirements, specific energy consumption and specific extraction per energy consumption.

Extraction was calculated using Equation. (1)

$$EXT = B/(A+B) \times 100 \quad (1)$$

where EXT is the extraction from sugar cane milling in percent, A is the weight of sugar from bagasse in grams and B is the weight of sugar from the extracted juice in grams [12].

Power requirement was calculated using Equation (2)

$$POW = 1.732 \times VOLT \times I \times PF \quad (2)$$

where POW is the power requirement in watts, VOLT is the voltage, I is the current in ampere and PF is the power factor.

Specific energy consumption was determined using Equation (3)

$$SEC = POW/FR \quad (3)$$

where SEC is the specific energy consumption in kWh/t, POW is the power requirement in watts and FR is the feed rate of sugar cane in t/h.

Specific extraction per energy consumption was determined using Equation (4)

$$SEE = EXT/SEC \quad (4)$$

where SEE is the specific extraction per energy consumption in % .t/kWh, EXT is the extraction from sugar can milling in percent and SEC is the specific energy consumption in kWh/t.

2.4 Model development

The Backward elimination and stepwise regression is used for model development. All the independent variables (X1, X2, ...) are entered into the first equation and each one is deleted one at a time if they do not contribute to the regression equation.

3 Results and discussion

3.1 Effects of compressed pressure and tandem mill speed on milling performance

Data from Table 1 were used to create analysis of variance and regression equations between the compressed pressure and the tandem mill speed, which affected milling performance such as the EXT, POW, SEC and SEE.

Table 1. Effects of compressed pressure and tandem mill speed on the extraction, power requirements, specific energy consumption and specific extraction per energy consumption.

P (N/m ²)	V (m/s)	EXT (%)	POW (W)	SEC (kWh/t)	SEE (%.t/kWh)
2.7x106	0.0844	43.09±3.02	954±8.50	4.72±0.11	9.13±0.53
2.7x106	0.1238	32.44±2.70	1,362±6.93	4.60±0.09	7.05±0.47
2.7x106	0.1631	25.53±2.63	2,012±17.00	5.15±0.08	4.95±0.44
6.0x106	0.0844	57.41±2.42	1,093±5.20	5.45±0.02	10.53±0.40
6.0x106	0.1238	56.06±2.16	1,573±12.00	5.35±0.04	10.48±0.48
6.0x106	0.1631	53.72±1.80	2,187±40.73	5.64±0.10	9.52±0.31
10.0x106	0.0844	68.11±2.28	1,358±10.00	6.77±0.05	10.06±0.35
10.0x106	0.1238	63.02±0.55	1,895±13.5	6.44±0.05	9.78±0.16
10.0x106	0.1631	57.32±1.44	2,642±10.39	6.82±0.03	8.41±0.22

P = Compressed pressure, V = Tandem mill speed, Values shown as mean±SE.

3.2 Effects of compressed pressure and tandem mill speed on the extraction

The EXT model in Table 2, indicating the relationship between the compressed pressure and the tandem mill speed affecting the extraction, is shown in Figure 3 for clarifying in optimization. From the graph, when the compressed pressure increased, the extraction of the tandem mill had a tendency to increase from 2.7 to 6.0×10^6 N/m² and slightly increased from pressure 6.0 to 10.0×10^6 N/m². Effects of speed, when increased the speed of the tandem mill, the extraction of the tandem mill had a tendency to decrease.

Table 2. Equation from regression analysis of compressed pressure (P) and tandem mill speed (V) on the extraction (EXT), the power requirements (POW), the specific energy consumption (SEC), and the specific extraction per energy consumption (SEE).

Equation	Adj. R2	SE	P-value
$EXT = 21.56 + (1.25e^{-5})P - 135.71V - (7.72e^{-13})P^2$	0.950	3.183	0.000
$POW = -575.29 + (7.21e^{-5})P + 14552.10V$	0.977	84.24	0.000
$SEC = 6.40 + (2.56e^{-7})P - 43.62V + (187.70)V^2$	0.968	0.150	0.000
$SEE = 5.54 + (2.31e^{-6})P - 28.97V - (2.56e^{-13})P^2$	0.813	0.793	0.009

Adj. R² = Adjusted coefficient of determination.

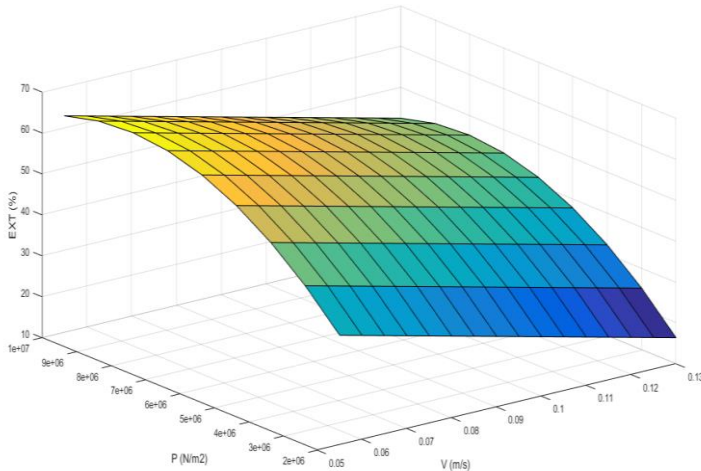


Fig. 3. Effects of compressed pressure and tandem mill speed on extraction (EXT).

3.3 Effects of compressed pressure and tandem mill speed on the power

The POW model in Table 2, indicating the relationship between the compressed pressure and the tandem mill speed affecting the power requirements, is shown in Figure 4 for clarifying in optimization. From the graph, when the compressed pressure increased, the power requirements of the tandem mill slightly increased from 2.7 to 10.0×10^6 N/m². Effects of speed, when increased the speed of the tandem mill from 0.0844 m/s to 0.1631 m/s, the power requirements tended to increase their tendency.

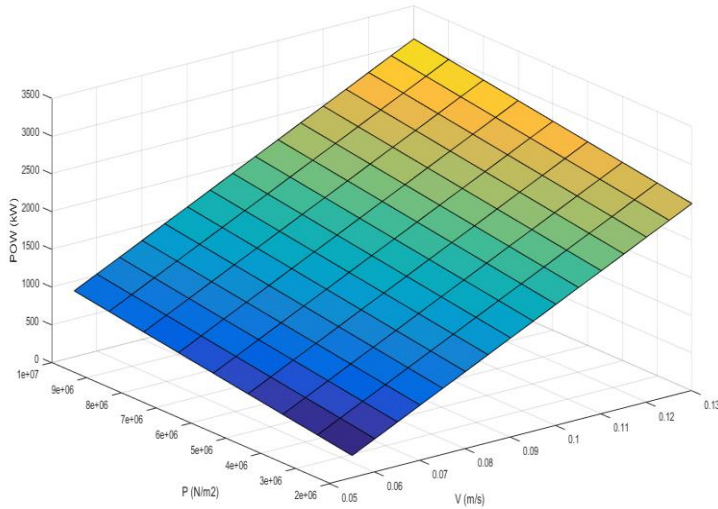


Fig. 4. Effects of compressed pressure and tandem mill speed on power requirements (POW).

3.4 Effects of compressed pressure and tandem mill speed on the specific energy consumption

The SEC model in Table 2, indicating the relationship between the compressed pressure and the tandem mill speed affecting the specific energy consumption, is shown in Figure 5 for clarifying in optimization. From the graph, when the compressed pressure increased, the specific energy consumption of the tandem mill tended to increase its tendency from pressure 2.7 to 10.0 x 10⁶ N/m². Effects of speed, when increased the speed of the tandem mill, the specific energy consumption slightly decreased from 0.0844 m/s to 0.1 m/s and slightly increased from 0.1 m/s to 0.1631 m/s.

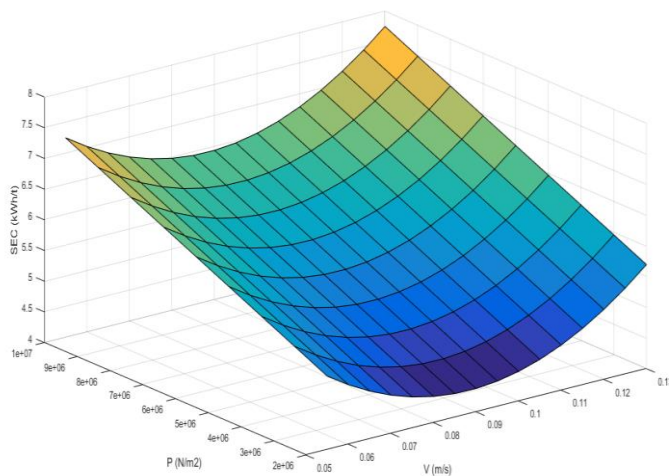


Fig. 5. Effects of compressed pressure and tandem mill speed on specific energy consumption (SEC).

3.5 Effects of compressed pressure and tandem mill speed on the specific extraction per energy consumption

The SEE model in Table 2, indicating the relationship between the compressed pressure and the tandem mill speed affecting the specific extraction per energy consumption, is shown in Figure 6 for clarifying in optimization. From the graph, when the compressed pressure increased, the specific extraction per energy consumption slightly increased from pressure 2.7 to 6.0×10^6 N/m² and severely decreased from pressure 6.0 to 10.0×10^6 N/m². Effects of speed, when increased the speed of the tandem mill from 0.0844 m/s to 0.1631 m/s, the specific extraction per energy consumption slightly decreased.

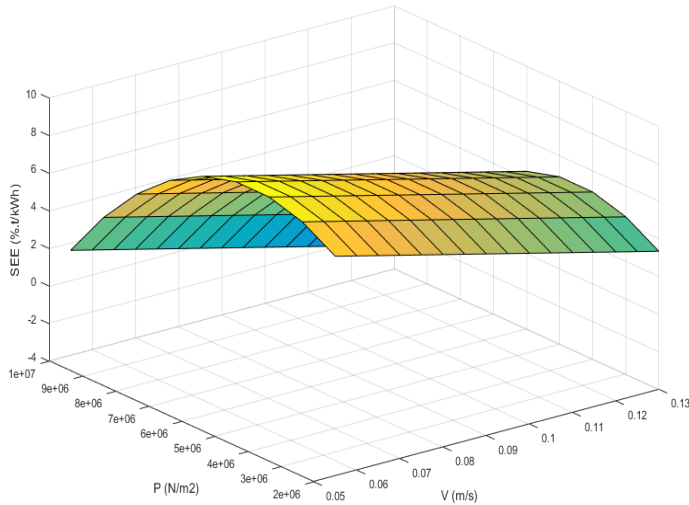


Fig. 6. Effects of compressed pressure and tandem mill speed on specific extraction per energy consumption (SEE).

4 Conclusions

The increase in the compressed pressure tended to increase the extraction of sugar, the power requirement, the specific energy consumption, and the specific extraction per energy consumption (from pressure 2.7 to 6.0×10^6 N/m²) while the specific extraction per energy consumption (from pressure 6.0 to 10.0×10^6 N/m²) tended to decrease. The increase in the speed tended to decrease the extraction of sugar, the specific energy consumption (from speed 0.0844 m/s to 0.1 m/s), and the specific extraction per energy consumption while the power requirements and the specific energy consumption (from speed 0.1 m/s to 0.1631 m/s) tended to increase.

The maximum EXT is earned at the compressed pressure 8.6×10^6 N/m² and the speed 0.0844 m/s. The minimum POW is earned at the compressed pressure 2.7×10^6 N/m² and the speed 0.0844 m/s. The minimum SEC is earned at the compressed pressure 2.7×10^6 N/m² and the speed 0.1162 m/s. The most important thing is the maximum SEE that is earned at the compressed pressure 4.51×10^6 N/m² and the speed 0.0844 m/s. The method and results of this study can benefit for sugar factory to find performance and to make the decision on process operation.

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