An Assessment of Energy Saving Potentials in Thai Sugar Industry

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Abstract: *Thailand is the world's fourth largest sugar producer and the second largest sugar exporter after Brazil, producing annually about 95 Mt and 9.5 Mt of sugarcane and sugar respectively. Because sugarcane is one of the most efficient biomass-producing crops, the Thai sugar industry is a significant green energy producer using bagasse as fuel, not only for supplying steam and power for its own use in sugar mills but also for selling surplus electricity to the grid. Currently the industry is already supplying approximately 610 MW of electricity to the grid. However the average specific energy consumption of Thailand's 47 sugar mills is about 1,330 MJ per ton cane as compared to 1,028 MJ per ton cane in high-efficiency mills in Thailand and international standard of 1,349 MJ per ton cane; while the average export of electricity is only 14.25 kWh per ton cane as compared to 70 and 100 kWh per ton cane in more efficient mills in Thailand and Brazil, respectively. This indicates that there is significant potential for energy efficiency improvement in Thai sugar mills. In fact any such improvement would have positive impact on Thailand's economy as well as on the environment since it would result in bagasse saving, and local pollutant and CO_2 emission reduction per unit of energy consumed. The purpose of this paper is to present some of the process-specific energy saving technologies and measures that can be applied in Thai sugar mills to improve end-use energy efficiency. To identify the relevant energy-saving technology and measures, process technology and their operation practices and energy consumption patterns in 3 sugar mills representing 3 ranges of milling capacities have been surveyed as background information. Energy saving potentials of various technologies and measures are then assessed based on: i) experiences of 4 sugar mills as reported by the Thai Office of the Cane and Sugar Board (OCSB), and ii) experiences of 5 local sugar mills obtained in this study. Altogether, about 20 energy-saving technologies and measures have been identified. The highest saving potential of an individual technology/measure being 11% of total energy consumption of the plant. A survey of the three sugar mills on the application these technologies and measures have been applied found that in the higher efficiency mills more than half of these technologies and measures have been implemented, while in the less efficient mills only one third have been applied.*

Keywords: Thai sugar industry, energy efficiency, process-specific end-use energy-saving technologies and measures

1. INTRODUCTION

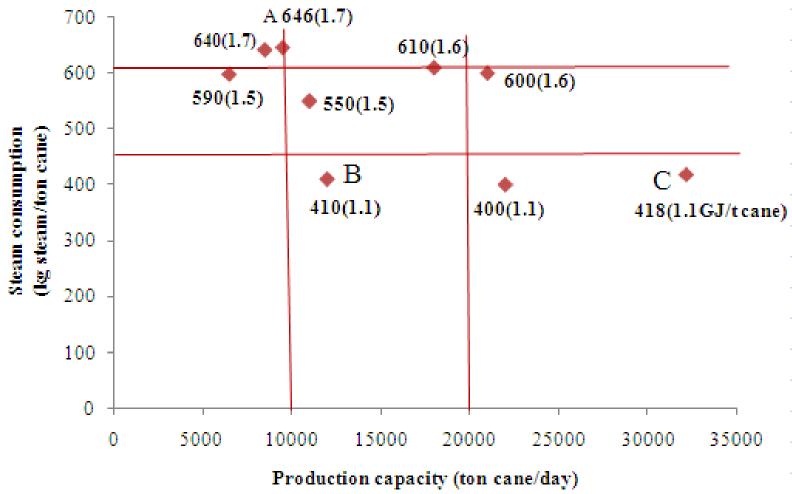
In Thailand the industrial sector is the largest energy-consuming sector with a share of 36% of total final energy consumption in 2010 [1]. Although there have been numerous efforts in improving energy efficiency in this sector in general over the years, well-structured approaches for specific industry types based on energy-saving potential analysis of process-specific technologies are lacking [2]. Since Thailand is the world's fourth largest sugar producer and the second largest sugar exporter after Brazil, producing annually about 95 Mt and 9.5 Mt of sugarcane and sugar respectively [3-4], energy efficiency improvements in this sector can have positive impact on both the Thai economy and the environment. Currently there are 47 sugar mills distributed throughout Thailand and the growth of sugar cane production is expected to reach more than 100 Mt cane in 2012 [3]. The sugar mills do not only produce sugar but also supply green electricity to the grid [5-7]. In fact the Thai sugar industry is already supplying approximately 610 MW of electricity to the grid using bagasse as fuel and generating a large amount of steam for its own use in the mills [5]. However the average export of electricity is only 14.25 kWh per ton cane as compared to 70 kWh per ton cane [8] and 100 kWh per ton cane in more efficient mills in Thailand and Brazil respectively [9]. In the sugar production process, the average specific steam consumption is about 1,330 MJ per ton cane as compared to 1,028 MJ per ton cane and 1,349 MJ per ton cane in high-efficiency mills in Thailand and international standard practice respectively [10- 12]. Therefore, any improvement in energy efficiency in the sugar milling process would result in large amount of energy and CO_2 savings, thus making available more bagasse for green electricity generation, the surplus of which could be sold to the grid for additional tariff.

The overall goal of this study is to construct the cost supply curves of energy conservation and CO_2 mitigation in Thai sugar mills, and to propose policy recommendations. In this paper, as part of the study, we analyze the potential for the reduction of energy demand by investigating the energy consumption patterns and appropriate energy efficiency technologies and measures that could be applied in the sugar production processes. A detailed description of the applications of each energy efficiency technology and measure is also given. In most existing literature, only major forms of energy efficiency measures are given, see Sattari [13] for example.

2. METHODOLOGY

2.1 Collecting baseline data related to steam and electricity consumption

Thai sugar mills could be categorized into three production capacity ranges: i) Small (less than 10,000 t cane/day), ii) Medium (10,000 to 20,000 t cane /day) and iii) Large (more than 20,000 t cane/day), each contributing about 41%, 42% and 17%, respectively, of total sugar production capacity [14]. In this study, field surveys have been carried out to collect the baseline data of nine factories from their daily production report and measured electric and steam consumption of each process equipment, such as boiler, cane tumble, knives, shredders, milling, evaporators, vacuum pan, crystallizer, centrifuge. Baseline data on steam consumption and corresponding energy use in selected sugar mills are shown in Fig. 2.1. The nine mills are categorized into three groups, each group consists of three mills, representing production capacities of 22%, 15% and 18% within the small, medium and large categories mentioned above. In this paper, we analyze in detail one sugar mill from each category, i.e. mill A, B and C, who have provided the most complete data required for analysis.



SEC<450 kg steam/ton cane, SEC=451-601 kg steam/ton cane, SEC>611 kg steam/ton cane
Fig. 1 Baseline data on steam consumption and corresponding energy use in selected sugar mills

2.2 Identification of energy efficiency technologies and measures

Energy efficiency technologies and measures that could potentially be applied to Thai sugar industry have been identified by i) reviewing the best practices that had been reported earlier by the Office of the Cane and Sugar Board (OCSB) based on the experiences of 4 sugar mills [14], and ii) examining the experiences of 5 energy efficient mills belonging to a large sugar produce group. Out of about 20 technologies and measures identified, about half (11) are cited from the OSCB. They include, for example: extended period of blow down inside the boiler, optimum/sufficient hot water use in the crush cane, raw syrup brix improvement, energy efficient insulation, bagasse dryer, replacing steam turbine by motor in furnace, replacement of open gear by planetary gear on first crusher stage, additional jet vacuum on evaporator and vacuum pan, replacement of AC motor by DC motor on vacuum pan, replacement optimum (smaller) motor on drying blower. The additional items identified in this study include: replacement of turbine drive by AC motor for cane cutting knives, replacement of turbine drive by AC motor drive for feed water pumps, installation of inverter to modulate the motor for driving feed water pumps, replacement of existing lighting by high efficiency lighting, installation of capacitor for adjusting the power factor from 0.75 to 0.85, and installation of additional evaporator for improving raw syrup Brix (70).

2.3 Investigating the Extent of Energy Efficiency Improvement Efforts

To investigate the extent to which the above energy efficiency technologies and measures have been implemented in Thai sugar mills, a detail survey of the above-mentioned 3 sugar mills were conducted. A comparison on energy performance of these mills were then made on the basis of the number and type of technology/measure implemented and their specific energy consumption.

3. RESULTS AND DISCUSSIONS

3.1 Baseline steam and power demand

A simplified process flow diagram for sugar production process is illustrated in Figs. 2-7 indicating the major energy flows (steam and electricity) in each process. The information is obtained from a mill with a production capacity of 12,000 ton cane/day [5, 14].

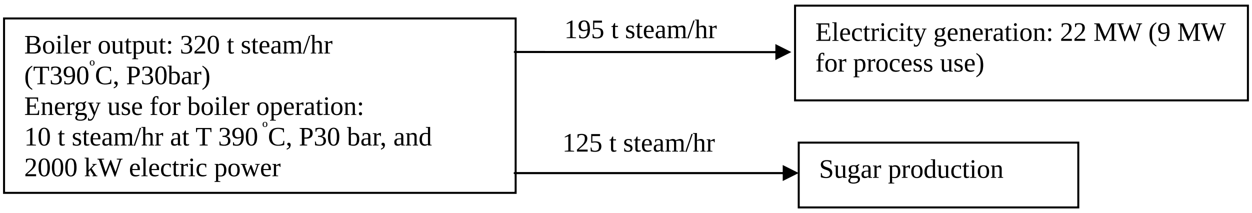


Fig. 2 Overall steam and power flow of a sugar mill of 12,000 t c/day

In this particular sugar mill, bagasse is used in the boiler to produce steam, about 60% of which is used to generate electricity in a co-generation plant to produce electricity and the remaining steam at 1.2 bar is supplied to the sugar production process. Surplus electricity from in-house usage in the boiler and sugar production is sold to the grid.

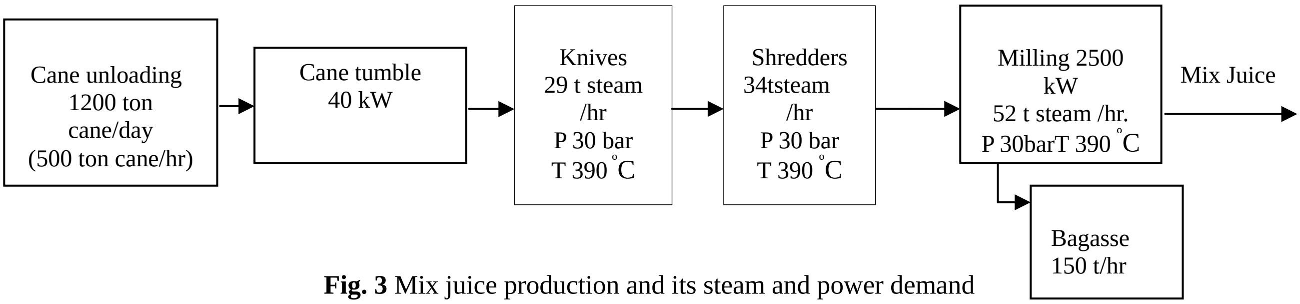


Fig. 3 Mix juice production and its steam and power demand

The first step in sugar production is the extraction of juice from the cane (Fig. 3). The unloaded cane is cleaned from dirt and fed through cane tumble, which is provided with arms arranged in a helix along its length to ensure that the cane falls into the carrier in small lots. Then the cane is fed to size reduction (combination of knives and shredders) and milling processes, which consume 115 t steam/hr (P30 bar T390 ºC) and use 2,540 kW power.

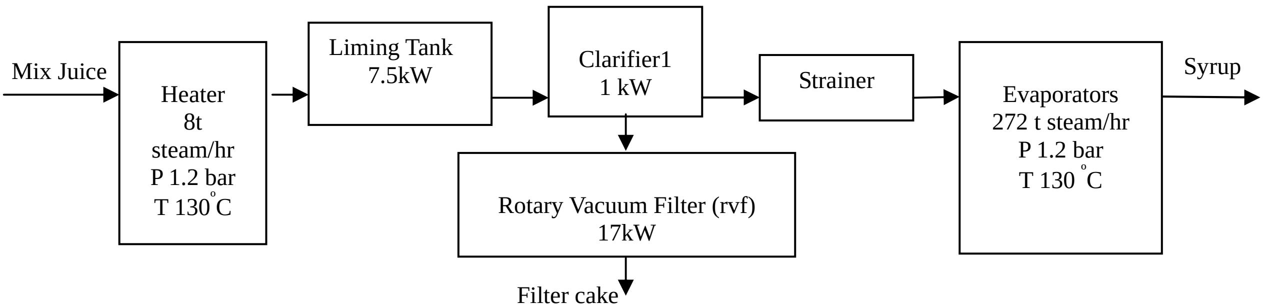


Fig. 4 Syrup production

The mixed juice is heated, limed and clarified to separate the insoluble particles (Fig. 4). The insoluble particulate mass, called "mud", is separated from the limed juice by gravity or centrifuge, and then filtered by rotary vacuum filter to produce filter cake, which is washed with water. Prior to evaporation, clarified juice goes to a strainer [6]. Evaporation is one of the most energy intensive unit operations in sugar mills [15] and is classified in two stages: First stage is an evaporator station in which the juice is concentrated. Second stage is the vacuum pans to crystallize the sugar. The clarified juice is passed through the evaporator stations, which consist of five-effect evaporators. Some of the lost steam in the first three evaporators is used in various process heaters in the plant. The final product of the evaporator station is syrup, which is then filtered and goes to the vacuum pans for crystallization. This syrup production process consumes 280 t steam/hr (P1.2 bar T130ºC) and requires 25.5 kW power.

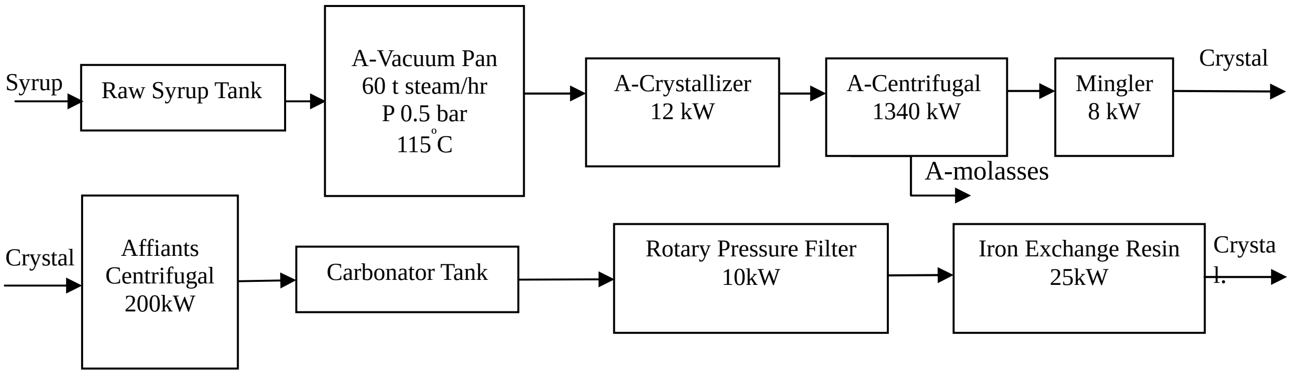


Fig. 5 Crystal production process

The A-vacuum pans perform crystallization of the sugar (Fig. 5). The product of this crystallization process is a mixture of liquor and crystals, known as massecuite, which is then discharged to the crystallizer, whose function is to maximize the sugar crystal removal from the massecuite. From the crystallizer, the massecuite is transferred to centrifugal machines (A-centrifugals), in which the mother liquor (termed "A-molasses") is centrifuged and the crystals introduced to the mingler where they are washed with hot water. The wash water is then centrifuged by the affiants centrifugal. Then, crystals are removed from powdered carbon in the carbonator tank and clarified by the rotary pressure filter and finally, in the sugar whitening process, the synthetic resins are removed by ion exchange resin. In this process 60 t steam/hr (P0.5 bar T115ºC) and 1,595 kW are required.

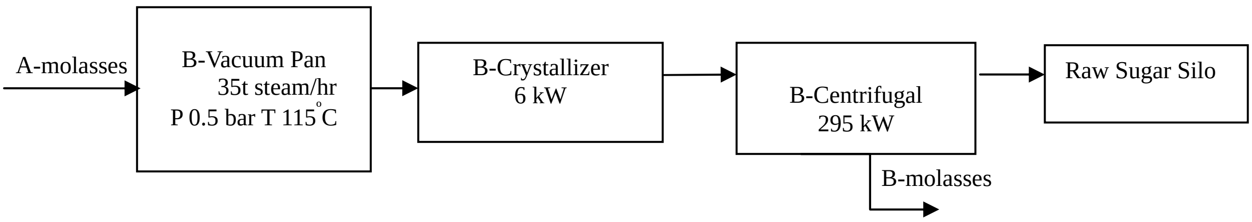


Fig. 6 Raw sugar production process

The mother liquor (A molasses) from the A- centrifugal [16] (Fig. 5) is returned to a B-vacuum pan as shown in Fig. 6. The raw sugar is separated from the molasses and introduced to storage at raw sugar silo. The steam consumption is 35 t steam/hr (P0.5 bar T115ºC) and the power demand being 301 kW.

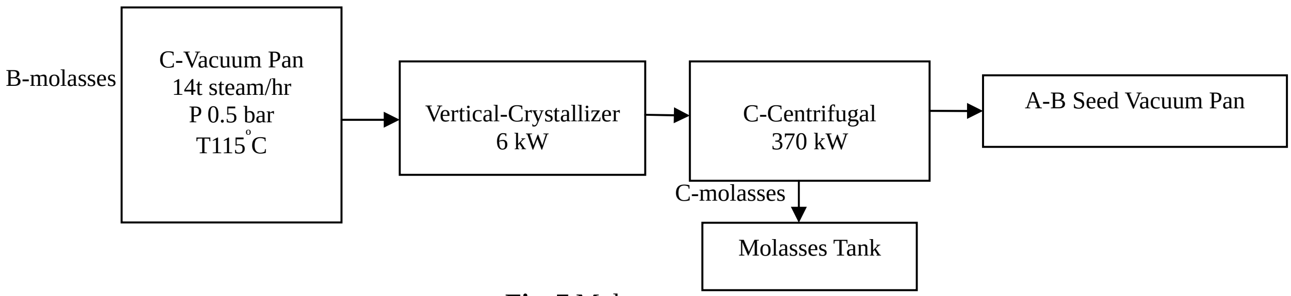


Fig. 7 Molasses process

As shown in Fig. 7, the B-molasses, being of much lower purity than the first molasses, is re-boiled to form a low grade massecuite (C-vacuum pan), which goes to a vertical crystallizer and then to a C-centrifugal. The output is a low-grade cane sugar, which is mingled with syrup and is sometimes used in the vacuum pans as a "seeding" solution. The final molasses from the C-centrifugal is a heavy, viscous material stored in molasses tank. The total power demand is 376 kW and the steam consumption being 14 t steam/hr (P 0.2 bar T 105ºC).

In addition 1,860 kW is needed for lighting and liquid pumping system. Table 1 summarizes the electricity and steam demand in each process of the A, B, and C mills. It can be seen that the main energy requirement of sugar production is thermal energy, being 10 times more than electrical energy. The highest thermal energy demand is evaporation in raw syrup production, followed by crystallization, and the raw sugar process involving crystallization in vacuum pans.

Table 1 Summary of steam and electricity consumption in sugar production in mills A, B and C

Process	*Factory*	*Electricity consumption*		*Steam consumption*		*Total Energy consumption*
		kWh/t cane	*MJ/t cane*	*kg steam /t cane*	*MJ/t cane*	*MJ/t cane*
Boiler	A B C	4.6 4 3	16.5 14.4 10.8	25 (P 20bar T360ºC) 20 (P 30bar T390ºC) 15 (P 20bar T360ºC)	11.0 9.7 6.5	27.5 24.1 17.3
Mix juice production	A B C	2.5 5.08 NA	9 18.23 NA	401 (P 20bar T360ºC) 230 (P 30bar T390ºC) 239 (P 20bar T360ºC)	174 111.1 104	183 130 104
Raw syrup production	A B C	1.12 0.05 1.5	4 0.18 5.5	621 (P1.2 bar T130ºC) 560 (P1.2 bar T130ºC) 448 (P1.2 bar T120ºC)	772 607 460	776 607.2 465.5
Crystal production	A B C	1.8 3.19 5.33	6.4 11.48 19.2	101 (P0.5 bar T115ºC) 120 (P0.5 bar T115ºC) 90 (P0.5 bar T115ºC)	230.8 273.8 204.3	237.2 285.3 223.5
Raw sugar production	A B C	1.08 0.6 1.3	3.89 2.16 4.7	88 (P0.5 bar T115ºC) 70 (P0.5 bar T115ºC) 49 (P0.5 bar T115ºC)	201.7 159.7 110	205.6 161.9 114.7
Molasses production	A B C	2.47 0.75 2.11	8.9 2.7 7.6	38 (P0.5 bar T 115ºC) 28 (P0.2 bar T 105ºC) 30 (P0.5 bar T 115ºC)	86.4 63.4 68.1	95.3 66.1 757
Lighting and liquid pump system	A B C	3.75 3.72 3	13.5 13.4 10.8	NA		13.5
Other process system	A B C	4.7 0.61 0.21	16.9 2.19 0.76	NA		16.9
Office & Service	A B C	3 3 4.5	10.8 10.8 16.2	NA		10.8
Total SEC	A B C	25 21 21	90 75.6 75.6	646(P20bar T360ºC) 410(P30bar T390ºC) 418(P20bar T360ºC)	1,475.9 1,224.8 953	1565.9 1300.4 1028.6
International SEC		15-35 [12]	54-126 [12]	500 (P21barT300ºC) [17, 15]	1,216 [12]	1,349 [12]

The total energy consumption of mill A is much higher than others due to the use of old equipment and the lack of efficient technologies and measures [13]. The electrical, thermal and total energy consumption of A, B, and C mills are: 25, 21 and 21 kWh/t cane; 953, 1,225 and 1,476 MJ/t cane, and 1,566, 1300, and 1,028 MJ/t cane, respectively. Internationally the SEC (electric) ranges from 15 to 35 kWh/t cane, the average SEC (thermal) being 1,216 MJ/t cane, and the SEC total (electric and thermal) 1,349 MJ/t cane [12]. While the performance of mill A is significantly better than the international average, that of mill C is significantly worse. A comparison of energy consumption in specific processes among the three mills reveals that some of them, for example office and services, evaporation, crystallization, milling and loss, consume similar level of energy. Some sugar mills use electricity to operate some of their process/equipment and others use steam instead, which explains the variation in electricity consumption.

3.2 Energy efficiency technologies and measures

A description of the technologies and measures identified and the estimated energy saving potentials is given in Table 2.

Table 2 Energy-efficiency technologies and measures and their saving potentials in sugar production (ETM refers to information obtained from an efficient Thai sugar mill)

NO	Technology/measure	Description	Saving potential
1	Extended period of blow down inside the boiler [14]	To keep the total dissolved solids (TDS) concentration in a boiler below 3,000 ppm, Thai sugar mills usually drain off water from the boiler every 12 hours without measuring TDS, causing unnecessary heat loss. Based on review of best practice in Thailand the period of blow down should be extended from 12 to 18 hours when it is found that TDS would normally reach the allowed limit of 3,000 ppm.	0.2-1%
2	Optimum hot water supply to cane crushing process [14]	This measure is applied in juice extraction process. The juice extraction is aided by introducing hot water to cane crushing process. The optimum hot water is 28% by weight of cane. This measure is used by almost all sugar factories in Thailand but they may use more than 28% of hot water, which is not optimum.	10-11%
3	Raw syrup Brix improvement [14]	This measure is applied in evaporation process. Some plants do not control the syrup concentration, which leaves continuously at the last evaporator. The syrup, which contains about 65% solids and 35% water, is suitable for crystallization in vacuum pans. When solid content is less than 65%, more energy is needed for crystallization in the vacuum pans.	2-3%
4	Energy efficient insulation [14]	Surface temperatures of boiler walls and steam pipes should be insulated to prevent heat loss. Ceramic Rockwood is generally used as wall insulation for boilers and steam pipes. With this insulation the surface temperature should not exceed about 50Cº.	0.02-0.07%
5	Bagasse dryer [14]	Bagasse from the milling process usually contains high moisture of about 51%, which causes a reduction in combustion efficiency in the furnace. To lower the moisture content to 35%, a bagasse dryer should be used prior to combustion.	2-9%
6	Replace steam turbine drive by motor drive for ID fan [14]	Many of the ID fans of the old plants with steam turbine drives have been remodeled by motor drives, which have better control, easier maintenance and are more energy-efficient.	1.5-6.5%
7	Replace open gears by planetary gears on first crusher stage [14]	Older plants in Thailand use open gears for power transmission in the cane crushers. These gears can be replaced by the higher efficiency planetary gears, which have been introduced in Thailand recently.	5.5-7%
8	Additional jet vacuum for evaporator [14]	For efficient evaporation in the evaporator, a number of plants use vacuum pumps to lower the pressure. A jet vacuum, utilizing the pressure from the cooling water pump, can be more energy-efficient.	0.3-0.7%
9	Additional jet vacuum for vacuum pan [14]	Many of old plants use vacuum pumps to lower the pressure in the vacuum pan. For energy-efficient evaporation, the vacuum pumps have been remodeled by jet vacuums, which utilize the pressure from the cooling water pump.	1-3.5%
10	Replace AC motor by DC motor on vacuum pan [14]	The operation of a vacuum pan is controlled by a motor whose speed being varied continuously. The use of DC motor consumes only 1/3 of the electric energy needed to drive the AC motors. Moreover the DC motors can re-generate power back into the system more than AC motors do.	0.6-1.5%
11	Optimum (smaller) motor for drying blower [14]	Many of the motors used for driving hot air blowers in dryers have been over designed, causing excess electricity usage. Replacing them with optimum (smaller) motors can potentially save electricity use.	0.01-0.05%
12	Replace steam turbine drive by AC motor drive for cane cutting knives [ETM]	Many of the old designs of cane cutting knives with steam turbine drives have been remodeled by AC motor drives, which have better control, easier maintenance and are more energy-efficient.	1.8%
13	Replace steam turbine drive by motor drive for boiler feed-water pumps [ETM]	Many of the old boiler feed-water pumps with steam turbine drives have been remodeled by motor drive, which have better control, easier maintenance and are more energy-efficient.	0.4%
14	Install inverter to AC motors in feed water pumps [ETM]	AC motors consumes more energy at startup and while changing speed. An inverter can help save energy by providing soft start and gradually changing the speed of the motor.	0.16%
15	Efficient lighting [ETM]	Replacement existing lighting by energy efficient lighting.	0.1%
16	Install power factor adjustment capacitor from 0.75 to 0.85 [ETM]	Changing the power factor from 0.75 to 0.85 at fixed power and voltage reduces the current and hence saving energy.	1.25%
17	Install additional evaporator to improve raw syrup brix [ETM]	Experience in some plants has shown that additional evaporator could increase syrup concentration to about 72% solids and 28% water [10]. This concentration aids energy saving in the vacuum pans by accelerating crystallization.	0.8%

The above list reveals that there are a number of energy efficient measures/technologies that could potentially be applied in Thai sugar mills, with potential savings ranging from 0.01% to 11% of total energy consumption of the mill. The provision of optimum hot water supply to cane crusher (for juice extraction) appear to have the highest potential (10-11% saving), followed by replacing the open gears by planetary gears on the first crusher stage (5.5-7% saving) and installing bagasse dryer (2-9% saving). Other measures of interest include: syrup concentration control in the evaporator (2-3% saving), installing additional jet vacuum in the evaporator (0.3-0.7% saving)and vacuum pan (1-3.5%), replacing inefficient steam turbines by electric motors (0.4-6.5%), and installing power factor adjustment capacitor (1.25%).

3.3 Extent of application of energy efficiency technologies and measures

In order to determine the extent to which the above energy efficiency technologies and measures have been applied in Thai sugar mills, a survey by using questionnaires was conducted for three sugar mills mentioned above (mills A, B, and C), and the results summarized in Table 3. It can be seen that mill C has implemented the largest number of energy efficient technologies and measures; while mill A has applied the least. Note that this result is consistent to the specific thermal energy consumption of each mill reported in table1. Mill A in particular is old and lacks preventive maintenance. Mill C on the other hand is much more modern.

Table 3 Summary of energy efficient technologies and measures applied in selected sugar mills (A, B, C) (numbers refer to the order of technologies/measures appearing in Table 2, and measures 18 and 19 are those additional measure where no specific energy saving potentials have been estimated)

Process/ Equipment	Energy efficiency technologies and measures	Mills		
		A	B	C
Boiler	1, Bottom blow down timing	✓	✓	✓
	5, Bagasse dryer			✓
	6, Replace steam turbine drive by motor drive for ID fan	✓		✓
	13, Replace steam turbine drive by motor drive for boiler feed-water pumps	✓		✓
Mix juice production				
- Knives	12, Replace steam turbine drive by AC motor drive for cane cutting knives			✓
- Milling	2, Optimum hot water for cane crushing	✓	✓	✓
	7, Replace open gears by planetary gears	✓	✓	✓
Raw syrup production - Evaporator	3, Raw syrup Brix improvement (65%)	✓	✓	✓
	8, Install jet vacuum in evaporator		✓	✓
	17, Additional evaporator to improve raw syrup Brix (70%)		✓	
	18, Add more evaporator area		✓	
	19, Add heater using vapor pothead		✓	
Crystallization Raw sugar production Sugar production Molasses production for vacuum pan	9, Install jet vacuum pump in vacuum pan		✓	✓
Other	4, Efficient insulation	✓	✓	✓

4. CONCLUSION

This study attempts to investigate the energy consumption pattern and the potentials for energy saving by applying various efficiency technologies and measures in Thai sugar industry. Detailed analysis of steam and electricity consumption in three sugar mills, each representing a particular capacity range, were conducted. The results show that the specific energy consumption (SEC) of the large, modern plant is significantly lower than the international value, while the medium sized plant is about on par with international practice. The small, older plant, on the other hand has a significantly higher SEC than the international benchmark, indicating room for energy efficiency improvement in both the small and medium sized plants. In total, about 20 potential energy efficiency technologies and measures have been identified – some reported by a previous study of the Thai Office of The Cane and Sugar Board (OCSB) and others obtained by surveys in this study. The highest potential for energy saving of individual technology/measure is 11% of the total plant energy consumption. These energy efficiency technologies and measures for sugar production may be divided into the following categories: five measures related to the boiler, one measure to the knives, two measures to the milling process, three measures to evaporators, two measures to vacuum pan and four measures to other processes. The survey of current practices in applying these technologies and measures in the three sugar mills revealed obviously that the more efficient mills have several of these technologies and measures in place.

5. ACKNOWLEDGEMENT

The financial support provided by the Center for Energy Technology and Environment through the Joint Graduate School of Energy and Environment (JGSEE) is gratefully acknowledged. The cooperation of the OCSB (Office Of The Cane and Sugar Board), the Pilot Plant Development and Training Institute, King Mongkut's University of Technology Thonburi, and various sugar mills in providing information and assistance are also deeply appreciated.

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