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Reduction of specific energy consumption (SEC) in cement factories through FMEA and energy management

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ABSTRACT

The cement industry is one of the energy intensive industries with energy costs reaching 35% - 50% of the total production costs. The main energy sources in cement plants are coal and electricity. Energy use performance can be seen from the specific energy consumption (SEC) of the factory concerned. This paper discusses the possibility of decreasing SEC in a cement production unit with a capacity of 7800 tons per day. The plant operates using a dry process with a calciner and a 4 stage cyclone preheater. The study focuses on three process lines, namely the raw mill process, the kiln & coal mill process, and the finish mill process. The results of the energy audit show that the performance of the raw mill process line is still close to the design price. Meanwhile, for the kiln & coal mill process line and the finish mill process line, the performance is below the design price. The Failure Mode Effect Analysis (FMEA) method is used to analyze the causes of the high SEC value of each process series. Based on the results of the FMEA, recommendations are given to reduce SEC and the potential for SEC reduction is estimated at 14.93 kWh/ton of cement.

ABSTRAK

Industri semen termasuk salah satu industri intensif energi dengan biaya energi yang mencapai 35% - 50% dari total biaya produksi. Sumber energi utama pada pabrik semen adalah batu bara dan listrik. Kinerja penggunaan energi dapat dilihat dari konsumsi energi spesifik (KES) dari pabrik yang bersangkutan. Pada makalah ini dibahas kemungkinan penurunan KES di sebuah unit produksi semen dengan kapasitas 7800 ton per hari. Pabrik ini beroperasi dengan menggunakan proses kering dengan sebuah kalsiner dan siklon preheater 4 tingkat. Kajian dititikberatkan pada tiga lini proses, yaitu proses raw mill, proses kiln & coal mill, dan proses finish mill. Hasil audit energi menunjukkan bahwa kinerja pada lini proses raw mill masih mendekati harga desain. Sedangkan untuk lini proses kiln & coal mill dan lini proses finish mill, kinerjanya berada di bawah harga desain. Metoda Failure Mode Effect Analysis (FMEA) digunakan untuk menganalisis penyebab tingginya nilai KES dari setiap rangkaian proses. Berdasarkan hasil dari FMEA, rekomendasi diberikan untuk menurunkan KES dan potensi penurunan KES diperkirakan mencapai 14,93 kWh/ton semen.

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1. Introduction

National energy demand is still dominated by the energy-intensive industrial sector. This group is a manufacturing industry engaged in the food and beverage sector, paper and pulp, chemical fertilizers and rubber, cement and non-metals, as well as iron and steel base metals [1]. In this case, 30–70% of the total energy consumption of the industrial sector is associated with the cement industry [2].

For the cement factory itself, around 40% - 60% of the cost of production (HPP) comes from energy consumption costs [3]. Cement factories in India are reported to have incurred energy costs of 35% to 50% [4].

Meanwhile, the cost for energy at the Lafarge Malaysia cement plant reaches around 40% – 45% [5]. Cement factories in Europe spend an average of 35% on energy components [6]. In the cement factory that is the case study in this article, the cost for energy reaches around 48% of the HPP [7].

Cement factory is one of the industries with energy intensive category. An increase or decrease in energy use by a few percent will have a significant impact on the economy of production.

Energy audit is an effort to find out patterns of energy use and to identify potential energy savings in all facilities, facilities and equipment that use energy [8]. Energy audit aims to establish an energy audit system and reduce production costs [9]. A decrease in energy use can have an impact on the company's financial balance, so energy conservation and energy audits are carried out to assess the performance of various sub-sections in the plant for energy and cost savings [10].

Cement factories use two main energy sources, namely coal which is used for the calcination process in the kiln and electricity as a motor drive in various unit operations and a small part for lighting. The range of energy required from coal is greater than energy from electricity. However, in terms of costs, the supply of the two types of energy sources has almost the same range. Given that the supply of coal, both quality and quantity, often depends on the supply of third parties and cannot be fully controlled, the study in this paper is limited to electricity consumption. Based on the results of the evaluation on the profile of electrical energy use and accompanied by an analysis of the failure mode effect analysis (FMEA), then a recommendation is drawn up in an effort to increase process efficiency or decrease specific energy consumption.

2. Research Method

All numbers must be numbered with Arabic numerals (1, 2, 3 ...). Every image must have text. All photographs, schematics, graphics and diagrams must be referred to as drawings. Line drawings must be in good quality scans or actual electronic results. Low-quality scanning is not acceptable. Numbers must be embedded into the text and not provided separately. In MS word input the numbers must be coded correctly. Letters and symbols must be clearly defined in the information or legend provided as part of the picture. Numbers should be placed at the top or bottom of the page whenever possible, as close as possible to the first reference to them in the newspaper.

In this paper, an assessment or evaluation is carried out on the performance of energy use, especially electrical energy, in a cement production unit with a capacity of 7800 tons per day. The study is limited to the cement production process starting from the withdrawal of raw materials from raw material storage in the raw mill process line to filling into cement silos at the finish mill (Fig. 1). At this stage, the study does not cover the cement mining and bagging process.

SEC was obtained through the 2020 factory energy audit (2019 operational data) and then compared with typical factory SEC at national and international levels as a best practice example. The Failure Mode Effect Analysis (FMEA) method is used to analyze the causes of the high SEC value of each of these processes.

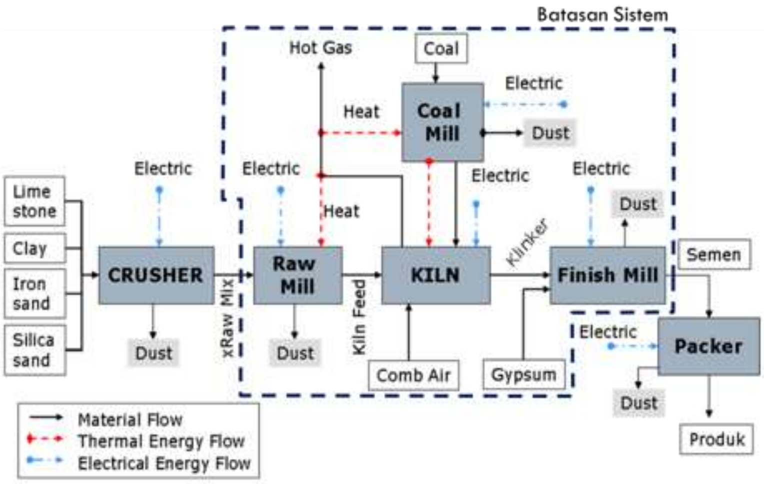

Figure 1. Boundary System

Specific energy consumption (SEC) is the ratio between the actual amount of electric power and the amount of cement production in the same time period.

$$SEC = P / X \quad (1)$$

where P is the amount of actual electric power (kWh) and X is the amount of cement production (tonnes). The relationship between the actual amount of electric power and the amount of production can be approximated in a linear equation through the regression of the power and production data, as stated in Eq. (2).

$$Y = a.X + b \quad (2)$$

where Y is the amount of power (kWh), X is production (tonnes), a and b are constants. The constant b can be interpreted as the base load or energy consumed when production activities are not available. The value of Y is the amount of electrical power that is expected (desired) to be used based on the amount of production. The saving potential is the difference between the actual used power (P) and the desired power (Y) as in Eq. (3).

$$Saving\ potential\ (kWh) = P - Y \quad (3)$$

The sum of various saving potentials (kWh) is called Cummulative Summary (CUSUM). The factory is declared 'wasteful' if the number of kWh used is higher than the desired number of kWh (positive CUSUM) and 'saving' if the desired kWh is higher than the used kWh (negative CUSUM). In this study, the baseline period taken is 2018 and the review period is 2019.

In addition to the CUSUM evaluation, benchmarking is also carried out, namely comparing the energy performance of individual factories or all similar factory sectors with general metrics that represent "standard" or "optimal" performance. Benchmarking is carried out to (1) evaluate all industrial sectors, (2) compare separate factories within a sector, and (3) set energy efficiency goals [11].

If there are components or sub-systems that have a high SEC value, the Failure Mode Effect Analysis (FMEA) method is applied to find the cause of the high SEC value. FMEA is a method used to identify the form of malfunction, the causes and effects of the failure [12]. FMEA is an efficient evaluation technique to identify potential failures in process products and services [13].

The FMEA evaluation begins in seven steps with the following basic questions in FMEA: (1) What do you want from the equipment?; (2) How can equipment fail?; (3) What causes functional failure?; (4) What happens when failure occurs?; (5) How important is each failure or what are the consequences of that failure?; (6) Can failure be predicted or prevented and should it be done?; and 7) How should failure be managed if prediction or prevention is not an option? The answers to these basic questions are then compiled in an FMEA table.

Furthermore, the basic questions that make up the FMEA are adopted as needed in the energy management analysis related to: (1) problems that occur (high SEC); (2) the cause of the increase in SEC; (3) effects and consequences with increasing SEC; and (4) improvement efforts. By answering all the questions from the modified FMEA table, a recommended activity is prepared to find energy saving opportunities.

3. Results and Discussion

3.1 Factory Performance

Table 1 shows the monthly average performance of each process line for 2019 in SEC along with the frequency of unplanned stops, equipment availability and utilization. The frequency of unplanned stops is the number of equipment stops outside the planned maintenance schedule in one month. Meanwhile, availability is the percentage of time that can be used for production outside the planned maintenance schedule. Meanwhile, utilization is the percentage of production capacity to design capacity. From Table 1, it can be seen that Raw Mill 1 (RM-1) and Raw Mill 2 (RM-2) in 2019 did not reach their design capacity with an average utilization of 85% and 81%, respectively. SEC in both sectors is above design (16.6 kWh/ton rawmix), and availability is above 80%. This is due to the high frequency of equipment unplanned stops. The milling efficiency of raw materials increases when the air temperature and moisture content of the raw materials are reduced [14].

Table 1. SEC, freq. unplanned stop, availability and utilization of each area (monthly average in 2019)

Area/ Processes	SEC Design (kWh/t product)	SEC (kWh/t product)	Unplanned stop (Amount)	Availaibility	Utilisation
RM-1	16.6	18,78	30,6	81%	85%
RM-2	16.6	19,02	23,3	87%	81%
Kiln & CM	39	45,06	6,2	96 %	82%
FM-1	34.4	42,33	10,75	95%	78%
FM-2	34.4	38,97	9	92%	82%

Furthermore, SEC Kiln & Coal Mill (CM) from the table appears to always be above the design price with an average utilization of 82% and availability of 96%. The operation of the secondary combustion system affects the operation of the kiln. This is because the raw materials and fuel during combustion contain various materials that are vaporized in the high zone which have a detrimental effect on the quality of the clinker [15].

At Finish Mill-1 (FM-1) and Finish Mill-2 (FM-2) the SEC value is above the design, with an average utilization of 78% and 82% and availability of 95% and 91%. There are many different parameters that affect the efficiency of raw mills including grinding size, ball mill rate, mill shape, incoming raw material temperature and humidity, material circulation in the system, mill rotation speed and temporary shutdowns for system maintenance [16].

From Table 2, it can be seen the regression of power and production of RM-1 and RM-2, where to make an additional one tonne of raw mix product required power of 17.45 kWh, 16.10 kWh and base load of 165,656 kWh and 357,399 kWh. The RM-1 and RM-2 process lines in 2019 produced 0.46 GWh of energy and 0.86 GWh higher (waste) with the 2018 base load.

From the regression of power and production of the Kiln & CM process, namely Y = 31.65X + 2E+06, to make an additional one tonne of clinker product, 31.65 kWh of power is required and a baseload of 2E+06 kWh is required. The high base load on the kiln is usually caused by conditions where, when there is a disturbance, all equipment (especially transportation equipment) will still be operated to avoid material accumulation or other minor disturbances. The savings obtained were 9.33 GWh with the base load of 2018 data. Table 2 shows the baseline with regression between the production and consumption of electrical energy in 2018 and the CUSUM for the review period is 2019.

Table 2. Base expenses and CUSUM.

Unit	Baseline	R^2	CUSUM (2019)	Description
RM-1	Y = 17,45X + 165.656	0.983	0,46 GWh	Wasteful
RM-2	Y = 16,10X + 357.399	.939	0,86 GWh	Wasteful
Kiln	Y = 31,65X + 2E+06	0.965	-9,33 GWh	Economical
FM-1	Y = 44,92X + 31.646	0.975	6,25 GWh	Wasteful
FM-2	Y = 35,99X + 221.137	0.982	2,48 GWh	Wasteful

Furthermore, in the FM-1 and FM-2 regressions, to add one tonne of cement products requires power of 44.9 kWh and 35.9 kWh with a base load of 0.03 GWh and 0.2 GWh. FM-1 and FM-2 operations in 2019 generated 6.25 GWh of energy and 2.48 GWh higher (waste) than 2018.

3.2 Operasional History (2017-2019)

Operational data from 2015 to 2019 are shown in Table 3. From the table it can be observed that in 2017 the total SEC can approach the design of 82.32 kWh/ton of cement. The design SEC is 81.11 kWh/ton of cement, when compared to the achievement of SEC in 2017 and 2019 there has been an increase of 13.41 kWh/ton of cement in Figure 2 [26].

Table 3 Historical data of factory SEC studied per-process in 2015-2019

Raw Mill						**Finish Mill**					
						Kiln					**Total SEC**
No	**Year**	**RM -1 kWh/t. raw mix**	**RM -2 kWh/t. raw mix**	**Total kWh/t.raw mix**	**Total kWh/t. cement**	**kWh/t. clinker**	**kWh/t. cement**	**FM-1 kWh/t. cement**	**FM-2 kWh/t. cement**	**Total kWh/t. cement**	**(kWh/t. Cement)**
1	2015	18.03	16.41	17..22	20.13	39.57	27.70	33.58	37.93	35.75	83.58
2	2016	16.63	15.76	16.20	18.93	41.29	28.90	39.26	39.41	39.33	87.17
3	2017	16.77	16.11	16.44	19.22	40.89	28.62	34.26	34.7	34.48	82.32
4	2018	18.24	18.65	18.45	21.56	47.22	33.05	38.57	35.86	37.21	91.83
5	2019	18.78	19.02	18.90	22.09	45.06	31.54	45.22	38.97	42.09	95.73

3.3 Comparison per factory line against National (typical) and Designer factories

The national factory for comparison is a typical national factory with the factory being the object of research. All mills large capacity of 7500 tpd clinker, dry process, minimum 4 preheater levels (eight mills). SEC data from several comparison factories is shown in Figure 2.

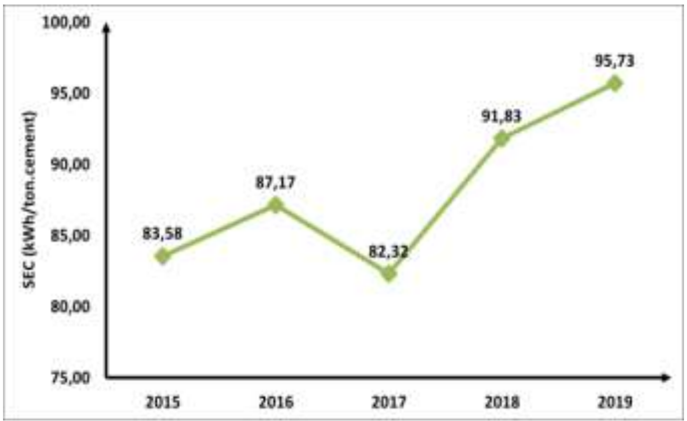

Figure 2. Total SEC in 2015 – 2019 (Design SEC 81.11 kWh/ton of cement)

Plants 1,3,4 and 8 achieved relatively low SEC (78.7 – 83.40 kWh/t.cement) and plants 2,5,6 and 7 had relatively high SEC (89.40 – 99.20 kWh /t.cement) (Ministry of Industry, 2019).

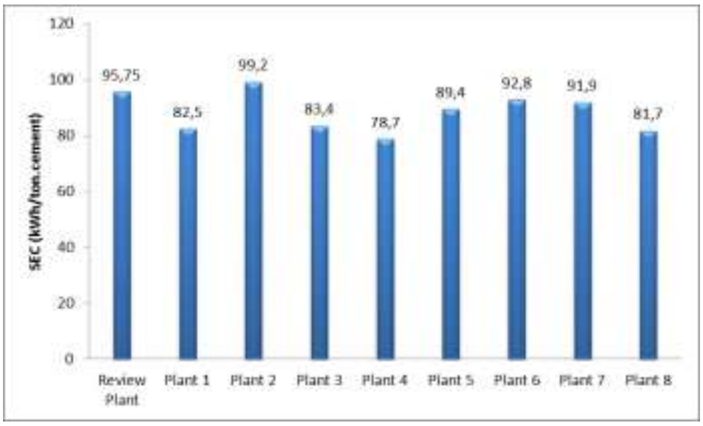

Figure 3. Comparison of SEC for Cement Plants (typical) in Indonesia

3.4 Global Factory SEC & Efforts to Reduce SEC

Cement factories that have received SEC below 70 kWh/ton. The cement in Table 5 uses the latest technology and the Vertical Roller Mill in the cement milling process.

Table 5. World Factory SEC

No	Country	Factory	Capacity. (tpd)	SEC (kWh/t Cement)	Reference
1	Japan	Taiheiyo Cement Corporation	7350	65	[17]
2	China	Best China	-	68	[18]
3	India	Best India	-	66	[19]
		Factory of Rajashree	10000	79.05	
		JK Lakshmi Cement LTD.	6000	79.71	[20]
		Kotputli Cement Works	8000	92.85	
4	Eropa	Best Eropa	-	80	[21]
5	Columbia	Cementos Argos Plant	5000	85	[22]
6	Turki	Best Turkey Cement Plant	-	100	[23]

From Table 6 it can be seen the efforts that have been made by the world's cement manufacturers to reduce the value of SEC. The efforts made in the Raw Mill and Finish Mill processes are relatively the same, including replacing the Ball Mill with a Vertical Roller Mill, adding a Roller Press and replacing the Separator/Classifier with a High Efficiency Classifier. At Kiln & CM a large reduction in SEC can be obtained using low-pressure drop cyclones. Efforts to reduce SEC throughout the process include replacing motors.

Table 6. Good practice for reducing the ESE of global cement plants

No	Area/ Processes	Description	Savings		Location	Reference
1	Raw Mill	Installation of high efficiency roller mill	6–7	kWh/t bahan baku	Arizona Portland Cement (Rillito, Arizona, U.S.)	[24], [25]
			5.4	kWh/t bahan baku	Xinxiang Cement Company, Henan province	[26]
		Roller Press Installation (RP-10)	5	kWh/t bahan baku	Dalla cement factory, India	[20]
		Modification of vertical roller mill with high efficiency classifier	2.8-3.7	kWh/t bahan baku	Tilbury Cement (Delta, British Columbia, Canada	[25]
		Replacing pneumatic transport systems with mechanical systems in homogenizing silos	1-2.5	kWh/t bahan baku	Birla Cement Works, Chittorgarh Company in India	[27]
2	Kiln & CM	Installation of low-pressure drop cyclones	4.4	kWh/t klinker	Lehigh Cement plant	[28]
		Replacing the liquid motor regulator in the precalciner speed control system in the kiln	0.62	kWh/t klinker	the Birla Cement Works, Chittorgarh in India	[27]
		Installed float switch with high level sensor limit in overhead tank for water cooler	0.08	kWh/t klinker	the Birla Cement Works, Chittorgarh in India	[25]
		Inlet modification from cooling fan	0.048	kWh/t klinker	Chittor Cement Works, Chittorgarh Company in India	[27]
3	Finish Mill	Installation of high pressure roller press on finish grinding	15	kWh/ton semen	Coplay Cement’s Nazareth I Plant	[25]
		Ball mill replacement is replaced with vertical mill	10	kWh/ton semen	the Ramla Cement Plant in Israel	[27]
		Installation of high efficiency roller mill	7	kWh/ton semen	Tianjin Zhenxing Cement Co, Ltd.	[29]
		Installation of high-efficiency classifiers	7	kWh/ton semen	cement plant in Origny-Rochefort (France)	[25]
		Installation of VVVFD (MV Drive)	3.48	kWh/ton semen	Mangalam Cement Limited, India	[20]
		Installation of advanced process control mills	3 -3.5	kWh/ton semen	the Roanoke Cement Company in Virginia	[25]
4	General	Use of Adjustable or Variable Speed Drives	8	kWh/ton semen	Pabrik di Davenport, California,	[29]

No	Area/ Processes	Description	Savings		Location	Reference
		(VSD) on fans in kilns	6	kWh/ton semen	Shandong Province Cement Plant	[30]
			5.5	kWh/ton semen	Lafarge Canada's Woodstock plant	[25]
		Replacement of fans with high efficiency fans	0.13	kWh/ton semen	Siam White Cement Co., Ltd., located in Saraburi, Thailand,	[29]
			0.13	kWh/t semen	Birla Cement Works, Chittorgarh Company in India	[20]
			0.11	kWh/t klinker	Satna Cement Works, Birla Corporation Limited, in India,	
		Motor replacement with high efficiency motors and drives	4.58	kWh/t klinker	Shandong Province Cement Plant	[30]
			0.415	kWh/ton klinker	Tamilnadu Cements, India	[31]
		Replacement of the separator with a high-efficiency separator/classifier	9.15	kWh/ton klinker	Shandong Province Cement Plant	[20]
			2–3	kWh/ton semen	Huaihai China United Cement Company	[29]
			1.62	kWh/t clinker	The Satna Cement Works of Birla Corporation Limited in India	[27]

3.5 Evaluation of SEC based on FMEA

The SEC value is strongly influenced by the amount of electrical power consumed, the amount of production, utilization, availability and frequency of process interruptions. For more detail in Table 7, FMEA analysis is used to see all the possibilities, causes and activities for the follow-up plan

Table 7. Evaluation of SEC based on FMEA

No	Description of Problems	Causes of Problems	Effects & Consequences	Activities
1	High Power Consumption (kWh)	Motor is not in optimal operating condition	Power Quality is not up to standard (cos phi < 0.85) there will be a fine payment to PLN	Power Factor (PF)
		Low motor efficiency	The factory uses IE 1 motors and is >20 years old so that the electricity consumption is higher than Class IE 2 motors	List IE motor
			Motor that has been re-winded efficiency decreases by 4-10% so that electricity consumption is greater	List of installed motors that have been rewinded
		High frequency of unplanned stops	To start it taSEC initial energy and after stopping it usually taSEC energy to empty the material, so it will increase the basel card or energy used by not producing a product.	Unplanned stop frequency data collection
		Adjusting gas flow using a damper	The actual power consumption of the motor does not match the load rating of the motor (example: damper opening (need) 70%, but the motor operates at 100%), so the electrical energy used is higher	Comparison of kWh using damper and VSD
		Leaking ducting (False Air)	The volume of air that is sucked in/blown by the fan is bigger causing the motor kW to increase	O2 measurement and calculation
		Equipment consumes higher power	Equipment is run in parallel with a load between 55-75% greater power consumption	Parallel road equipment list
			Supporting equipment is still operating when the main equipment stops	List of equipment that is operated when the main tool stops
		High wear on roller tires or tables	The mill load increases due to the accumulation of material in the mill (material circulation in the mill) due to a decrease in tire/table milling capacity (high coarse fraction)	Tire & grinding table wear measurement
		Raw material out of specification	harder material so that Raw Mill capacity decreases	QC Raw Material
			High water content lowered capacity to maintain smooth operation of Raw Mill	QC Raw Material
		Insufficient hot gas temperature	Gas temperature is below operating requirements, production capacity is reduced, operators are worried about increasing feeding	Operational Data

No	Description of Problems	Causes of Problems	Effects & Consequences	Activities
		High wear on roller tires or tables	The decrease in rolling ability of the Roller Tire causes the accumulation of material in the mill, the mill tends to be full and the capacity decreases.	Tire & grinding table wear measurement
		Unreliable equipment	Equipment inspections are not carried out properly resulting in an unplanned stop	PdM inspection such as vibration, bearing, lubricant etc
			Replacement equipment/parts below specifications	Check metal composition (lab. Inspection)
			The quality of the repair work is not appropriate, resulting in repeated stops	QC Inspection
			The equipment protection system (sensor) is not working/damaged	Check the suitability of sensor measurement values in the field with CCR
		Raw material out of specification	Harder material so that Raw Mill capacity decreases	Raw Material QC Data
			High water content reduced capacity to maintain smooth operation of raw mill	Raw Material QC Data
		Insufficient hot gas temperature	Hot gas temperature is below operating requirements, production capacity is reduced, operators are worried about increasing feeding	Operational Data
		High wear on roller tires or tables	The decrease in rolling ability of the Roller Tire causes the accumulation of material in the mill, the mill tends to be full and the capacity decreases.	Tire & grinding table wear measurement
		Impact of previous Process	Withhold feeding because the contents of the CF silo are below the allowable standard	Production report
		Impact of after Process	Withhold feeding because the contents of the CF silo are below the allowable standard	Production report
		There is a failure of the part / equipment	During the replacement of failed parts, the kiln continues to operate at minimal capacity	Production report
		3rd material out of specification	Harder material so that the Finish Mill capacity decreases	Raw Material QC Data
			High water content lowered capacity to maintain smooth operation of Finish Mill	Raw Material QC Data
		Wear of the diaphragm	Because the dimensions of the diaphragm slot 1 are widened, the material/grinding media moves from room 1 to room 2 so that it is able to grind the finish mill down	Mill Inspection
			Because the dimensions of the diaphragm 2 slot are widened, coarse material is transferred to the product so that rejects are high and capacity is reduced	Mill Inspection
		Wear on the liner	The liner can't lift the grinding media so it can reduce the impact as a result the capacity decreases	Mill Inspection
		Composition of grinding media	Grinding media a lot of small diameter, Milling becomes ineffective so the capacity goes down	Mill Inspection

3.6 Opportunity to Decrease SEC

3.6.1 *Normalization of Power Factor (PF)*

Requirements from PT. PLN PF min. 0.85, if it is lower, a fine will be imposed. From the measurement of the PF value for one factory line it is greater than 0.85 so there is no chance of a decrease in terms of Power Factor (PF)

3.6.2 *Use of High Efficiency Motors*

All Low Voltage (LV) motors installed at the factory are still standard efficiency or IE1 and are more than 20 years old. LV motors with a power of 1.1 – 160 kW totaled 470 units. The rewinding machine in the workshop has a limit of up to a 160 kW motor. Motor replacement IE1 to IE2, this replacement will increase the efficiency of 3%-7%. Meanwhile, rewinding the IE1 motor will reduce the efficiency by 4%-10%.

Replacing an IE1 motor that has been re-winded with an IE2 motor, there will be savings opportunities, which can be seen in Table 8. The opportunity to reduce SEC RM-1 by 0.32 kWh/ton raw mix, SEC RM-2 by 0.33 kWh/ton raw mix , SEC Kiln & CM of 1.22 kWh/ton of clinker and SEC FM-1 of 0.52 kWh/ton of cement and SEC FM-2 of 0.60 kWh/ton of cement.

3.6.3 Damper Replacement with VSD on Motor

The use of a damper aims to regulate the volume of gas that is flowed according to operational needs. Of the seven motors that use a damper, data on the power used and the hourly opening of the damper is made, the percent of the damper opening is multiplied by the maximum power used to get an estimate of the motor's power usage when using a VSD. The use of VSD reduced the SEC RM-1 value by 0.73 kWh/ton raw mix, the SEC RM-2 decreased by 0.63 kWh/ton raw mix and the SEC Kiln & CM value decreased by 1.74 kWh/ton clinker.

3.6.4 Minimizing False Air

The entry of fresh environmental air into a process system is called False Air and is very detrimental. False water in the system resulted in a 23% increase in fan motor power. In 2019, the power used for ESP/Filter fan operations was 7.60 GWh. By minimizing false air in the system, savings of 1.42 GWh can be obtained.

Table 8. Decrease in SEC due to the Use of High Efficiency Motors

No	Area/ Processes	Operational 2019		Savings (IE1 to IE2)			Description
		Working Hours (h)	Production (ton)	(kW)	(kWh)	SEC (kWh/ton)	
1	Raw Mill 1	7270,55	1.494.282	65,15	473.692	0,32	kWh/ton raw mix
2	Raw Mill 2	7387,98	1.473.178	65,15	481.343	0,33	kWh/ton raw mix
3	Kiln	8315,13	1.806.878	265,51	2.207.755	1,22	kWh/ton raw clinker
4	Finish Mill 1	7560,40	1.037.537	74,11	560.269	0,54	kWh/ton cement
5	Finish Mill 2	7353,42	891.444	74,11	537.520	0,60	kWh/ton cement

The probability of decreasing SEC Kiln 0.79 kWh/ton of clinker, SEC RM-1 and RM-2 is calculated based on the ratio of increase in oxygen value. The decrease in the value of SEC RM-1 was 0.25 kWh/ton raw mix and SEC RM-2 was 0.34 kWh/ton raw mix.

Table 9. Decrease in SEC due to the use of VSD

No	Area/ Processes	Description	Actual Power (kWh)	VSD Power Estimate (kWh)	Savings (kWh)	Production (ton)	Decrease SEC (kWh/ton)	Description
1	Raw Mill 1	Mill Fan 1	12.922.861	11.827.015	1.095.846,62	1.494.282	0,73	kWh/ton raw mix
2	Raw Mill 2	Mill Fan 2	13.056.984	12.134.200	922.783,60	1.473.178	0,63	kWh/ton raw mix
3	Kiln	Exhaust Fan 1	11.816.996	10.627.246	1.189.749,66			
		Exhaust Fan 2	13.028.395	12.065.084	963.311,08			
		Filter Fan	7.600.272	7.117.622	482.649,97			
		Excess Fan	4.650.983	4.355.819	295.164,31			
		Fan Coal Mill	435.471	4.131.463	222.007,56			
		Total Klin			**3.152.883**	**1.806.878**	**1,74**	**kWh/ton clinker**

3.6.5 Minimizing equipment operating in Parallel

For operational security, several transport equipment are designed in parallel, such as belt bucket elevator (cement transport), apron conveyor (clinker transport). The equipment should be operated alternately but in fact they are operated simultaneously/parallel.

The motor power installed in the cement transport equipment is 2x132 kW and the clinker transport is 2x132 kw, if one of the equipment is stopped or standby then there is an opportunity for savings in one year of 132 kw x 24 hours x Kiln/Finish Mill operating hours in 2019 then get a saving opportunity of 1.90 GWh a year. Table 10 shows the decrease in SEC due to the minimization of parallel road equipment, SEC Kiln & CM values can be reduced by 0.61 kWh/ton of clinker, SEC FM-1 is 0.48 kWh/ton cement and SEC FM-2 can be reduced by 0,54 kWh/ton of cement.

3.6.6 Operating at Optimal capacity

Raw Mill, Kiln and Finish Mill equipment operations can still be improved, the average utilization is at most 85%. The baseline utilization is defined from the maximum utilization that has been achieved in that year, then multiplied by the average SEC to get the target SEC. The actual reduction of SEC with the target is obtained the opportunity for saving SEC.

Table 10. Opportunities for Savings in SEC

No	Area/ Processes	Operational 2019		Savings			Description
		Working Hours (h)	Production (ton)	(kW)	(kWh)	SEC (kWh/ton)	
1	Raw Mill 1	7270,55	1.494.282	-	-	-	kWh/ton raw mix
2	Raw Mill 2	7387,98	1.473.178	-	-	-	kWh/ton raw mix
3	Kiln	8315,13	1.806.878	132,00	1.097.598	0,61	kWh/ton raw clinker
4	Finish Mill 1	7560,40	1.037.537	66,00	498.986	0,48	kWh/ton cement
5	Finish Mill 2	7353,42	891.444	66,00	478.726	0,54	kWh/ton cement

The decrease in SEC value per process by optimizing the capacity for RM-1 was obtained by 1.31 kWh/ton raw mix, SEC RM-2 of 1.52 kWh/ton raw mix, SEC Kiln & CM of 2.7 kWh/ton clinker, and SEC FM-1 of 6.78 kWh/ton of cement and SEC FM-2 of 4.68 kWh/ton of cement. From the calculation, the total potential savings is 20.29 GWh a year.

3.6.7 Chance of SEC Decrease per process/area and Total SEC

The total probability of decreasing the value of SEC per process/area can be seen in Table 4-11. SEC RM-1 can be reduced by 2.62 kWh/ton raw mix, RM- by 2.81 kWh/ton raw mix, SEC Kiln & CM by 1.07 kWh/ton clinker, SEC FM-1 and FM-2 can be reduced reduced by 7.07 kWh/ton cement and 7.80 kWh/ton cement.

Table 11. Opportunities for Decreasing SEC with Optimal Capacity

No	Area/ Processes	Average SEC 2019	Base Line Utility	Average SEC After Correction	SEC Saving Potential	Description
1	Raw Mill 1	18,78	93%	17,47	1,31	kWh/ton raw mix
2	Raw Mill 2	19,02	92%	17,49	1,52	kWh/ton raw mix
3	Kiln	45,06	94%	42,36	2,70	kWh/ton raw clinker
4	Finish Mill 1	45,22	85%	38,44	6,78	kWh/ton cement
5	Finish Mill 2	38,97	88%	34,29	4,68	kWh/ton cement

The total opportunities for decreasing the value of SEC can be seen in Table 12 where if all saving opportunities can be realized, SEC can be achieved at 79.35 kWh/ton of cement, 1.75 kWh lower than the design.

Table 12. Opportunities for SEC Decreasing per process/area and Total SEC Decreasing

No	Area/ Processes		SEC (kWh/ton.product)				Description
			2019 Average	Total Savings	Average After Saving	Design	
1	Raw Mill	RM-1	18,78	2,62	16,16	16,60	kWh/ton raw mix
			21,95	-	18,90	19,41	kWh/ton.cement
		RM-2	19,02	2,81	16,21	16,60	kWh/ton raw mix
			22,23	-	18,94	19,41	kWh/ton.cement
		Average	22,09	-	18,92	19,41	kWh/ton.cement
2	Kiln		45,06	7,07	37,99	39,00	kWh/ton raw clinker
			31,54	-	26,59	27,30	kWh/ton raw clinker
3	Finish Mill	FM-1	45,22	7,80	37,42	34,40	kWh/ton cement
		FM-2	38,97	5,82	33,15	34,40	kWh/ton cement
		Average	42,10	-	35,28	34,40	kWh/ton cement
Total			**95,73**		**80,80**	**81,11**	**kWh/ton cement**

4. Conclusions

From the data analysis, it can be concluded that the Raw Mill process can achieve the performance according to the design. Meanwhile, the Kiln process and the Finish Mill process are under design performance. It is estimated that SEC reduction opportunities can be obtained from replacing motors with high efficiency motors, using VSD, minimizing false air and avoiding equipment that runs parallel and operates with utilization above 90%. From the energy audit, it was found the opportunity to reduce SEC by 2.72 kWh/ton raw mix at the Raw Mill, 7.07 kWh/ton clinker at Kiln & CM and by 6.81 kWh/ton cement at the Finish Mill. With the implementation of all existing savings opportunities, the estimated SEC reduction that can be achieved is 14.93 kWh/ton or the overall SEC to 80.80 kWh/ton.

Recommendations that can be given are replacing motors with high efficiency motors, replacing dampers with VSD, replacing worn/thin ducting. Furthermore, the completeness of inspection and measurement tools as well as the use of online energy monitoring programs will greatly assist the course of energy management. In addition, the awareness of all parties regarding energy efficiency and conservation at all lines and levels must be increased.

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