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Green Practice in Cement Industry: Energy and Economic Analysis on The Substitution of Limestone by Cement Kiln Dust

Devani Khairunnisa [a], *Aulia* Salamah [a], *Ida* Adriani Idris [b], and *Choerudin* C. [a,1]

[a] Chemical Engineering, Institut Teknologi Nasional, Jl. PKH. Mustofa No. 23 Bandung, Indonesia
[b] Chemical Engineering, Politeknik Negeri Ujung Pandang, Jl. Perintis Kemerdekaan KM. 10 Makassar, Indonesia

Abstract. The cement industry is one type of industry that is highly consuming energy. Cement production generally involves several stages: mining, raw milling, burning, finishing mill, and packaging. The finish mill is the stage where the clinker (output of burning stage) is mixed with other materials such as gypsum, limestone, and additives (trass or fly ash). This study is aimed to examine the substitution of limestone in the finish mill by cement kiln dust (CKD) that is generated from raw mill. The approach of study was simulations to calculate the mass and energy balance and economic aspects (production cost and profit) based on the varied percent of CKD that substitute the limestone. Simulation results show that energy requirements are reduced by 469,730 kJ/ton for each addition of %CKD thanks to lower water content of CKD than limestone. Less energy requirements means less fuel requirements thus lowering production costs by IDR 66,500 /ton of raw meal /%CKD. In addition, CKD substitution to limestone can reduce waste and pollution from the cement industry so that it can increase profit by IDR 312,000 /ton of product /%CKD.

1 Introduction

Cement is an adhesive that can set in water or hydraulically. Cement is produced by pulverizing clinker which consists of the main ingredient calcium silicate and another additional ingredient, namely gypsum where these compounds can react with water and form new substances that are adhesive to rocks. The industrial-scale cement manufacturing process occurs in several stages, beginning with mining, crushing, raw material mill, preheater, kiln, cooler, and finish mill), packing. One stage of the process that produces dust is Raw Mill. The dust produced is Cement Kiln Dust (CKD).

This problem is related to the economic aspect where high energy means high energy costs while producing waste means the cost of waste treatment must also be taken into calculation. Efforts of greener practice in the cement industry are already existing including replacing fossil fuels (coal) that produce more carbon dioxide with biomass (rice husk) that is carbon neutral [1]. Another way is to utilize Cement Kiln Dust (CKD) waste by substituting it into one of the cement producing materials [2]. Cement Kiln Dust (CKD) is a

[1] Corresponding author: choerudin@itenas.ac.id

by-product of cement production which is similar in appearance to portland cement. This CKD consists of micron-sized particles that are collected from an electrostatic precipitator during the cement clinker production process. The use of CKD provides many advantages, namely that it can improve the quality of building materials, can maximize and optimize capacity because CKD is in the form of a powder with a low water content so that CKD will be easily sucked up into products, and can be used to reduce waste and pollution from the cement industry.

From the description above it can be seen that CKD has many advantages in the cement industry, so this study simulates the effect of variations in the use of CKD to the energy consumption. The simulation is carried out by modelling calculations using mass and energy balances to determine good energy utilization in the finish mill when using CKD. in other hands, this study also calculating the effect on the profits earned, so that the use of CKD can be carried out in the long term and becomes an alternative to reduce cement industry waste.

2 Methods

2.1 Simulation Design and Scenarios

This study used a simulation method to evaluate the effect of using cement kiln dust (CKD) as a raw material substitute in the finish mill unit during the cement production process. Simulations were conducted on three CKD content scenarios: (1) 0% CKD as the baseline condition, (2) 6.14% CKD as the medium substitution scenario, and (3) 11% CKD as the maximum substitution scenario. The CKD content range (0–11%) was chosen to represent operational conditions that are still technically feasible without changing the main equipment configuration. All simulation scenarios were analysed using Microsoft Excel® software.

2.2 Mass and Energy Balance Calculation

Mass balance calculations were performed for each CKD usage scenario to determine material requirements for the finish mill process. The mass balance included calculations of material inflows and outflows, including clinker, gypsum, additives, and CKD [3]. The mass balance results are used to determine the amount of raw materials required for each scenario, calculate material costs based on the price of each component, and determine the cost of the resulting cement product.

An energy balance is calculated to evaluate the effect of variations in CKD content on energy consumption in the finish mill process. This calculation includes the electricity and/or fuel requirements used in the grinding and mixing processes. From the energy balance, the following are obtained: energy efficiency values for each scenario, total process energy consumption, and energy costs calculated based on prevailing energy prices.

2.3 Production Cost and Profitability Analysis

Production costs are calculated by combining material costs from the mass balance and energy costs from the energy balance. The production costs analysed include raw material costs, energy costs (electricity and/or fuel), and direct operating costs relevant to the finish mill process. Calculations are performed for each variation in CKD usage to compare changes in production costs between scenarios.

The selling price of cement is determined based on the production costs and certain assumed margins. Furthermore, profit is calculated as the difference between the selling price and total production costs. Profitability analysis is conducted to estimate profit margins for each scenario, to compare economic performance between conditions without CKD and with CKD, and to assess the potential use of CKD as a more economical and efficient alternative.

3 Results and Discussion

The Finish Mill is used as the final grinding site of a cement-making process where the results from the kiln unit, namely clinker, are homogenized again along with other ingredients to become a cement product. The composition of the raw materials that enter the finish mill uses composition from Ordinary Portland Cement (OPC) (58% clinker, 3.6% gypsum, 24.4% limestone, 14% trass, and 0% CKD). CKD is dust produced from the process of grinding cement raw materials in the raw mill which is then accommodated in a bin before being reused as additional cement raw material in the final cement mill or finish mill [4].

This simulation uses three scenarios for the first scenario to compare variations in the use of CKD on energy efficiency. Table 1 shows that the greater the use of CKD, the lower the energy requirement for the finish mill unit. This is because CKD carries heat, so the heat required for the finish mill unit is lower when compared to those without CKD [5]. In addition, CKD has a lower water content than limestone.

Table 1. Comparison of %CKD Usage to Energy Requirements (kJ)

CKD (%)	Energy Requirements (kJ/ton)	Qsystem (%)
0	96.478.728	-3,29
2	95.539.269	-2,22
4	94.599.810	-1,15
6.14	93.593.497	0,00
9	92.251.161	1,53
10	91.781.432	2,06
11	91.311.702	2,60

The results obtained from the calculation, in point one, explain that the use of 0% CKD in the finish mill unit requires a very large amount of energy and results in a Q system worth -3.29. Q negative means that there is energy wasted/out of the system. Qsystem (%) is the percent of energy produced from the system or finish mill unit. In addition, the 0% Q system value when using CKD of 6.14% will get heat from CKD of 2,885,000 kJ. Q system equal to zero means adiabatic, no energy is lost or formed from the system [6]. While the use of 11% CKD requires lower energy of 91,311,702 kJ and obtains energy from a larger CKD of 5,167,000 kJ. Qsystem at the use of 11% CKD is 2.60%. Q positive is the energy obtained in the system. A positive Q can be obtained because the water content in CKD is lower than limestone. This causes the energy requirement to evaporate water from CKD to be lower than limestone. Lower energy requirements lead to lower fuel requirements. Therefore, for every % CKD used, there will be a decrease in energy requirement of 469,730 kJ/ton.

Scenario two, compares the effect of variations in the use of CKD on production costs. Production is an activity related to the manufacture of goods and services. The term production tends to be associated with factories, machines, or assembly lines because initially the techniques and methods in production management were used to operate factories or other activities. Production costs are costs incurred to process raw materials into finished products that are ready for sale. Production costs can be one of the factors that can affect the company's profit increase. Production costs affect operating profit because production costs are an economic resource that is sacrificed to produce output, the output value is expected to be greater than the input sacrificed to produce that output so that organizational activities can generate profits or residual business results. Profit is income from sales minus procurement and marketing costs.

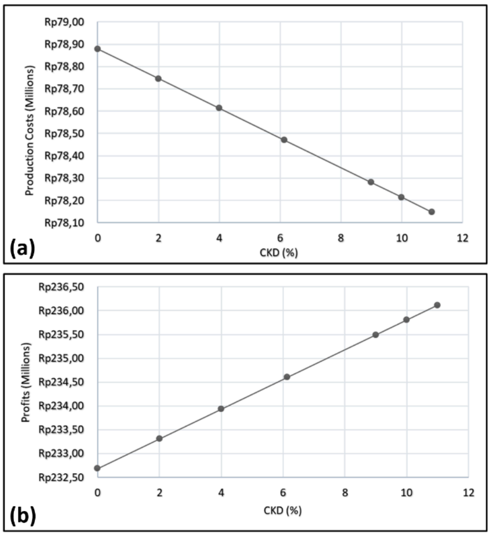

Fig. 1. Effect of varied %CKD usage on production costs (a) and profits (b).

The results obtained show that the greater the use of %CKD, the lower the required production costs. This can happen because CKD is considered as a production process waste that is reused. In addition, the price per ton of CKD is cheaper than the price per ton of limestone [2]. When using CKD at 6.14%, the required production costs are IDR 78,470,774 so as to reduce production costs by IDR 408,211/ton. While the use of CKD was 11%, the required production costs were obtained in the amount of IDR. 78,147,939/ton so that it could reduce production costs by IDR. 598,129/ton. So, every additional 1% CKD will reduce production costs by IDR 66,500/ton.

Scenario three, comparing the effect of CKD variations on profits. Based on the calculation results, the greater the use of %CKD, the greater the profits obtained. The use of CKD as much as 11% resulted in a higher profit of IDR 236,117,771/ton, with an increase of IDR 3,433,987/ton. This is influenced by low production costs, and gains from cement sales are getting bigger. The increase in cement products produced is due to the powder-like form of CKD, causing CKD to be easily reprocessed at the finish mill. Cement products obtained from the use of 11% CKD amounted to 234.53 tons, with a selling price of IDR. 314,265,710/ton cement. Above is a figure 1 comparing the use of %CKD to production costs and profits.

4 Conclusions

Substituting CKD on the limestone has some effects that can reduce energy demand in the finish mill unit and lower production costs in the cement industry. Every %CKD usage, there will be a decrease in energy needs by 469,730 kJ/ton. The use of 11% CKD requires lower energy of 91,311,702 kJ compared to the use of 0% and 6.14% CKD. Obtaining energy from CKD is greater by 5,167,000 kJ. On the other hand, the lower production costs it requires. At the use of 11% CKD, the production cost required is IDR 78,147,939 and the profit obtained is IDR 236,117,771.

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