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Enhancing Energy Efficiency in the Cement Industry

Ogbeide SO*

Department of Mechanical Engineering, Faculty of Engineering, Ambrose Alli University, PMB 14, Ekpoma, Edo State

***Corresponding Author:** Ogbeide SO, Department of Mechanical Engineering, Faculty of Engineering, Ambrose Alli University, PMB 14, Ekpoma, Edo State.

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Abstract

Cement has been a part of almost everything that man has built to improve his life. The chemistry and technology involved in its production have significantly contributed to the development of the world that we have today. The cement industry is one of the largest industrial energy consumers, contributing significantly to global CO2 emissions. Enhancing energy efficiency in the cement industry is crucial due to its high energy consumption and significant carbon emissions. The industry is responsible for approximately 7-8% of global CO2 emissions, making energy efficiency improvements a key strategy for reducing its environmental impact. The present paper will study the energy consumption in cement industry in Nigeria through real auditing and identify technological opportunities in order to decrease energy consumption of the relevant factories, increase the productivity, and improve the production process. Relevant standards planned by government that can provide significant potentials, are discussed too, Moreover, the results prove that consulting sector experts enables the collection of updated ideas for improving technologies, thus giving valuable inputs to the scientific research. One of the challenges for the cement industry in developing countries is the wet manufacturing process. Outdated technologies consume a huge amount of energy, which negatively affects the competitiveness of products. In addition to switching to a dry process in cement production, our engineering company implements other projects leading to increase the efficiency of existing cement plants. This includes the modernization of cement kilns, the introduction of vertical cement mills, as well as the design and installation of renewable energy equipment. The increase in production and efficiency is reflected in the achievement of the impressive financial results that our customers demonstrate shortly after modernization.

Keywords: Cement Industry; Energy Efficiency; CO2 Emissions; Industrial Energy

Introduction

Nigeria, Africa's most populous country, went from being a significant net importer of cement in the early 2000s (producing nearly 4 million tonnes [Mt] p.a. while importing nearly 20 Mt p.a.) to being one of Africa's largest cement producers (nearly 50 Mt capacity in 2018) and exporting nearly a quarter of its output. Cement production is now Nigeria's leading manufacturing industry. It is also Nigeria's largest greenhouse gas (GHG) emitter in its industrial sector Cement is a commodity that is derived from the processing of limestone and other minerals at high temperatures then cooled afterward and reduced in size until it becomes a fine powder (Environmental Protection Agency [EPA], n.d.). It has become part of man's lives since the ancient civilizations have used mortars and binders to be able to construct different structures including the great pyramids of Egypt. Through time and innovations, different types of cement have been formulated to be able to meet the demands of engineering. And with these innovations, issues have also risen especially in terms of the generation of wastes and the safety of the people involved in the manufacture of cement. This report documents an analysis of the potential to improve the energy efficiency of NSP kiln cement plants in Nigeria. Sixteen NSP kiln cement plants were surveyed regarding their cement production, energy consumption, and current adoption of energy-efficient technologies and measures.

Cement Industry in Nigeria

Cement production in Nigeria is dominated by three companies: Dangote Cement, Lafarge Africa and the BUA Group. These companies produced around 61%, 22% and 18% of Nigeria's cement, respectively, in 2019. While being a more recent entrant to cement production, Dangote is now, by far, Nigeria's top producer. Lafarge Africa is Nigeria's second largest producer. It is a subsidiary of the Holcim Group, the world's largest cement company, and has five plants at four sites: Ewekoro and Sagamu in Ogun State, Mfamosing in Cross River State, and Ashaka in Gombe State. Nigeria's cement industry has traditionally used natural gas, imported and domestic coal, and some domestic petroleum to supply heat for co-processing limestone into clinker, the main ingredient of cement. While fossil fuels are plentiful in Nigeria, Lafarge Africa has taken the lead among Nigeria's cement companies to increase use of bioenergy to supply their process heat. This drive has been led by Lafarge Africa's alternative fuels subsidiary, Geocycle7, which is now co- processing biomass (oil palm residues and rice husks) with fossil fuels at four of its five plants.

Nigerian Cement Market

Nigeria's cement sector is marked by consistent demand that in recent years has resulted in significant domestic supply gaps. Infrastructure project growth - which made up 8.9% of Nigeria's 2022 government budget - the private retail sector, and the real estate sector are all driving this rising demand for cement. In real estate, for example, Nigeria faces an estimated 17-million-unit housing deficit in urban areas [1].

The resulting domestic cement shortages in the face of strong demand have encouraged cement producers to continue adding capacity to existing facilities. Indeed, demand has proven resistant in the face of recent economic challenges; during the covid-19 pandemic, domestic cement demand rose by approximately 40% between September 2020 and April 2021 alone, and Nigeria's cement production increased by almost 15% at the time [2]. Experts suggest that Nigeria could require as much as $5 billion in further investment to meet this local cement demand.

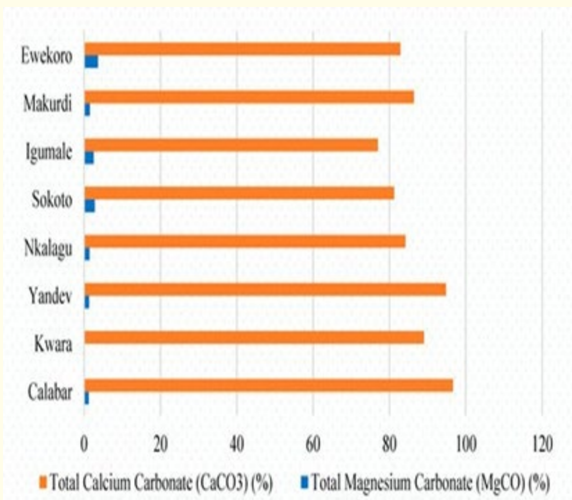

Figure 1: Percentage Quantity of Calcium Carbonate and Magnesium Carbonate in Nigerian Limestone Deposit.

Energy Consumption in Cement Production

The theoretical amount of thermal energy for the production of cement clinker is determined by the energy necessary for burning clinker (about 1700-1800 MJ/t) and the heat necessary for drying and preheating of raw materials. Consumption mainly depends on its initial moisture content. Practice shows that the energy consumption of dry process cement plants with multi-stage cyclone pre-heaters and furnaces varies widely. These differences are due to shutdowns and even restarts of equipment, as well as to significant differences in the quality of raw materials. The main consumers of electrical energy are cement mills, as well as exhaust fans. This equipment accounts for more than 80% of total energy consumption. On average, energy costs (including fuel and electricity) account for approximately 40% of total cement production costs. Electrical energy accounts for up to 20% of the energy consumption of a cement plant. Electricity consumption varies from 90 to 150 kWh / t of cement, while a wet process is much more energy intensive than a semi-wet or dry process. Electricity consumption also depends on the nature of the product and the degree of grinding. In many cases, energy use can be minimized by replacing obsolete clinker production lines. Production waste is often used to generate energy and reduce dependence on traditional fuels. This trend has been growing steadily over the past few decades [3].

Being a highly developed and established industry, the cement industry does not expect radical changes that could significantly reduce energy consumption. Over the past 25 years, the efficiency of the global cement industry has improved mainly due to the dry process. An energy conservation supply curve is an analytical tool that captures both the engineering and the economic perspectives of energy conservation. Energy conservation supply curves for both fuel and electricity savings were constructed for the 16 surveyed plants to determine the potentials and costs of energy-efficiency improvements by taking into account the costs and energy savings of 34 different technologies that could be used in the plants [4]. Using the bottom-up electricity conservation supply curve model, the cost-effective electricity efficiency potential for the studied cement plants in 2008 is estimated to be 373 gigawatt-hours (GWh), which accounts for 16% of total electricity use in the 16 surveyed cement plants in 2008. Total technical electricity-saving potential is 915 GWh, which accounts for 40% of total electricity use in the studied plants in 2008. Carbon dioxide (CO2) emission reduction potential associated with cost-effective electricity saving is 383 kiloton (kt) CO2, while total technical potential for CO2 emission reduction is 940 ktCO2 [5]. The fuel conservation supply curve model shows the total technical fuel efficiency potential equal to 7,949 terajoules (TJ), accounting for 8% of total fuel used in the studied cement plants in 2008. All the fuel efficiency potential is shown to be cost effective. The CO2 emission reduction potential associated with fuel saving potentials is 950 ktCO2.

Energy Measurement

There are three basic types of VSKs: ordinary, mechanized, and improved. In ordinary VSKs, high-ash anthracite coal and raw materials are layered in the kiln, consuming high amounts of energy while producing cement of inferior quality and severe environmental pollution. Mechanized VSKs use a manually operated feed chute to deliver mixed raw materials and fuel to the top of the kiln. Improved VSKs been upgraded and produce higher quality cement with lower environmental impacts [6].

Rotary kilns can be either wet or dry process kilns. Wet process rotary kilns are more energy-intensive. Energy-efficient dry process rotary kilns can be equipped with grate or suspension pre-heaters to heat the raw materials using kiln exhaust gases prior to their entry into the kiln. In addition, the most efficient dry process rotary kilns use pre-calciners to calcine the raw materials after they have passed through the pre-heater but before they enter the rotary kiln [6]. Construction of these modern NSP kilns has been growing rapidly in Nigeria since about 2000. Globally, coal is the primary fuel burned in cement kilns, but petroleum coke, natural gas, and oil can also be combusted in the kiln. Waste fuels, such as hazardous wastes from painting operations, metal cleaning fluids, electronic industry solvents, as well as tires, are often used as fuels in cement kilns as a replacement for more traditional fossil fuels. In Nigeria, coal is used almost exclusively as the fuel for the cement kilns, while electricity - both provided by the grid and through the generation of electricity on-site using waste heat - is used to power the various grinding mills, conveyers, and other auxiliary equipment [7].

Chinese cement kilns used 174 Mt of mostly raw coal and 119 terawatt-hours (TWh) of electricity. There is very little use of alternative fuels (defined as waste materials with heat value more than 4000kcal/kg for cement clinker burning) or coprocessing of waste materials (defined as the incineration of wastes for disposal purposes even if the calorific value of the waste can be used as a fuel) in cement production in China. Less than 20 cement facilities either burn alternative fuels or co-process waste materials as demonstration or pilot projects, but Chinese laws and industrial policies now encourage the use of alternative fuels and the National Development and Reform Commission (NDRC) has begun efforts to develop a Cement Kiln Alternative Fuel Program that will expand the demonstration projects, prepare regulations, develop a permitting-type system, and establish financing mechanisms. Once clinker has been produced in either a shaft or rotary kiln, it is inter-ground with additives to form cement. Common Portland cement is comprised of 95% clinker and 5% additives. “Blended cement” is the term applied to cement that made from clinker that has been inter-ground with a larger share of one or more additives. These additives can include such materials as fly ash from electric power plants, blast furnace slag from iron-making facilities, volcanic ash, and pozzolans. Blended cements may have a lower short-term strength (measures after less than 7 days), but have a higher long-term strength, as well as improved resistance to acids and sulfates. In 2007, 5.4% of the cement produced in China was Pure Portland Cement, which is defined as either being comprised of 100% clinker and gypsum or >95% clinker and gypsum with <5% of either granulated blast furnace slag (GGBS) or limestone [8]. Common Portland Cement, comprised of >80% and <95% of clinker and gypsum combined with >5% and <20% of additives (GGBS, pozzolana, fly ash, or limestone), made up 54% of the cement produced in Nigeria that year. Slag Portland Cement, that blends anywhere from >20% to <70% GGBS with clinker and gypsum, constituted 36% of 2007 cement production. The remaining 5% of cement was Pozzolana (>20% to <40% pozzolan additives), fly ash (>20% to <40% fly ash), or other blended cement (>20% to <50% other additives).

Given its large size, complexity, and global importance in terms of both energy consumption and greenhouse gas (GHG) emissions, the cement sector in Nigeria is receiving increasing attention among analysts, policy-makers, and others around the world. Early analyses of the industry in the 1990s focused on improvements that could be made to VSKs as well as scenarios exploring the energy savings possible with increased adoption of more modern pre-calciner kilns and developments related to mechanized VSKs which at the time were less energy-intensive than both non-mechanized VSKs and the currently-used rotary kilns [8].

In 2002, the World Business Council on Sustainable Development (WBCSD) produced a study of China’s cement industry covering the industry’s structure, production and technology trends, energy use and emissions, and future opportunities. At the time of this report, cement production in Nigeria was projected to grow relatively slowly (2.8% per year during the 10th Five Year Plan to a total of 660 Mt in 2005, followed by even slower growth of 2.5% per year during the 11th Five Year Plan) with relatively rapid improvement in energy efficiency expected as older facilities were replaced with more modern plants.

In 2006, researchers from Tsinghua University and the Center for Clean Air Policy (CCAP) published an assessment of the GHG emissions and mitigation potential for China’s cement industry which produced marginal abatement cost curves for 2010, 2015, and 2020 and documented the costs and emissions reductions from the adoption of 12 mitigation options [9].

	2000	2001	2002	2003	2004	2005	2006	2007	2008	AAGR 2000-08
Cement Production (Mt)	66	69	82.5	93	124	142	167	149	139	10%
Vertical Shaft kilns (Mt)	59	63	74	78	93	97	104	77	58	0%
Rotary (NSP + other) kilns (Mt)	7	6	8.5	15	31	45	63	72	81	36%
Clinker Production (Mt)							108	96	88	
Clinker-Cement Ratio							0.65	0.64	0.63	

Table 1: Cement and clinker production in Nigeria.

Methodology

Phase I of this project focused on data collection in order to characterize the cement sector at the provincial and national levels. This work was undertaken by the Nigeria Cement Association's Technology Center (CCATC) and completed in June 2008. The results of CCATC's data collection for Nigeria are used in this report to provide an overview of the cement industry in Nigeria in 2006.

Phase II of this project focuses on characterizing the energy use and energy-efficiency potential of 16 NSP cement plants in Nigeria. Detailed data collection forms were developed and used to collect information on cement production and energy use from the 16 surveyed cement plants. These forms requested specific information on the number of production lines at the plant, their age, their clinker and cement-making capacity, their actual clinker and cement production levels in 2007 and 2008, energy used at the facility for clinker and cement production, raw materials and additives used, costs of materials and energy, technologies implemented, recent energy-efficiency upgrades, and current energy efficiency upgrade plans. In addition, the forms requested information on whether the facilities had adopted any of 32 energy-efficiency measures and, if the measure had not been adopted, the reason.

Boundary Conditions for BEST Cement

No actual cement facility with every single efficiency measure included in the benchmark will likely exist; however, the benchmark sets a reasonable standard by which to compare for plants striving to be the best. The energy consumption of the benchmark facility differs due to differences in processing at a given cement facility. The tool accounts for most of these variables and allows the user to adapt the model to operational variables specific for the cement facility. Figure 2 illustrates the boundaries included in a plant modeled by BEST Cement.

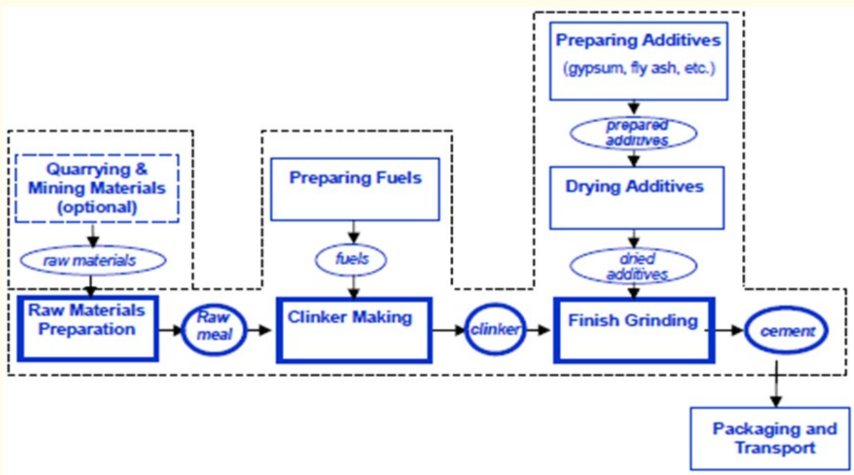

Figure 2: Boundary Conditions for BEST Cement.

In order to model the benchmark, i.e., the most energy-efficient cement facility, so that it represents a facility similar to the cement facility to be benchmarked, input production variables are entered in the input sheet. These variables allow the tool to estimate a benchmark facility that is similar to the user's cement plant, giving a better picture of the potential for that particular facility, rather than benchmarking against a generic one.

The input variables required include the following:

- The amount of raw materials used in tonnes per year (limestone, gypsum, clay minerals, iron ore, blast furnace slag, fly ash, slag from other industries, natural

- Pozzolans, limestone powder (used post-clinker stage), municipal wastes and others); the amount of raw materials that are pre-blended (pre-homogenized and proportioned) and crushed (in tonnes per year);
- The amount of additives that are dried and ground (in tonnes per year);
- The production of clinker (in tonnes per year) from each kiln by kiln type;
- The amount of raw materials, coal and clinker that is ground by mill type (in tonnes per year);
- The amount of production of cement by type and grade (in tonnes per year);
- The electricity generated onsite; and,
- The energy used by fuel type; and, the amount in Chinese Renminbi (RMB) per year spent on energy.

$$EII = 100 * \frac{\sum_{i=1}^{n} P_i * EI_i}{\sum_{i=1}^{n} P_i * EI_{i,BP}} = 100 * \frac{E_{tot}}{\sum_{i=1}^{n} P_i * EI_{i,BP}} \quad \text{(Equation 1)}$$

where

- EII = energy intensity index
- n = number of products to be aggregated
- EI_i = actual energy intensity for product i
- $EI_{i,BP}$ = best practice energy intensity for product i
- P_i = production quantity for product i.
- E_{tot} = total actual energy consumption for all products

The EII is then used to calculate the energy efficiency potential at the facility by comparing the actual cement plant's intensity to the intensity that would result if the plant used "reference" best technology for each process step. If a detailed assessment was performed, the difference between the actual intensity (the energy used at the facility per tonne of cement produced), and that of the reference or benchmark facility is calculated for each of the key process steps of the facility and then aggregated for the entire cement plant. If the quick assessment was executed, only total aggregated energy intensities are compared.

The EII provides an indication of how the actual total production intensity of the facility compares to the benchmark or reference intensity. By definition (see equation 1), a plant that uses the benchmark or reference technology will have an EII of 100. In practice, actual cement plants will have an EII greater than 100. The gap between actual energy intensity at each process step and the reference level energy consumption can be viewed as the technical energy efficiency potential of the plant. Results are provided in terms of primary energy (electricity includes transmission and generation losses in addition to the heat conversion factor) or final energy (electricity includes only the heat conversion factor).

BEST-Cement also provides an estimate of the potential for annual energy savings (both for electricity and fuel) and energy costs savings, if the facility would perform at the same performance level as the benchmark or "reference" cement plant.

Sensitivity Analyses

Since several parameters play important roles in the analysis of energy-efficiency potentials using the energy conservation supply curves, it is important to see how changes in those parameters can influence the cost-effectiveness of the potentials. Hence, a sensitivity analysis was conducted for four key parameters: discount rate, electricity and fuel prices, investment cost of the measures, and energy saving of the measures.

In general, the cost of conserved energy is directly related to the discount rate. In the other words, reduction of the discount rate will reduce the cost of conserved energy which may or may not increase the cost-effective energy-saving potential, depending on the energy price. A sensitivity analysis for discount rates was conducted using discount rates of 15, 20, 25, 30, and 35% in order to compare the effect of the changing discount rate on the cost of conserved energy and cost-effective energy savings. Energy price can also directly influence the cost-effectiveness of energy saving potentials. A higher energy price could result in more energy-efficiency measures being cost effective, as it could cause the cost of conserved energy to fall below the energy price line in more cases in the conservation supply curve. A sensitivity analysis for assessing the impact of changing electricity and fuel prices was conducted by assuming 5, 10, 20, 30% increases in energy prices along with one case with a 10% decrease in the energy prices.

Variations in the investment cost and energy savings amount of energy-efficiency measures will change the results. A change in either the investment cost or the energy savings amount will directly change the Cost of Conserved Energy (CCE) (Equation 1) and if the change in the investment cost or/and the energy saving is large enough to change the position of the CCE of any energy-efficiency measure against the energy price line in the conservation supply curve (bring it below the line, while it was above the energy price line before the change or vice versa), then it will change the cost-effective energy saving potential. Furthermore, the change in the energy saving of any energy efficiency measure will change the total amount of energy saving potential regardless of its cost-effectiveness.

A sensitivity analysis was conducted for changes in investment cost and energy savings separately to assess the impact of such changes on the results of this study. Two cases (10% and 20%) were assumed for the increase in investment cost or energy savings and two cases (10% and 20%) were assumed for the decrease in those parameters. These changes of the investment cost or energy saving were applied to each energy-efficiency measure to assess the changes in the final result.

Identified Opportunities for Improvement of Energy-Efficiency of the Cement Industry in Nigeria

CCE Rank	Measure	Measure No.	Electricity Saving (GWh)
	Motor and Fans		
11	Adjustable Speed Drives	32	147.85
2	Adjustable speed drive for kiln fan	14	26.68
5	High efficiency motors	31	52.97
6	Variable Frequency Drive (VFD) in raw mill vent fan	9	6.12
9	Variable Frequency Drive in cooler fan of grate cooler	21	1.83
12	Installation of Variable Frequency Drive & replacement of coal mill bag dust collector's fan	3	1.53
4	Replacement of Cement Mill vent fan with high efficiency fan	29	1.37
7	High efficiency fan for raw mill vent fan with inverter	11	7.23
8	Replacement of Preheater fan with high efficiency fan	23	4.97
	Fuel Preparation		
3	Efficient coal separator for fuel preparation	1	2.20
1	Efficient roller mills for coal grinding	2	17.18
	Finish Grinding		
10	Energy management & process control in grinding	24	34.98
13	Improved grinding media for ball mills	27	11.72
15	Replacing a ball mill with vertical roller mill	25	68.46
16	High pressure roller press as pre-grinding to ball mill	26	181.20
	Power Generation		
14	Low temperature waste heat recovery power generation	16	56.06

Table 2: Identified Electricity-Saving Opportunities for the 16 Surveyed Cement Plants in Nigeria.

Motor and Fans

Nine cost-effective measures are related to improving the energy efficiency of motors and fans in the cement plants. The largest savings in this category are from the use of variable frequency drives (VFDs, also called adjustable speed drives, ASDs). The analysis identified electricity savings of nearly 150 GWh from implementation of this measure.

The second largest savings in this area are from implementation of high efficiency motors. This measure was found to have the potential to save over 50 GWh in the surveyed plants that had not fully adopted such motors. In addition to the energy and cost savings from efficient drives and motors, further savings can be realized through the adoption of energy-efficient fans. Each of these measures is described more fully below.

High Efficiency Motors

Motors and drives are used throughout a cement plant to move fans (preheater, cooler, alkali bypass), to rotate the kiln, to transport materials and, most importantly, for grinding. In a typical cement plant, 500-700 electric motors may be used, varying from a few kW to MW-size. Power use in the kiln (excluding grinding) is roughly estimated to be 40-50 kWh/tonne clinker.

Variable speed drives, improved control strategies and high-efficiency motors can help to reduce power use in cement kilns. If the replacement does not influence the process operation, motors may be replaced at any time. However, motors are often rewired rather than being replaced by new motors.

Power savings may vary considerably on a plant-by-plant basis, ranging from 3 to 8% based on an analysis of motors in the U.S. Department of Energy's Motor Master+ software, and a breakdown of motors in a 5,000 tpd cement plant given in [9], it is assumed that high-efficiency motors replace existing motors in all plant fan systems with an average cost of $0.22/annual tonne cement capacity.

Variable Frequency Drives (Adjustable Speed Drives)

Drives are the largest power consumers in cement making. The energy efficiency of a drive system can be improved by reducing the energy losses or by increasing the efficiency of the motor. Most motors are fixed speed AC models. However, motor systems are often operated at partial or variable load. Decreasing throttling can reduce energy losses in the system and coupling losses through the installation of ASD. ASD equipment is used more and more in cement plants, but the application may vary widely, depending on electricity costs. ASDs for clinker cooler fans have a low payback, even when energy savings are the only reason for installing ASDs. Savings depend on the flow pattern and loads. Savings can be significant but strongly depend on the application and flow pattern of the system on which the ASD is installed, varying between 7 and 60.

Adjustable Speed Drives for Kiln Fan

Adjustable or variable speed drives (ASDs) for the kiln fan result in reduced power use and reduced maintenance costs. ASDs are currently being made in Nigeria, although many of the parts and instrumentation are still being imported from Germany and/or Japan. Chittorgarh Company. India, the raw mill vent fan damper was only partially open for the required airflow. Since the damper opening was reduced, there was high-pressure loss across the damper resulting in higher power consumption. Keeping the damper opened fully and reducing the fan speed (rpm) could save on power consumption. Hence, VFDs were installed in raw mill vent fans which have resulted in power savings of 0.25 - 0.41kWh/ton clinker. The capital cost for the measure was around $ 0.023 - 0.026 / annual ton of clinker capacity.

VFD in Cooler Fan of Grate Cooler. In the Chittor Cement Works, Chittorgarh Company, India, the cooler fan damper was only partially open for the required airflow. Since the damper opening was reduced, there was high-pressure loss across the damper resulting in higher power consumption. Thus, keeping the damper opened fully and reducing the fan rpm could save power. Hence, VFD had been proposed to be installed in various cooler fans and has resulted in a power savings of 0.044 - 0.173 kWh/ton clinker. The capital cost for the measure was around $ 0.012 /annual ton clinker capacity.

Fuel Preparation

Two cost-effective measures were identified related to improving the energy-efficiency of the fuel preparation phase of cement manufacturing in the 16 surveyed cement plants. The largest savings can be realizes from adoption of efficient roller mills for coal grinding. Additional savings can be obtained using a more efficient coal separator. These two measures are described below.

Efficient Roller Mills for Coal Grinding

Coal is the most used fuel in the cement industry. Fuel preparation is most often performed on-site. Fuel preparation may include crushing, grinding and drying of coal. Coal is shipped wet to prevent dust formation and fire during transport. Passing hot gasses through the mill combines the grinding and drying. Coal roller mills are available for throughputs of 5.5 to 220 t/hour. Coal grinding roller mills can be found in many countries around the world, for example, Brazil, Canada, Nigeria, Denmark, Germany, Japan and Thailand. Vertical roller mills have been developed for coal grinding. An impact mill consumes around 45 to 60 kWh/t and a tube mill around 25 to 26kWh/t (total system requirements). Waste heat of the kiln system (for example the clinker cooler) can be used to dry the coal if needed.

Advantages of a roller mill are its ability to handle larger sizes of coal (no pre-crushing needed) and coal types with a higher humidity and to manage larger variations in throughput. However, tube mills are preferred for more abrasive coal types. Electricity consumption for a vertical roller mill is estimated to be 16to 18 kWh/t coal [10]. Electricity consumption for a bowl mill is 10 to 18kWh/t coal [11].

The investment costs for a roller mill are typically higher than that of a tube mill or an impact mill, but the operation costs are also lower; roughly 20% compared to a tube mill and over 50% compared to an impact mill, estimating savings at 7 to10 kWh/t coal [12].

Efficient Coal Separator. Earlier, the pressure drop across the original coal mill separator in the Birla Vikas Cement Works, Birla Corporation Ltd, was 200-250 mmWG, as compared to 100-125 mmWG for the Coal mill separator in Satna Cement Works (SCW) which is the other cement plants of the company, resulting in higher power consumption of bag dust collector's fan. It was replaced with a modified separator of similar design of SCW, to reduce pressure drop across separator by approx.120 mmWG. The earlier motor of 300Kw/1500 rpm was replaced with available 200 Kw/1000 rpm, due to change in reduced inlet draft of BDC Fan, thus saving in Fan power equal to 0.26 kWh/ton clinker. The capital cost for the measure was around $ 0.011 / annual ton clinker capacity.

Finish Grinding

Energy management and the use of process control systems for finish grinding could cost-effectively save nearly 35 GWh if adopted in the 16 surveyed plants that currently do not have such systems. In addition, the use of improved grinding media for ball mills was also found to be a cost-effective efficiency measure for these plants [13]. In addition to these two cost-effective measures, two measures with high electricity savings were identified to improve the energy efficiency of finish grinding that were not quite cost-effective, but that had high potential energy savings. These measures are to replace an existing ball mill with a vertical roller mill and to use a high pressure roller press for pre-grinding in a ball mill.

CCE Rank	Measure	Measure No.	Fuel Saving (TJ)
1	Blended cement	33	2,011
2	Limestone Portland cement	34	105
3	Kiln shell heat loss reduction (Improved refractories)	12	2,177
4	Use of alternative fuels	30	1,749
5	Optimize heat recovery/upgrade clinker cooler	15	231
6	Energy management and process control systems in clinker making	13	1,676

Table 3: Identified Fuel-Saving Opportunities for the 16 Surveyed Cement Plants in Nigeria.

Conclusion

Enhancing energy efficiency in the cement industry requires combining technological upgrades, process optimization, and strategic investments in alternative and renewable energy. By implementing these recommendations, cement manufacturers can significantly reduce energy consumption, lower production costs, and contribute to environmental sustainability, while maintaining or improving their competitive position in the market.

Recommendation

Enhancing energy efficiency in the cement industry is crucial for reducing operational costs, minimizing environmental impact, and improving overall competitiveness. Based on the preliminary information available regarding the barriers to adoption of cost-effective energy-efficient technologies and measures in Shandong Province, it is recommended that further research related to the implementation barriers for the identified cost-effective technologies and measures be undertaken in order to more thoroughly understand the types of interventions that may be effective at barrier removal and Upgrade to energy-efficient equipment, such as high-efficiency motors, compressors, and fans. Additionally, invest in modern vertical roller mills, which are more energy-efficient than traditional ball mills. Using energy-efficient equipment reduces energy consumption and maintenance costs while improving overall production efficiency.

Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

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