Chapter

Energy and Economic Comparison of Different Fuels in Cement Production

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Abstract

Cement clinkerisation is the major energy-consuming process in cement manufacturing due to the high-temperature requirement. In this paper, energy data including specific energy consumption, forms, and types of energy used at different units of cement manufacturing processes were analyzed and compared for effectiveness, availability, cost, environmental, and health impact. Data from three different cement industries in Nigeria labeled as A, B, and C were used for the analysis in this study. The results of this research work established that coal is the cheapest energy source but environmental issues exonerate it from being the choice energy source. LPFO and Natural gas give better production output while minimizing pollution and health issues. When benchmarked against each other, Factory B was found to be the most energy-efficient in terms of output and cost of production. Although coal is cheaper compared to fuel oil and supposed to contribute a share of fuel used in cement industries, the industries are moving towards the use of alternative and conventional fuels to reduce environmental pollution. It is therefore recommended that deliberate effort to achieve appreciable energy-efficient levels should be the priorities of the cement industries in Nigeria.

Keywords: Cement, Coal, Fuel oil, Natural gas, Energy Consumption, Energy source, Clinkerization

1. Introduction

Cement is regarded as a binder, a material useful in building and civil construction that hardens and adheres to other substances to bind them together. Cement is rarely used only, but to bind other building materials such as gravel and sand together. When mixed with fine aggregates, it is used to produce mortar for mansory or with gravel and sand, it produces concrete. Energy consumption in the Industrial sector ranges from 30–70% of the total energy used in some selected countries as previously reported by [1]. The cement sub-sector utilizes nearly 12–15% of entire industrial energy usage [1, 2] due to the high temperatures required in the kilns. Cement is a vital product used in society for constructing modern infrastructure as well as safe and comfortable buildings. Cement manufacturing is an energy-intensive process due to the high temperature required in the kilns for clinkerization. Energy cost contributes to about 40–50% of cement production cost in Nigeria depending on the production process and type of cement with 1 tonne of cement requiring 60–130 kg of fuel or its equivalent and about 105 kWh of electricity [3].

Fossil fuels like coal, pet coke, fuel oil, and gas are the primary fuels used in the cement kilns. These fuels which exist in solid, gaseous, and liquid also provide most of the global energy needs and demand. Some of these fuels e.g. coal and natural gas are utilized in their natural form while energy resources like petroleum, shale, and bituminous sands require processing, refinement, and distillation to produce consumable fuels.

The conservation of energy is an essential step to take towards overcoming the mounting problems of the worldwide energy crisis and environmental degradation. In particular, developing countries are interested in increasing their awareness of the energy efficiency in power generation and consumption in their countries. However, usually, only limited information/sources on the rational usage of energy are available [4].

The energy source or mix to be implemented will have to meet the varying energy demand of the countries, industry, or organizations as well as improving the security against the energy crisis. Fuel availability, ease of processing and handling, environmental pollution, storage, and cost are some of the factors that determine the selection of fuel [5].

In cement production, the energy use is distributed as 92.7% for pyro-processing, 5.4% for finishing grinding, and 1.9% for raw grinding [6]. The type of fuel used determines the quantity of greenhouse gases (GHG) emission, cement product quality, and cost. Large volumes of CO_2 are emitted during cement production and it is believed that this sector represents 5%–7% of the total CO_2 anthropogenic emissions [7, 8]. Environmental concerns are of great importance since cement and the production of its raw materials are extensively based on fossil fuels.

There are three processes in cement manufacturing plant [9]: raw material mixing, pyroprocessing (burning), and grinding.

Raw material processing: this can be the wet process or dry process depending on the method of milling. In the wet process, raw materials other than plaster are crushed to a diameter of approximately 20 mm by a crusher and mixed in an appropriate ratio using an automatic weigh balance. Its particle size is further reduced to finer particles by tube mill of 2–3.5 m diameter and length 10–14 m in the presence of water from a slurry of 35–40% [10]. In the dry process, the raw materials (calcareous and argillaceous) are separately crushed to about 2–5 cm. They are later dried in a cylindrical rotary drier having a diameter of 2 m and a length of about 20 m, pulverized into fine particles, and stored. The pulverized fine raw materials are then mixed automatically in proportions to form a uniform dry mix and sent to a kiln for clinker production where about 80% of the energy used in cement production is consumed [4, 11]. The electrical energy requirement of the dry process is higher compared to the wet process while the thermal energy consumption is very low compared to the wet process. The primary energy consumption in a typical dry process is about 75% fossil fuel and up to 25% electrical energy [1].

The pyroprocessing in the kiln generates about 81% of cement production CO_2 emission; 36.8% from fuel combustion while 46.3% is from pyroprocessing reaction [6]. Hence, the choice of fuel and energy conversion efficiency have a net effect on cement CO_2 emission. The exact consumption of energy in the production of cement varies from one technological approach to another." The major fuel used in clinker production is coal and petroleum coke but alternate energy source like biomass, waste heat, fuel oil, solvent, tyres, gas, etc. are becoming attractive in recent years [12]. A considerable amount of energy is consumed in manufacturing cement. Thus, the focus should be centered on energy savings and energy-associated environmental emissions both locally and universally [13–17]. The chief share of the total thermal energy consumption is required by pyro-processing and it accounts for approximately 93–99% of the entire fuel consumption [1]. Though electrical energy is principally used for the operation of the raw materials which accounts for 33% of its consumption, and clinker crushing and grinding equipment which accounts for 38% of its consumption. Electrical energy is needed to operate equipment such as combustion air blowers, kiln motors, and fuel supply, etc. accounting for 22% of its consumption to sustain the pyro-process.

The calorific value of common fuels used in cement production is shown in **Table 1**. Natural gas has the highest energy content followed by fuel oil while coal has the least energy content of the three fuels.

Coal is regarded as the most abundant fossil fuel on earth, with a global recoverable reserve estimated at 216 years [18]. Coal provides 26% of global primary energy consumption and contributes 41% of global electricity generation.

Fuel oil is a distillate or a residue fraction produced from petroleum distillation. It is any liquid from petroleum that is burned in a furnace for heat and power generation In terms of industrial use of fuel especially in cement kiln firing, heavy fuel oil, or low pour fuel oil (LPFO). Heavy oil is a long residue obtained from the atmospheric distillation column. Heavy fuel oil is used mainly to produce electricity, to fire boiler and furnace in industry, notable the cement, pulp, and paper, and to power large marine and other vessels.

Natural gas is a fossil fuel like oil and coal, thus it is essentially the remains of plants, animals, algae, and microbes that lived millions of years ago. Over the years, natural gas has secured its vital role in every aspect of world development, particularly its role to replace coal and oil with having a high energy content that the two aforementioned.

In Nigeria, cement production has increased exponentially from 2 million tonnes in 2002 to about 17 million in 2011 [19]. Thus, making Nigeria's cement industry contributing about 60% of the West African region's cement output in 2011. Since the sector consumes a considerable amount of energy, it is necessary to identify and reduce energy wastage [20]. Also, the unit fuel cost for cement production in Nigeria is $30 per tonne which is very high compared to an advanced country like China ($6 per tonne) thereby contributing to the high cost of unit price cement [21]. The use of energy utilization analysis for energy and financial savings has generated research interest in recent years [22]. Therefore, this research work aims to analyse the cost vis-à-vis the pollution tendencies of each energy source and its consequence on health and the environment from the energy data obtained from the cement industries.

S/N	Fuel	Energy Content (MJ/Kg)
1	Coal	36.3
2	Natural gas	54.0
3	Fuel oil	45.6

Source: Engineering ToolBox, (2008). Fossil and Alternative Fuels Energy Content. *[online] Available at: https://www.engineeringtoolbox.com/fossil-fuels-energy-content-d_1298.html [Accessed: 23/2/2021].*

Table 1.
Energy contents of coal, fuel oil, and natural gas.

2. Methodology

2.1 Data collections

Three major Cement producers in Nigeria (Dangote Cement in Obajana, Kogi State; United Cement Company in Calabar, UNICEM - Cross River and Nigerian Cement Company in Nkalagu, NIGERCEM, Ebonyi State), labeled Factory A, B and C were approached for the Data on energies consumed during cement production and were collected for the analysis.

2.1.1 Calculations involved in the analysis

Specific heat:

The standard or universally accepted specific fuel consumption for clinker production is 720 Kcal/m^3 of clinker from:

$$\frac{Calorific\ value\ of\ gas \times Total\ consumed}{total\ clinker\ x\ 1000} = \frac{720Kcal}{m^3} \tag{1}$$

Let n = 1.

From ideal gas law: PV = nRT

$$R = \frac{P_{act} \times V_{act}}{T_{act}}\ at\ a\ given\ temperature\ and\ pressure \tag{2}$$

$$R = \frac{P_o \times V_o}{T_o}\ at\ normal\ condition\ (0\ °C\ and\ 1.0\ atm) \tag{3}$$

Therefore

$$\frac{P_{act} \times V_{act}}{T_{act}} = \frac{P_o \times V_o}{T_o} \tag{4}$$

$$\text{Volumetric flow rate}\ \ Q = \frac{V}{t} \tag{5}$$

Substituting Eq. (4) into (1) and simplifying we have

$$Q_o = Q_{act} \times \left[\frac{P_{act}}{P_o}\right] \times \left[\frac{T_o}{T_{act}}\right] \tag{6}$$

Where Q_o = Q_N = Gas flow rate at normal condition.

Q_{act} = measured flow rate in m^3/hr.

P_{act} = P measured + P ambient

P ambient = 1.01325 bar.

P_o = pressure at normal condition

T_o = temperature at normal condition

Therefore

$$Q_N = Q_{act} \times \left[\frac{P_{measured} \times P_{ambient}}{P_O}\right] \times \left[\frac{T_O}{T_{act}}\right]\left(\frac{Nm^3}{hr}\right) \tag{7}$$

Since we are dealing with volume and not flow rate. Then equation becomes this

$$V_o = V_{act} \times \left[\frac{T_o}{T_{act}}\right](Nm^3) \tag{8}$$

V_o = volume at normal condition.

Since all the pressure and temperature are in atmospheric and absolute units. In Eq. (8) the fluid in meter cubic (m^3) is converted to Normal cubic meter (Nm^3). The reversal of Eq. (8) converts the fluid in Normal cubic meter to meter cubic. Therefore Eq. (8) becomes:

$$V_{act} = V_o \times \left[\frac{P_o}{P_{act}}\right] \times \left[\frac{T_{act}}{T_o}\right](m^3) \tag{9}$$

V_{act} = measured volume in m^3.
n = number of moles.
R = molal gas constant.
T_{act} = temperature in Kelvin.
P_{act} = $P_{measured}$ + Pambient.

2.1.2 Cost analysis

The following cost of material for fuel oil, natural gas, and coal was as obtained [23–25], respectively;

Fuel oil (diesel) = ₦223.740 ($0.587) per litre.
Natural gas = $2.76 per 1000 ft^3.
Coal = $68.9 per tons.

The calculated cost in **Table 2** is subject to some conversions as the consumption of coal, fuel, and energy is given in tonnes. The cost for natural gas is given in $/$ft^3$ and the cost of fuel oil is given in $ per liters. For the two cases where volume is used, the quantity consumed is converted from tonnes to ft^3 and liters for natural gas and fuel oil, respectively.

Density of fuel oil (diesel) = 0.85 kg/litre.
Density of natural gas = 0.68 kg/m^3.
Density of coal = 1506 kg/m^3.
1 tonnes = 1,000 kg.
1 m^3 = 35.315 ft^3

$$volume = \frac{mass}{density} \tag{10}$$

3. Results

3.1 Flue gas composition

Table 2 shows the various proportions of flue gases in coal, fuel oil, and natural gas (**Figure 1**).

4. Discussion of results

From the specific heat of consumption point of view, it is observed that of the three different cement companies that were used for analysis; the specific heat of

		COAL				FUEL				NATURAL GAS			
SN	**Factory**	**Prod., tons**	**Total Fuel**	**C_P, Kcal/kg**	**Cost, $**	**Prod., tons**	**Total Fuel**	**C_P, Kcal/kg**	**Cost, $**	**Prod., tons**	**Total Fuel**	**C_P, Kcal/kg**	**Cost, $**
1	A	6,000	720	600	49,608	6,014	428,755	697	2.96×10^8	6,081	470,470	698	67,435,924
		6,088	735	604	50,641.5	6,013	421,850	676	2.91×10^8	6,095	466,260	690	66,832,474
		6,148	745	606	51,330.5	6,074	425,987	686	2.94×10^8	6,168	460,000	673	65,935,182
		6,074	725	597	49,952.5	6,148	424,586	675	2.93×10^8	6,081	471,363	699	67,563,925
2	B	4,600	595	647	40,995.5	5,028	428,577	834	2.96×10^8	4,074	313,647	694	44,957,331
		4,720	608	644	41,891.2	5,145	412,580	784	2.85×10^8	3,563	310,840	787	44,554,983
		4,175	540	646	37,206	5,111	417,255	798	2.88×10^8	3,612	306,666	766	43,956,693
		4,834	621	642	42,786.9	5,273	435,674	808	3.01×10^8	3,554	314,242	798	45,042,616
3	C	5,125	612	597	42,166.8	5,412	385,789	697	2.65×10^8	3,798	282,283	670	40,461,698
		5,175	625	604	43,062.5	5,466	383,298	689	2.65×10^8	3,908	276,000	637	39,561,109
		5,164	616	596	42,442.5	5,533	382,037	675	2.64×10^8	3,807	279,756	662	40,099,485

Prod = 24 hours Production in tons; C_P = Specific heat, Kcal/kg; Total fuel = Total fuel consumed during the 24 hours of production, tonnes.

Table 2.
Calculated specific heat consumption and cost for the different fuel.

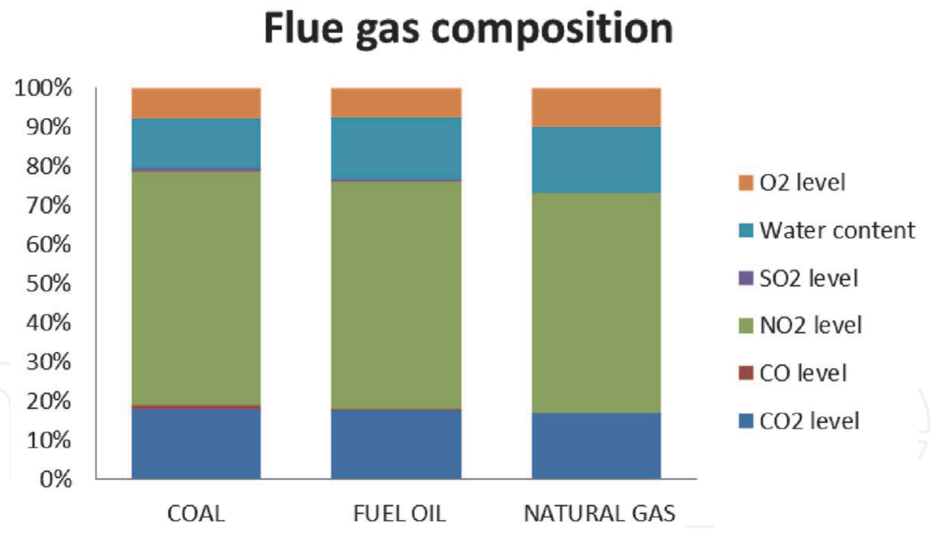

Figure 1.
Flue gas from Coal, Fuel oil, and Natural gas from gas analyses.

consumption of coal was less compared to that of fuel oil and natural gas (**Table 2**). This indicates that coal, as a good source of energy for firing in the clinker considering its high calorific value. On the other hand, the cost analysis revealed coal as the cheapest energy used by these cement companies as shown in **Table 2**, that is, 1 m^3 of coal was consumed at \$103.766. For natural gas, 1 m^3 of it was consumed at \$9.747 while 1 m^3 of LPFO was consumed at \$586.8513.

Natural gas is the most readily available, and highly economical source of energy in use for the production of cement, compared to coal and fuel oil. Related results were reported by Ohunakin et al., [3] for Energy and Cost Analysis of Cement Production Using the Wet and Dry Processes in Nigeria. Based on the flue gases produced from these three sources of energy at Dangote cement (**Table 3**), Sulphur oxides emissions are relatively higher in coal and fuel oil than in natural gas. For carbon monoxide emission, this is high in coal followed by fuel oil while it is low in natural gas. Nitrogen oxide emissions are high in coal and fuel oil compared to natural gas. Also, Carbon Dioxide emission is high in coal and fuel oil compared to natural gas. In a similar study, Worrell et al., [26] report that fuels like coal and coke contribute to an increase in specific carbon dioxide emissions. Similarly, the Oxygen content is high in natural gas compared to coal and fuel oil. Based on the flue gases, natural gas presents itself as the most efficient and the most environmentally friendly source of energy.

DANGOTE	FLUE GAS (%) (From Gas Analyzer)		
Compound	**Coal**	**Fuel Oil**	**Natural Gas**
CO_2	18.01	17.73	17.02
CO	0.89	0.10	0.002
H_2O	12.80	15.51	16.71
NO_2	59.78	58.01	55.85
SO_2	0.82	0.92	0.05
CH_4	0.00	0.00	0.00
O_2	7.70	7.67	9.90

Table 3.
Comparison of flue gas from coal, fuel oil, and natural gas.

5. Conclusion

Although coal gave a cheaper consumption cost compared to fuel oil, for the production of cement, as expected, which could be used as an immediate substitute for natural gas, if peradventure its unavailability arises. Nevertheless, the environmental issues presented from its use as an energy source cannot be ignored. The LPFO (fuel oil) is quite expensive and would unavoidable impact on the cost of the final product. Benchmarking these three factories against each other, the cheapest energy consumption cost per ton production of cement was from Factory B while Factory A was the most expensive – for all three energy sources under investigation. From the analysis of the work, natural gas is one of the fossil fuels used in the production of cement. It is the cheapest amongst the three-fuel used in the production of cement and readily available. Also, natural gas emits lesser greenhouse gases to the environment, thereby lowering its effect on plant and animal health. Coal which is a close substitute is unavailable due to the closing down of Nigeria's coal mine and it poses too much threat to the environment and the health of plants and animals. Fuel oil is also available but as of now it is the most expensive fuel used in Nigerian cement industries and it also poses a high threat to the environment and life.

6. Recommendations

Energy sources have a direct impact on the market price of cement, the environment, and human health. Natural gas is an available energy source in Nigeria, and more economical and environmentally friendly compared to coal and fuel oil. It is therefore recommended - to cut down energy costs, guarantee power supply to the power plant, and minimize the emission of threats caused by cement industries to the environment. Factory B was most energy-efficient and a closer understanding of their process should be considered by Factory A and C. The unit cost of fuel oil component, the commonly used energy source in cement production in Nigeria is very high, over $15 as against $6 in China [3]. This is responsible for the high cost of cement in Nigeria. Thus, the need for an energy-efficient production process is recommended.

Conflict of interest

There is no conflict of interest associated with this work.

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References

[1] N. A. Madlool, R. Saidur, M. S. Hossain, and N. A. Rahim, "A critical review on energy use and savings in the cement industries," *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 2042–2060, 2011, Accessed: Nov. 08, 2020. [Online]. Available: https://ideas.repec.org/a/eee/rensus/v15y2011i4p2042-2060.html.

[2] J. P. John, "Parametric Studies of Cement Production Processes," *J. Energy*, vol. 2020, 2020, doi: 10.1155/2020/4289043.

[3] O. S. Ohunakin, O. R. Leramo, O. A. Abidakun, M. K. Odunfa, and O. B. Bafuwa, "Energy and Cost Analysis of Cement Production Using the Wet and Dry Processes in Nigeria," *Energy Power Eng.*, vol. 05, no. 09, pp. 537–550, 2013, doi: 10.4236/epe.2013.59059.

[4] C. Galitsky and L. Price, "Opportunities for Improving Energy Efficiency, Reducing Pollution and Increasing Economic Output in Chinese Cement Kilns," *ACEEE 2007 Summer Study Energy Effic. Ind.*, pp. 1–12, 2007.

[5] P. Oladunjoye, "Nigeria: Cement Production And Survival of the Construction Industry - allAfrica.com," *Daily Independent*, Jun. 04, 2011. https://allafrica.com/stories/201106061192.html (accessed Nov. 08, 2020).

[6] W. T. Choate, "Energy and Emission Reduction Opportunities for the Cement Industry," *Energy Effic. Renew. Energy*, pp. 1–41, 2003.

[7] M. Schneider, M. Romer, M. Tschudin, and H. Bolio, "Sustainable cement production-present and future," *Cement and Concrete Research*, vol. 41, no. 7. Elsevier Ltd, pp. 642–650, 2011, doi: 10.1016/j.cemconres.2011.03.019.

[8] M. G. Rasul, W. Widianto, and B. Mohanty, "Assessment of the thermal performance and energy conservation opportunities of a cement industry in Indonesia," *Appl. Therm. Eng.*, vol. 25, no. 17–18, pp. 2950–2965, 2005, doi: 10.1016/j.applthermaleng.2005.03.003.

[9] P. A. Alsop, *The Cement Plant Operations Handbook*, Third. Portsmouth: David Hargreaves, International Cement Review, 2001.

[10] Portland Cement Association, "Report on Sustainable Manufacturing," 2006. [Online]. Available: www.cement.org/smreport11.

[11] R. G. Bond and C. P. Straub, *CRC handbook of environmental control*, vol. 4. Cleveland: CRC Press, 1974.

[12] WSP Parson Brinkerhoff and DNV GL, "Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050: Cement," 2015.

[13] Engin & V. Ari, Energy auditing and recovery for dry type cement rotary kiln systems. *Energy Conversion and Management*, 46, 2005

[14] D. Gielen, & P. Taylor, Indicators for industrial energy efficiency in India. *Energy*, 34, 2009

[15] C. Sheinbaum, & I. Ozawa, Energy use and CO2 emissions for Mexico's cement industry. *Energy 23(9)*, 725–32, 1998

[16] J. Soares, & M. Tolmasquim, Energy efficiency and reduction of CO2 emissions through 2015. *Mitigation and Adaptation Strategies for Global Change*, 5, 297–318, 2000

[17] E. Worrell, & N. Martin, Potentials for energy efficiency improvement in the US cement industry. *Energy, 25*, 189–214, 2000

[18] IEA (2004), *Coal Information 2004*, OECD Publishing, Paris, https://doi.org/10.1787/coal-2004-en.

[19] Olayinka S. Ohunakin, Oluwafemi R. Leramo, Olatunde A. Abidakun, Moradeyo K. Odunfa, Oluwafemi B. Bafuwa, 2013, "Energy and Cost Analysis of Cement Production Using the Wet and Dry Processes in Nigeria", Energy and Power Engineering, 2013, 5, 537-550

[20] N. A. Madlool, R. Saidura, M. S. Hossaina, and N. A. Madloo Rahim, "A Critical Review on Energy Use and Savings in the Cement Industries," Renewable and energy Reviews, Vol. 15, No. 4, 2011, pp. 2042-20 http://dx.doi.org/10.1016/j.rser.2011.01.005

[21] http://www.nigerianbestforum.com/blog/?p=59984

[22] A. Avami and S. Sattar, "Energy Conservation Opportunities: Cement Industries in Iran," International Journal of Energy, Vol. 3, 2007, pp. 101-110.

[23] globalpetrolprices.com. (2021, January 15). *Nigeria Diesel Prices, liter, 11 - Jan - 2021*. Retrieved from GlobalPetrolPrices.com: https://www.globalpetrolprices.com/Nigeria/diesel_prices/

[24] Market Insider. (2021, January 15). *Natural Gas (Henry Hub)*. Retrieved from Market Insider: https://markets.businessinsider.com/commodities/natural-gas-price

[25] Market Insider. (2021, January 15). Coal. Retrieved from Market Insider: https://markets.businessinsider.com/commodities/coal-price

[26] Worrell, K. Kermeli, & C. Galitsky, *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making.* Utrecht, United states ENERGY STAR, 2013