Influence of Variable Clinker Proportions and Alternate fuels on Carbon-Dioxide emissions: Case Analysis of Cement Manufacturing Units in India

Kshitij Sharma[0000-0003-1296-8628], Rajeswara Rao KVS[0000-0003-1592-5578]

Student, Associate Professor
Department of Industrial Engineering & Management,
RV College of Engineering, Bangalore, India

Abstract : The Cement manufacturing sector in India is among the high energy consuming and Carbon Dioxide emission-intensive sectors accounting for nearly 7-8% of the global carbon dioxide emissions. Carbon Dioxide contributes to nearly 60% of the total pollutants generated from cement production units. In the past few years, the demand for cement has increased by 5.9% CAGR and hence the emissions have also increased. After the Paris Agreement, the industry is under tremendous pressure from the clients, government, and society to decarbonize rapidly. Different measures have been taken by the cement industries in reducing emissions such as improving thermal efficiency, use of alternative fuels, clinker reduction, novel cement and Carbon Capture and Storage technologies. The authors in this research paper analyzes the impact of Clinker Reduction and the use of alternative fuels on the process emission, combustion emission, and total emission in a cement manufacturing unit. To simulate the studies a Decision Support Framework was built for calculating process emissions and combustion emissions considering a multitude of variables. These types of studies enable organizations to decide on input variables aimed at reducing emissions at different stages of cement manufacturing process, there by contributing towards addressing two major goals Affordable and Clean Energy and Climate Action of Sustainable Development Goals 2030.

Keywords – Cement, Carbon Dioxide, Emission, Alternative fuels, Clinker Proportion, Decarbonization, Sustainable Development Goals, Decision Support Framework, Simulation.

I. Introduction

There is undeniable proof that the build-up of man-made greenhouse gases in the environment is changing the global climate rapidly, which will have serious repercussions on Humans, the Environment, and Economics in the coming years. This severe problem of climate change has been addressed by major international agreements such as the 2015 Paris agreement, the 1997 Kyoto Protocol, and the 1992 United Nations Framework Convention on Climate change (UNFCCC). The primary objective of these agreements is to limit the GHG in the atmosphere, which otherwise will have a detrimental impact on global climate. Several countries across the globe have set a target to achieve net-zero carbon emission by mid-century. To reach this decarbonization goal by 2050, three things are important - Improved thermal efficiency followed by shift towards renewable energy, and improved technologies. Out of seventeen Sustainable Development Goals (SDGs), the paper focuses on two major goals – Affordable and Clean Energy and Climate Action. **Affordable and Clean Energy,** goal 7 of 17 SDGs focuses on shifting to cleaner energy sources such as solar energy, wind energy and thermal Energy by maintaining cost standards for various energy efficient technologies that can help in reducing the global energy consumption by industries and buildings by up to 15%. **Climate Action**, goal 13 of the 17 SDGs focuses on strengthening resilience and adaptive capacities of countries to different climate related hazards and natural disasters by integrating different climate change measures into a country's national strategies, policies, and planning. According to the SDG performance report, India ranks 117 on the SDG index. The country is working rapidly to shift towards cleaner energies and focusing on climate actions.

Concrete is an important construction ingredient and is the second most-consumed man-made resource after water. Cement is the primary component of concrete used for civil engineering developments. The Cement Industry is one of the most important sectors when it comes to the economic development of any country, especially in developing countries where the construction industry is the spine of the economy. However, it is also one of the top sectors contributing to the highest carbon emission globally. In 2019, the cement industry produced approximately 3.6GGT of CO2 which is greater than the total CO2 emission from the EU-28 countries. For each ton of cement produced, approximately 925 kilograms of CO2 is released.

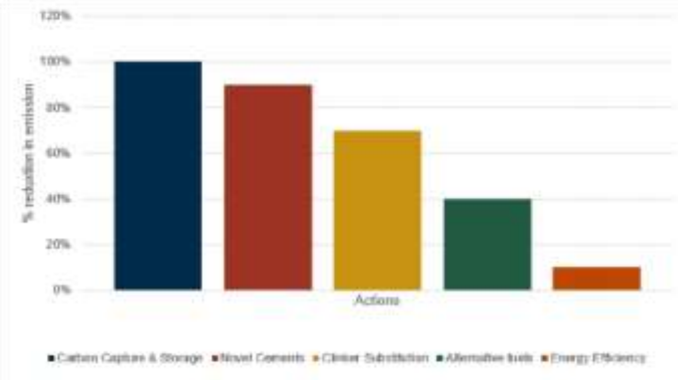

Figure:1 Different Strategies for Emission Reduction.

After the Paris agreement in 2015, which aims to limit the global temperature below 2 degrees from the preindustrial levels, cement industries have taken certain measures to reduce carbon emissions. A few of the pathways taken by the cement sector are **a) Improving thermal efficiency** by using efficient technologies in the kiln. Technologies like waste heat recovery technology can reduce the overall emission by up to 15%. Only 5% of the waste heat utilization can reduce the fuel requirement by up to 50%. **B) Using alternative fuels** is one of the most efficient pathways of reducing carbon emissions. A shift toward energy-efficient fuels such as biofuels, waste, etc can reduce carbon emission by more than 30%. **C)Clinker Reduction** is another strategy to reduce carbon emissions. The construction industry has adapted this alternative as a strategic approach to meet CO2 reduction goals. Less clinker content cement can help in saving energy, minimize pollutants, reduce raw material consumption, and can influence the utilization of waste products that otherwise could be hazardous to the environment. High blended cement can reduce emission per kilogram up to four times. **D)Novel Cement** is another way of reducing carbon emission by substituting the OPC in all manner. Novel cement takes several alternatives of clinker to build the cement which has got the same strength. However, not many novel cements have been commercialized yet on a large scale and are currently used only in niche applications. **E) Carbon Capture and Storage,** which is the most crucial pathway to achieve net-zero by 2050. It can reduce carbon emissions by up to 100%. There are three steps involved in this. Carbon Capture, which is the easiest part, transportation, and storage which is complex because of the current most feasible alternatives being pumping of CO2 in different oil wells and geological formations. However, because of the cost of technology and the low-level support for decarbonization, CCS adoption is likely to be seen after 2030.

II. Cement Manufacturing

The manufacturing of Cement is a complex process. After querying and grinding and blending in the correct chemical composition, the raw meal is heated at a high temperature of nearly 1500 degrees Celsius in the rotary kiln, which is a fuel-intensive process called pyro processing. This gives rise to the formation of clinker, which can be a final product for a clinker plant or a raw material for a grinding plant. This clinker is further ground with gypsum and other additives to manufacture different types of cement. The manufacturing of cement can be classified into several basic stages:

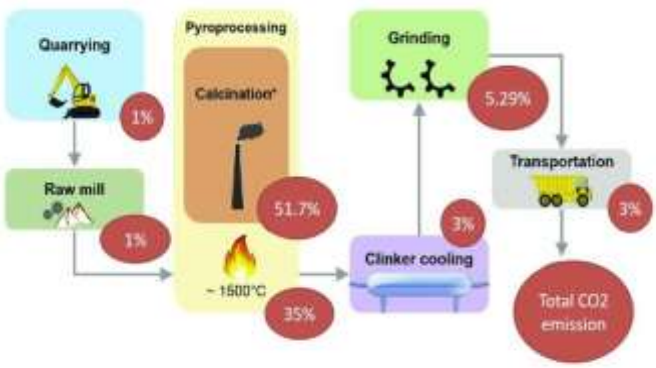

Figure 2: Different Stages of Cement Manufacturing Unit with their CO2 contribution

A. Crushing and Grinding – In this step, the raw materials are crushed and then ground, usually in a rotating cylindrical ball or tube mill containing steel grinding balls. The grinding could be wet or dry based on different processes. Cylindrical rotary dryers are used to dry raw materials for dry grinding. Soft materials break by the vigorous moving with water in wash mills, producing a fine slurry, then enter a compartment of screens to remove bigger particles.

B. Blending – The dry mixes are stored in the silos whereas the slurry tanks are used for wet processes. To mix the dry materials homogeneously, high agitation and vigorous circulation is induced using compressed air in the silos. Whereas the wet mixture in the slurry tank is homogenized by mechanical means. The amount of water is reduced in slurry from 35-40% to 20-30% and then the cake is fed to the kiln. This reduces the consumption of fuel for burning.

C. **Burning –** This is the most energy-consuming and carbon dioxide emitting stage of cement manufacturing. The process is also called pyro processing, a stage in which calcium carbonate reacts with silica-bearing minerals to form a mixture of calcium silicates. It involves 3 steps: a) drying/preheating, b) calcining and c) burning(sintering).

D. **Cement Grinding –** The clinker produced in the previous stage is ground with gypsum and other additives based on the type of cement manufactured in the cement mill. Gypsum and /or natural anhydrite are added to regulate the setting time of the cement.

III. Emission in Cement Industry

The cement Industry is a very high energy intensive and carbon intensive sector and hence correspondingly requires an adequate quantity of resources in form of raw materials, thermal fuels, and electrical power. There are three different types of emission in cement industry:

a. **Process Emission –** This emission is a result of creating clinker from limestone in the rotary kiln. When the fine ground limestone mix is heated and transformed into a clinker, a calcination process occurs. In this process, CO_2 is released from the limestone. This process contributes to nearly 55% of the total carbon emission from cement production.

b. **Combustion Emission –** It results from creating energy in association with heating of the preheater tower and Kiln. Kilns are usually heated by coal, oil or natural gas that results in 35% of the total carbon emissions.

c. **Indirect Emissions –** It accounts for only 5-10% of the total emission which comes from electricity used to power additional plant machinery and the transportation of cement.

IV. Simulation of Carbon Dioxide Emissions

One of the major problems faced during modeling is the quality of the result. For industry, in which only cement production data is available, it becomes necessary to consider several factors and assumptions to calculate precise emissions. Total emission in the cement industry is the sum of Process Emission, Combustion Emission, and Indirect emission. However, for the simulation and to analyze how clinker reduction and use of alternative fuels influence carbon emissions, the focus is on Process emission and combustion emission. According to the International Panel on Climate change (IPCC) it is not recommended to use cement production data for modelling CO_2 emissions because most of the emissions in the cement industry results from the production of clinker. To produce one ton of clinker, approximately 3100MJ of energy is required. To produce this amount of energy, different fuels are used based on availability and feasibility. Different factors influence these three emissions

A.) Calculating Process Emission

Process emission results from the calcination process, which is the process of formation of clinker. Therefore, Process emission is a function of clinker concentration (if we know the type of cement manufactured) or clinker production (if we only know the production data). The formula for calculating the Process Emission is:

$$Ep = Pcl * EFcl \quad \text{------------------------------(1)}$$

Where **Ep** is the Process Emission**, Pcl** is the Clinker Production **and EFcl** is the Emission factor for the clinker. The above equation (1) can be used in the clinker plants where the final product obtained is Clinker. The second case could be of an integrated or grinding plant, where the final product is the Cement. Different types of cement have different clinker concentration. For eg: Ordinary Portland Cement has 95% clinker content, Pozzolan Portland Cement has 80%, etc. Based on these Clinker to Cement ratios, we estimate the process emission. The revised Process Emission equation is as follows:

$$Ep = \sum_{i=1}^{m} EFci * Pc * Rclc * Ai \quad \text{------------------------------(2)}$$

Where **Ep** is the Process Emission, **I** the types of cement (OPC, PPC, BFSC etc), **Pc** is the Total Cement Production, **Rclc** is the Clinker to Cement Ratio and **Ai** is the amount of specific cement produced (in%). Equation 2 is useful when the total cement production is segregated based on the cement type.

b.) Calculating Combustion Emission

Combustion Emission results due to the burning of fuels to provide thermal energy to the Preheater and kiln for preprocessing to take place efficiently. There are different types of fuels used based on availability, costs, technology, etc. However, coal is the most prominent fuel used in the cement industry. The formula for calculating combustion emission is:

$$Ec = FR * CFVj * EFj * OCFj \qquad \text{------------------------------(3)}$$

$$Fr = ENc/CFVf \qquad \text{------------------------------(4)}$$

Where **Ec** is the Combustion Emission, **FRt** is the Total Fuel required, **CFVj** is the Calorific Value of fuel j, **EFj** is the Emission factor for fuel j, **OCFj** is the Oxidized Carbon Fraction for fuel j, **ENc** is Energy required to produce the amount of clinker. Equations 3 and 4 are used when there is only one fuel used. If certain combinations of fuel are used, the equations could be modified as follows:

$$Ec = \sum_{j=1}^{n} Fr * CFVf * EFf * OCFf \qquad \text{------------------------------(5)}$$

$$FRj = \left(\frac{ENc}{CFVj}\right) * Bj \qquad \text{------------------------------(6)}$$

$$ENc = \sum_{j=1}^{n} CFVj * FRj \qquad \text{------------------------------(7)}$$

$$FRt = FRj1 + FRj2 + \ \ldots\ldots\ldots \qquad \text{------------------------------(8)}$$

Where j is the type of fuel used (Coal, Natural Gas, Oil etc), Bj is the amount of fuel to be used (in %) (for eg: 80% coal and 20% Natural Gas)

V. Simulation Result

Using the above equations, a simulation was performed to analyze the impact of Clinker Reduction and Shift to alternative fuels. To analyze the impact of Clinker reduction, 4 different types of Cement were used.

Cement Type	Clinker to Cement Ratio
OPC	95%
PPC	80%
BFSC	60%
MC	75%

A linear graph was seen between the production and process emission for all the cement types with 100% of coal consumption. Since the Blast Furnace Slag Cement has the least clinker content, it has the least emission among all cement types.

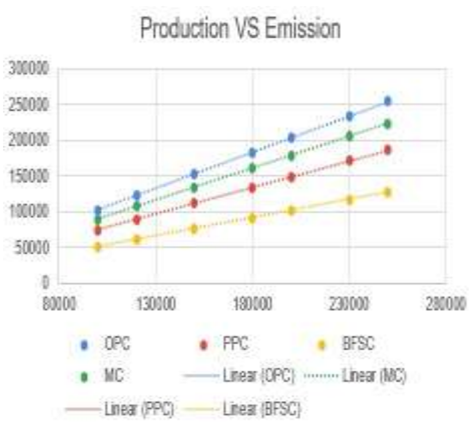

Figure 3: Linear Graph between Cement Production and total Emission

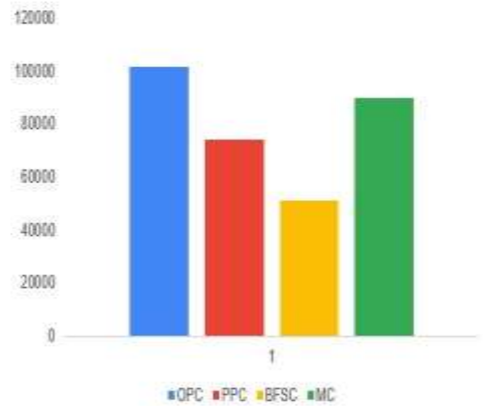

Figure 4: Emission for Different Types of Cement

Figure 4 confirms the hypothesis that the clinker concentration is directly proportional to the carbon emission. Since the BFSC has the least clinker content, the total emission is the least for given 100000 tons of cement produced.

To analyze the impact of alternative fuels, three cases were considered. The goal is to see the impact of the replacement of coal with alternative fuels.

Case 1: In the first case (figure 5), a combination of only two fuels was considered. Coal and Natural Gas and Coal and Biofuel. The concentration of coal was decreased as 100%, 80%, 50%, 20%, 0%, and in the same proportion, the other fuels were increased.

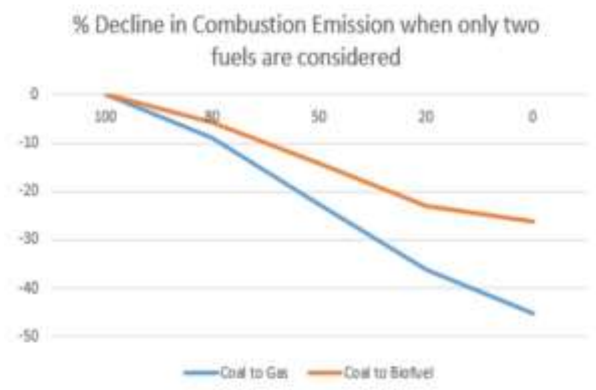

Figure 5: Combination of 2 fuels

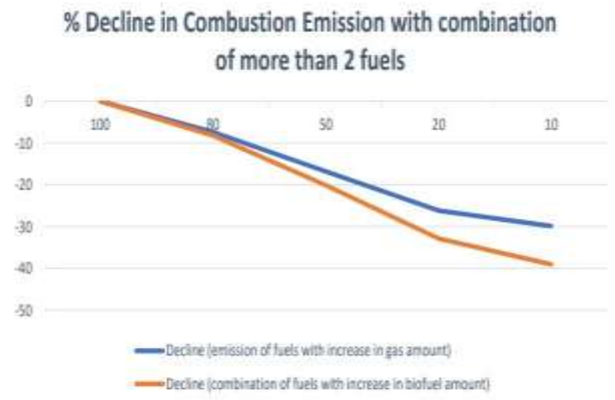

Figure 6: Combination of 3 fuels

Case:2 The second case (figure 6) considers the combination of 3 fuels with the goal of reducing coal concentration. In the first scenario, with a decline in coal, the concentration of gas was increased rapidly as compared to the concentration increase of biofuel and in the second scenario, biofuel was increased rapidly. With the combination of fuel with making Natural gas as the primary fuel, a reduction of 40% was seen whereas with Biofuel as the primary fuel in the combination, the reduction was 30%. However, when considering 3 fuels, the increased use of biofuel with natural gas increased the carbon reduction by 4% to 30% whereas increased use of Natural gas with biofuel, reduced the carbon reduction by 5% to 40%.

Case 3: The coal was replaced directly by renewable sources of energy (figure 7). The result was a straight-line decline in emission since coal was the only source of emission in the combustion process.

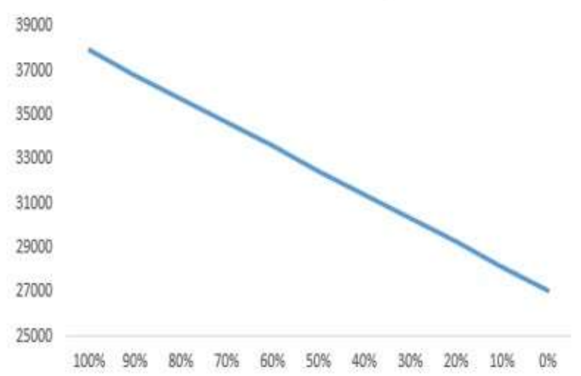

Figure 7: Direct Replacement of Coal with Renewable Energy

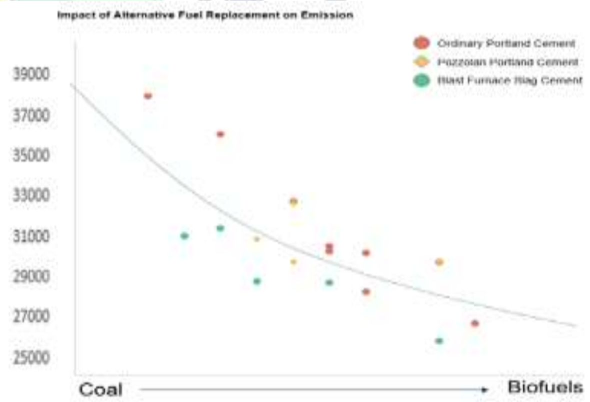

Figure 8: Impact of Alternative fuel on emission for different Cement

VI. Conclusion

It is obvious that clinker proportion in cement manufacturing plays an important role in reducing carbon emission. The lower is the clinker proportion, lesser is the emission. However, clinker proportion in cement can be a function of different functions such as

1. Quality of Cement
2. Strength of Cement
3. Binding power of Cement
4. Setting Time of Cement

Similarly, Different combinations of fuels can result in different levels of carbon reduction. Different alternatives discussed in the paper can contribute in different ways for reducing emission and energy waste. However, to use different fuels with different combinations, certain factors need to be taken into consideration.

1. Availability of fuel
2. Procurement cost of fuel
3. Calorific Value of fuel
4. Fuel Storage
5. Technology used
6. Government Regulations

Using different combinations of fuels, a maximum reduction of 45% could be observed in combustion emission and decline of 20-22% could be observed in the total emission in a cement industry. However, the economic analysis and the feasibility study is important before deriving the decision. Cement manufacturers are getting closer to the truth. Challenges such as decarbonization, persistent disruption of the value chain and resistance to the entire mosaic of actors in the development ecosystem are great. With the right mindset, decarbonization and reinvention can go hand in hand. Of the traditional threats posed by cement and the urban face, the sum of new ideas, innovations and new business models could be decisive in ensuring a profitable and greener future.

REFERENCES

[1]. Imbabi, M.S.; Carrigan, C.; McKenna, S. Trends and developments in green cement and concrete technology. Int. J. Sustain. Built Environ. 2012, 1, 194–216.
[2] Phair, J.W. Green chemistry for sustainable cement production and use. Green Chem. 2006, 8, 763–780. [3]. U.S. Geological Survey. Mineral Commodity Summaries 2018; U.S.
Geological Survey: Reston, VA, USA,
2018.
[4]. Smith, R.A.; Kersey, J.R.; Griffiths, P.J. The Construction Industry Mass Balance: Resource use, wastes and emissions. Construction 2002, 4, 680.
[5]. World Business Council for Sustainable Development. Toward a Sustainable Cement Industry. March 2002. Available online: http://citeseerx.ist.psu.edu/viewdoc/downlo ad?rep=rep1&type=pdf&doi=10.1.1.123.
3145 (accessed on 24 October 2018).
[6]. Mehta, P.K.; Monteiro, P.J.M. Concrete Microstructure, Properties, and Materials, 3rd ed.; McGraw-Hill: New York, NY, USA, 2006; ISBN 0071589198.
[7]. Hasanbeigi, A.; Price, L.; Lu, H.; Lan,
W. Analysis of energy-efficiency opportunities for the cement industry in Shandong Province, China: A case study of 16 cement plants. Energy 2010, 35, 3461– 3473.
[8]. Turner, L.K.; Collins, F.G. Carbon dioxide equivalent (CO2 -e) emissions: A comparison between geopolymer and OPC cement concrete. Constr. Build. Mater. 2013, 43, 125–130.
[9]. Valipour, M.; Yekkalar, M.; Shekarchi, M.; Panahi, S. Environmental assessment of green concrete containing natural zeolite on the global warming index in marine environments. J. Clean. Prod. 2014, 65, 418–423
[10]. Rashad, A.M.; Zeedan, S.R. The effect of activator concentration on the residual strength of alkali-activated fly ash pastes subjected to thermal load. Constr. Build. Mater. 2011, 25, 3098–3107.
[11]. Rashad, A.M. An exploratory study on high-volume fly ash concrete incorporating silica fume subjected to thermal loads. J. Clean. Prod. 2015, 87, 735–744.
[12]. Rashad, A.M.; Bai, Y.; Basheer, P.A.M.; Milestone, N.B.; Collier, N.C. Hydration and properties of sodium sulfate activated slag. Cem. Concr. Compos. 2013, 37, 20–29.
[13]. Lund, P. Impacts of EU carbon emission trade directive on energy-intensive industries— Indicative micro-economic analyses. Ecol. Econ. 2007, 63, 799–806.
[14]. World Business Council for Sustainable Development. The Cement Sustainability Initiative, Cement Industry Energy and CO2 Performance: “Getting the Numbers Right”; WBCSD: Geneva,
Switzerland, 2009; Volume 44, ISBN 9783-940388-48-3.
[15]. Kartini, K.; Hamidah, M.S.; Norhana, A.R.; Nur Hanani, A.R. Quarry dust fine powder as substitute for ordinary 625ortland cement in concrete mix. J. Eng. Sci. Technol. 2014, 9, 191– 205.
[16]. Yang, K.H.; Jung, Y.B.; Cho, M.S.; Tae, S.H. Effect of Supplementary Cementitious Materials on Reduction of CO2Emissions From Concrete. Handb. Low Carbon Concr. 2016, 103, 89–110. [17]. Crossin, E. The greenhouse gas implications of using ground granulated blast furnace slag as a cement substitute. J. Clean. Prod. 2015, 95, 101–108.
[18]. European Commission DG A New Approach to Evaluating the Sustainability of Substituting Raw Materials: Science for Environmental Policy; The University of the West of England: Bristol, UK, 2018.
[19] Deterministic approach for calculation of Carbon Footprint for Cement plants in India Amit K. Shrivastava*, Aman Vashishth1 , Bhagya Jayant2