Scope of Energy and Thermal Management in Cement Production in India

Abhishek Ghosh *ME21BTECH11001*
Aditya Verma *ME21BTECH11002*
Harshit Shambharkar *ME21BTECH11019*
Loukik Kalbande *ME21BTECH11028*

ME5480
Sustainable Energy Technology: Energy Sources, Energy Efficiency, Storage and Optimization
Department of Mechanical Engineering, IIT Hyderabad

1 Introduction [*Abhishek*]

The cement industry is one of the largest energy consumers among industrial sectors, using about 4 GJ of energy to produce one ton of cement. In India, the cement industry accounts for 10.3% of total fuel consumption in the manufacturing sector. Energy costs form a significant part—around 26% of the total manufacturing cost of cement. On average, the energy input is split into 75% thermal energy and 25% electrical energy. India has achieved a specific energy consumption of 3.06 GJ/t for cement production, but this is still higher than some countries, where it is below 2.95 GJ/t. The higher consumption in India is attributed to the use of rigid raw materials and lower fuel quality. To improve efficiency, heat modelling and thermal performance assessments of kilns have been adopted in Indian plants.

The Indian cement industry is the second largest in the world, producing 330 million tons annually, contributing significantly to the country's infrastructure growth. It plays a critical role in meeting the demands of rapid urbanisation. Coal is the primary fuel for thermal energy in Indian cement plants, fulfilling 94% of the demand, while the remaining comes from fuel oil and diesel. Unlike some other countries, India lacks sufficient natural gas for cement production.

Energy usage in cement production in India varies across processes. Crushing and grinding consume a major share of electricity, while thermal energy is mostly used for clinker production in rotary kilns. The modern dry process, which is now widely adopted in India, uses 75% of its

energy for thermal needs and 25% for electrical purposes, making it more efficient than the older wet process.
India's cement industry has been making strides toward energy efficiency and emission reductions. Initiatives such as advanced rotary kilns and five-stage cyclone preheaters are becoming standard. These improvements aim to reduce energy costs and bring India closer to international benchmarks for energy consumption. This report focuses on energy conservation and emission reduction strategies in cement production, particularly in the Indian context. It reviews effective methods, highlights areas for improvement, and explores the role of thermal performance assessments in enhancing kiln efficiency. By implementing these strategies, India's cement industry can achieve greater sustainability and maintain its competitive edge in the global market.

2 Cement Manufacturing Process and Energy Utilisation

Cement production involves a series of steps that transform raw materials into Portland cement, a critical component in construction. The process is energy-intensive, relying on both thermal and electrical energy to produce high-quality cement efficiently. Below are the key stages of cement manufacturing, with a focus on energy usage and efficiency measures.

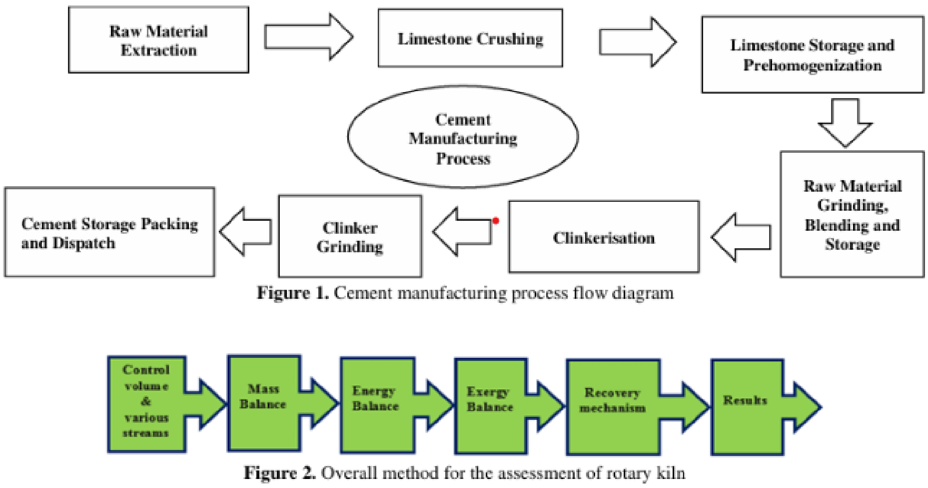

Figure 1: Cement manufacturing process flow diagram

2.1 Raw Materials and Their Preparation

- Raw Materials: The primary raw materials for cement are limestone (for calcium oxide, CaO) and silica (usually from iron-bearing aluminosilicates). Pure silica, such as quartz, is scarce and unreactive, requiring aluminum and iron oxides as fluxing agents to lower fusion temperatures.

- Material Preparation: Consistent composition is crucial for quality cement. Depending on material hardness and process preferences, the preparation involves either the wet process or the dry process:
- Wet Process: Suitable for soft raw materials like chalk and clay. Materials are mixed with water to form a slurry, ensuring uniform composition.
- Dry Process: Preferred for hard raw materials. Materials are crushed, dried, ground into fine powder, and mixed mechanically or pneumatically in precise proportions.

2.2 Final Processing and Energy Use

- Clinker Grinding: The cooled clinker is ground with gypsum to control the setting properties of cement. Grinding consumes a significant share of electrical energy, approximately 38% of total electricity use in cement plants.
- Storage and Blending: Ground cement is stored in silos and blended to ensure consistency before being packaged.

3 Scope of Energy Improvement [*Harshit*]

3.1 Energy in Cement Manufacturing

Energy efficiency in cement manufacturing is vital, as energy costs represent 26% of the total production cost in India.

- Thermal Energy: Accounts for 75% of total energy consumption, mainly used in kilns during the clinkering process. India's best practices report a specific energy consumption of 3.06 GJ/t, while global benchmarks are lower, around 2.95 GJ/t.

- Electrical Energy: Used primarily in crushing, grinding, and operating kiln systems, accounting for 25% of total energy. Raw material crushing consumes 33%, while clinker grinding consumes 38%.

The cement industry is a highly energy-intensive sector, with significant portions of energy consumed in thermal and electrical processes. As global energy costs continue to rise, improving energy efficiency has become critical for sustainable and cost-effective production. The two primary areas of focus for energy improvement are thermal energy in the clinkering process and electrical energy in crushing, grinding, and kiln operations.

3.2 Thermal Energy Improvements in the Clinkering Process [*Loukik*]

The clinkering process, being the most energy-demanding stage of cement production, consumes approximately 70–80% of the total thermal energy required. Key opportunities for thermal energy improvements include:

Optimization of Kiln Design and Operation: Enhancing kiln insulation can significantly reduce radiation and convection heat losses, particularly along the kiln walls, which account for 41% of total thermal energy losses. Modern kiln technologies, such as secondary shell systems with thermal insulation, have proven effective in minimising heat losses. These systems can improve overall kiln efficiency by approximately 5%.
Advanced Preheating and Precalcination: The use of multi-stage preheaters and precalciners has revolutionised heat recovery. With up to 94% calcination occurring in the preheater, the energy required in the kiln is greatly reduced. Incorporating efficient heat exchangers in preheaters can maximise the utilisation of waste heat from flue gases, reducing fuel consumption and thermal losses.
Fuel Switching and Alternative Fuels: The use of alternative fuels such as biomass or waste-derived fuels can lower specific heat consumption while reducing dependency on traditional fossil fuels. Low primary air burners, such as pyrojet burners, help improve combustion efficiency, producing sharper flames with reduced fuel consumption.
Heat Recovery Systems: Heat recovery from hot gases in the kiln and cooler systems can be harnessed to preheat raw materials or generate electricity through waste heat recovery (WHR) systems. Improved clinker coolers with optimised air management ensure minimal heat loss while maintaining clinker quality.

3.3 Electrical Energy Improvements in Crushing, Grinding, and Kiln Operations [*Aditya*]

Electrical energy constitutes 20–30% of total energy consumption in cement manufacturing, primarily utilised in the mechanical processes of crushing, grinding, and operating the kiln systems. Areas for improvement include: Energy-Efficient Grinding Technologies: Replacing traditional ball mills with high-pressure grinding rolls (HPGR) or vertical roller mills can lower energy consumption during raw material grinding by up to 30The introduction of advanced grinding aids and process optimizations can further enhance the efficiency of existing systems. Variable frequency drives (VFDs) in crushers, fans, and conveyor systems can significantly reduce electricity usage by optimising motor speeds. Efficient Material Handling Systems: Improvements in conveyor belt design and layout can reduce energy losses during the transport of raw materials and clinker. Pneumatic conveying systems, if upgraded, can minimise resistance and improve material flow efficiency. Utilisation of Waste Heat for Power Generation: Waste heat from the kiln and clinker cooler can be utilised to generate electricity through steam turbines or organic Rankine cycle (ORC) systems, offsetting part of the plant's electrical demand. Energy Audits and Benchmarking: Conducting regular energy audits to identify inefficiencies in equipment and processes provides a basis for targeted improvements. Benchmarking plant energy performance against global best practices can drive adoption of advanced technologies and operational standards.

4 Conclusion

Focusing on thermal energy efficiency in the clinkering process and electrical energy efficiency in supporting systems presents significant opportunities for reducing overall energy consumption in cement production. Implementing advanced technologies, optimising processes, and adopting alternative fuels and heat recovery systems are critical steps toward achieving a more sustainable and energy-efficient industry.

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