A Study of Energy Efficiency in the Indian Cement Industry

Center for Study of Science, Technology and Policy

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Preface

As the world population and its affluence increases, greater demands are placed on sources of energy. Equally important is energy efficiency or energy conservation which has been called the fifth fuel. Energy Efficiency has been increasing, but has to be accelerated by devising new technologies as well as new policies.

It is very timely that the Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India is launching a programme Perform, Achieve and Trade (PAT) to incentivize the reduction of energy consumption in major industries. Such reductions will also lead to reduction in greenhouse gas emissions.

CSTEP is happy to have contributed to an effective implementation of the PAT program with a study of the Indian cement sector. Our team has worked hand in hand with various stakeholders on shop floors, in seminars, with industry associations and experts on energy and cement manufacturing. Our efforts have been rewarded by the insights we gained and the excitement of participating in a national mission. This report summarises our findings on the current state of the industry, the PAT methodology, the technology initiatives to promote energy efficiency and discusses a way forward. This report presents several case studies from the cement sector and is part of a larger study on major manufacturing industries.

I congratulate the people involved in this study, specially Dr. S. S. Krishnan. I thank BEE and the cement industry for their encouragement and thank the Shakti Sustainable Energy Foundation for their support. I look forward to further work in the area of industrial energy efficiency and a successful implementation of PAT in our industries.

(Dr.V.S. Arunachalam)
Chairman, CSTEP

ENERGY IS LIFE ऊर्जा दक्षता ब्यूरो

(भारत सरकार, विद्युत मंत्रालय)

BUREAU OF ENERGY EFFICIENCY

CONSERVE IT *(Government of India, Ministry of Power)*

अजय माथुर, पीएच.डी

महानिदेशक

Ajay Mathur, Ph.D

Director General

Foreword

The regulations associated with the Perform, Achieve, and Trade (PAT) programme of the Bureau of Energy Efficiency promote enhancement of energy efficiency in 7 industrial sectors and in the thermal power generation sector through the specification of energy consumption norms to be achieved by plants in these sectors by the end of the first-cycle of the programme. The programme also enables those plants that are able to reach energy performance levels that are better than their targets to secure their excess savings in the form of Energy Saving Certificates. These certificates can be procured by the units who are unable to meet their targets, so as to enable their compliance. This process would be repeated in a second-cycle, and so on.

The cement industry in India is probably the most efficient in the world, and has a well deserved reputation for technological intervention. As the cement industry plans for the PAT programme, this report would be helpful in assessing the technological interventions that are available, as well as an assessment of the viability of these interventions.

I congratulate CSTEP on this work, which is technologically detailed, industry-specific, and reader-friendly. I particularly compliment Dr. S.S. Krishnan for his hard work, and for his interaction with the cement industry, which has made this report possible. I am sure that this report would be an important and necessary first step in the future technological journey of India's cement plants.

(Ajay Mathur)

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The support and encouragement of Dr. V.S. Arunachalam, Chairman and Dr. Anshu Bharadwaj, Executive Director of CSTEP is deeply appreciated. We are especially grateful to Dr. R. Krishnan and Dr. N. Balasubramanian for their diligent review and invaluable feedback.

The financial support of Shakti Sustainable Energy Foundation during the course of this study is gratefully acknowledged.

Special thanks to Dr. Sharath Chandra Rao and Dr. K.C. Bellarmine for their help in economic analysis and assistance in the preparation of this report.

Sincere thanks are due to Saptak Ghosh, Tejas Pande, Bhargavi Kerur, Smita K. Dolly and Niket Narang for their efforts and contributions in bringing out this report.

Executive Summary

The National Action Plan on Climate Change (NAPCC) released by the Honorable Prime Minister seeks to promote sustainable development through increased use of clean technologies. NAPCC has a mission specifically dedicated to energy efficiency – National Mission on Enhanced Energy Efficiency (NMEEE).

Under NMEEE, Perform, Achieve and Trade (PAT) is one of the flagship programs launched by Bureau of Energy Efficiency (BEE), Ministry of Power and Government of India to enhance the cost effectiveness of improvements in energy efficiency in energy intensive large industries (known as Designated Consumers or DCs). BEE is implementing the PAT mechanism and has developed various elements of the methodology through a consultative process which has resulted in the PAT consultation document.

Specific Energy Consumption (SEC) norms are in the process of being established for DCs identified under the purview of PAT through a process of data collection and baselining. The DCs which reduce their SECs beyond their targets will be awarded Energy Saving Certificates which can be traded with DCs unable to comply with their specific targets.

The identified cement DCs have a minimum annual energy consumption equivalent to 30,000 tonnes oil equivalent (toe) or above. These DCs together consumed about 14.47 Mtoe in 2007 and have been apportioned energy reduction targets equivalent to 0.6 Mtoe which will have to be achieved in a three year timeframe.

The objective of this study has been to model the Energy Efficiency (EE) of the Indian cement industry, in the context of the diversity and the challenges in operating conditions, in order to provide analysis and insights for the successful implementation of PAT.

The primary motivation of this report is to present the current status of the cement industry, different sub processes in cement manufacturing and energy efficiency measures which could be adopted by the industry. It then explains the PAT methodology and provides several case studies based on measurements at sample cement plants. Financial analysis of several EE measures has been included. A PAT calculator for EE planning by DCs and an initial design of an agent based tool for policy implementation has been developed. In conclusion, the report discusses various technical, economic and policy related challenges faced by the cement industry in the context of improved energy efficiency as required by PAT.

Linkage to GHG emissions

Global Green House Gas emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004**.** The impact of emissions from anthropogenic sources on the global climate and the environment is of grave concern.

India along with China has been subjected to increasing international pressure to undertake binding emission targets to limit its aggregate level of emissions. In this context, India announced a voluntary 20-25 per cent carbon emission intensity reduction by 2020 on the 2005 levels, ahead of the UNFCCC's COP15 summit held in Copenhagen.

The effect of climate change on the Indian industrial sector is well documented. Competitiveness concerns arise when the costs of climate change policies - which are well pronounced for carbon intensive industries such as cement, iron and steel, and aluminium - lead to a loss of market share to imports from countries not facing similar carbon costs.

Globally, trade measures have been proposed under cap and trade systems as a means of addressing the competitiveness concerns that arise when one country prices carbon and others do not. For example, the proposed US cap and trade legislation required importers of goods from countries taking different climate change approaches, to purchase allowances which reflect the costs to domestic producers of the cap and trade system. The EU has periodically considered similar trade barriers to ameliorate some of the costs of its cap and trade system.

The PAT mechanism focuses on continuous improvement of EE across energy intensive industrial units. However, implementation of PAT would lead to corresponding emission intensity reduction benefits for Indian industry and contribute to a low carbon roadmap for the Indian economy.

Cement Industry

The Indian cement industry is the second largest producer of cement in the world after China. In 2011, the installed capacity of Indian cement Industry was 244.4 Million Tonnes (Mt), while cement production was 174.29 Mt. The final energy consumed by the Indian cement industry was 607 Peta Joules (PJ) in 2007. This accounted for 9% of the total energy consumed by the industrial sector.

In 2005, the average thermal Specific Energy Consumption (SEC) of a cement plant was 734 kCal/kg clinker, while the average electrical SEC was 89 kWh/t cement. However, the thermal SEC of the best plant in India was 663 kCal/kg clinker, while the best electrical SEC of an Indian cement plant was 63 kWh/t cement which are comparable to the best figures of 650 kCal/kg clinker and 65 kWh/t cement in a developed country like Japan.

Energy use – and in particular fuel use – is a major price factor in the production of cement. Energy accounts for almost 40% of the total manufacturing cost in some of the cement plants whereas coal accounts for 15%-20% of the total cost. This has motivated companies to invest in energy efficiency measures, such as converting wet kilns to dry kilns, or adding precalciners and multi stage suspension preheaters or cyclones to their cement production process making it more efficient in terms of fuel use.

Energy Efficiency in Cement Industry

Cement manufacturing comprises of various subprocesses - Raw meal grinding, Preheating, Precalcining, Clinkerization and Grinding. Energy is consumed in each of the sub processes. Major portion of the energy consumed is thermal energy (80-90%) and the rest is electrical. The clinkerization subprocess consumes the largest share of thermal energy whereas cement grinding mills consume the highest electrical energy.

High preheater exit gas volume and temperature, high pressure drop across preheater, high moisture content in fine coal, incomplete combustion of coal, low heat recuperation efficiency of grate cooler, high cooler air exhaust temperature, high clinker temperature, low efficiency of major process and cooler fans and under loading of motors resulting in low operating efficiency, are some of the major factors that result in higher energy consumption within the major sub processes.

Several energy audit studies have estimated 5% to 10% energy savings in thermal and electrical energy consumption by adopting different energy conservation measures. It is estimated that the saving of 5 kCal/kg of thermal energy and 1 kWh/t cement of electrical energy will result in total savings of about Rs 6 Million per annum in a typical 1 Million tonne plant.

PAT - Methodology and Gate to Gate (G2G) SEC

PAT follows Gate to Gate (G2G) approach for establishing baseline SEC. G2G refers to the physical boundary of a cement plant and the processes within it. A DC's baseline energy could be calculated taking into consideration the average thermal and electrical energy of three years. The ratio of total energy consumption to cement production gives a measure of the SEC.

However, product mix (OPC, PPC, PSC, any other type of cement), DC's with CPP vis. a vis. without-CPP and DC's trading intermediate products or supplying electrical energy to the grid are some of the key factors that need to be considered while establishing baseline SEC. Normalization of baseline SEC may be required in order to increase the robustness in the presence of variations in certain operating conditions.

Energy Conservation Measures

Under PAT, DCs could adopt energy efficiency measures or purchase energy saving certificates. There are several energy efficiency measures that have either already been adopted or could be adopted by the industry. However, the actual set of measures that is suited for a particular DC would be based on the specific operating conditions.

Some of the key energy efficiency measures include:

- EE Technologies :
  - In Preheaters and Precalciners, low pressure drop and high efficiency cyclones could be used instead of conventional cyclones. In addition, pressure drop could be reduced by installing an additional cyclone parallel to the existing top stage cyclone
  - In a typical kiln, the charge composition and quantity could be modified. Additional measures include arresting the false air entry and optimization of several operating parameters.
  - High efficiency ESPs and pollution control devices.
  - Existing ball mills could be replaced by vertical roller mills (VRM). The SEC of a ball mill is about 20-26 kWh/t of raw meal (RM) while a VRM consumes 14-18 kWh/t-RM, resulting in a 30% SEC reduction.
  - Installation of Variable Frequency Drives (VFD) in major electrical motors and fans.
  - Captive Power Plant (CPP): In 2007, around 2250 MW capacity of CPP was installed by the cement industry. Reduction of net station heat rate and auxiliary power consumption, installation of high efficiency boilers and condensers are some of the ways to increase the efficiency of CPPs.

- Waste heat recovery system: The waste heat available in the exhaust gases can be recovered and used for drying the moisture in the raw material and coal or for generating power.
- Blending: According to a study, around 20-30% of fly-ash and 45-50% of blast furnace slag is currently being blended with clinker which could be increased to 35% and 65% respectively.
- Alternative Fuel Resources (AFR): Presently, a very small percentage of alternate fuels are being used in cement plants in India, whereas, a high percentage of thermal substitution has been achieved in some plants abroad. There is a large scope of increasing the percentage of AFR such as industrial wastes, rice husks, tyres etc.

Analysis and Modeling

The research showcases nine case studies of sample plants employing different cement manufacturing processes, product mix, quantities of cement produced and energy consumed. Scenarios were developed considering six different actual SEC reductions by the sample DCs to highlight the performance of these plants during the three year PAT cycle. Total energy consumed and annual energy savings were calculated and compared. A preliminary agent based model was developed to simulate the behavior of plants in response to SEC norms. The model has five agents of type 'firm' (each firm representing a plant in the cement sector) and an agent of type 'policy regulator' which reads plant's current SEC and assigns baseline SEC norms. The model simulates the behavior of plants over a compliance period of three years based on parameters such as cost and time of technology up gradation, current capital, firm's investment behavior and target SEC.

Economic analysis of energy efficiency interventions was performed. Investments for different types of energy efficient interventions along with the corresponding annual savings were used to calculate the payback, net present value and internal rate of return.

The calcinations process was modeled using the ASPEN system. This tool models the thermodynamic reactions taking place and provides a mass and energy balance estimate for the process. Coal stream, primary air and limestone are the primary inputs using which material and energy balance were performed for the gas and solid streams. The results from the computation modeling tools are preliminary; however they provide a basis for further modeling.

Eco-Friendly Cement

In 2007, the total emissions from the industry were 130 MtCO_2 eq. which is equivalent to 6.8% of the total emissions across all the sectors. The emission intensity of the industry was 0.84t CO_2/t cement. Within the cases considered in this study, the specific emission was between 0.046 and 1.155 tCO_2/t cement.

As technology continues to progress and institutional pressures to reduce GHG emissions and energy intensities start to mount, the cement industry is resorting to cleaner and more sustainable methods of producing cement. Alinite cement, carbon absorbing cement, sea water resistant cement, and portland limestone and magnesium (Novacem) based cements are the different types of alternate low carbon cements. In a similar manner, conversion of CO_2 to carbonates by CALERA technology and formation of semidolime by Calix technology are two innovative technologies that have been examined in this study.

Policy Suggestions

Indian cement industry is probably one of the most energy efficient in the world today. Some of the plants have thermal and electrical SECs comparable to the best in the world resulting in low emission intensities as well. Although there is room for improvement, certain factors inhibit the industry from attaining higher efficiencies. Increasing the percentage of fly-ash and blast furnace slag in blended cement up to the standards recommended by the Bureau of Indian Standards is one of the options to reduce consumption of raw material as well as energy. However, the price for BF slag and fly-ash that could be blended with clinker has been increasing over the years and this has negatively impacted the blending potential of certain plants.

However, there are other options that the industry could adopt to conserve natural resources. Alternate Resources and Materials (ARM) such as coating residue, industrial lime and lime sludge, gypsum from gas desulphurization are promising options. Rigorous research and experimentation needs to be pursued to establish the standards and rates at which ARMs could be blended.

Bureau of Indian Standards has prescribed standards for different grades of cement. The standards prescribe the compressive strength of cement for a given fineness at particular curing intervals and the allowable blending ratios. The National Council for Cement and Building Materials could play an active role in conducting further research in this direction in order to increase the production of blended and composite cements. The use of blended cements in the public and private sectors needs to be encouraged.

AFRs such as refuse derived fuel, rice husk, wood chips, tyre waste etc. could redress the shortage of coal being experienced in the country. In 2008-09, against a coal consumption of

29.58 Mt by the industry, 14.29 Mt was domestically supplied, meeting only 48% of the total requirement.

The Central Pollution Control Board has notified the norms for managing hazardous waste and their usage in cement kilns through incineration. The safe alternative to consider is incinerating the high calorific value hazardous wastes in cement kiln as compared to conventional incineration. The field trials by CPCB suggest that monitoring hazardous air pollutants followed by a compliance notification of emission norms needs to be promoted. In addition, the various CPCB and state PCB guidelines on this subject need to be rationalized in order to encourage substantially increased thermal substitution rates in cement kilns in the country.

The competitiveness of the Indian cement industry is of foremost concern, considering that the cement industry is a core sector of the Indian economy. The current financial downturn, coupled with fuel shortage, which has led to an increase in coal price, has affected the growth and performance targets of the industry. Additionally, fluctuating demand profiles of specific product types, high transportation costs and variations in freight charges impact the cement sector as a whole.

Cement DCs will need to invest in EE measures which will result in a decrease in energy consumption. This report studies the potential of PAT to improve the energy efficiency of the cement sector and showcases the environmental and economic benefits of implementing various measures. This study can be used as a guidance tool for the industry to better understand the PAT mechanism, study the impact of specific options available in their respective plants and incorporate viable measures to reduce their SEC.

Outline of the report

A brief overview of the cement industry, which justifies its selection for further comprehensive analysis, is provided in the first chapter. Subsequently, current scenario of the Indian cement industry and its estimated growth rate is discussed. It also provides a brief background on the legislative framework addressing energy efficiency - Energy Conservation Act, 2001 and the roles played by policy regulators such as BEE. This chapter also expands the missions instituted under the National Action Plan on Climate Change (NAPCC), and introduction of mechanisms such as PAT undertaken to achieve specific objectives.

Cement manufacturing involves many subprocesses. These are described in the second chapter. Energy and heat flow of the different subprocesses of a sample plant is described in the third chapter to understand the energy consumption at various stages of cement manufacturing. The chapter examines electrical and thermal SEC of the subprocesses. The variation in operating parameters at major equipments across the different subprocesses of the sample plant over a sample time period is also examined. The ASPEN modeling tool has been utilized to simulate the calcination process and provide a material balance.

The major factors that affect the energy consumption of various equipments used in the different subprocesses along with the associated technical details are mentioned in chapter four. The critical operational parameters impacting the efficiency of the equipment are also highlighted.

The fifth chapter describes how the PAT methodology applies to the cement sector followed by the formulae used to calculate the G2G SEC. This includes the calculation of various sources of energy inputs and the methodology for calculation of baseline SEC. A discussion of the need for normalization of baseline SEC is provided along with sample results.

The PAT methodology is applied to several sample plants in chapter six. Plant-specific variations are described. Both simple and normalized baseline G2G SECs are estimated and a summary table comparing the two indicators is provided.

Levers to improve Energy Efficiency (EE) across the different sub processes, with respective technology upgradation options, are illustrated in the seventh chapter. Several energy efficiency measures were evaluated based on financial criteria viz. Payback period, Net Present Value (NPV) and Internal Rate of Return (IRR). Other EE options like Blending, Waste Heat Recovery (WHR), and Alternative Fuel Resources (AFR) are also discussed. The technology databank is an initiative to develop a database on available technologies from equipment manufacturers and has been included in this chapter.

The eighth chapter – PAT Focussed Scenario Analysis - analyses and showcases the potential performance of DCs under different SEC reduction scenarios. The plant specific economic impact and the energy savings for different scenarios have been estimated. Simulations visualizing the behavior of sample plants in the first cycle of PAT have been conducted using a preliminary agent based model.

Sustainable forms of cement are discussed in the ninth chapter. Here, standards recommended by Bureau of Indian Standards are discussed. The emission intensity of sample plants is also calculated in this chapter.

Lastly, challenges and policies associated with the cement industry in the context of PAT are discussed along with standards and guidelines to manage hazardous waste in cement kilns. Environmental pollution norms, financing to meet EE goals, guidelines for Monitoring and Validation, and ISO 50001 (Energy Management Standard) have also been discussed. The conclusions of the report are presented in the final chapter.

Contents

List of Tables

List of Figures

1. Introduction

Cement is a crucial sector for the development of the nation's infrastructure. With the GDP expected to grow at around 8% in the coming years, cement production will witness rapid growth as well. However, cement is a highly energy intensive industry and it also contributes around 7% of the national GHG emissions (1).

In 2008, the Government of India announced its intent to reduce the carbon intensity by 20 - 25% of 2005 levels by 2020 (2). This could possibly be accomplished by a series of options including energy efficiency and renewable sources of energy.

1.1 India's Energy Consumption and GHG Emissions

In the year 2009, India's final energy consumption was 449.27 Mtoe. The residential sector consumed about 168 Mtoe followed by the industrial sector at around 136 Mtoe (3). The other sectors are depicted in Figure 1.

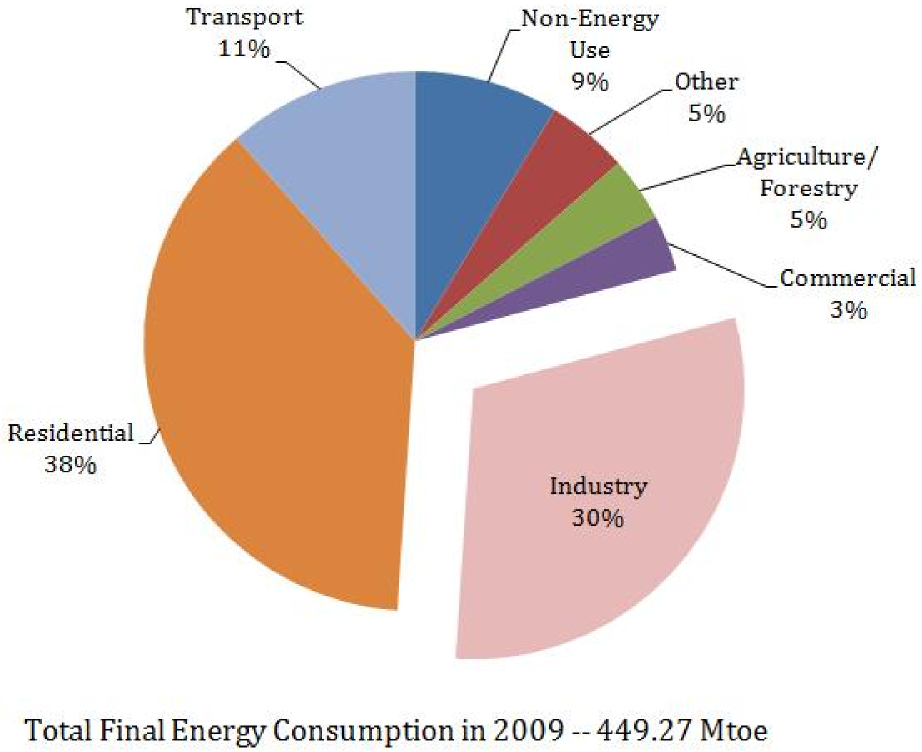


Figure 1. Sector-wise final energy consumption in 2009

In 2007, GHG emissions from the various sectors in India were 1905 $MtCO_2$ eq. (1) . According to MoEF, emissions from electricity generation were 38% of the total while those from the industry sector amounted to 22% (Figure 2).

1.2 Indian Cement Industry

India is the second largest producer of cement in the world after China. According to the Cement Manufacturing Association (CMA), its members' installed cement manufacturing capacity in 2009–10 was 215.78 Million tonnes (Mt), with a production of 160.74 Mt. The industry is growing at 9-10% (4) and is expected to continue in the near future (Table 1).

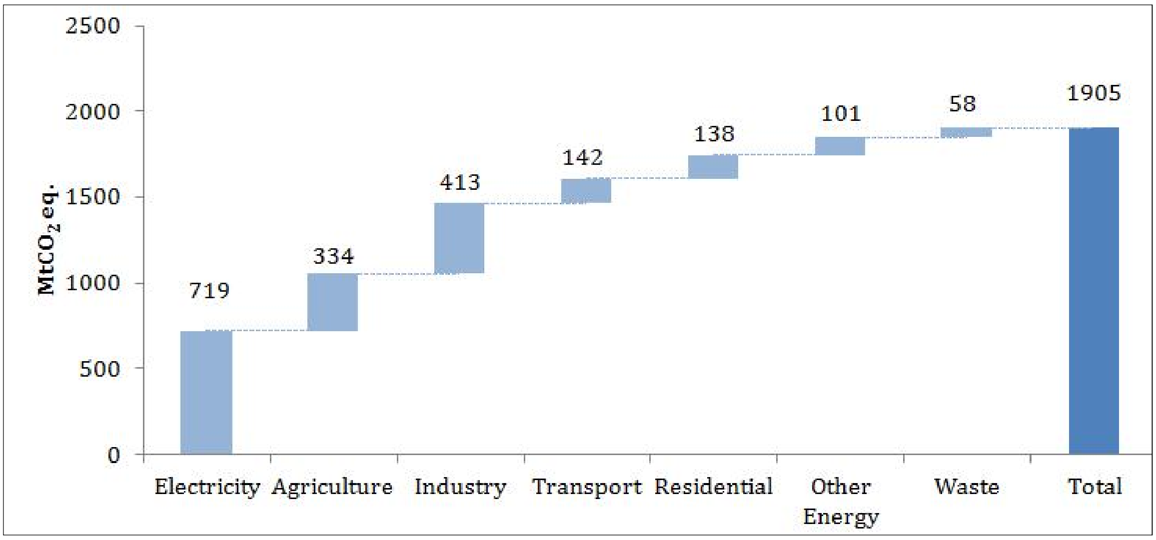


Figure 2. Sector-wise GHG emissions in 2007

Table 1: Cement production in India (1981 – 2011) (5)

Year	Cement Production Capacity (Mt)
1981	29
1991	61
2001	133
2010	234
2011	313

Figure 3 shows the growth in cement production capacity and actual cement production for 1955 - 2010. It is interesting to note that the cement production capacity almost doubled every 10 years till 2005. Further, the installed capacity in 2011 was double that of 2005(5). At this rate, the production capacity is expected to grow up to 572 Mt by 2017 (Figure 4).

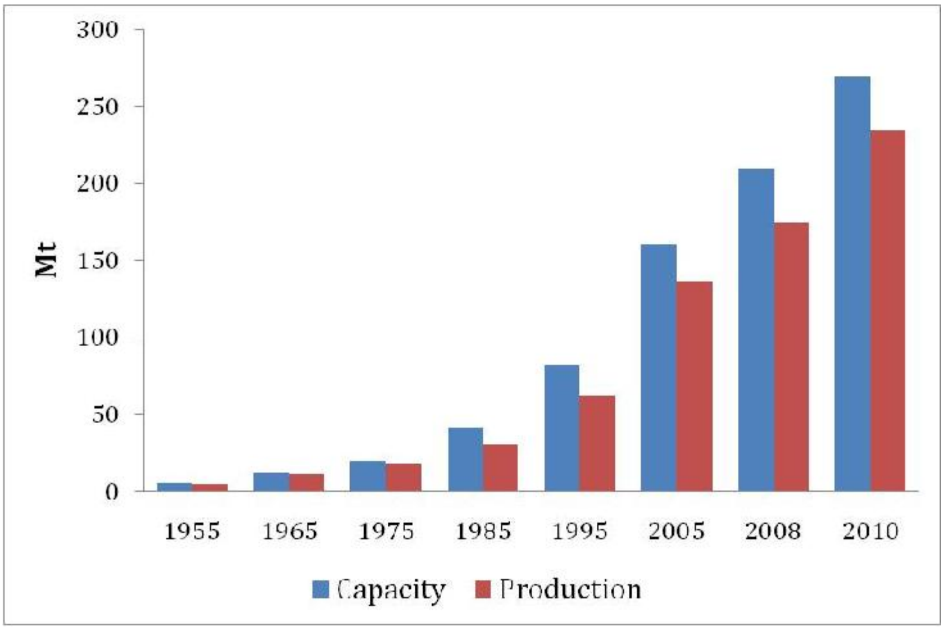


Figure 3. Historical cement production and capacity

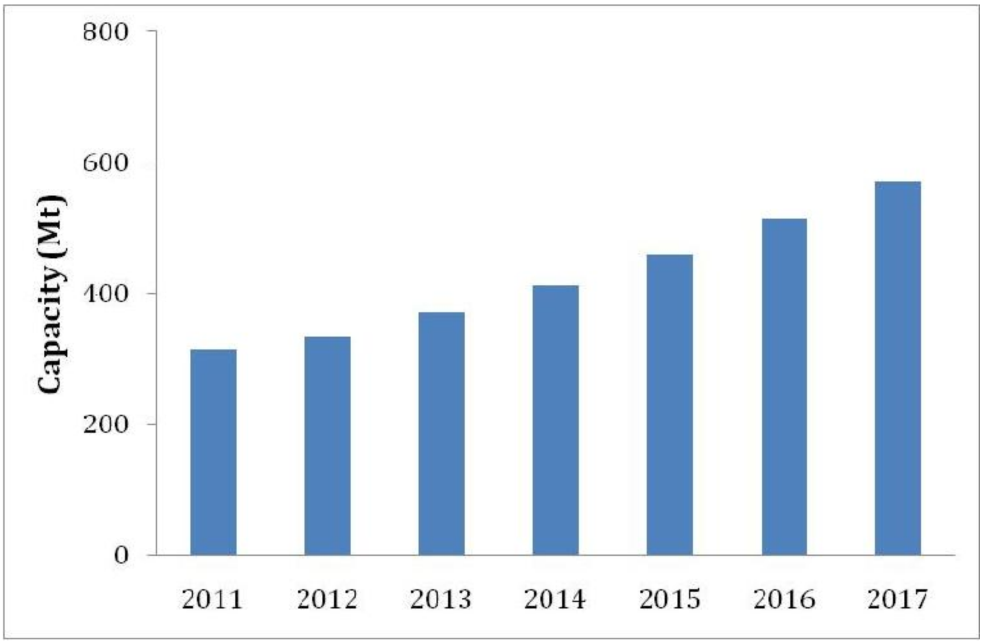


Figure 4. Projected cement production capacity

In 2007, cement was the third highest energy consumer amongst all the industries in the world (Figure 5) - the leaders being, chemical and iron and steel (6). India's cement sector consumed around 9% of the total energy amongst the various industries in the same year (Figure 6).

The rapid growth in cement production will lead to an increase in energy demand as well. The cement working group in the Planning Commission estimates the industry to grow at 11.5% per annum for a GDP growth rate of 9%.

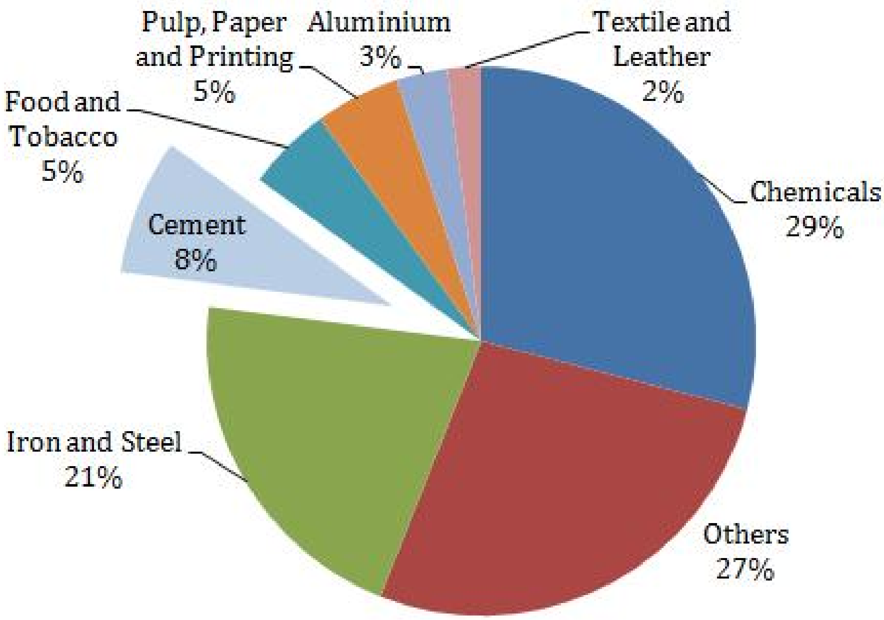


Figure 5. Sector-wise industrial final energy consumption in the world in 2007

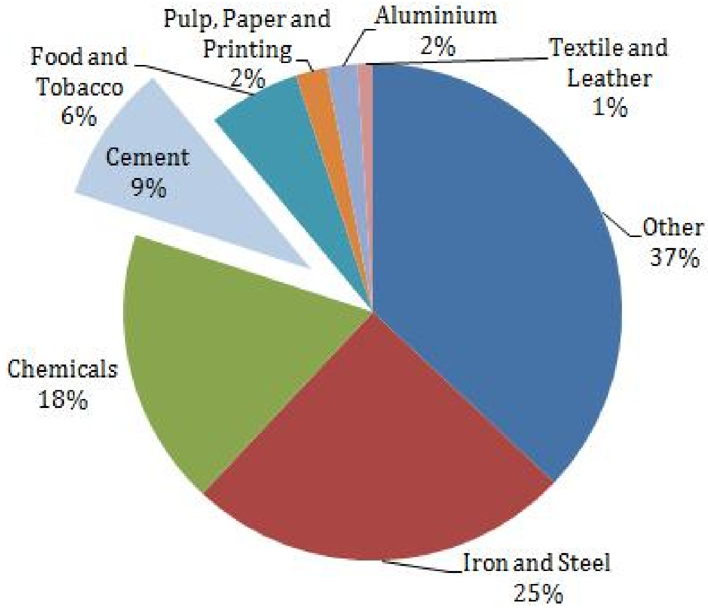


Figure 6. Sector-wise industrial final energy consumption in India in 2007

Projections for the increase in energy consumption in the cement industry in India are presented in Figure 7- Figure 9. Two scenarios have been considered - Business As Usual (BAU) and Best in India. Cement consumption growth rates of 11.5% and a more conservative 5% are the two cases analyzed for these two scenarios.

In both the scenarios, the total final energy consumption increases several fold from the present value. In the BAU scenario, the energy efficiency of new cement plants is the average of the existing units. In the second scenario (Best in India), we assume that all new plants are built with the best available technology.

The results show that there is a large potential for accomplishing savings in electrical and thermal energy using energy efficiency measures. The potential electrical energy savings from BAU (11.5%) is 59 Billion kWh, the potential thermal energy savings is 150 Million GCal and the combined final energy savings is estimated to be 850 PJ in 2035.

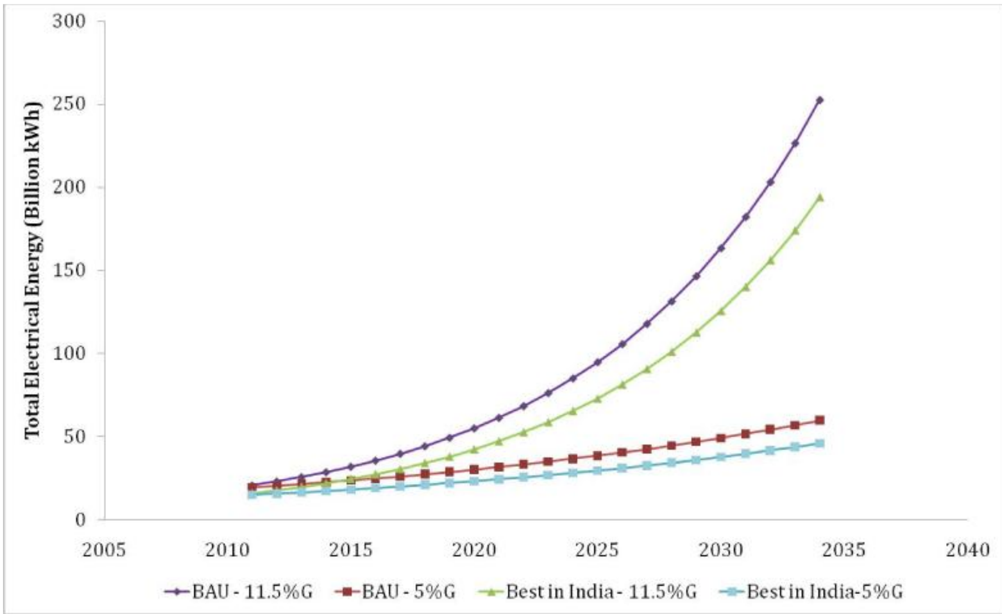


Figure 7. Projected electrical energy consumption (cement)

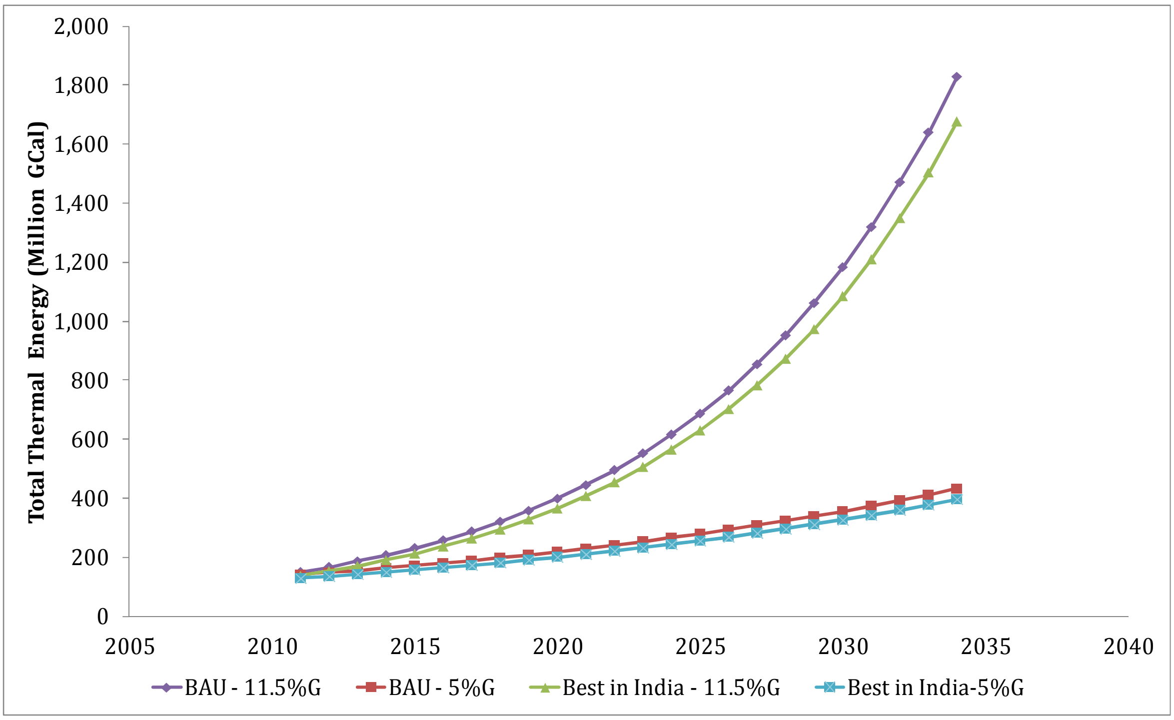


Figure 8. Projected thermal energy consumption (clinker)

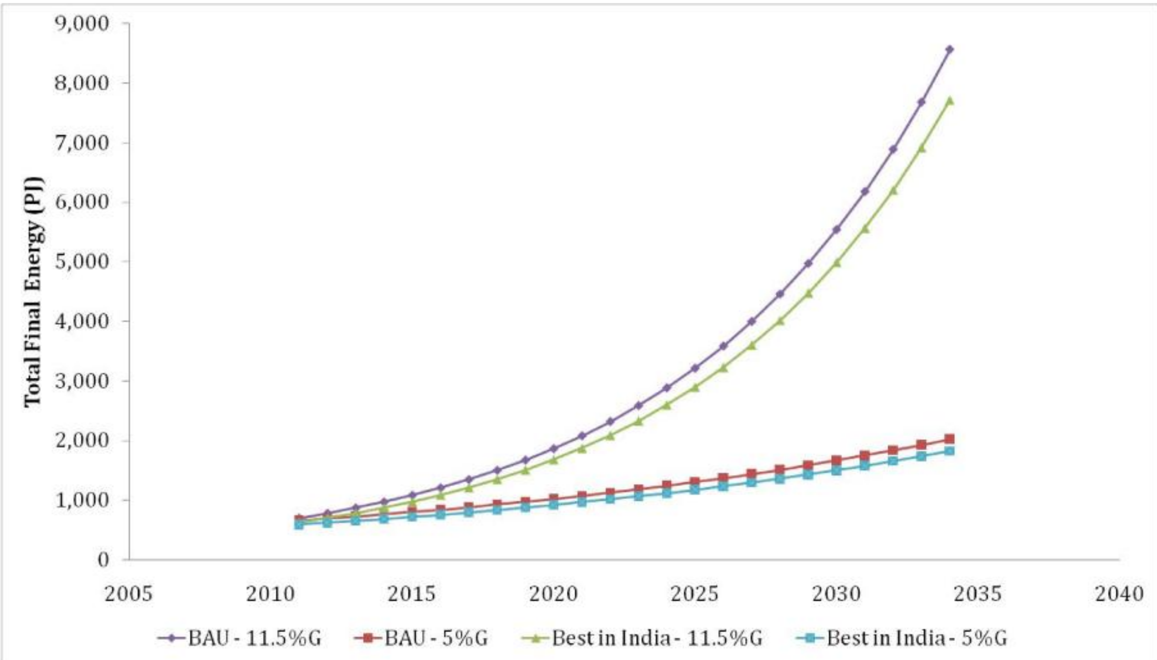


Figure 9. Projected final energy consumption

1.3 Energy Efficiency Legislative Framework

This section of the report looks at the existing legislations and policies with respect to energy efficiency measures in the cement industry.

1.3.1 National Mission on Enhanced Energy Efficiency (NMEEE)

The National Mission on Enhanced Energy Efficiency (NMEEE) is one of the eight missions under the National Action Plan on Climate Change (NAPCC). The mission provides measures and actions to unlock the energy efficiency potential in various sectors of the economy.

The key initiatives under the NMEEE are:

- Perform, Achieve and Trade (PAT) – A market based mechanism to enhance cost-effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that could be traded.

- Market Transformation for Energy Efficiency (MTEE) – Accelerating the shift to energy efficient appliances in designated sectors through innovative measures to make the products more affordable.

- Energy Efficiency Financing Platform (EEFP) – Creation of mechanisms that would help finance demand side management programmes in all sectors by capturing future energy savings.

- Framework for Energy Efficient Economic Development (FEEED) – Developing physical instruments to promote energy efficiency.

1.3.2 Energy Conservation Act

The Energy Conservation (EC) Act 2001 contains provisions to specify energy consumption standards for notified equipment and appliances, and to direct mandatory display of labels on them (7). It empowers the government to prohibit manufacture, sale, purchase and import of notified equipment and appliances not conforming to energy consumption standards. Notification of energy intensive industries and commercial buildings as Designated Consumers (DC) is one of the salient features of this Act. Furthermore, the government is authorized to establish and prescribe energy consumption norms and standards for DCs. DCs are required to appoint energy managers and to conduct periodic energy audits in order to increase the efficient utilization of energy.

1.3.3 Bureau of Energy Efficiency (BEE)

Under the provisions of the Act, the Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India, was established in March, 2002, to develop policy and strategies, and has been entrusted with the responsibility of implementing various mechanisms under the EC Act 2001.

1.3.4 PAT Mechanism

PAT is a market-based mechanism to incentivize improvements in energy efficiency in energy intensive large industries. Energy Saving Certificates (ESCs) are given to DCs who are able to reduce their specific energy consumption (SEC) beyond the specified target. The mechanism is being implemented in compliance with the EC Act 2001, situational analyses of DCs and consideration of the national energy saving goals.

ESCs earned by one DC can be traded on platforms with other DCs. DCs who find it difficult to comply with the whole or a part of their targets can purchase these ESCs. The PAT methodology involves setting up a baseline SEC for a DC, and providing a norm or target for reducing it over a three year time period. It also includes processes for data collection, data verification, and to verify the SEC of each DC in the baseline year and target year. In the target year ESCs will be issued to eligible DCs.

Table 2 below shows the sectors and number of DCs which are currently in the first PAT cycle based on information available in the PAT Consultation document of 2011. These sectors account for 231 Mtoe of energy consumption, which is about 54% of the total energy consumed in 2007-08 (7).

1.3.5 Designated Consumers (DCs)

DCs in the cement industry are plants that consume more than 30,000 tonnes of oil equivalent of energy per annum. The estimated list has 83 DCs in the cement sector.

Table 2: Minimum annual energy consumption and estimated number of DCs**(7)**

SECTOR	Minimum annual energy consumption for the DC (tonnes of oil equivalent - toe)	No. of DCs
Cement	30,000	83
Iron and Steel	30,000	101
Aluminum	7,500	11
Fertilizer	30,000	23
Pulp and Paper	30,000	51
Textiles	3,000	128
Chlor-Alkali	12,000	20
Thermal Power Plants	30,000	146
Railways (Diesel Loco Sheds and workshops)		8

1.4 Technology Trends in the Cement Industry

Figure 10 and Figure 11 show the minimum and the maximum values for the capacity, heat consumption and electrical SEC from 1950-60 to post 2000. In the period between 1950 and 1960, the predominant technology in place was the *Wet Process*. With the passage of time, the *Dry Process* became the norm in the Indian cement sector. In 1980, some cement plants had a Dry-4 Stage Preheater (PH) and Precalciner (PC) installed with the Dry process being adopted in 85% of the plants. In 1990, Dry-5/6 Stage PHs/PCs, Vertical Roller Mills (VRM) & Pre-grinders, and advanced coolers had been installed in a few plants (dry process in 90% of plants). Post 2000, double-stream PH, pyrostep coolers, High pressure grinding rolls, advanced kiln control system and Information Technology (IT) based plant operation were in place in some of the cement plants (dry process in 96% of plants). These innovations in technology have enabled India to progressively reduce its energy intensity in the cement sector.

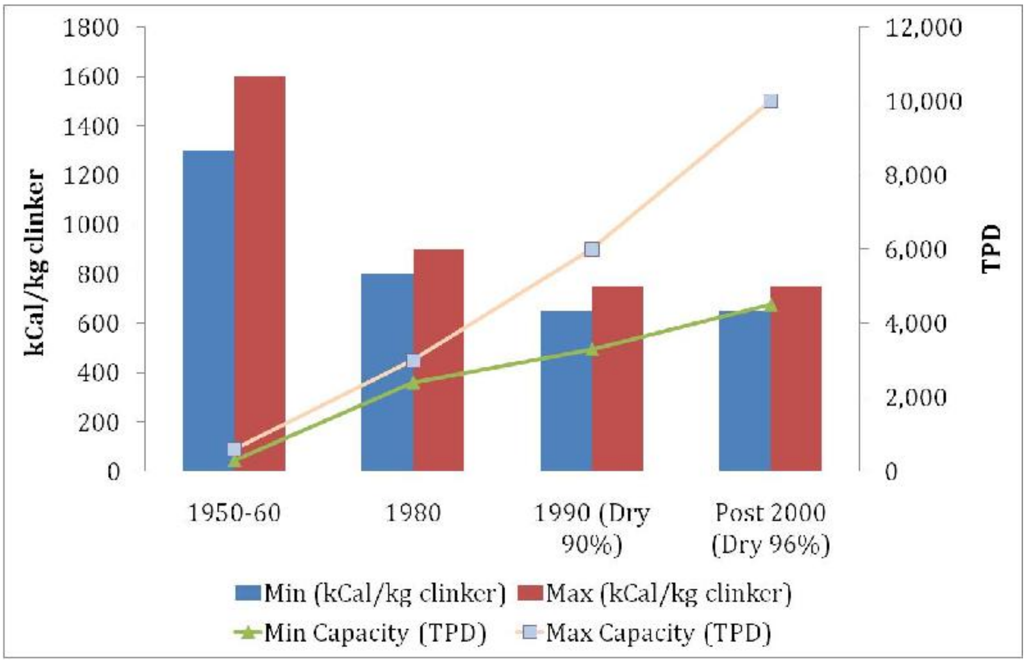


Figure 10. Historical thermal SEC over the last six decades (5)

Figure 10 and Figure 11 show reductions in the thermal (kCal/kg clinker) and electrical (kWh/t cement) energy intensity in the cement industry over the last six decades.

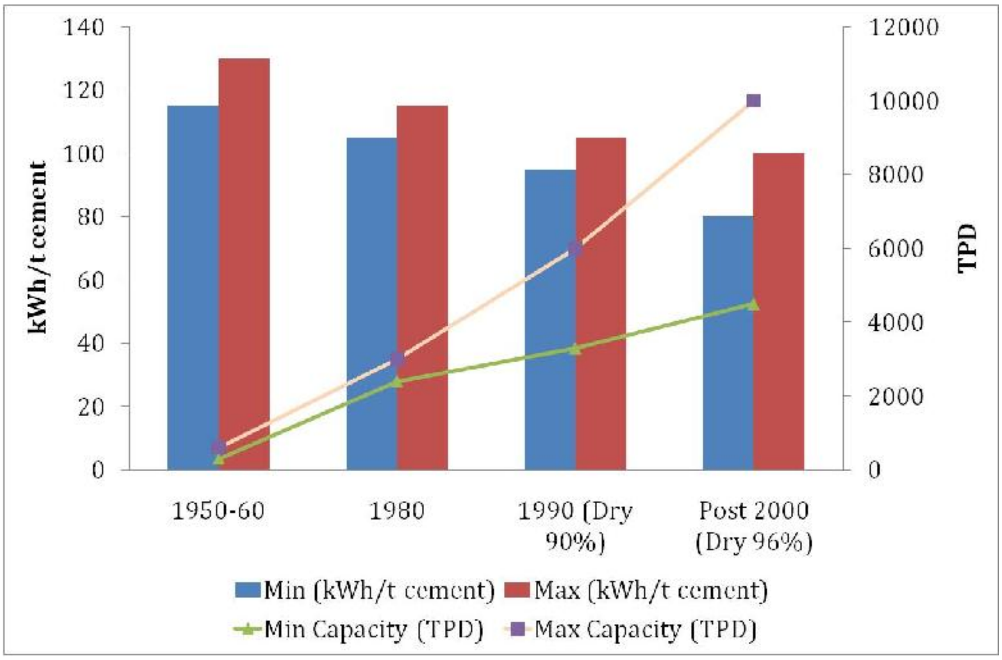


Figure 11. Historical electrical SEC for the last six decades (5)

2. Cement Manufacturing Process

The overwhelming majority of cement produced in India is manufactured through the dry process. This cement manufacturing process involves various subprocesses from mining to cement dispatch. The major energy consuming subprocesses are listed below:

- Raw meal grinding
- Coal grinding
- Preheating
- Precalcining
- Clinkerization
- Cement grinding

The raw meal is blended and then heated in the pre-heating system (cyclones) to start the dissociation of *calcium carbonate* to *calcium oxide*. In the next stage, the raw meal is fed to the kiln where it is heated to a temperature of 1450°C. Here, the calcium oxide reacts with other elements to form *calcium silicates* and *aluminates*. This is known as *clinker burning*. The gases that are emitted during this reaction from the kiln are made to pass through a precalciner after which they flow into the preheater (cyclone).

The product from the kiln is known as *clinker*. The temperature of clinker coming out of the kiln is in the range of 1200–1400˚C. This is cooled in a clinker cooler by passing air. A portion of this air enters the kiln and is called secondary air(8). Tertiary air is fed to the precalciner through the TA duct and remaining air from the cooler could be used to dry raw material or coal based upon moisture content and safety limits. Some excess cooler air is vented out through the cooler exhaust. The clinker coming out of the cooler is typically at 55˚C above ambient temperature.

In the final stage, clinker is ground with gypsum and other materials (additives) to make cement. Figure 12 shows a simplified process flow diagram highlighting the cement manufacturing process.

Cement industries typically produce Portland and masonry cement. Portland cement is a fine, gray powder comprising di-calcium silicate/alite (C2S), tri-calcium silicate/belite (C3S), tri-calcium aluminate (C3A), tetra-calcium aluminoferrite (C4AF), and several forms of calcium sulphate. C represents CaO, S represents SiO_2, A represents Al_2O_3 and F represents Fe_2O_3. Different types of Portland cement are produced based on the final use and the required chemical and physical properties. Some of the other types of cement for special applications include runway cement, railway sleeper cement, white cement, oil well cement and cement used for the construction of major structures such as dams.

2.1 Detailed Description of Subprocesses

The raw mill, preheater, precalciner, rotary kiln, clinker cooler and cement mill are described in following subsections.

2.1.1 Raw Mill

Raw milling involves mixing the extracted and crushed raw materials to obtain the appropriate chemical configuration, and grinding them to achieve a particle-size < 90 – μm in a *ball mill*. Grinding increases the surface area of the particle and ensures efficient combustion in the pyroprocessing section. Raw materials received by the plant contain a certain amount of moisture (3-8%) (9).

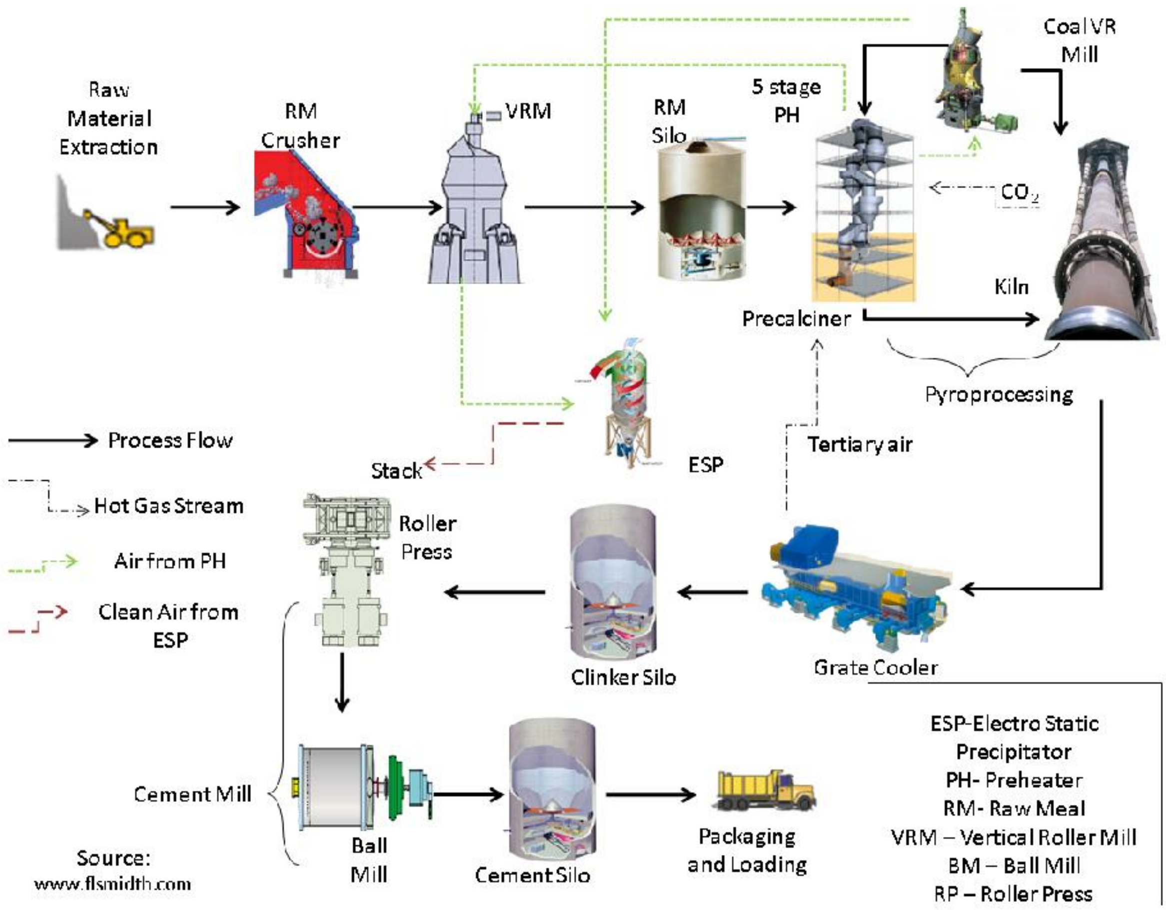


Figure 12. Flow diagram of cement manufacturing process

2.1.2 Preheater

It is essential to remove the moisture content from the raw material before it is fed to the kiln for combustion. The preheater transfer the heat of the flue gases generated in the process cycle to the raw meal which is introduced at the inlet duct (10).The flue gases are oriented in a counter current gas flow pattern and the raw meal is continuously collected and passed through different stages of cyclones from the preheater to the precalciner.

2.1.3 Precalciner

In the precalciner, raw meal is taken from the penultimate stage of the preheater to a vessel where heat for calcination is generated by firing fuel in it(11). Preheated air for combustion can come from the kiln or grate cooler. The preheater fan draws products of combustion and dissociated CO_2 through the calciner. Degree of calcination achieved is directly related to the amount of fuel fired in the calciner. When 60% of the fuel is fired in a calciner, degree of calcination achieved is 90-95 %. The temperature of raw mix begins to rise when calcination is complete, changing the flow characteristics. Therefore, in precalciner stage, calcination is limited to 90%. The following reactions take place inside the precalciner (8):

$$CaCO_3 \rightarrow CaO + CO_2$$

$$MgCO_3 \rightarrow MgO + CO_2$$

90-95% of the raw meal is calcined as per the above reactions and the remaining amount of raw meal is calcined in the kiln.

2.1.4 Rotary Kiln

The pyro-processing/clinkerization takes place in the rotary kiln. The calcined raw mix along with unconverted raw meal from precalciner is passed through the kiln system. The kiln is designed to maximize the efficiency of heat transfer from fuel to the raw material and also to ensure uniform mixing. In a dry rotary kiln, feed material with much lower moisture content (0.5%) is used when compared to the wet or semi-wet process, thereby reducing the need for evaporation and reducing kiln length. Recent developments have added multi-stage suspension preheaters (i.e. a cyclone) or shaft preheater. Precalciner, the latest technology, adds a second combustion chamber between the kiln and a conventional preheater, allowing for further reduction in specific fuel consumption.

The kiln contains four sections namely preheating zone, calcination zone, burning zone and cooling zone. In the preheater tower, the raw materials are heated rapidly to a temperature of about 1000°C, where the limestone forms burnt lime. In the rotating kiln, the temperature reaches 1450°C. At this high temperature, minerals fuse together to predominantly form calcium silicate crystals - cement clinker. The latest cement plants, which are mostly dry process based, have preheating zones and precalcination zones that are external to the kiln.

The unconverted raw meal undergoes complete calcination in the kiln by the reactions given in the section 2.1.3 and the following additional reactions takes place at around 1200 - 1300°C(8):

$$2CaO + SiO_2 \rightarrow 2CaO.\ SiO_2$$

$$3CaO + SiO_2 \rightarrow 3CaO\ .SiO_2$$

$$3CaO + Al_2O_3 \rightarrow 3CaO.\ Al_2O_3$$

$$4CaO + Al_2O_3 + Fe_2O_3 \rightarrow 4CaO.\ Al_2O_3.\ Fe_2O_3$$

The first reaction among the above reactions is the formation of C2S, second one is the formation of C3S, third reaction is the formation of C3A and the last reaction is the formation of C4AF. The molten phase of clinker contains all these compounds.

2.1.5 Clinker Cooler

The molten clinker is cooled as rapidly as possible to prevent damage to the clinker handling material. This is done to recover heat from the hot clinker and to enhance silicate reactivity, preventing alite transformation into belite and blocking the β form of C2S (12). The ambient air used to cool the clinker is then supplied to the precalciner as combustion air.

2.1.6 Cement Mill

Cement mill is used for grinding clinker along with approximately 5% of natural or synthetic gypsum for producing Ordinary Portland Cement (OPC). Fly-ash is blended with clinker to produce Portland Pozzolana Cement (PPC) and blast furnace slag is blended with clinker to produce Portland Slag Cement (PSC). The granules of clinker, gypsum and either slag or fly-ash are added in proportions as per the Bureau of Indian Standards specifications and then ground together either in a ball mill or a vertical roller mill. In some cases a roller press is used to reduce the particle size followed by final grinding in a ball mill. This usually increases the productivity and decreases the electrical SEC.

3. Material and Energy Flow in a Cement Plant

A general energy flow diagram and mass balance diagram are shown in Figure 13 and Figure 14. Electrical Energy flow at every subprocess is represented in kWh/ton, while the thermal energy is denoted in MJ/kg.

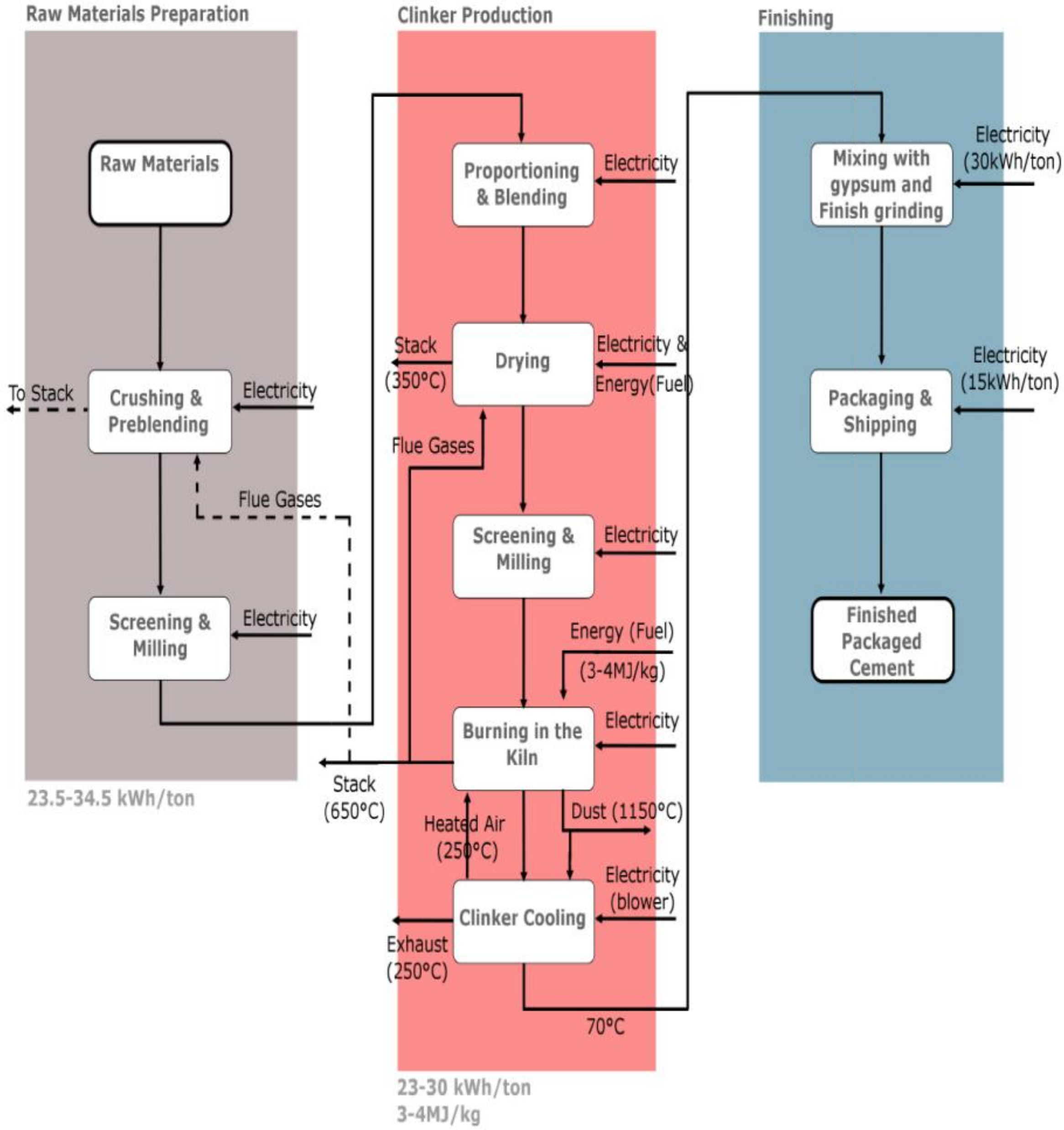


Figure 13. Energy flow in a cement plant(13)

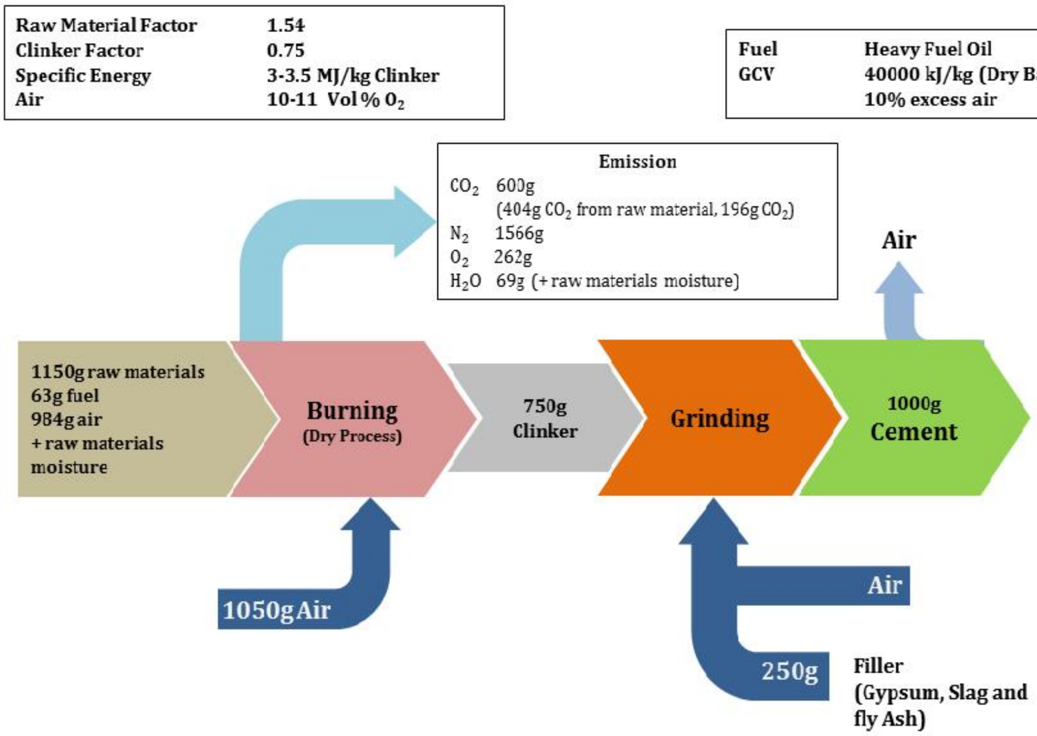


Figure 14. Mass balance for1kg of cement(14)

3.1 Electrical SEC within Subprocesses

In this chapter, we have studied the material flow and the energy flow of a sample cement plant. Figure 15 shows the electrical energy intensity flow of the sample cement plant. The electrical energy intensity is denoted in terms of kWh/t Eq.cement. Figure 16 shows the material flow diagram (tph) at major subprocesses.

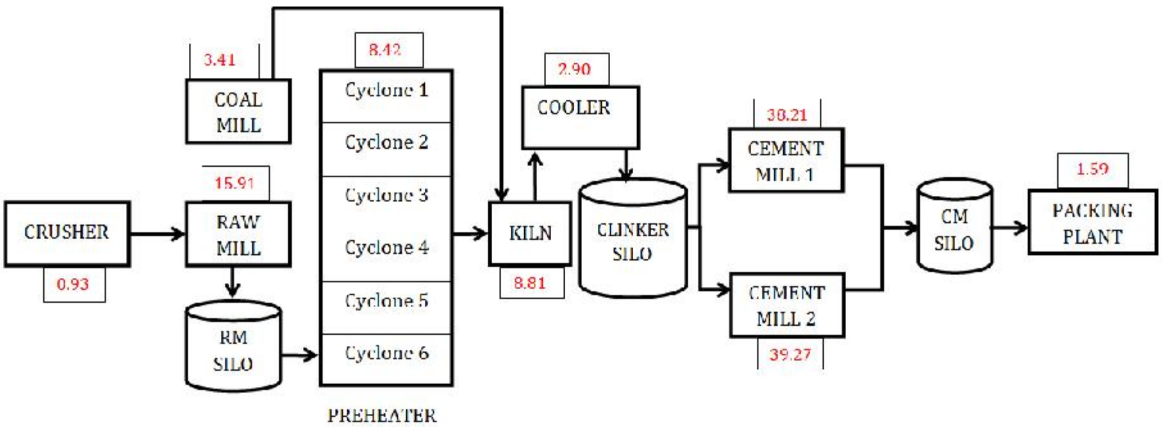


Figure 15. Electrical energy intensity flow diagram (kWh/t Eq.cement)

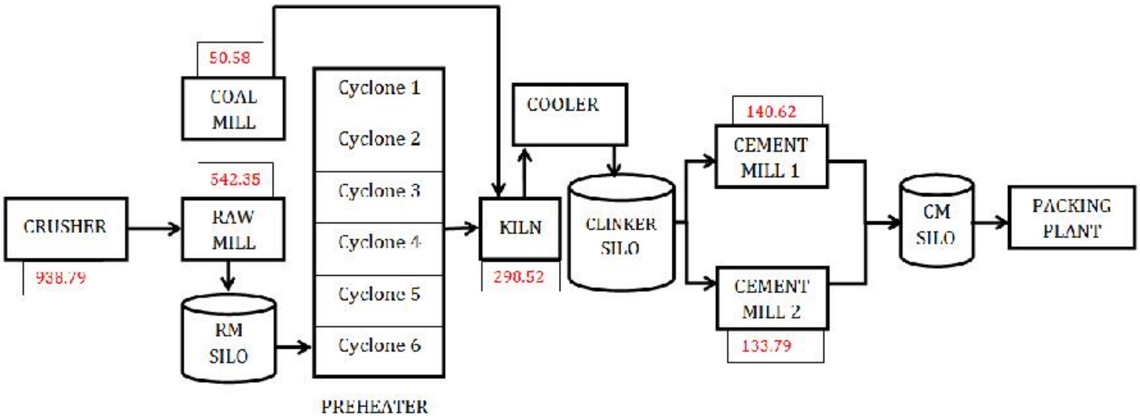


Figure 16: Material flow diagram (tph)

In Figure 17, the specific energy of a crusher is calculated to be 0.93 kWh/t Eq. cement. The main motor of the crusher consumes 0.35 kWh/t Eq. cement. The throughput of the crusher is 938.8 tph of raw material.

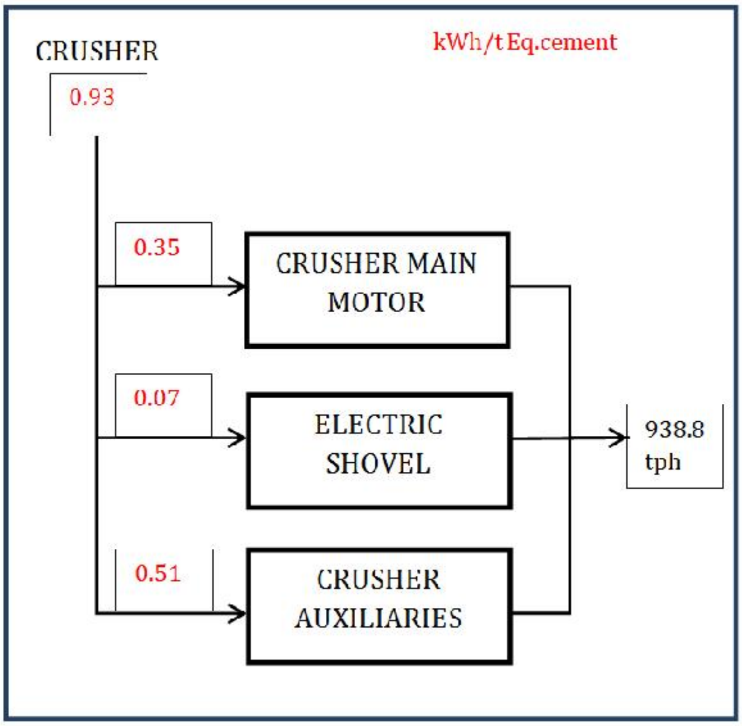


Figure 17. Crusher electrical SEC

In Figure 18, it is observed that the specific energy consumed in a Raw Mill is 15.91 kWh/t cement. Out of this, the main motor of the raw mill consumes 8.15 kWh/t Eq. cement, and the fan consumes 6.12 kWh/t Eq. cement. It is also noted that the auxiliaries of raw mill and preprocessing consume 1.63 and 0.02 kWh/t Eq. cement respectively. A total of 542.4 tph of raw meal is produced.

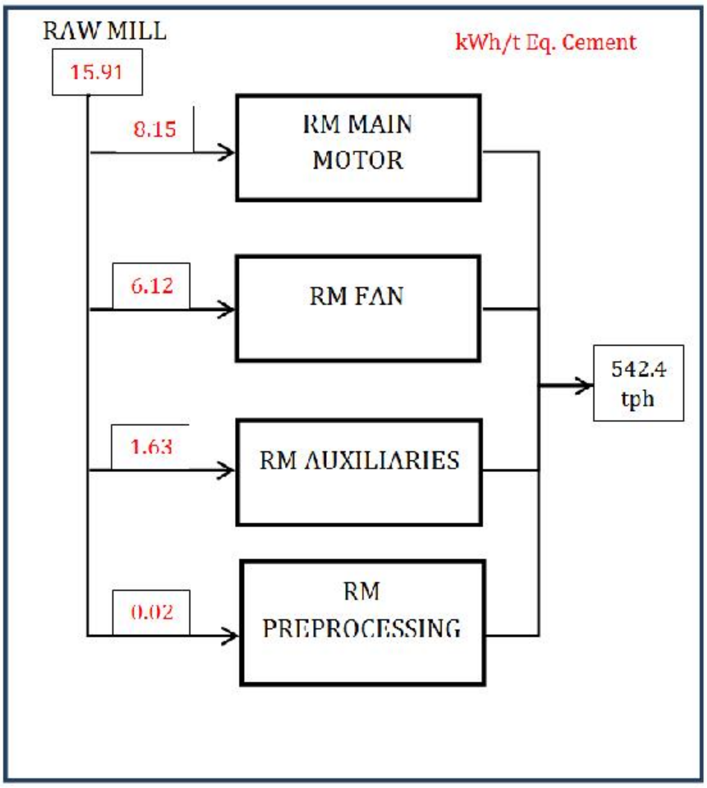


Figure 18. Raw mill electrical SEC

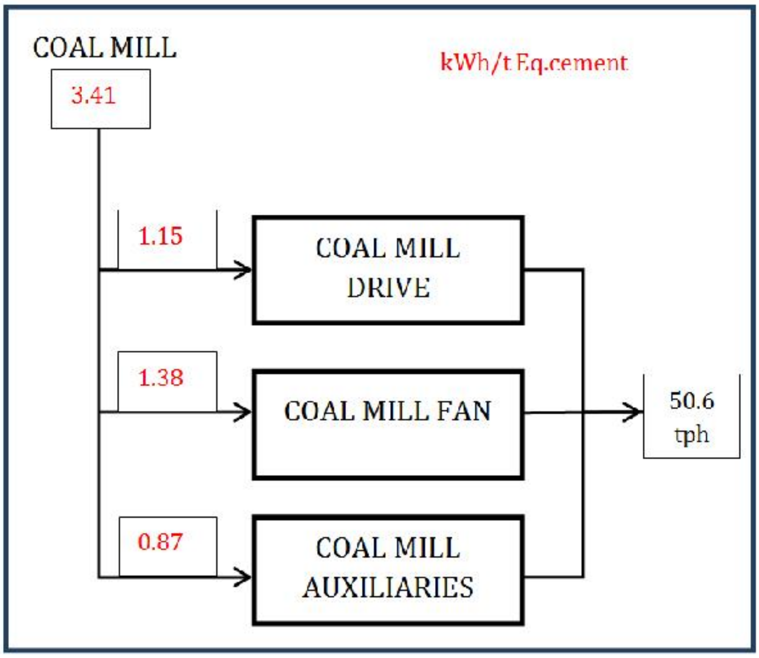


Figure 19. Coal mill electrical SEC

Figure 19 shows the specific electrical energy flow in a coal mill as 3.41 kWh/t Eq. cement. Here, the mill drive consumes 1.15 kWh/t Eq. cement, fan consumes 1.38 kWh/t Eq. cement and the auxiliaries consume 0.87 kWh/t Eq. cement. A total of 50.6 tonnes of coal is ground every hour.

The cement mills 1 and 2 are operated at nearly the same performance level (38.21 and 39.27 kWh/t respectively). The electrical SEC and throughput of these mills are shown in Figure 20 & Figure 21.

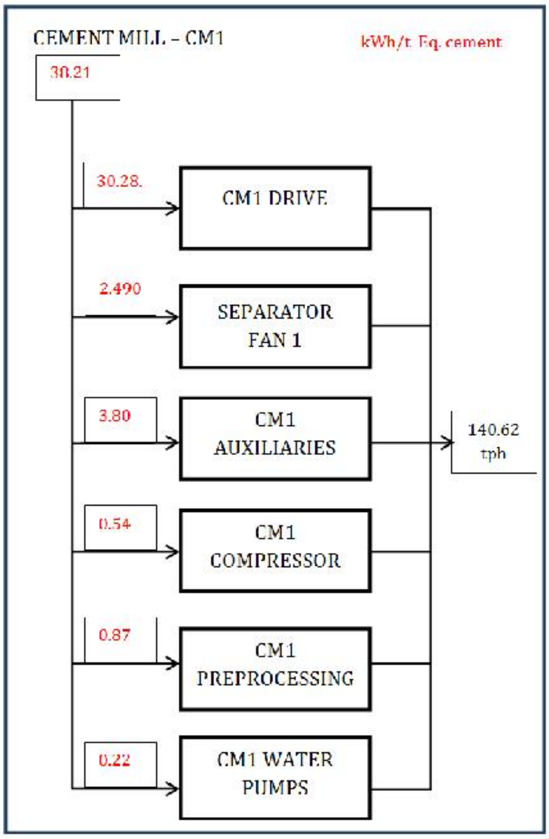


Figure 20. Cement mill 1 electrical SEC

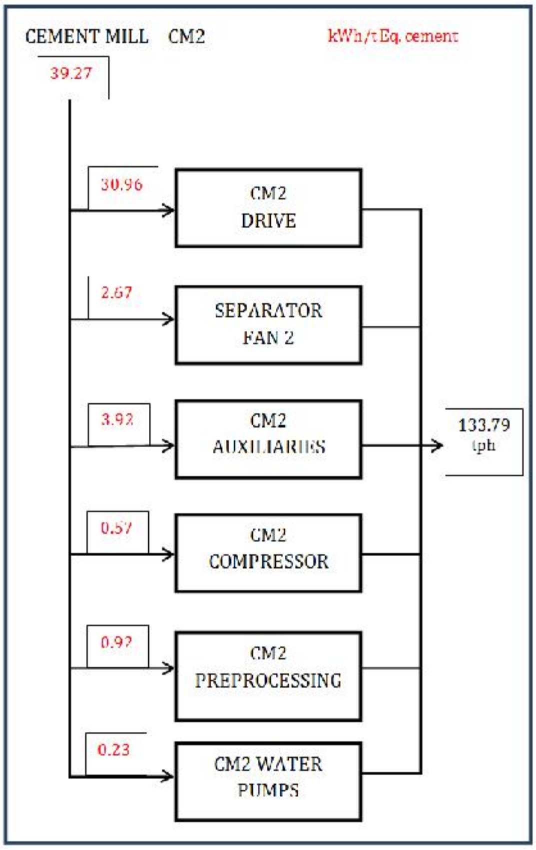


Figure 21. Cement mill 2 electrical SEC

3.2 Thermal SEC within Pyroprocessing

The material flow in a kiln is shown in Figure 22. Figures in black indicate mass input while those in red represent mass output. The figure shows the mass input and output for producing one kg of clinker.

The heat flow in kiln is shown in Figure 23. The sensible heat from kiln feed is 33.2 kCal/kg clinker, while heat from coal combustion was 703.8 kCal/kg clinker. Preheater gases and cooler exit losses were 161.3 kCal/kg clinker and 109.7 kCal/kg clinkers, respectively. The figures shown in black indicate heat input and those in red represent heat output.

Figure 24 shows the material flow in the clinker cooler. The secondary air is let out at 1136°C while the tertiary air is let out at 885°C. The cooler exit air is at 280°C with a specific volume of 1.25 m^3/kg clinker.

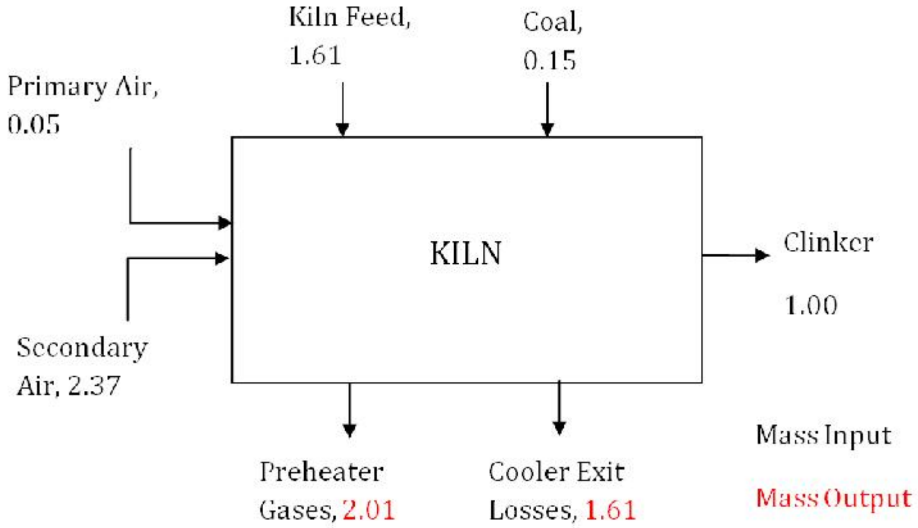


Figure 22. Kiln – material flow (kg/kg clinker)

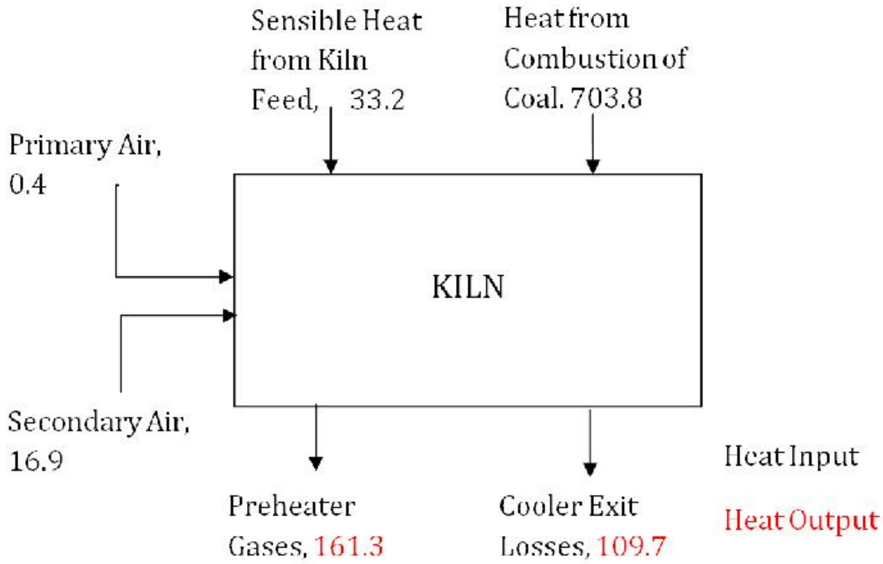


Figure 23. Kiln - heat flow (kCal/kg clinker)

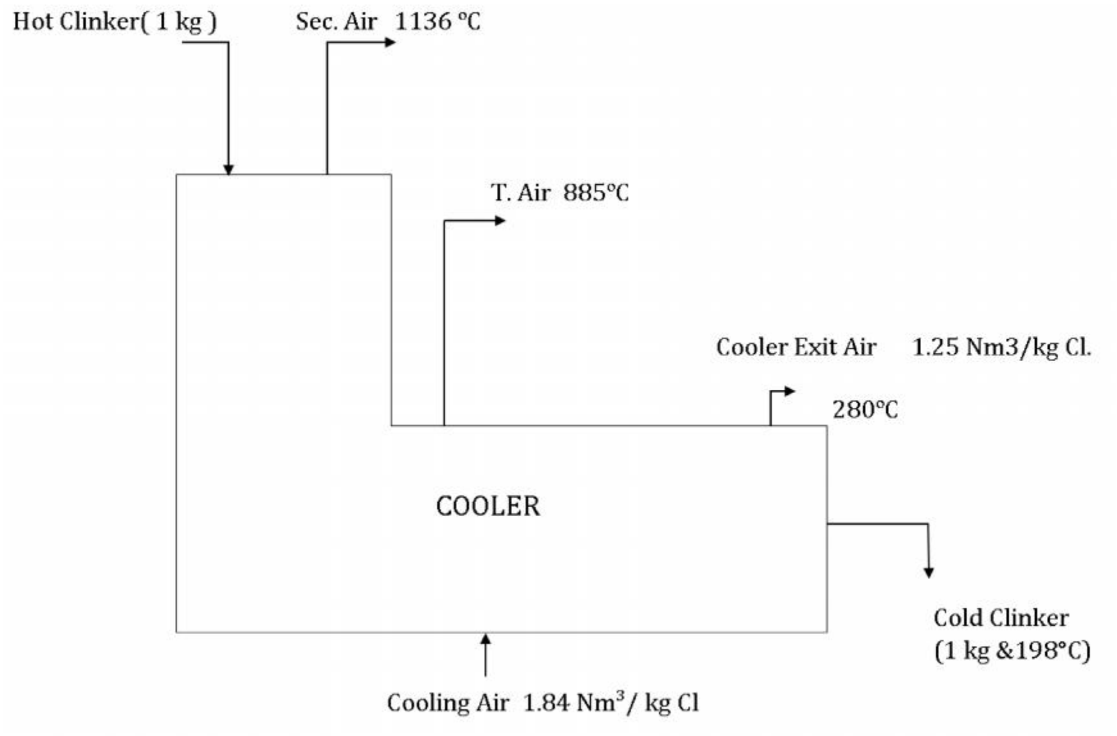


Figure 24. Clinker cooler material flow

3.3 Composition of SEC at each subprocess

The electrical and thermal energy consumption of a sample cement plant is discussed in this section. Figure 25 highlights the electrical SEC of a typical cement plant with subprocesses like crusher, raw mill, kiln and cement mill. The total electrical SEC of the cement plant is 83.71 kWh/t Eq. cement. Since the plant operates two cement mills, the weighted average (38.74 kWh/t Eq. cement) is used to compute the total SEC.

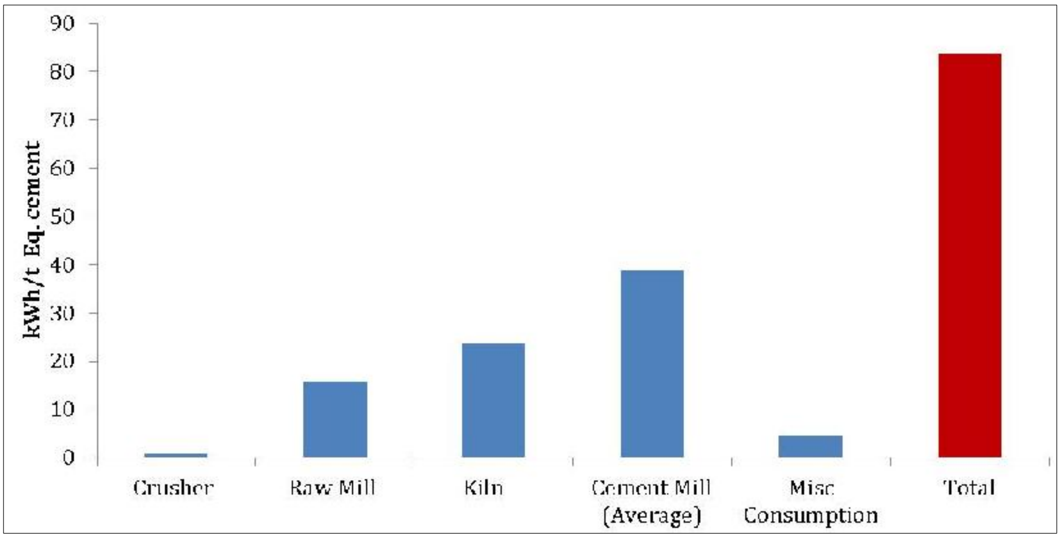


Figure 25. Electrical SEC at major subprocesses

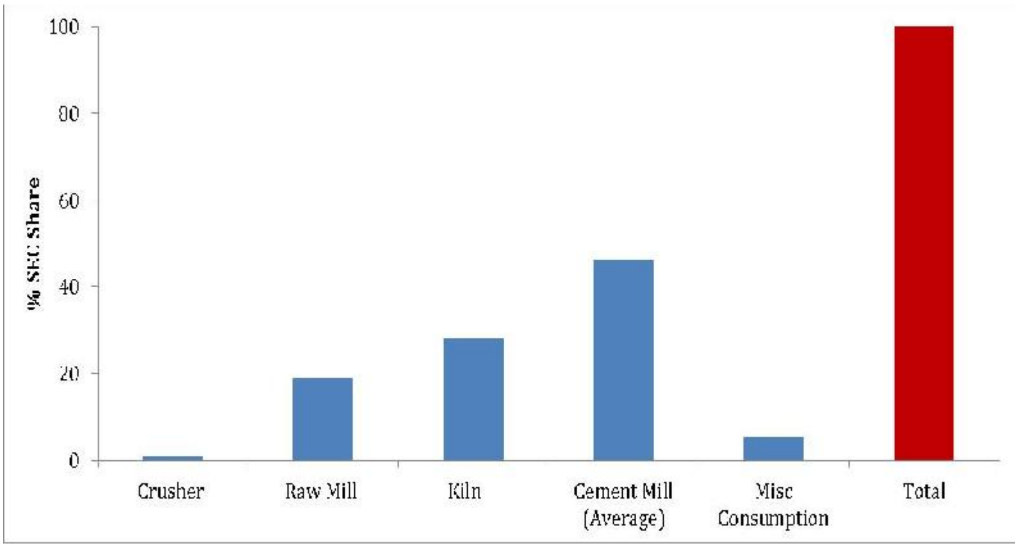


Figure 26. Electrical SEC share (%) across subprocesses

CRUSHER A crusher's energy balance is shown in Figure 27. The total electrical SEC of the crusher is 0.93 kWh/t Eq. cement. Among the three components, auxiliaries consume the maximum energy followed by the main motor.

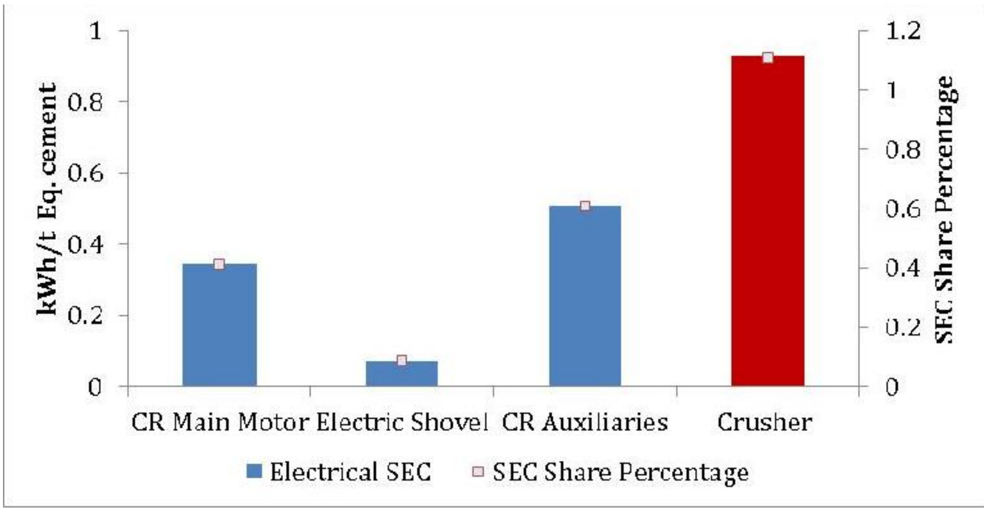


Figure 27. Electrical SEC and share of crusher components

RAW MILL Figure 28 shows the energy balance of a raw mill. From the figure, it is observed that the main motor in a raw mill consumes the highest energy (8.15 kWh/t Eq. cement) followed by the fan which consumes 6.12 kWh/t Eq. cement. A total of 15.91 kWh is consumed for every tonne of equivalent cement in a raw mill.

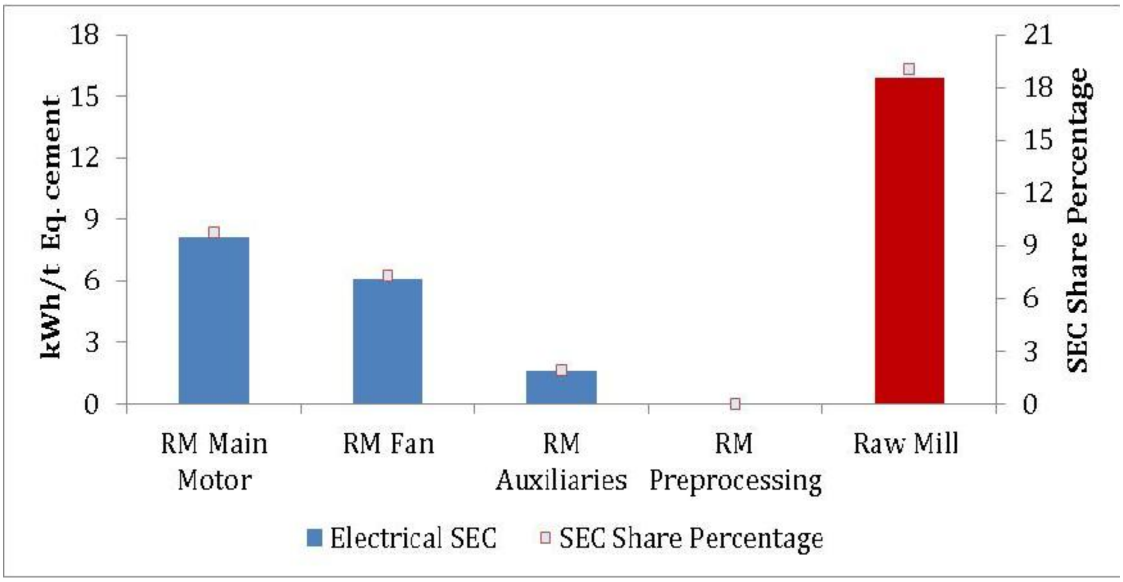


Figure 28. Electrical SEC and share of raw mill components

PYROPROCESSING The electrical SEC of the components of the pyroprocessing section is shown in Figure 29. The kiln auxiliaries consume 5.96 kWh/t Eq. cement, which is the highest among the components. The next highest is the preheater fan with 5.28 kWh/t Eq. cement.

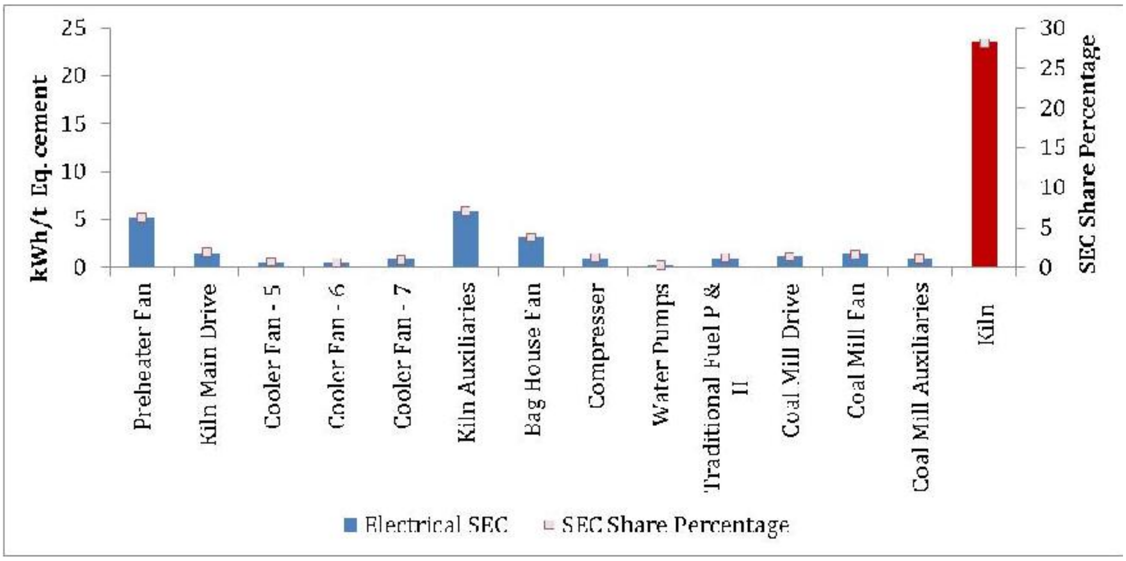


Figure 29. Electrical SEC and share of kiln and coal mill components

CEMENT MILL The electrical SEC of cement mill components is shown in Figure 30. The major portion of the energy is consumed by the mill drives.

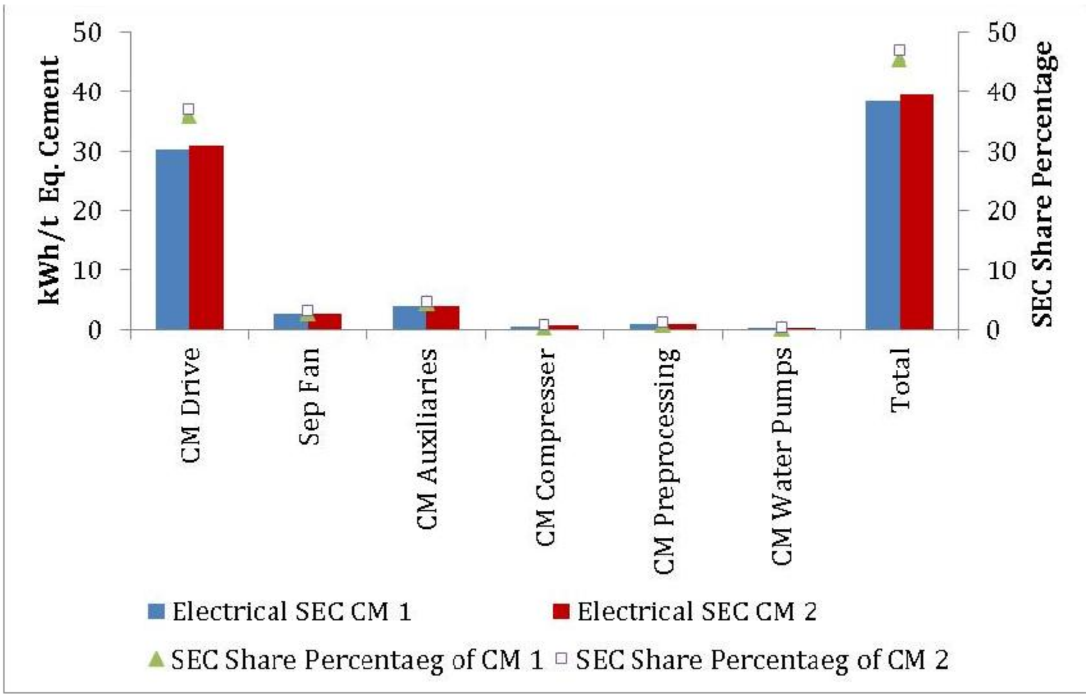


Figure 30. Electrical SEC and share of cement mill components

Figure 31 shows a sample of the running hours of each subprocess in a cement plant. The cement mills 1 and 2 recorded the maximum number of running hours for a month, followed by kiln, raw mill and crusher sections.

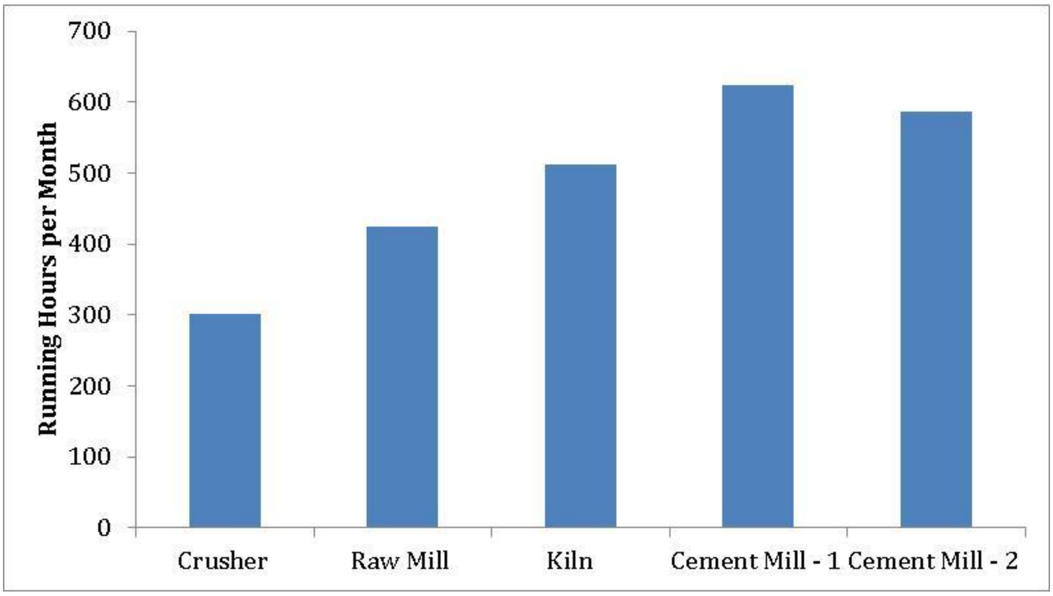


Figure 31. Running hours of subprocess

3.4 Heat balance analysis

The thermal energy balance shown in this section includes the heat input and heat output at the kiln and clinker cooler.

KILN HEAT BALANCE

The temperature of different inputs at the kiln is shown in Figure 32. The inputs considered are primary air, cooling air, conveying air from kiln feed, conveying air from coal, sensible heat from kiln feed, sensible heat from coal, sensible heat from cooler water spray and sensible heat from ingress air (including fresh air at cooler exit).

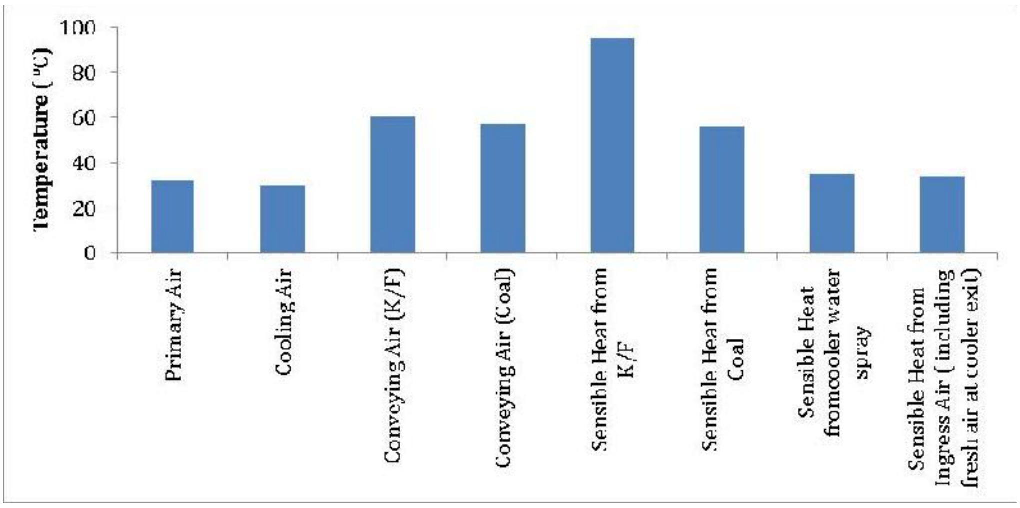


Figure 32. Temperature of different inputs to the kiln

The temperature of different outputs from the kiln is shown in Figure 33. The preheater exit dust losses and exit gases have the highest temperature among all the other outputs of the kiln.

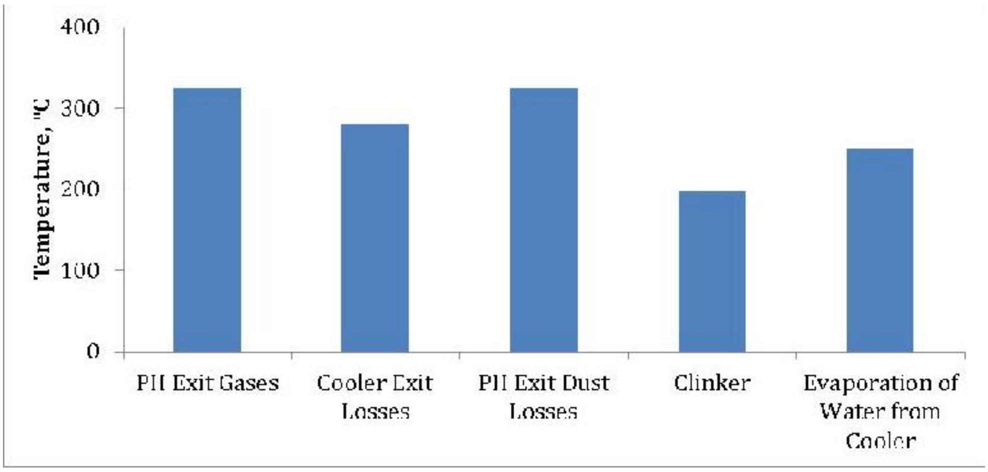


Figure 33. Temperature of different outputs from the kiln

The kiln heat balance is shown in Figure 34 and Figure 35. The heat inputs are shown in Figure 34. It is observed that the heat content from the coal combustion is 703.8 kCal/kg clinker. The heat outputs are shown in Figure 35. The theoretical heat of reaction accounts for 414.8 kCal/kg clinker, while the preheater exit gases and cooler exit losses account for161.3 kCal/kg clinker and 109.7 kCal/kg clinker respectively. It is also noted that the radiation losses are about 37.8 kCal/kg clinker.

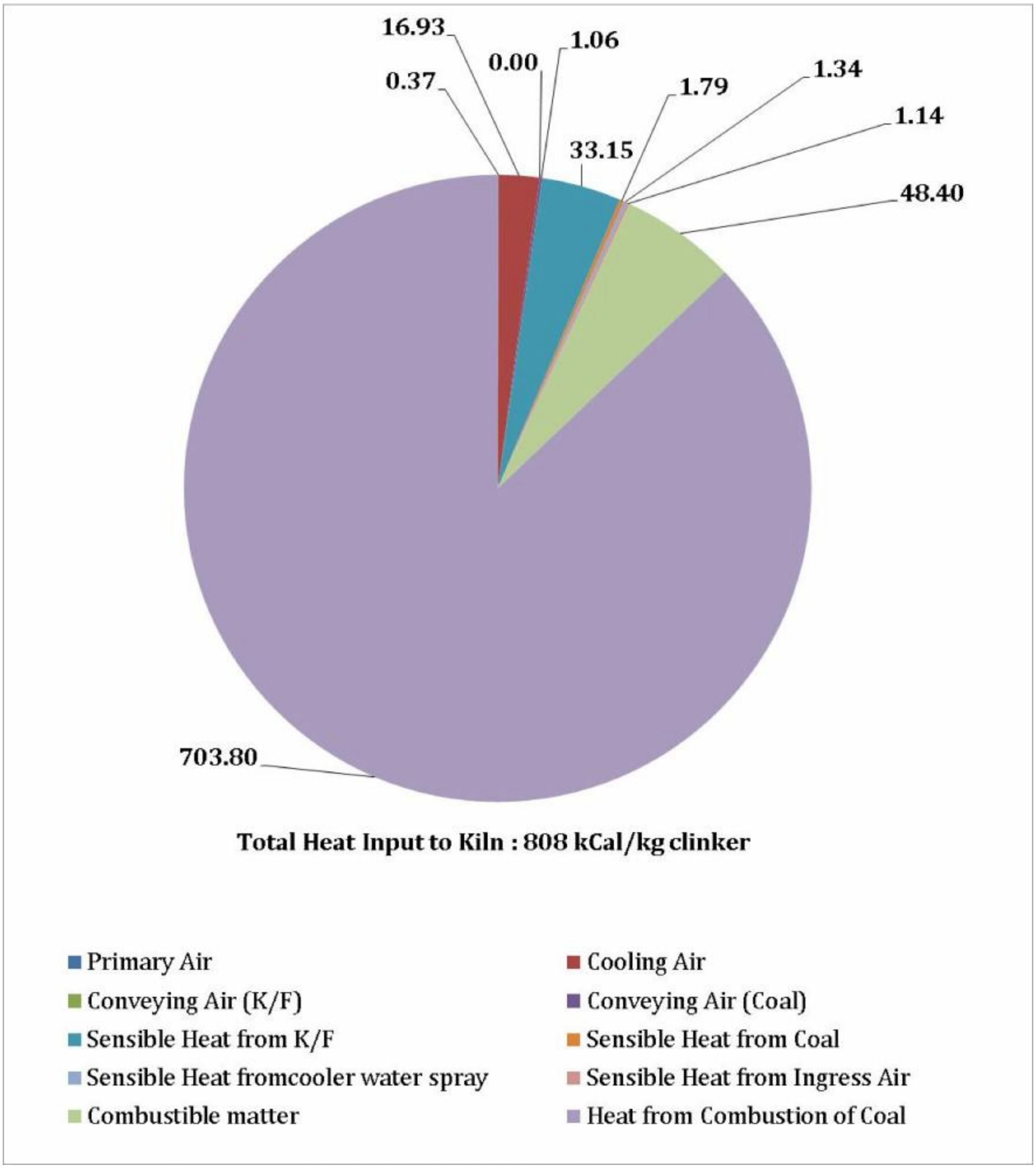


Figure 34. Kiln heat balance – heat input

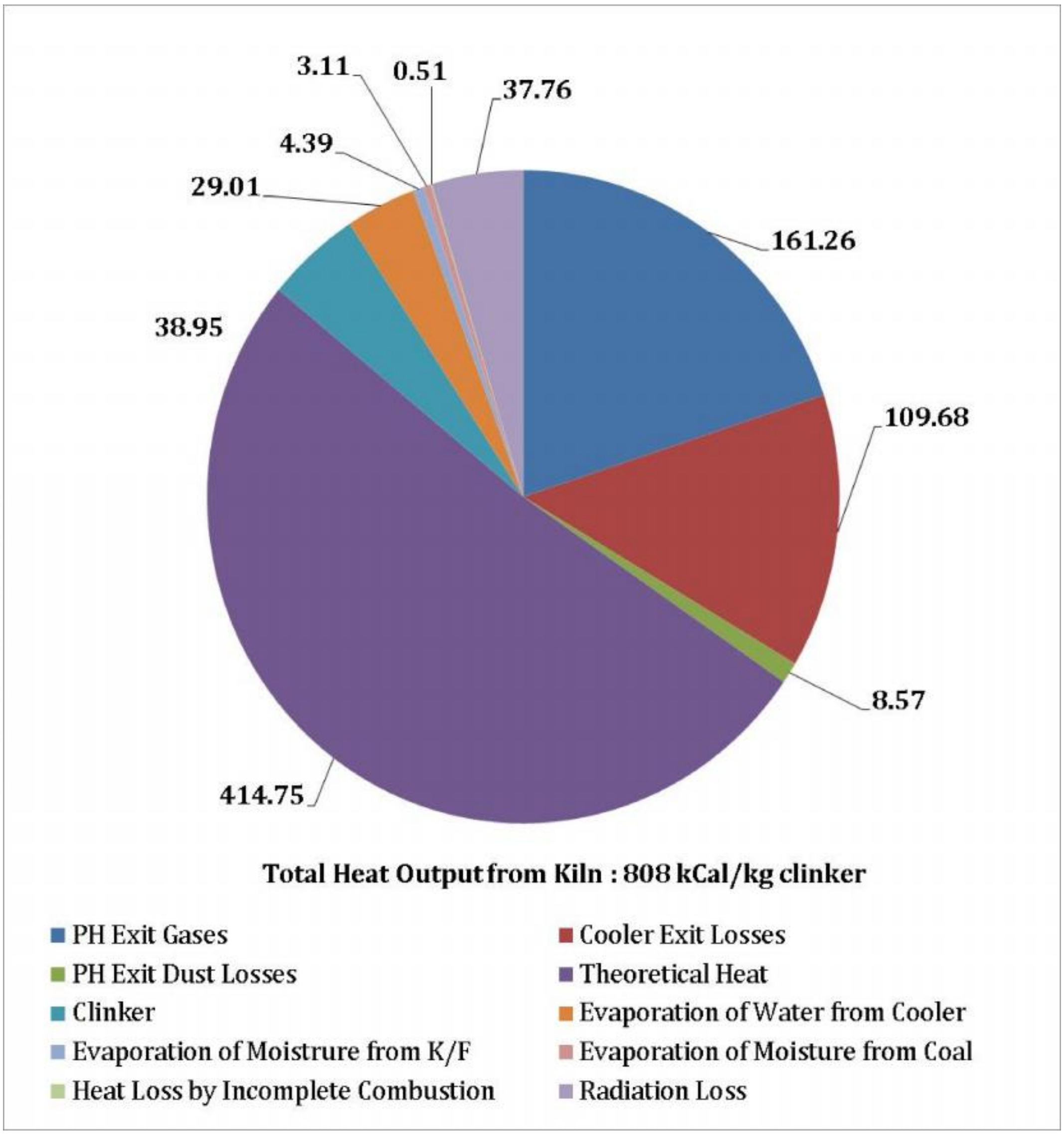


Figure 35. Kiln heat balance - heat output

COOLER HEAT BALANCE

The temperature of the clinker and the ambient air before it enters and after it exits the clinker cooler are shown in Figure 36 and Figure 37. The temperature of input heat at clinker cooler is shown in the graph drawn below. Clinker produced in kiln enters the clinker cooler at a temperature of 1450 ºC. The input temperature of cooling air is 32 ºC.

Figure 37 shows the temperature of outputs from the cooler. The vented air from the clinker cooler has 280 ºC and steam from cooler water spray has 250 ºC.

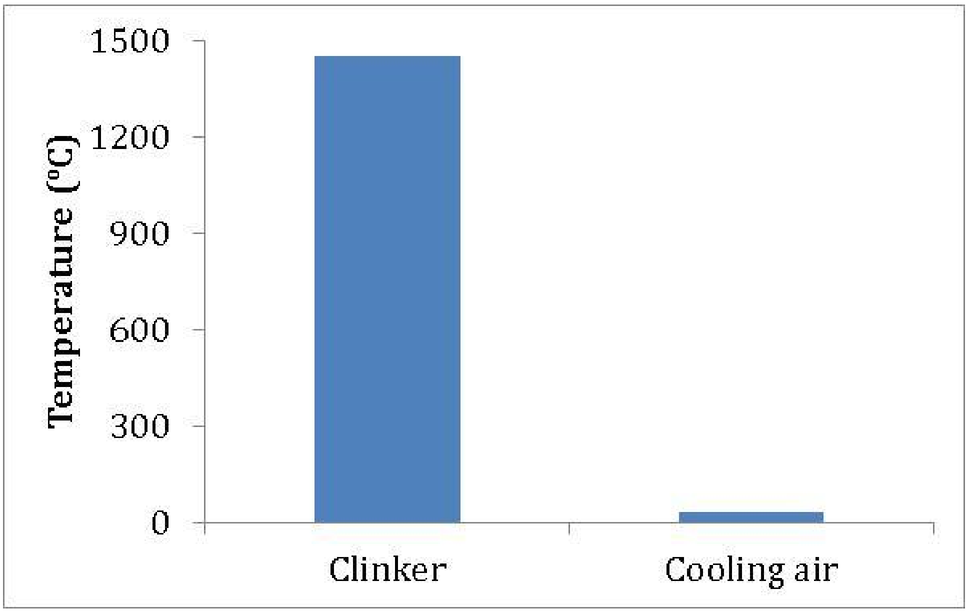


Figure 36. Temperature of inputs to the clinker cooler

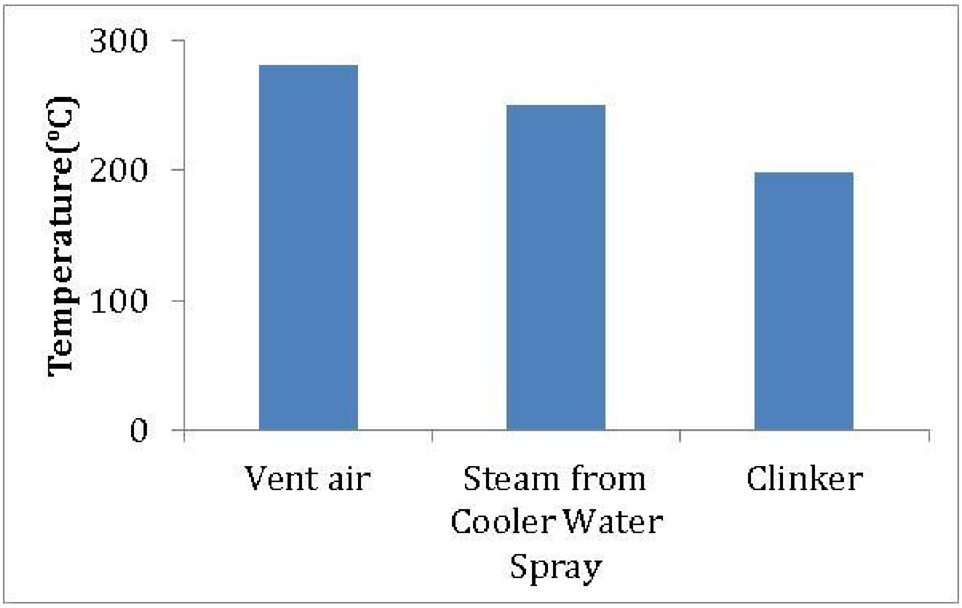


Figure 37. Temperature of outputs from the clinker cooler

The clinker cooler heat balance is shown in Figure 38 and Figure 39. The total heat input to the cooler is 401.3 kCal/kg clinker where 383.24 kCal/kg clinker is the heat content of the clinker and 18.06 kCal/kg clinker is the heat content of the cooling air.

The total heat output of the clinker cooler is 401.30 kCal/kg clinker. The vented air from the cooler contains 109.92 kCal/kg clinker while the steam from cooler water spray contains 32.07 kCal/kg clinker. The clinker that is cooled contains 38.95 kCal/kg clinker and the radiation loss is 0.56 kCal/kg clinker. The difference between the total heat content and the heat utilized in the system is 181 kCal/kg clinker, and this is the total heat loss.

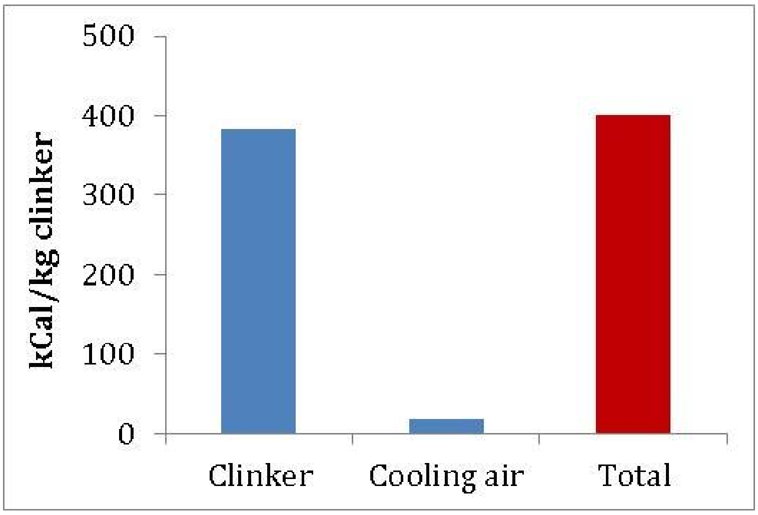


Figure 38. Heat input to the clinker cooler

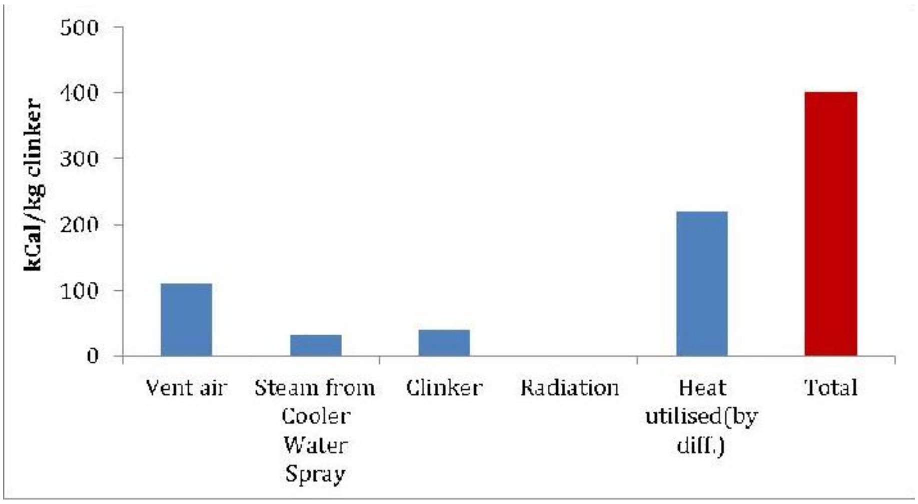


Figure 39. Heat output from the clinker cooler

The specific volume of air blown by each fan in the clinker cooler is shown in Figure 40. A total of 1.84 m^3/kg clinker is blown by fans in clinker cooler.

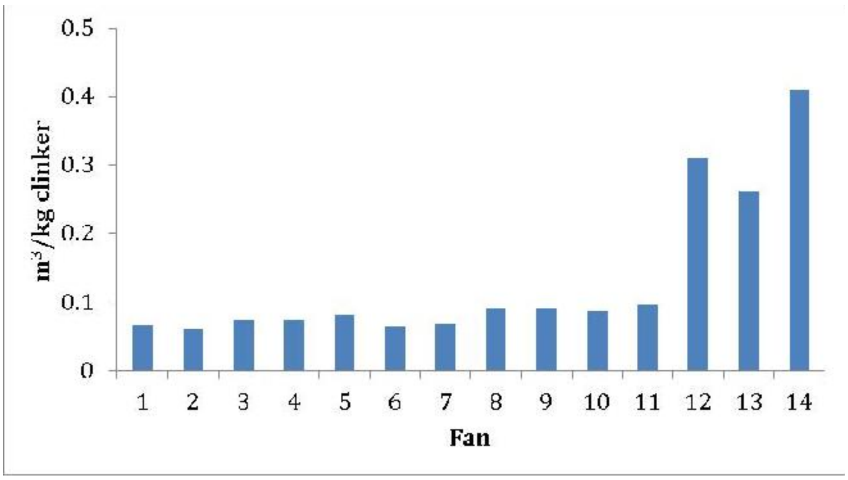


Figure 40. Specific volume of air blown in cooler

Summary

Table 3 summarizes the energy flow and heat flow for various subprocesses. The cement mill has the highest electrical SEC (46%) followed by kiln (28%) and raw mill (19%).

Table 3: Summary of Energy Consumption

Subprocess	Electrical Energy Consumption (kWh/t cement)	Thermal Energy Consumption (kCal/kg clinker)
Crusher	0.93	
Raw Mill	15.91	
Kiln & Cooler	20.12	808
Coal Mill	3.41	
Cement Mill	38.74	
Packaging Plant	1.59	
Lighting & Misc. load	3.00	
Total	**83.71**	**808**

3.5 Equipment Level Performance Analysis

This section demonstrates the sub-processes behavior over a period of 21 days of operation. These analyses show how critical parameters vary or are controlled in day to day operations.

Raw Mill

The damper position at mill fan, glass bag house fan etc. is shown in Figure 41. The y axis denotes the % opening of damper at various stages of the mill.

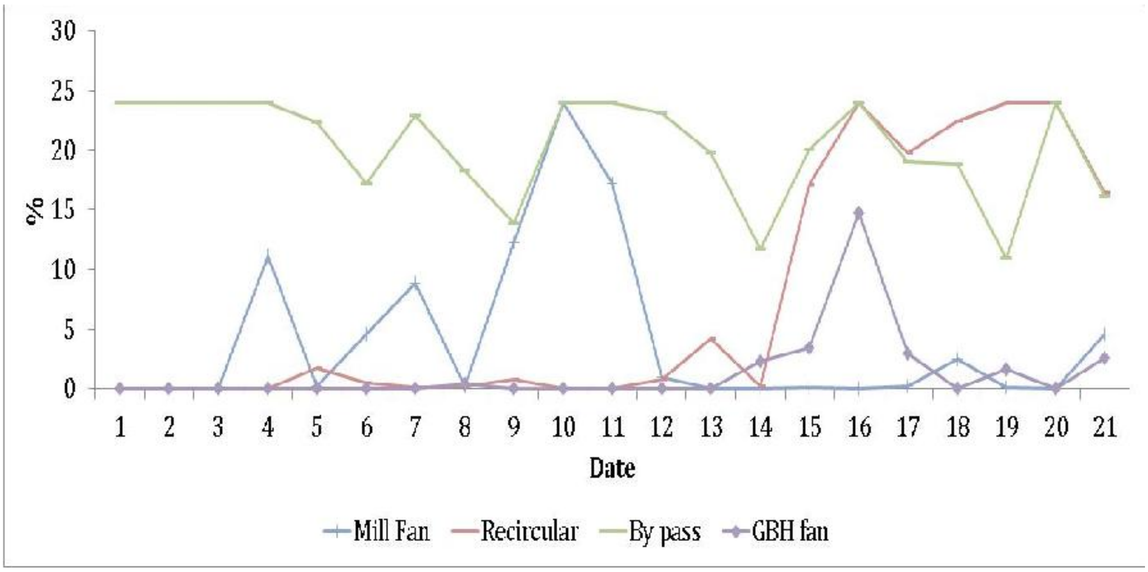


Figure 41. Damper position in raw mill

The motor load (kW) is shown in Figure 42. The kW drawn at various equipment of a raw mill is plotted in this graph. The raw mill fan draws more power than other components such as classifier, bag house fan, bucket elevators connected to silo. It is observed that the power drawn by raw mill fan is varying over the time period of 21 days.

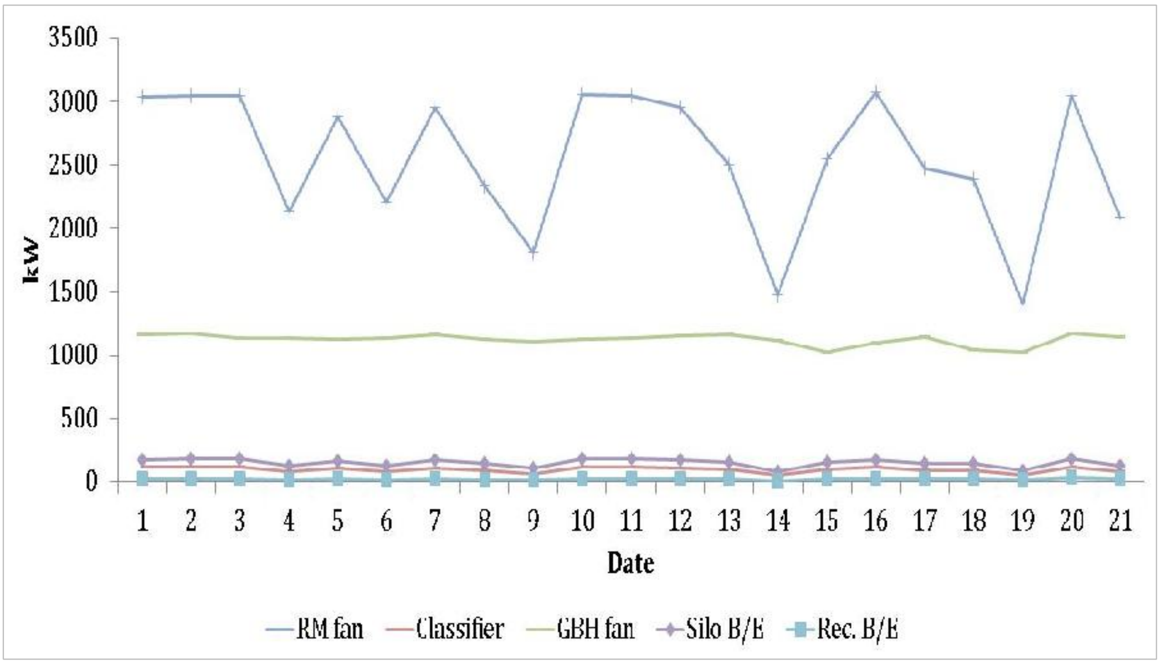


Figure 42. Motor load in raw mill

Feed rate of materials such as limestone, shale and laterite fed into the raw mill is shown in Figure 43. However, shale and laterite are shown in secondary axis of this graph.

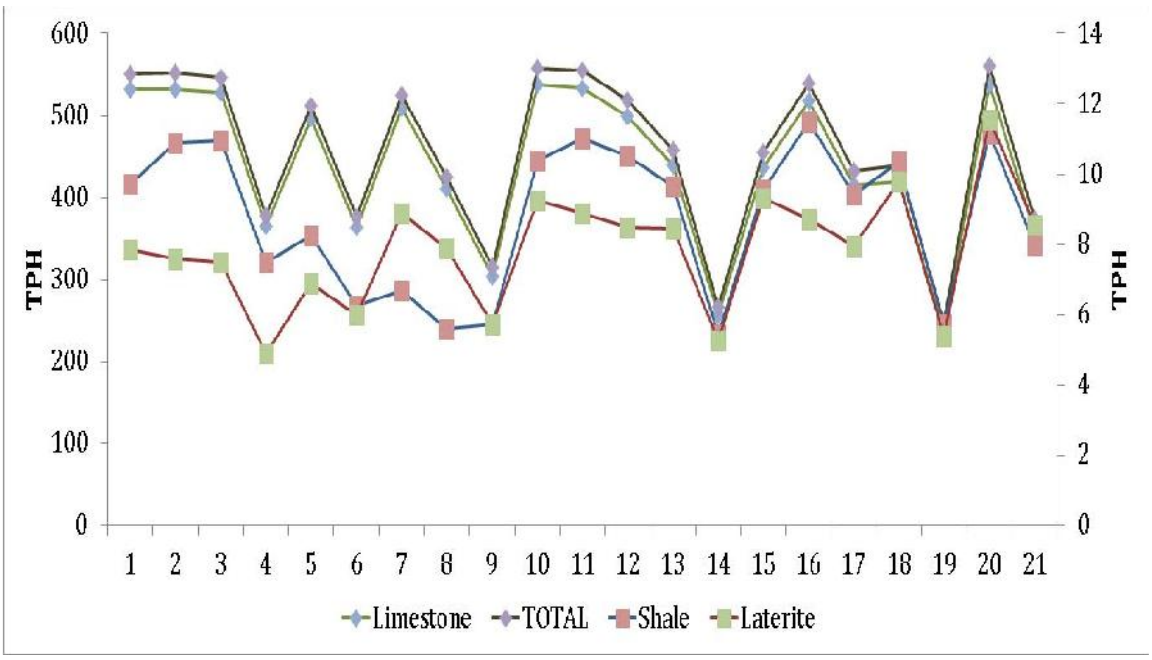


Figure 43. Feed rate in raw mill

The draught pressures after preheater fan, mill inlet and bag house inlet are shown in Figure 44

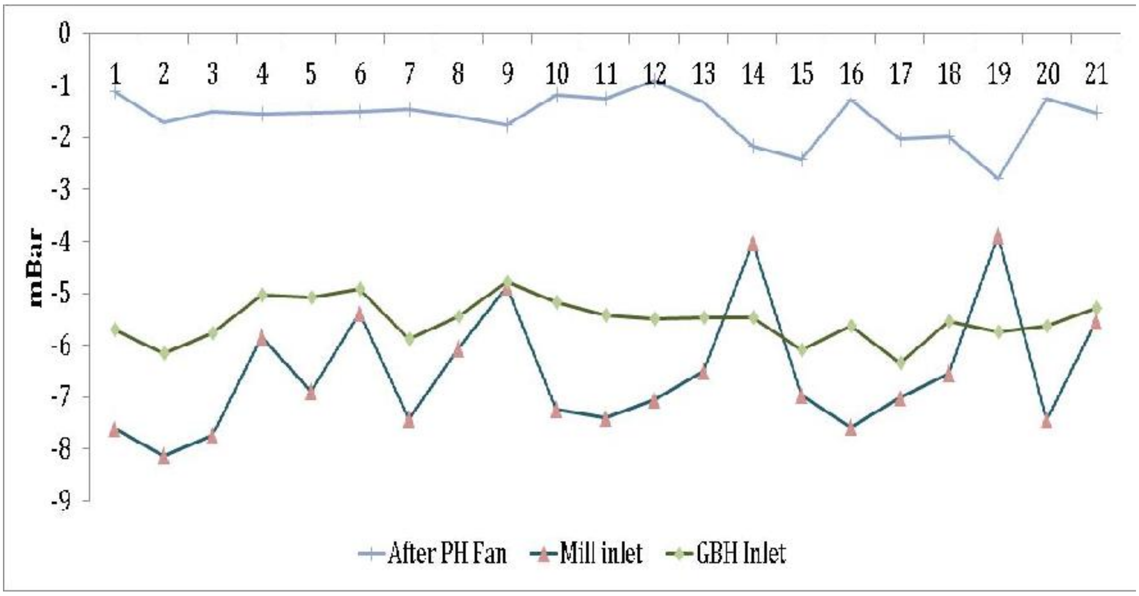


Figure 44. Draught in raw mill

The temperatures at raw mill are shown in Figure 45. Temperature at mill inlet, mill outlet and glass bag house inlet are plotted.

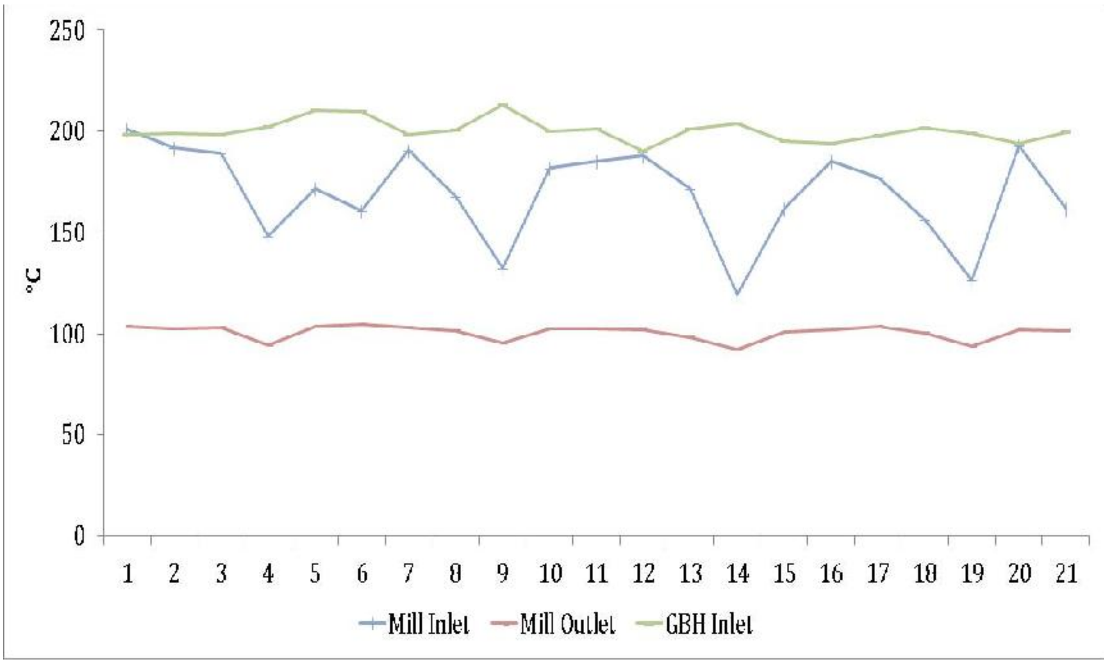


Figure 45. Temperature in raw mill

The draft pressure at auxiliary mill and glass bag house is plotted in Figure 46.

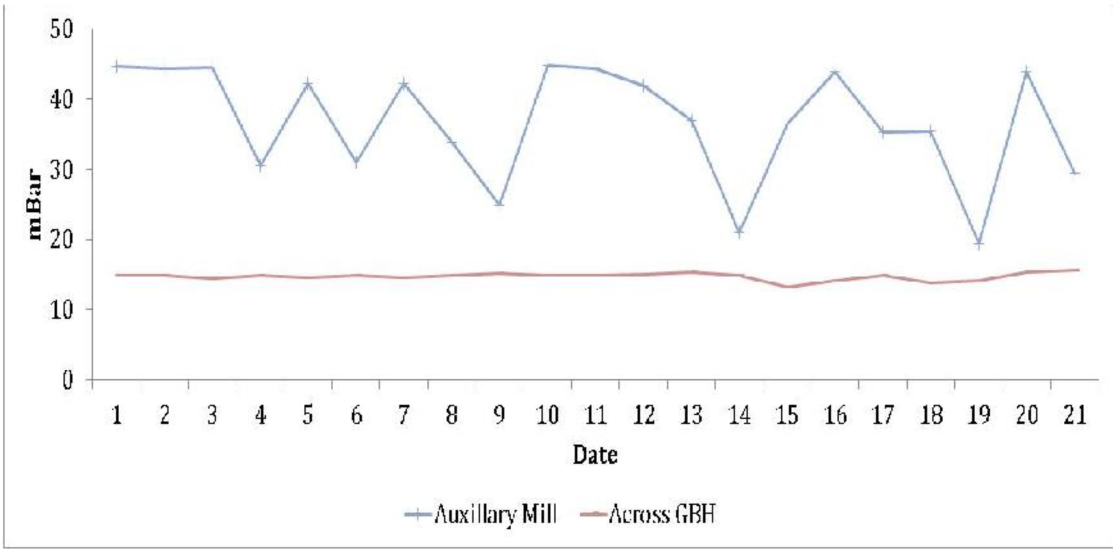


Figure 46. Draft pressure in raw mill

Coal Mill
Figure 47 shows the throughput across components of a coal mill. Throughput at mill inlet, mill outlet and PC silo are shown in the primary axis of the graph. The input and output of bag filter are plotted in the secondary axis.
The residue percentage of coal mill is shown in Figure 48. The coal ash level is the highest of all the residues, while the residue +212 (mesh size) is the least, less than 5%, throughout the month. Motor load (kW) at coal mill is shown in Figure 49. The load of mill, fan and separator are plotted.

Draught pressure at mill inlet, outlet, bag filter and mill is shown in Figure 50.

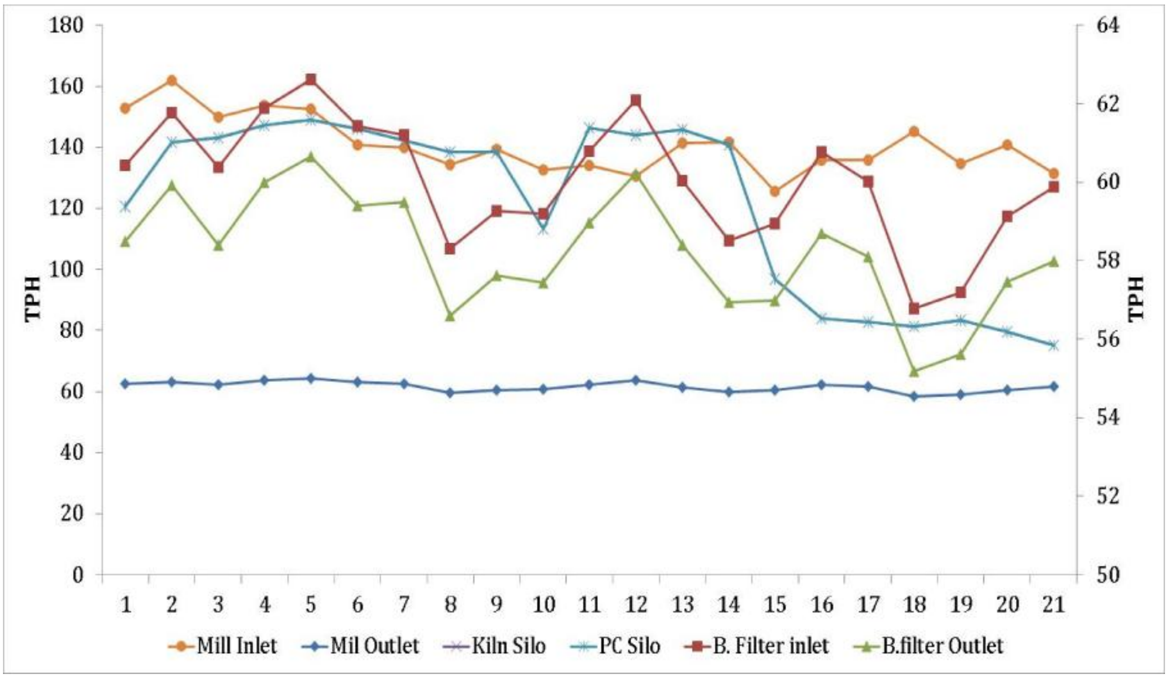


Figure 47. Throughput at coal mill

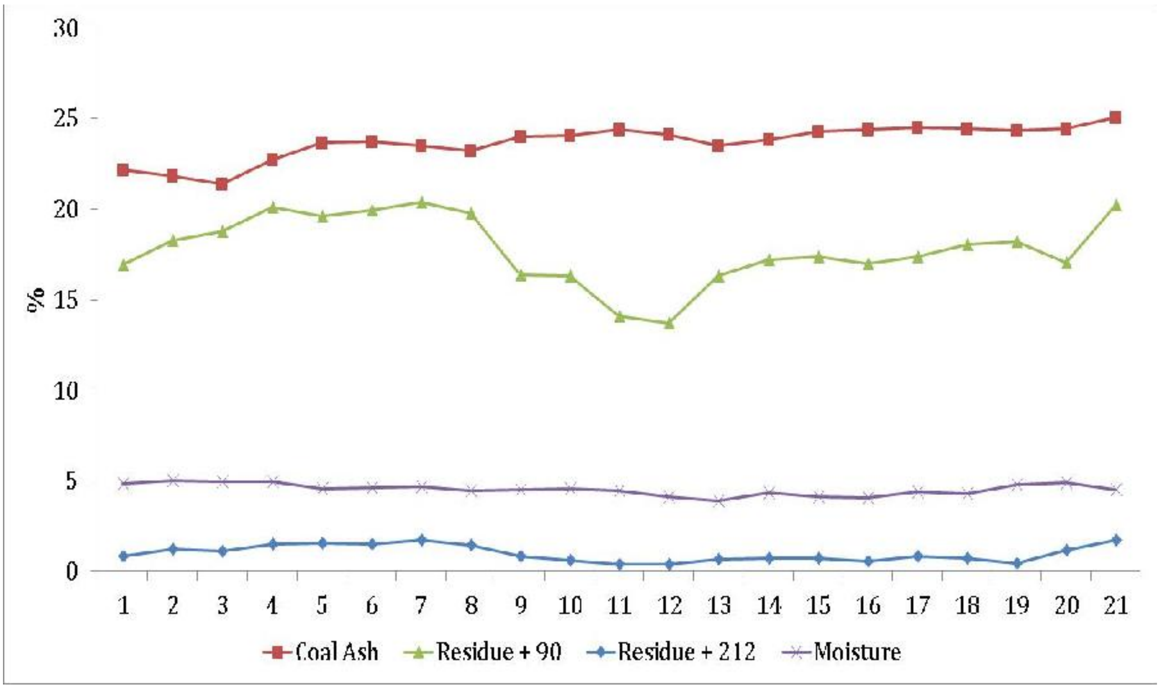


Figure 48. Residue (%) in a coal mill

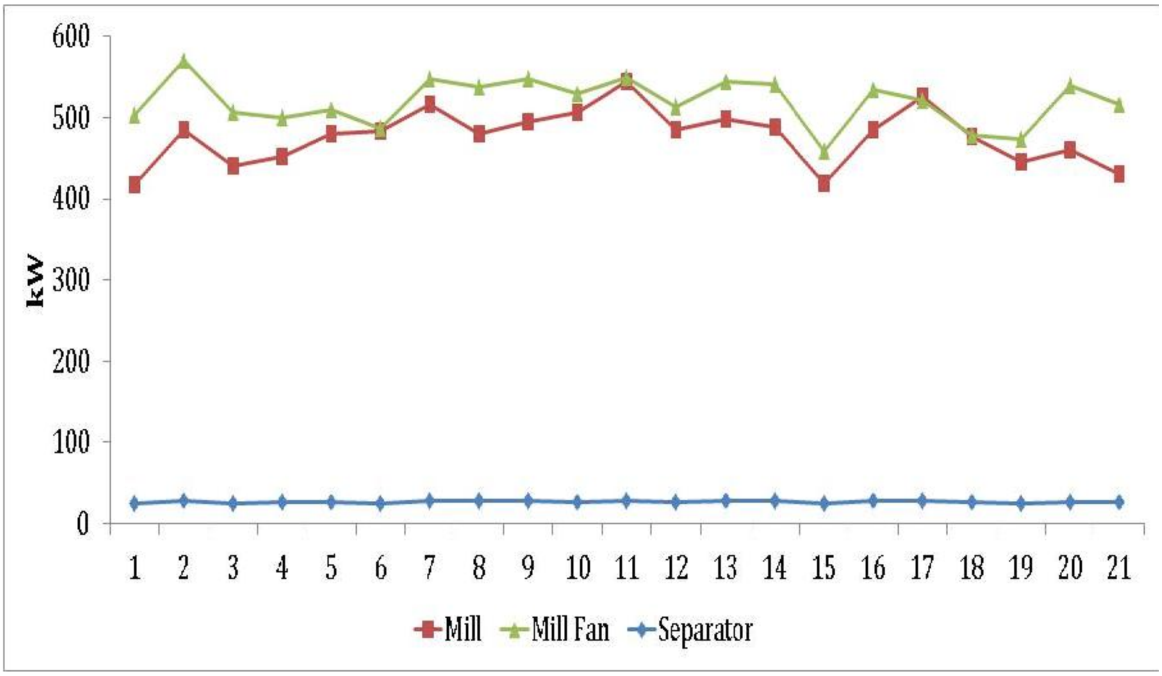


Figure 49. Motor load at coal mill

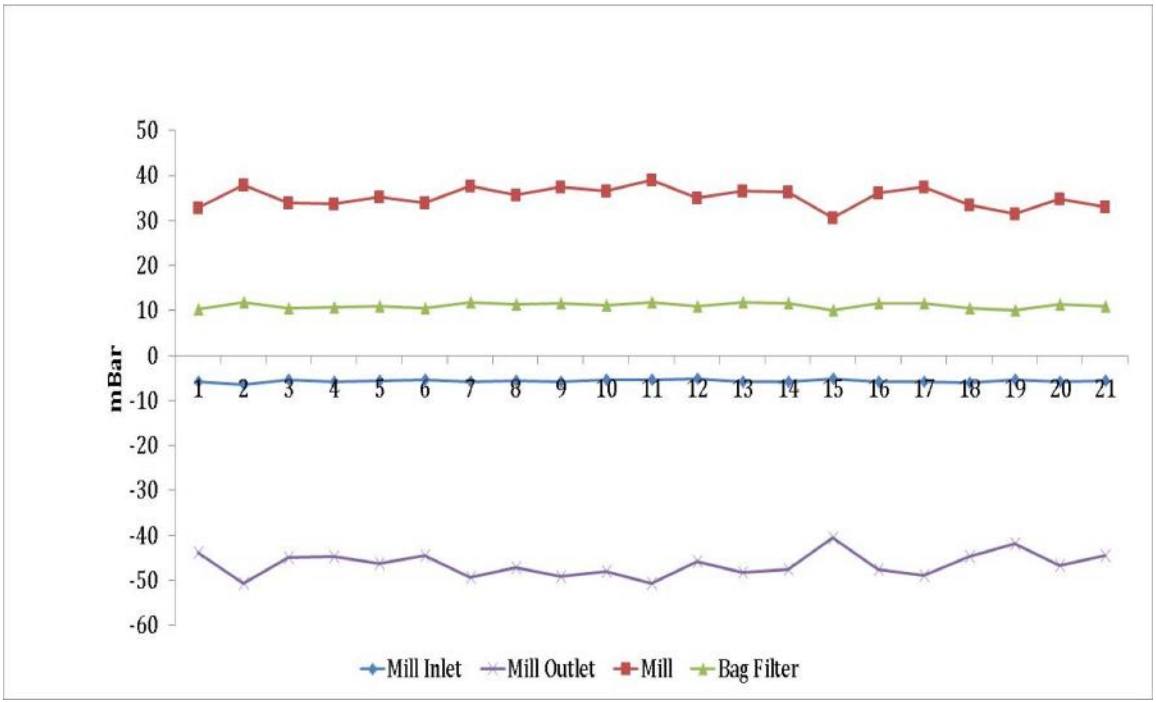


Figure 50. Mill inlet and outlet draught of a coal mill

Kiln

Feed rates at various stages of kiln operation are given in Figure 51.

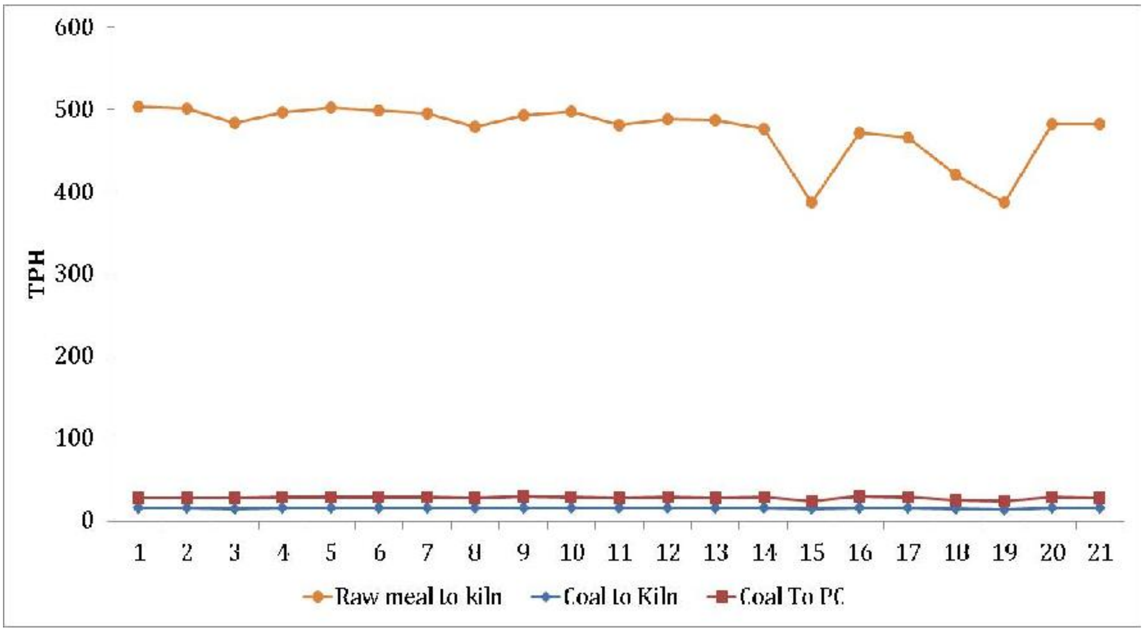


Figure 51. Feed rate at kiln and precalciner

The Preheater gas temperature at various stages is shown in Figure 52. The kiln inlet temperature is in the range of 900ºC.

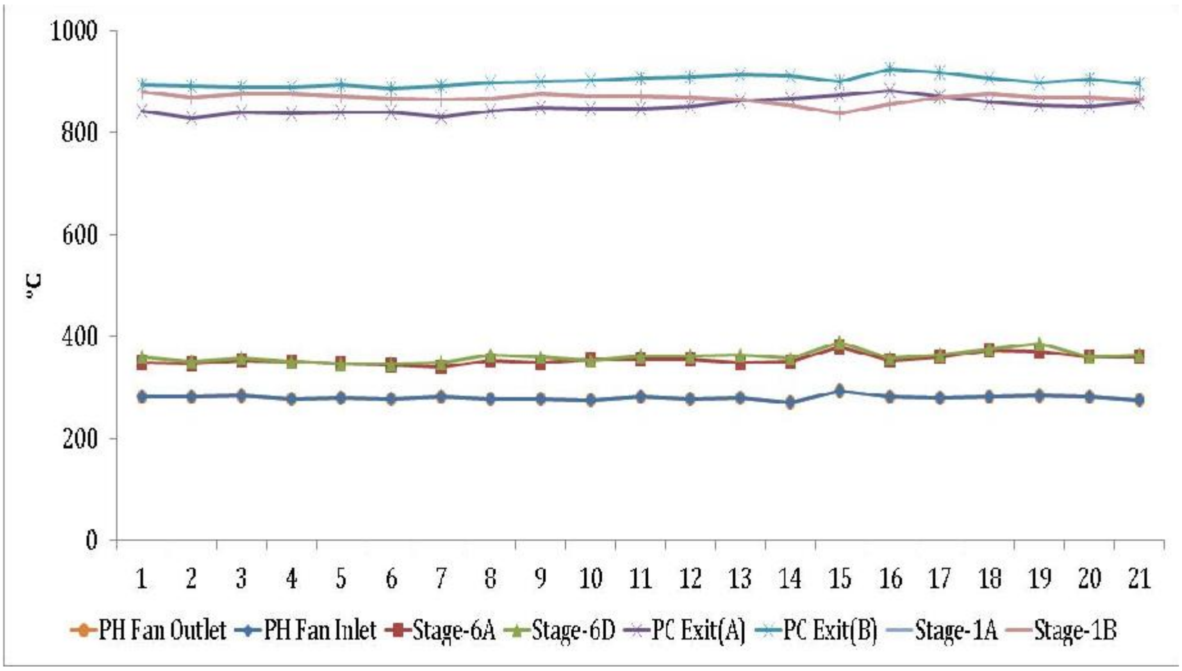


Figure 52. Preheater gas temperature

The preheater material temperature at the top two and bottom two stages are shown in Figure 53.

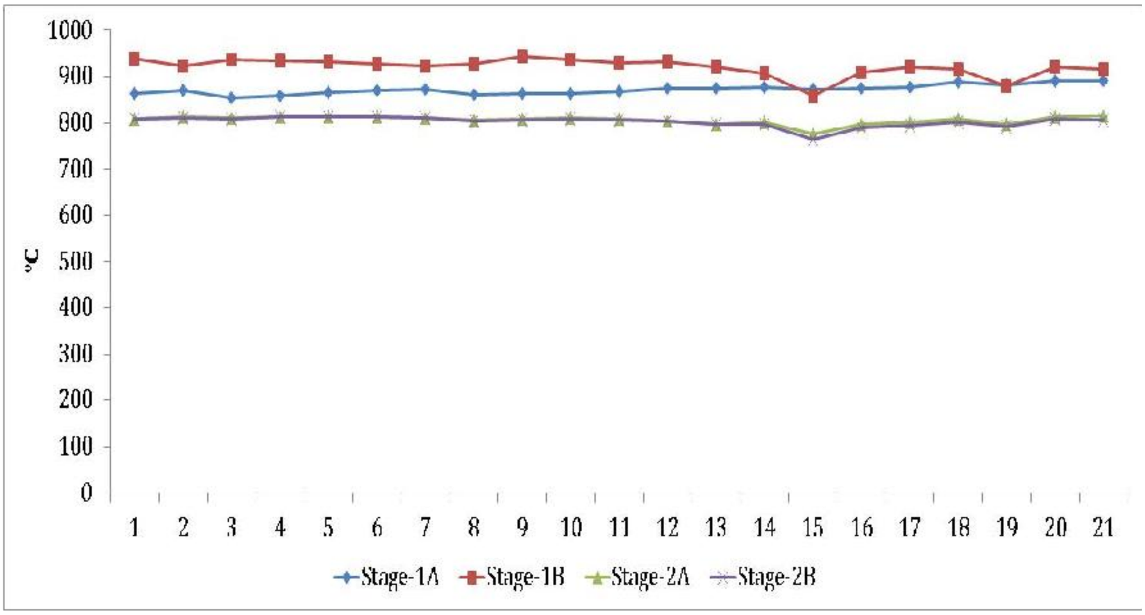


Figure 53. Preheater material temperature

The total air flow at grate 1 and grate 2 of the cooler is plotted in Figure 54 given below.

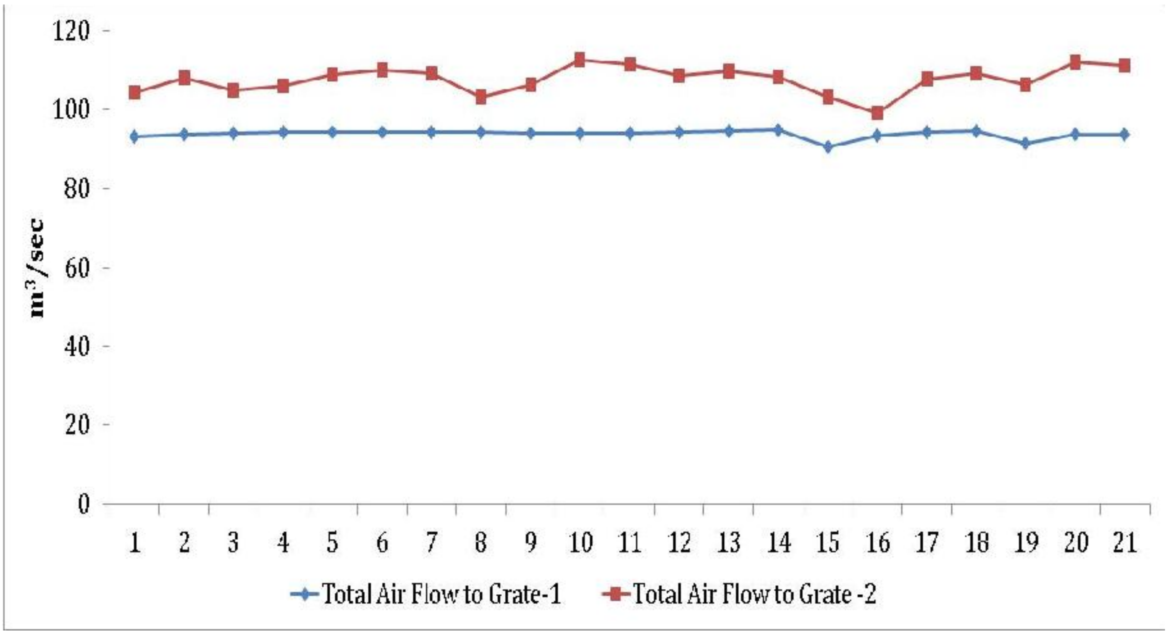


Figure 54. Airflow rate at cooler

The temperature of kiln at various stages is shown in Figure 55 .

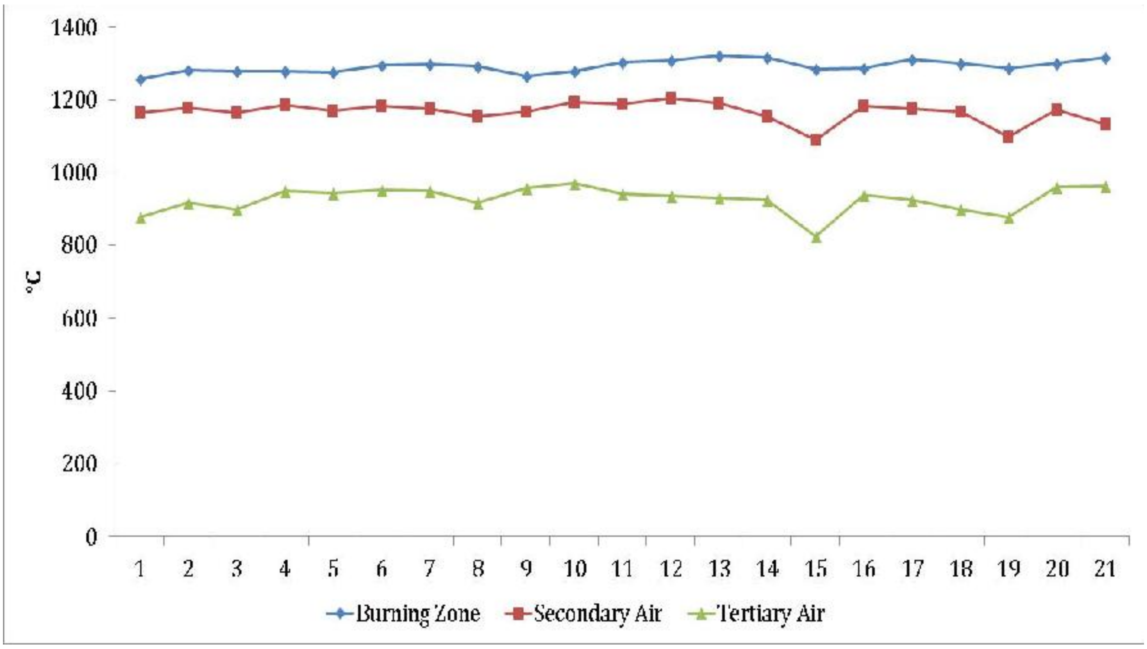


Figure 55. Kiln temperature

Radiation Losses

Radiation losses at various stages of the preheater cyclone 1A are shown in Figure 56. The line plot indicates the surface area (m^2).The radiation loss; convection loss and the sum of the two losses (kCal/kg clinker) are also shown here.

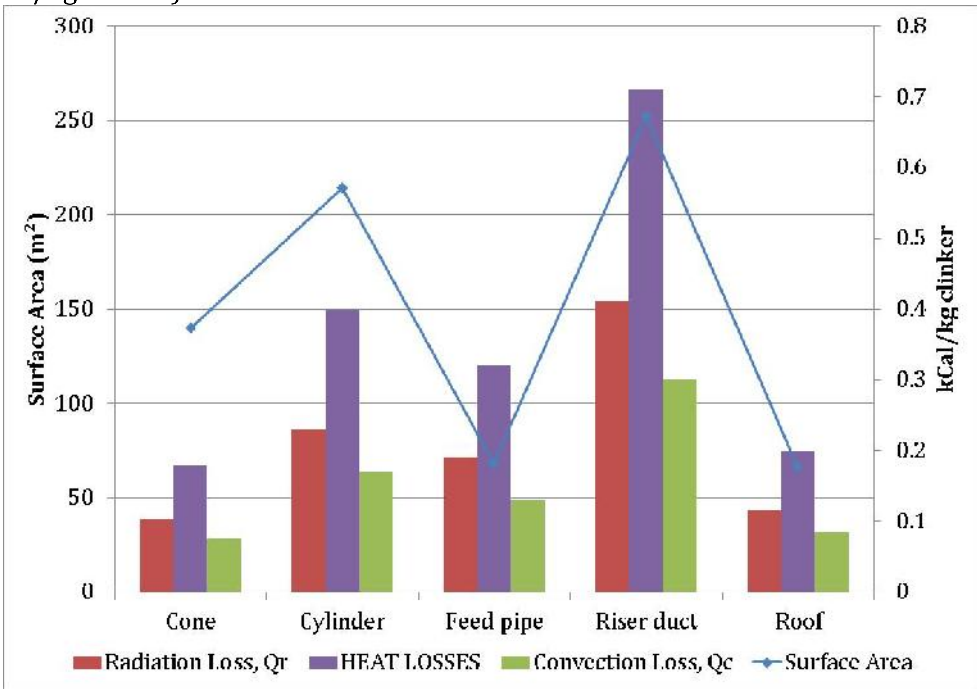


Figure 56. Radiation losses in cyclone 1A

Cement Mill

The DC Drive RPM (%) is shown in Figure 57 for both the cement mills. It can be inferred from the graph that RPM varied from 27% to 77% in cement mill 1 and 33% to 77% in cement mill 2.

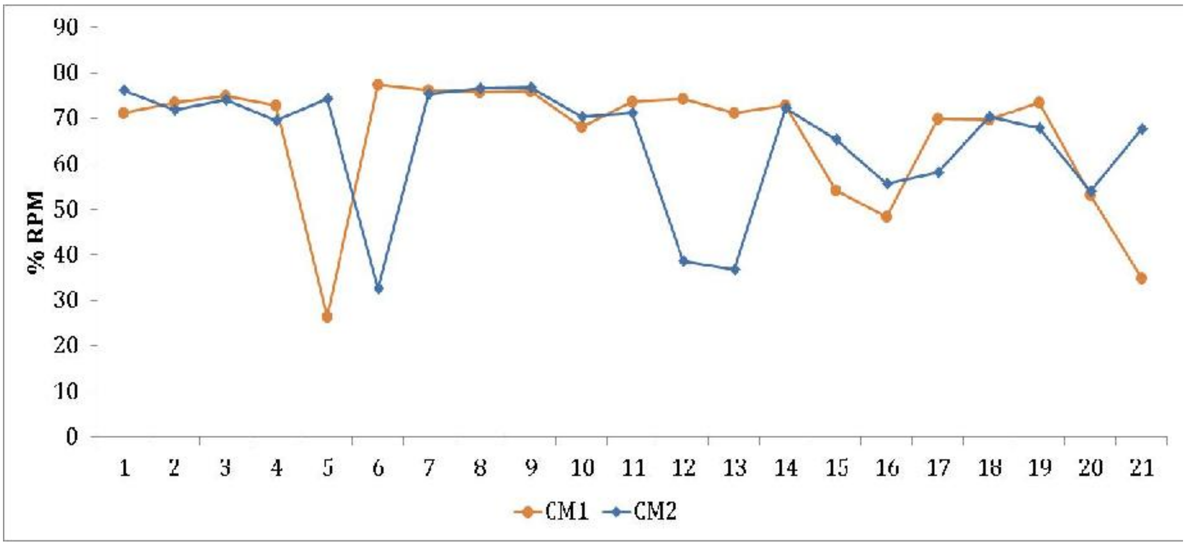


Figure 57. RPM (%) of DC drive in cement mills

Figure 58 shows the positional variations of ESP/BH fan damper in both the cement mills.

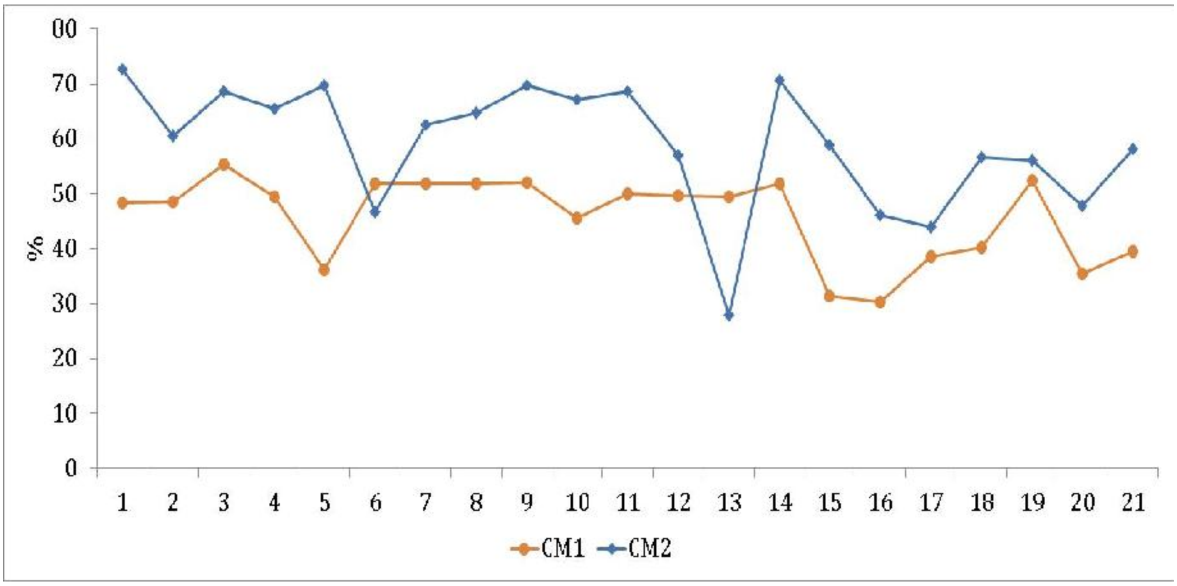


Figure 58. ESP/BH fan damper position in cement mills

Blaine (cm^2/gm), the measure of the particle size or fineness of cement, is shown in Figure 59. Both the cement mills follow a similar pattern ranging between 325 and386 cm^2/gm.

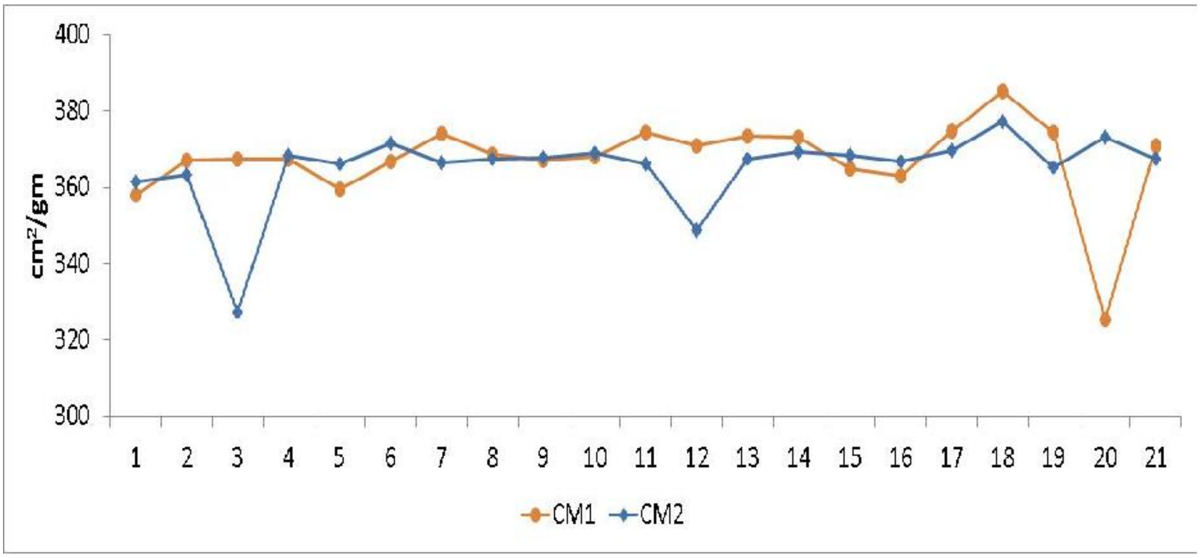


Figure 59. Blaine of cement in cement mills

Figure 60 shows the mill filling (%) for the cement mill 1 and 2.

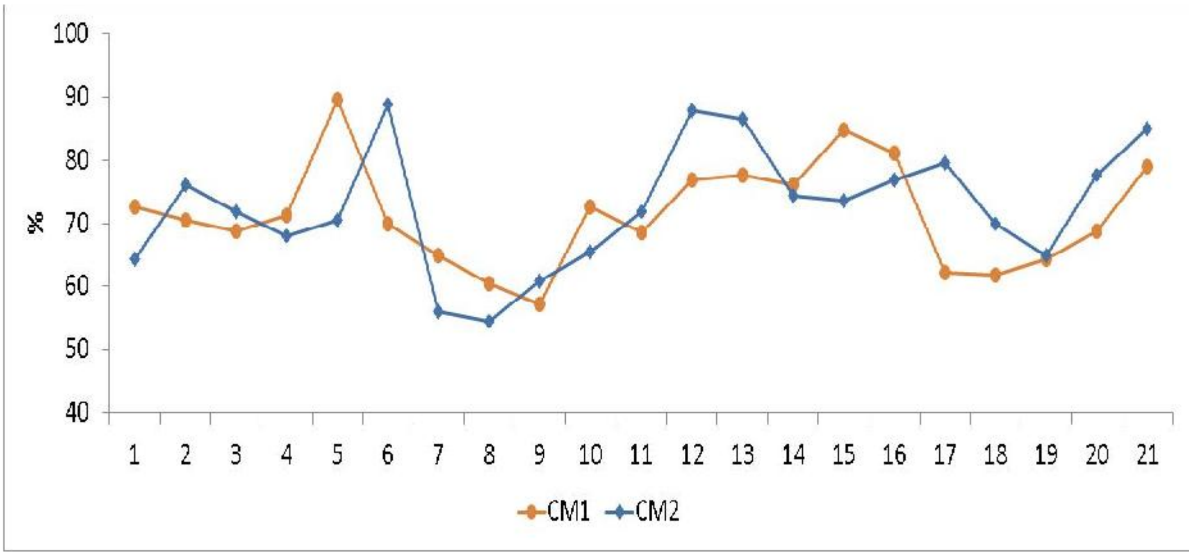


Figure 60. Mill filling (%) in cement mills

The motor load (kW) of both the cement mills is shown in Figure 61. The load of separator fan and separator DC Drive is plotted for 21 days.

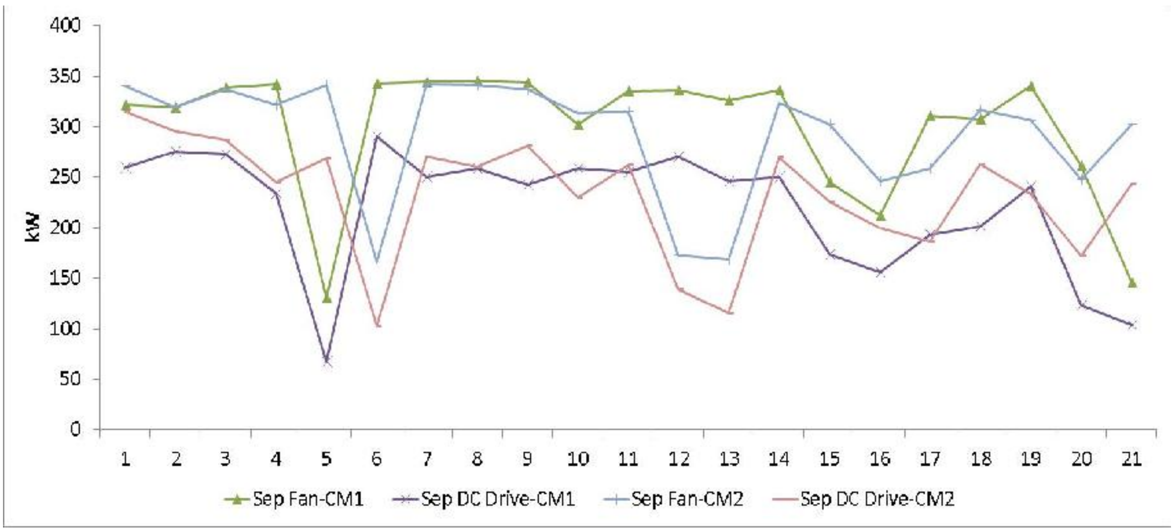


Figure 61. Motor load of cement mill CM1 and CM2

The draught pressure at mill inlet and outlet of cement mills are shown in Figure 62. The draught pressure is indicated in mBar.

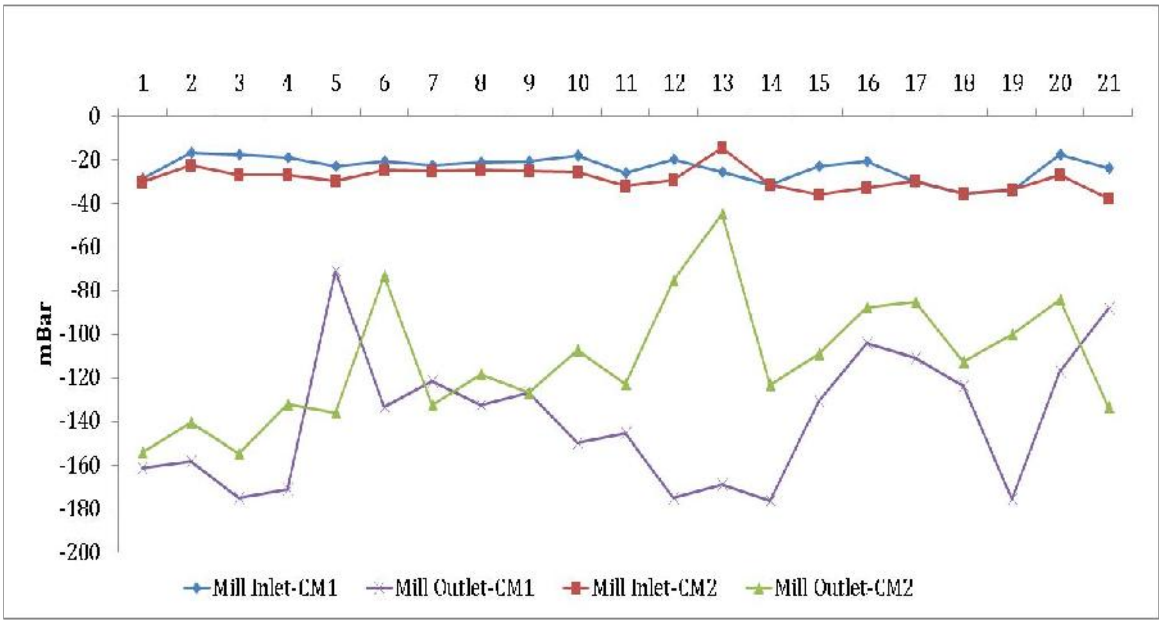


Figure 62. Mill inlet and out draught for CM1 and CM2

The temperature of material at different places of both the cement mills is shown in Figure 63. The material at cement mill 2 has the highest temperature of 120°C.

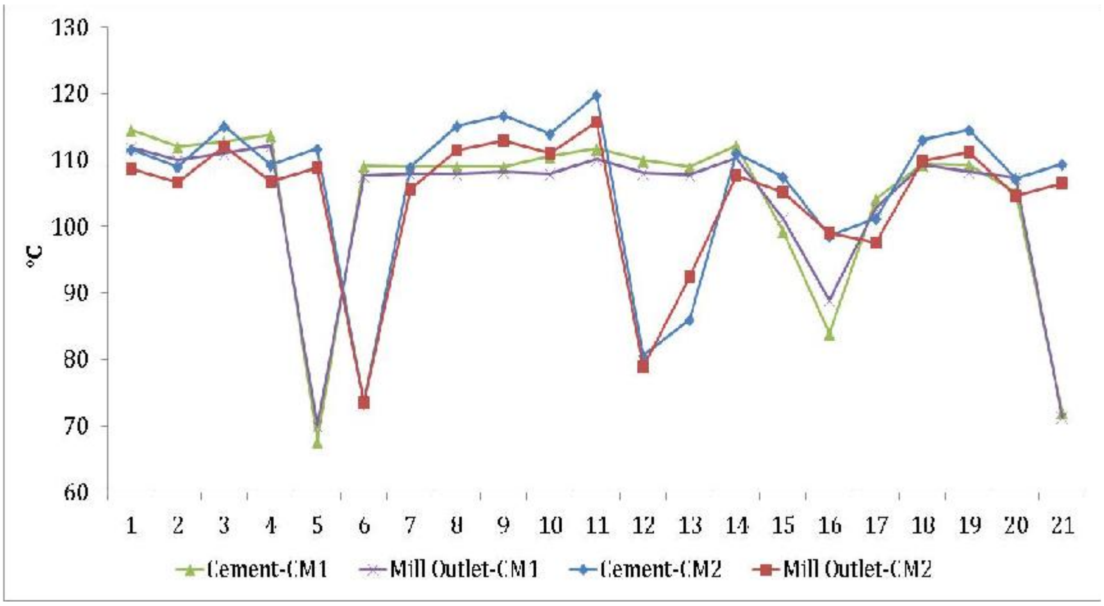


Figure 63. Temperature of materials in CM1 and CM2

The feed rate of pozzolana, gypsum, clinker and the total of both the cement mills are shown in Figure 64 and Figure 65.

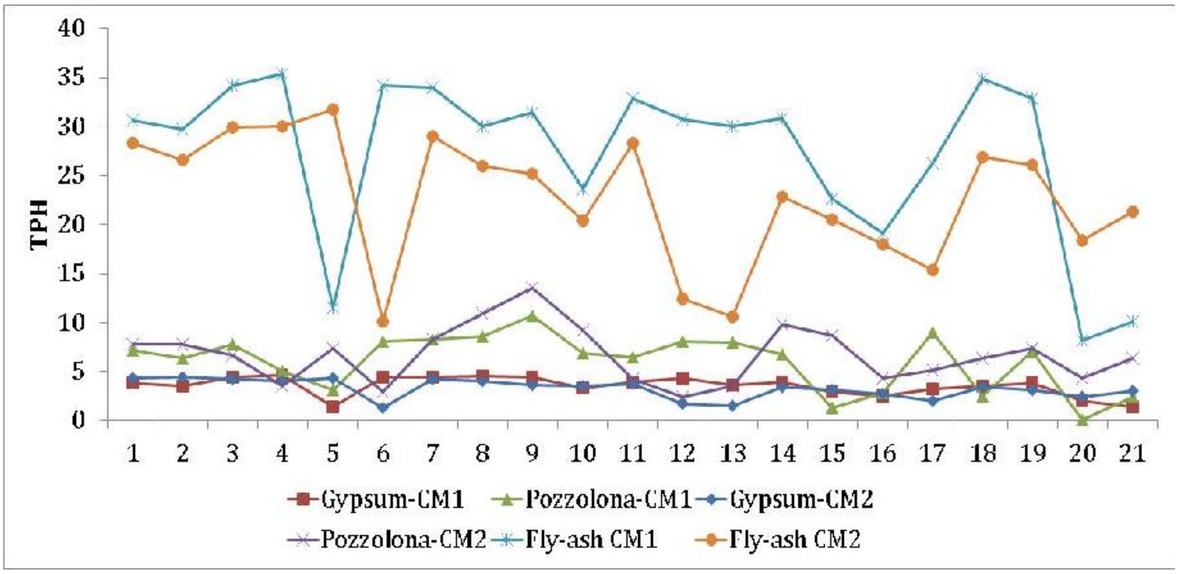


Figure 64. Feed rate of materials in CM1 and CM2

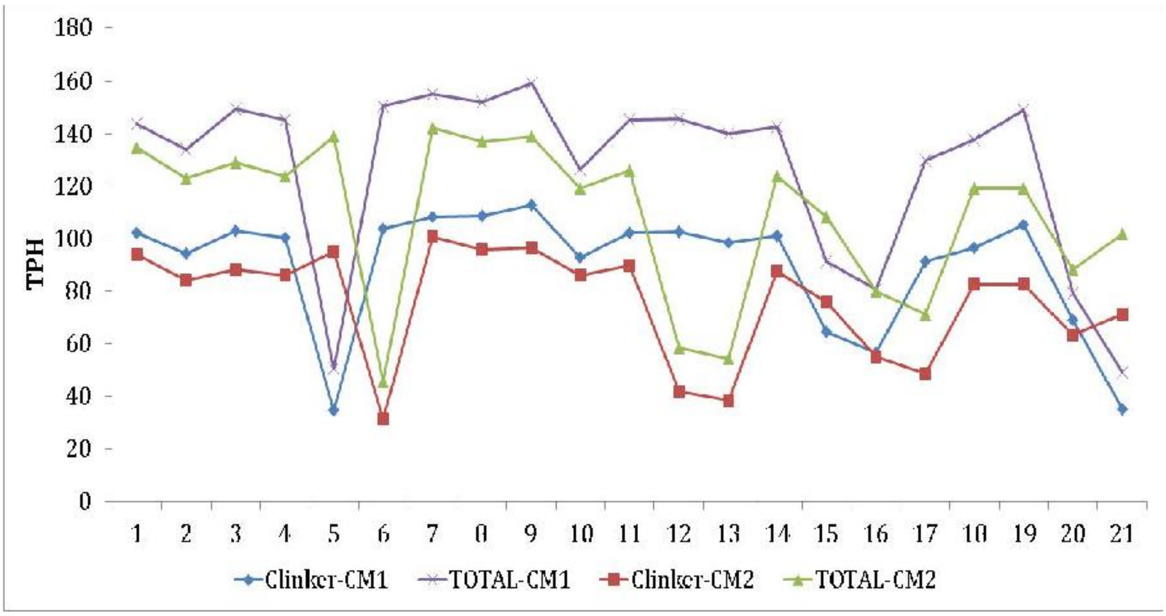


Figure 65. Clinker and total feed rate in CM1 and CM2

Figure 66 shows the blending percentage of fly-ash in cement mill 1 and cement mill 2.

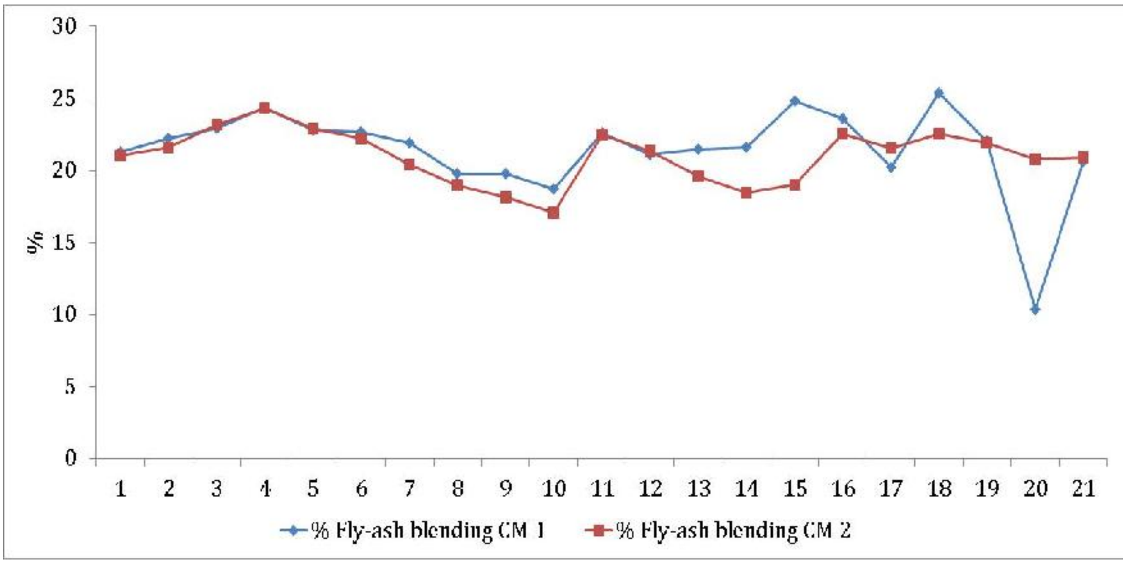


Figure 66. Blending percentage of fly-ash in CM 1 and CM 2

3.6 Process Modeling

In this study, ASPEN Plus was utilized to analyze the material balance in a cement manufacturing process. ASPEN is a process simulator used for equipment design, process simulation and sensitivity analysis.

The preheater, precalciner and kiln section flow process is depicted in this section to highlight the ASPEN analysis. The process flow diagrams are shown in Figure 67, Figure 68 and Figure 69. Preheater is considered as mixer followed by seperator. A three stage preheater is considered for pre heating the raw material (LSFEED). Each stage is shown as PH1, PH2 and PH3 in the following figure. Heat tranfer takes place between the limestone powder and the hot exhuast gases from previous stage as shown in Figure 67. The preheated raw material stream is fed to precalciner (CALCNATOR).

Calcination is modeled in two steps. In the first stage coal is combusted in a chamber and then calcination occurs in the next stage.

The calciner process model consists of the following sections:

- Mixer (MIX4 in Figure 68)
- Separator (F1)
- Combustor (COMBUSTOR)
- Calciner (CALCNTOR)

In the mixer, kiln gas containing mainly O_2, N_2 and CO_2 is mixed with limestone powder coming from the previous stage. The mixed stream is fed into the separator. Coal stream containing mainly carbon, hydrogen, and moisture is the other input to the combustor. The combustor is a RGIBBS model of Aspen Plus in which combustion occurs. The solid line shows the material stream, while the dotted line shows the energy stream (Figure 68).

The flue gases of coal combustion from the combustor are made to pass through the calciner (RSTOIC model of Aspen Plus) where the following reactions occur:

$$CaCO_3 \rightarrow CaO + CO_2$$
$$MgCO_3 \rightarrow MgO + CO_2$$

Calcined products along with flue gases of combustion are separated in the cyclone separator module. This stream is connected to the kiln section as shown in Figure 68.

The kiln section is considered in 3 stage operation, i.e., Kiln3, Kiln5 and Kiln7 as shown in Figure 69. Each stage in the kiln comprises of Mixer (K3IN), Reaction chamber (KILN3) and followed by separator (F3OUT).

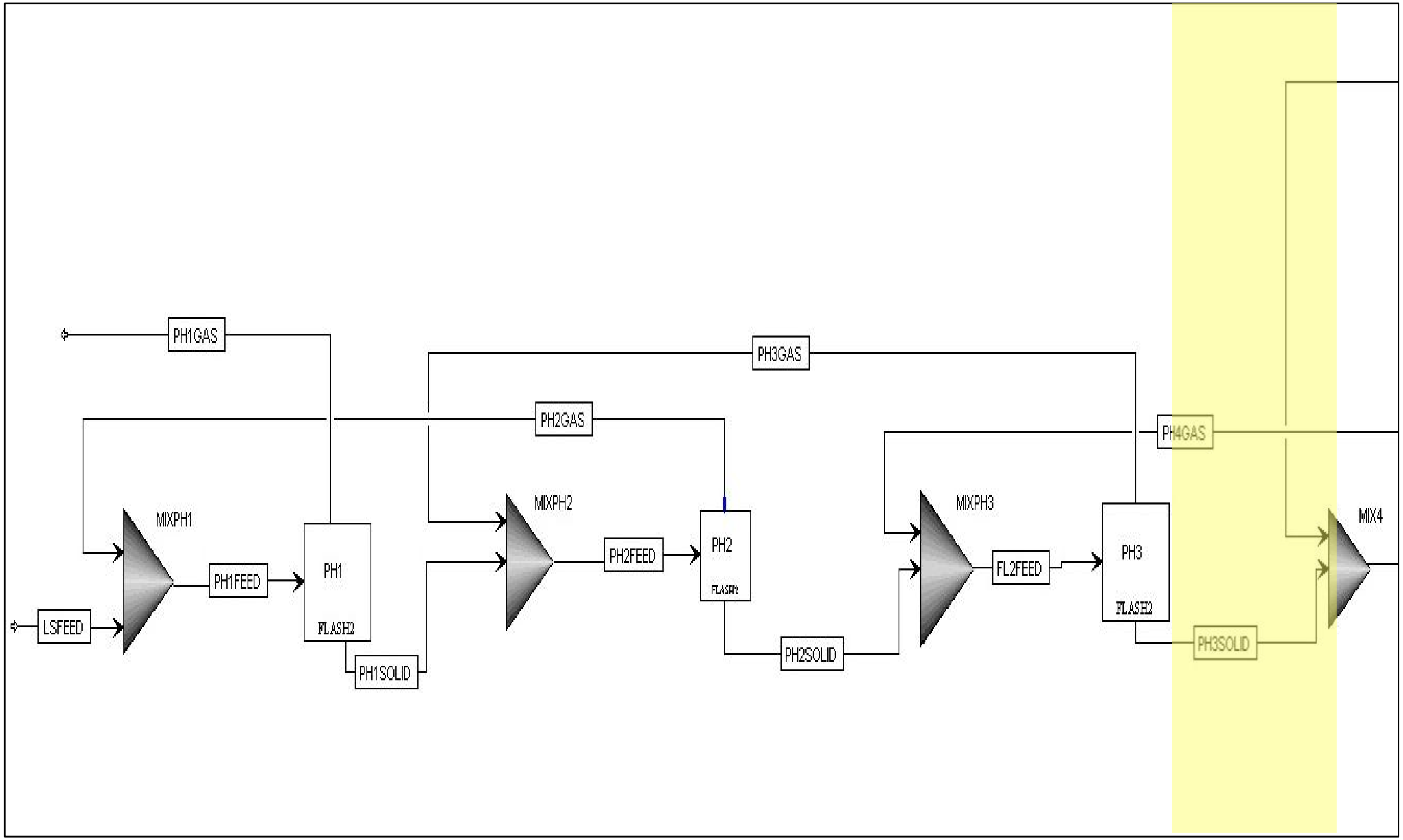


Figure 67. Preheater model

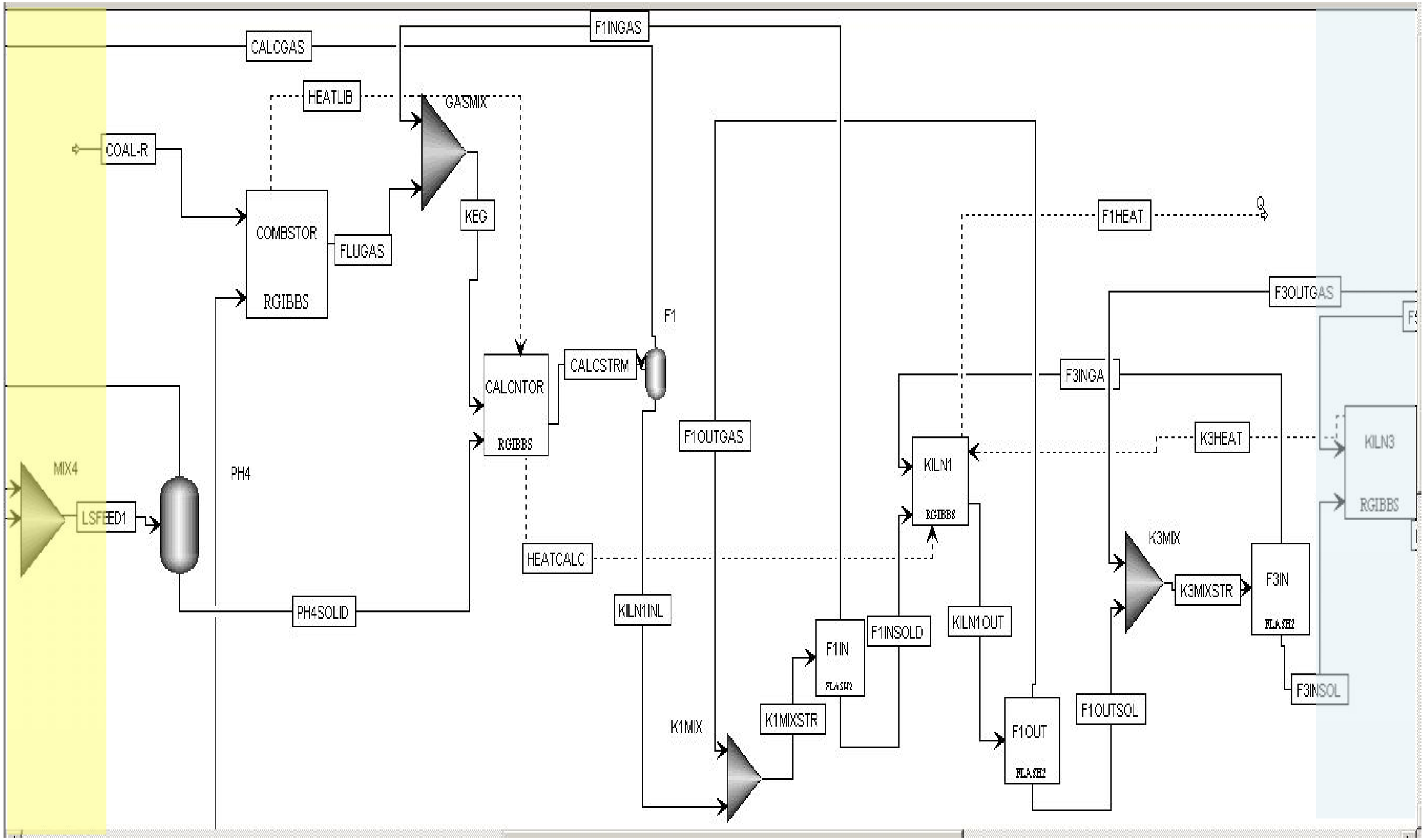


Figure 68. Calciner process model

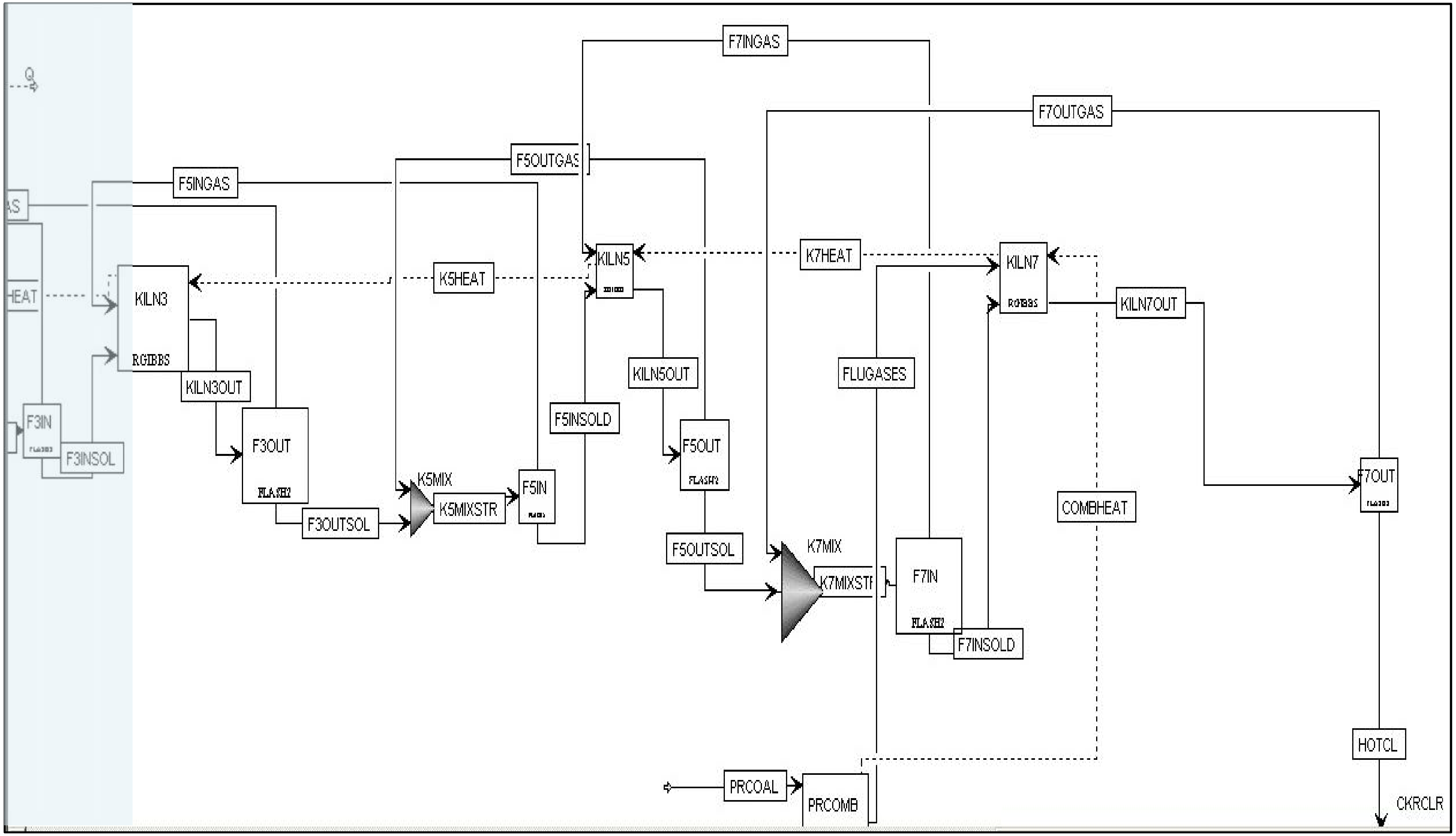


Figure 69. Kiln model

Results

The following are the input data to the model as shown in Table 4.

- Coal Stream
- Primary Air and
- Limestone Raw Material

The composition of the input coal stream is shown in Table 4.

Table 4: Composition of coal

Component	Percentage
Ash	21
Hydrogen	4.1
Carbon	61
Nitrogen	1.53
Oxygen	7.2
Sulfur	0.49
Moisture	4.68

The input data are normalized with clinker produced. Flow rates of raw material input which are based on solid-stream coming out of the separator are given in Table 5.

Table 5: Input Parameters

Input parameters	Value (in kg/kg clinker)
Air	2.66
LSFEED	1.55
Coal	0.18
Total	**4.40**

The input stream flow rates are normalized with output clinker flow rate. From Table 5, the total amount of material fed to the system is 4.40 kg/kg clinker.

The results from the simulation are: solid stream containing C3S, CaO, MgO, alumina and Fe_2O_3 of the input limestone feed from the separator. The clinker composition is shown in the Table 6.

Table 6: Composition of clinker

Composition of clinker	kg/hr	% by weight
CaO	9569.81	10.20
MgO	1662.84	1.77
Al_2O_3	6331.25	6.75
Fe_2O_3	2910.92	3.10
C3S	73336.48	78.17
Total	**93811.30**	**100**

Table 7: Output Parameters Computed by Aspen Model

Output parameters	Value (kg/kg clinker)
Kiln exhaust gas	2.82
Cooler exhaust gas	0.58
Clinker	1.00
Total	**4.40**

From the above Table 7, it is observed that the total amount of material coming out is 4.40 kg/kg clinker which is equal to the total input material.

Exhaust gas stream from the separator contains CO_2, N_2 and excess O_2 which are shown in Table 8. The percentages of N_2 and CO_2 are 57.1% and 37.9% respectively. The flue gases from cement plant have to follow pollution control board norms. This analysis could be helpful for following these norms.

Table 8: Preheater exhaust gas composition

Composition of exhaust gas	Flow rate, kg/hr	% by weight
N_2	151,196	57.1
CO_2	100,319	37.9
O_2	10,092	3.8
H_2O	2,367	0.89
H_2	740	0.28
SO_2	25	0.01

A sensitivity analysis can be performed with the model by varying the amount of coal, composition of the exhaust gas, pre heater gas temperature etc.

The model can be operated with different types of coal/fuel. Although the energy consumption of a plant is independent of the type of coal, the amount of coal varies based on its calorific value - more the calorific value of the fuel, lesser the amount of coal required for the manufacturing process. Also, the composition of exhaust gas depends on the type of coal used in the cement manufacturing process. Similarly, the pre heater exhaust gas temperature varies depending on the number of stages. Hence waste heat recovery feasibility can be performed based on the exhaust gas conditions.

4. Analysis of Energy Efficiency of a Cement Plant

The objective of this chapter is to analyze the energy efficiency of various sub-processes of cement manufacturing. The major factors which affect the energy consumption of different subprocesses are identified. Control and performance linkages are also briefly explained for the relevant pieces of equipment.

4.1 Subprocess equipment performance

4.1.1 Raw Mill

Raw mill consumes electrical energy and its SEC is in the range of 12 to 18 kWh/t cement (4). Energy required per tonne of ground product of size D_{pb} from feed of size D_{pa} is given by (15)

$$\frac{P}{\dot{m}} = 0.3162 \times W_i \times \left(\frac{1}{\sqrt{D_{pb}}} - \frac{1}{\sqrt{D_{pa}}} \right)$$

Where,

D_{pa}= Mesh size in mm where 80% of the feed pass through the mesh

D_{pb}= Mesh size in mm where 80% of the product pass through the mesh

P = Power required for crushing in kW

$\dot{m}$ = mass flow rate of inlet feed material, tph

W_i = Work index defined as gross energy requirement in kWh/t of feed needed to reduce a large feed where 80% of product passes a 100 µm screen. Typical W_i values are given in Table 9(15).

In a ball mill, there is a relation between the power drawn in kW/m and the inner diameter of the ball mill shell as shown in Figure 70 (11). For a given load and critical speed (%), power drawn increases exponentially with the inner diameter.

Table 9: Typical values of Work Index for different materials (15)

Material	Work Index, Wi
Limestone	16.99
Clay	8.4
Coal	17.34
Clinker	17.93

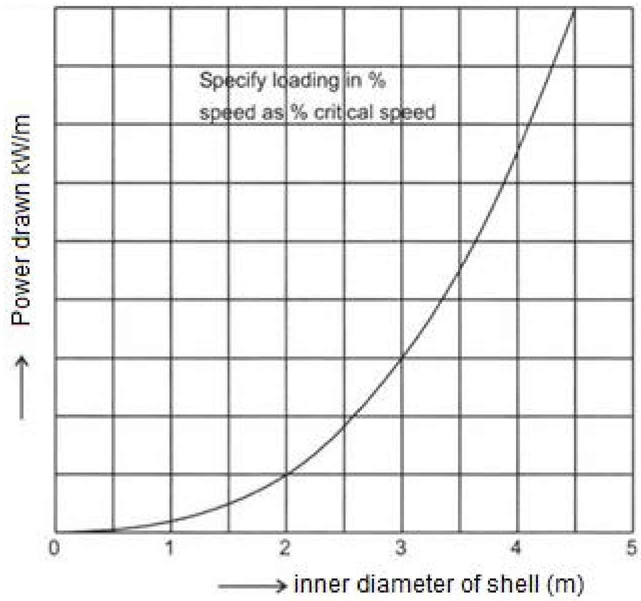


Figure 70. Relation between power drawn (kW/m) and the inside diameter of the shell (m) **(11)**

The major factors for the variation in power consumption or SEC in the raw mill are throughput of the feed, type of grinding mill, Bonds Grindability Index and Blaine factor of the raw material (11).

4.1.2 Coal Mill

A coal mill is used for grinding coal to the desired fineness for efficient combustion. Usually grinding of coal is performed either in a ball mill or vertical roller mill or roller press followed by a ball mill.

The major factors determining the SEC in the coal mill are the same as those of the raw mill. The electrical SEC of the coal mill is about 2.5 kWh/t cement (4).

The major parameters affecting the performance of the coal mill are (11):

1. Moisture content - If hot air is used for drying moisture in coal then the O_2 concentration inside the coal mill has to be controlled and monitored.
2. Flow rate of coal , kg/s.
3. Hardness of the coal.
4.

4.1.3 Preheaters

Energy consumption in the preheater is mainly due to preheater fans and electrical motors which transport the raw meal on the conveyor to the preheater. As the number of stages increases, the pressure drop at preheater increases and the exit gas temperature decreases (Table 10).

Table 10: Pressure drop and exit gas temperature of pre heater (11)

No of stages	Pressure Drop across preheater, mm.Wg	Temperature of gas °C at exit
4	280-300	350
5	320 - 370	300
6	400 - 450	270

The following are the factors governing the energy consumption:

1. Pressure drop – an increase in number of stages results in additional pressure drop which will increase the power consumption.
2. The number of stages is determined by the drying requirement in the different grinding systems.
3. The number of strings of cyclones is related to the plant's capacity requirements. The more the capacity required, more are the strings needed.
4. The selection of cyclone sizes: The need for having the smallest cyclone dimensions while maintaining the lowest overall pressure drop through the preheater. This is to minimize the induced draft (ID) fan power.

As the number of stages increases the thermal energy consumption decreases due to an increase in the temperature of solids which enter the calciner. Figure 71 depicts this relation with values from a typical cement plant. The presence of preheaters allows for the reduction in heating requirement.

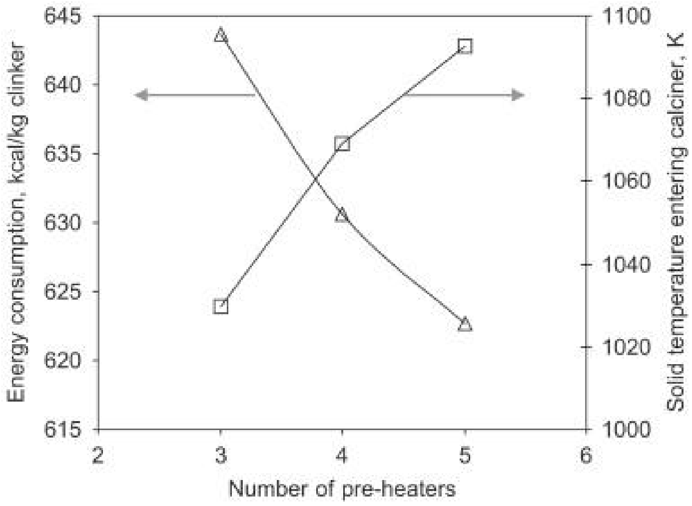


Figure 71. Effect of no. of preheaters with energy consumption and solids temperature entering calciner (11)

4.1.4 Precalciner

The introduction of pre-calcining has reduced the thermal energy consumption in the kiln by about 5-10%. The major factors affecting the SEC of the precalciner are (11):

1. Residence time of particles in the cyclone
2. Relevant kinetics for calcination reaction in calciners
3. % of calcination
4. Flow rate of raw meal coming from the preheater
5. Flow rate of the fuel needed for pre-calcination of raw meal

These five factors need to be optimized while designing the equipment to get required outputs at acceptable energy consumption levels.

4.1.5 Kiln

The following are the parameters impacting the sizing of a kiln:

1. Temperature profiles inside the kiln to ensure complete formation of clinker

2. Retention time: It is a function of various operations that take place inside the kiln. It is the shortest for the preheater and precalciner kilns.
3. Degree of filling: Degree of filling of the charge inside the kiln is important from the concept of proper heat transfer to the material
4. Thermal loading in the burning zone: heat released per hour per clear cross- sectional area of the kiln (kCal/h/m^2).

Thermal SEC of a cement kiln is given in Table 11. It is observed that only 66% of the total thermal energy is utilized in clinker formation; rest 34% is observed to be losses due to radiation, cooler losses, and losses in the preheater section.

Table 11: Thermal energy consumption in kiln and cooler system (4)

Parameter	SEC (kCal/kg clinker)
Theoretical heat consumption	410
Preheater loss	105
Cooler loss (Clinker & Cooler vent) gases)	90
Radiation loss	75
Heat Input	-30
Total	**650**

Table 12 shows the heat balance in different zones of a kiln. It can be seen that in a 6 stage section with a minimal increase in electrical energy consumption as compared to a 5 stage section, the thermal energy consumption decreases by a considerable extent (0.3 kWh/t cement increase in electrical SEC decreases the thermal SEC by around 13 kCal/kg clinker).

Table 12: Typical performance data on dry process kilns with preheaters, calciners, grate and planetary coolers (11)

S. No.	Item	Preheater zone		Calciner zone	
		Planetary cooler		Grate cooler	
	Preheater	**5 stage**	**6 stage**	**5 stage**	**6 stage**
1	**Heat balance. kCal/kg clinker**				
	Heat in exhaust gas	157	144	160	145
	Radiation loss from kiln and preheater	65	67	54	56
	Heat of reaction	385	385	385	385
	Cooler loss	141	143	116	116
	Heat in clinker at ambient temperature	3	3	3	3
	Heat in raw meal, fuel, air	34	34	33	33
	Net specific heat consumption	717	708	685	672
2	**Exhaust gas temperature °C**	295	272	311	283
3	Pressure loss in preheater mm.Wg	280	328	279	325
	Pressure loss in rest of system mm.Wg	71	71	140	140
	Total pressure loss	351	399	419	465
4	**Power consumption kWh/t clinker**				
	Preheater fan	4.6	4.9	5.6	5.9
	Cooler drive and fans	-	-	5.1	5.1
	Kiln	3.1	3.1	1.7	1.7
	Primary air fan	1.5	1.5	1	1
	Dust transport	1	1	1	1
	Total specific power consumption	10.2	10.5	14.4	14.7

Control and performance

Typical cement plants frequently monitor the composition of the preheater exit gas by which, the fuel and the combustion air input to kiln are regulated.

The effect of kiln tilt and grate speed are shown in Figure 72. As the tilt increases, SEC increases, with the decrease in residence time of solids. The optimized kiln tilt angle is around 1.75° wherein the thermal SEC is around 628 kCal/kg clinker and residence time is around 1300 s.

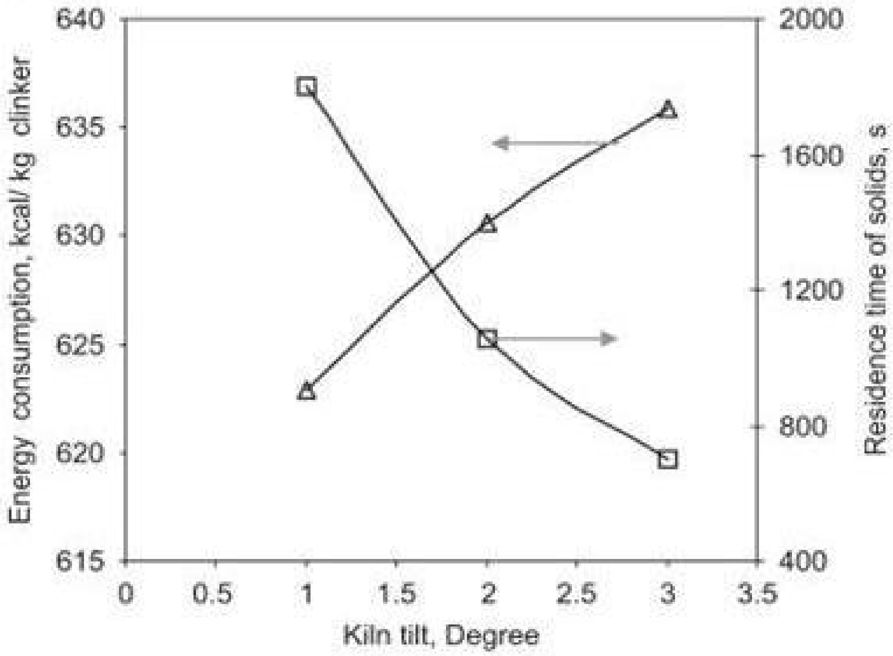


Figure 72. Effect of kiln tilt on energy consumption and residence time of solids(11)

4.1.6 Clinker cooler

Reciprocating grate cooler has become a dominant clinker cooler. The reciprocating grate has a number of drives for regulating cooling air and vent air. The cooling efficiency is around 70% and radiation losses are negligible (11).

Technical details

Peray (1979) provides the parameters and the corresponding calculations of cooler performance. These have been tabulated in Table 13 and

Table **14**.

Table 13: Calculations of the cooler performance

Symbol	Description	Units
w	Mass of clinker in cooler	kg
r	Clinker residence time	min
q	Cooling air required	kg
q_m	Cooling air required	kg/min
T_2	Temperature air out of clinker	kg
Q_c	Heat content of clinker, cooler in	kCal/kg
Q_1	Heat losses for grate cooler	kCal/kg
	Heat losses for planetary cooler	kCal/kg

E	Thermal Efficiency of grate / planetary cooler	%

Table 14: Input parameters of the cooler performance

Symbol	Name of the Parameter	Units
A	Cooler grate area	m^2
c_c	Mean specific heat of clinker	kCal/kg °C
c_a	Mean specific heat of air	kCal/kg °C
D	Clinker density	kg/m^3
F	Constant	
H	Clinker bed depth	m
t_1	Temperature clinker in	°C
t_2	Temperature clinker out	°C
T_1	Temperature air in	°C
T_2	Temperature air out of clinker	°C
W_{Cl}	Kiln output	kg/h

The objective of the calculation in Table 13 is to determine the thermal efficiency of a cooler.

Table **14** shows the parameters required for the formulae in Table 13. The thermal efficiency of the clinker cooler depends on (16):

1. Mass flow rate of clinker - determines the residence time of clinker inside the cooler.
2. Inlet and outlet temperatures of cooler - indicate the extent of heat recovery from cooling of clinker.
3. Temperature of air coming out of cooler - decides the flow rate of air that is needed per kg clinker.
4. Heat content of clinker inlet to cooler
5. Heat losses from cooler

$$\text{Thermal Efficiency} = \frac{\text{Heat transferred by the clinker to air}}{\text{Heat content of the clinker entering the cooler}} \times 100$$

4.1.7 Cement Mill

In the cement mill clinker is ground along with gypsum to make cement. It is ground to a certain fineness depending upon the specifications of the final cementitious product. Blending clinker with flyash from power plants or granulated slag from integrated steel plants produces a range of cements that have good hydraulic properties. Increasing the blending percentages of either slag or fly-ash decreases the overall SEC of the particular grade of cement.

5. Elements of the PAT Methodology

5.1 Data Collection

The EC Act 2001 suggests a template named Form-1. This questionnaire collects key information such as: production, capacity, type of fuel, quantity, Net Heat Rate (NHR), Gross Heat Rate (GHR), the calorific values of coal, cost, etc. It also has several sections pertaining to energy classification and corresponding fuel used to generate energy. All the above mentioned variables and parameters are used to calculate the gate-to-gate (G2G) SEC.

The following paragraphs describe the various sections of the form and the type of information collected or calculated from this questionnaire.

5.1.1 Production and capacity utilization

The DC provides the data on installed capacity and actual production which are used to calculate capacity utilization.

	Particulars	Unit	Year
A	Production and capacity utilization details		
(i)	Production Capacity	Mt	
(ii)	Actual Production	Mt	
(iii)	Capacity Utilization (%)	%	

The capacity utilization for any given year is defined as the following:

$$Capacity\ Utlization = \frac{Production\ in\ tonnes}{Installed\ Capacity\ in\ tonnes} \times 100$$

5.1.2 Electricity consumption and costs

A typical plant consumes large amount of electrical energy for production processes and also auxiliary power for lightings and housing colonies. Some plants rely entirely on the grid for their electricity supply while others have Captive Power Plants (CPP). In some cases, the CPP even exports surplus power to the grid. This section explains these various options for energy consumption and generation within the plant boundary.

Case I: Electricity supply from Grid/others

Form-1 tabulates the plant connected load, total number of running hours, contract demand with the utility, the total electricity purchased (Million kWh) and the electricity tariff (Rs/kWh). The above information is converted to corresponding kCal as per the following expression:

$$Purchased\ Electricity\ from\ Grid\ (kCal) = Purchased\ units(kWh) * 860\frac{kCal}{kWh}$$

B	Electricity Consumption and cost	Units	Year
B.1	Purchased Electricity from Grid / Other		
(i)	Units	M kWh	
(ii)	Total Cost	Rs. Million	
(iii)	Plant Connected Load	kW	
(iv)	Contract demand with utility	kVA	
(v)	Plant Run Hours	Hours	
(vi)	Purchased Electricity from Grid / Other	M kCal	

Case II: Diesel based back-up power generation

Every DC has Diesel Generators (DG) to supply uninterrupted power. The form collects information about type of fuel (HSD/ LDO/ LSHS/LSFO), GCV of the fuel, annual generation and cost of fuel. This impacts the process economics and the overall SEC. For instance,

B	Own Generation	Units	Year
B.2	*Through DG sets*		
(i)	Annual generation	kWh	
(ii)	Fuel used (HSD/ LDO/ LSHS/LSFO)	-	
(iii)	Cost of Electricity	Rs/kWh	
(iv)	Gross calorific value of Fuel	kCal/kg	
(v)	Annual fuel consumption	tonnes	
(vi)	Total annual fuel cost	Rs	

Case III: CPP using Steam turbines

Many industrial processes, in particular, cement manufacturing require large amount of thermal energy. Thermal energy accounts for 80% of total energy in a cement plant. A steam turbine based CPP can operate using coal, biomass or waste heat generated during the process. Many plants recover the waste heat generated during the process to produce steam for powering steam turbines. Waste heat recovery (WHR) is a promising option to improve the overall energy efficiency.

The form collects all relevant information type of fuel used (coal, biomass, waste heat), grade of coal, average gross heat rate, auxiliary power consumption and design heat rate of CPP.

B.2.2	*Through steam turbine/ generator*	Units	Year
(i)	Annual generation	M kWh	
(ii)	Fuel used (state which type of fuel was used (C = coal, B = biomass, w=waste heat)	-	
	If coal was used, state which grade i.e. C/I = imported or C/F = coal of grade F	-	
(iii)	Average Gross Heat Rate	kCal/ kWh	
(iv)	Auxilliary Power Consumption	%	
(v)	Design Heat Rate	kCal/ kWh	

Case IV: CPP using Gas turbine

Some plants use natural gas as a fuel for CPP. In such cases the information required is; units generated per annum, the type of fuel (NG, PNG, CNG, Naphtha), the gross calorific value of fuel, total amount of fuel consumed, cost of fuel, average gross heat rate, and auxiliary power consumption.

B.2.3	*Through Gas turbine*	Units	Year
(i)	Annual generation	M kWh	
(ii)	Fuel used (NG, PNG, CNG, Naphtha)	-	
(iii)	Gross calorific value	kCal/ SCM	
(iv)	Annual fuel consumption	Million SCM	
(v)	Total annual fuel cost	Rs. Million	
(vi)	Average Gross Heat Rate	kCal/ kWh	
(vii)	Auxiliary Power Consumption	%	
(viii)	Design Heat Rate	kCal/ kWh	

Case V CPP using Co-Generation

The co-generation refers to combined heat and power. This has the advantage that it can meet both thermal and electric energy requirement of the plant. The information collected is; the Co-Gen Capacity, annual generation, heat input and the heat output.

Overall electricity requirements

The total electricity generated within the boundary of the DC from various options is calculated as follows

$$Total\ Generation\ (kWh) = \sum Own\ generation\ types$$

This does not include the power supplied to housing colony or grid.

The total electricity consumed is therefore obtained as per the following:

$$Total\ electricity\ consumed (kWh) = Electricity\ Purchased\ from\ grid + Total\ Generation - Total\ Supply\ to\ grid\ or\ others$$

5.1.3 Solid fuels

This section discusses the energy input from solid fuels. This section computes the quantity of fuel consumed for process heating and power generation. Coal is the most commonly used fuel and the other form are lignite, biomass wastes. Many industries import high grade coal for efficient combustion.

Solid fuel inputs for Indian coal, imported coal and lignite are shown below.

C	Solid Fuel Consumption	Units	Year
C.1(a)	***Coal (Indian)***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	tonnes	
(iii)	Quantity used for power generation	tonnes	
(iv)	Quantity used for raw material	tonnes	
(v)	Quantity used for process heating	tonnes	
(vi)	Total Quantity Consumed	tonnes	
C.1(b)	***Coal (Imported)***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	tonnes	
(iii)	Quantity used for power generation	tonnes	
(iv)	Quantity used for raw material	tonnes	
(v)	Quantity used for process heating	tonnes	
(vi)	Total Quantity Consumed	tonnes	
C.2	***Lignite***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	tonnes	
(iii)	Quantity used for power generation	tonnes	
(iv)	Quantity used as raw material, if any	tonnes	
(v)	Quantity used for process heating	tonnes	
(vi)	Total lignite cost for process	Rs	
(vii)	Total Quantity Consumed	tonnes	

Biomass or other purchased solid fuels e.g. baggase, rice husk, etc.
Details of biomass and other solid fuel types including factors such as moisture content and GCV are shown below.

C.3	*Bio mass or Other purchased solid fuels (pl. specify) baggase, rice husk, etc.*	Units	Year
(i)	Average moisture content as fired	%	
(ii)	Average Gross calorific value as fired	kCal/ kg	
(iii)	Quantity purchased	tonnes	
(iv)	Quantity used power generation	tonnes	
(v)	Quantity used for process heating	tonnes	
(vi)	Total biomass cost for process	Rs	
(vii)	Total Quantity Consumed	tonnes	

Section C Output
The Total energy consumed from all solid fuels is obtained as follows.

$$Total\ Energy\ of\ Solid\ Fuels\ ('000\ kCal) = \sum (Quantity_n\ (tonnes) \times GCV_n)$$

$$n = type\ of\ fuel, GCV = Gross\ Calorific\ Value\ of\ the\ fuel\ (kCal/kg)$$

5.1.4 Liquid fuels
Section D and E estimate the energy consumed from different type of liquid fuels used for process heat and electricity generation. The information consists of: GCV, quantity purchased and quantity used to generate power, used as raw material, used for process heating, and the costs.

Furnace Oil

$$Total\ Furnace\ oil\ Consumption\ (tonnes) = (Q_{Process\ Heating} + Q_{Power\ Generation}) \times \delta ensity$$

D	Liquid Fuel Consumption	Units	Year
D.1	***Furnace Oil***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	kl	
(iii)	Average Density	kg/l	
(iv)	Quantity used for power generation	kl	
(v)	Quantity used as raw material, if any	kl	
(vi)	Quantity used for process heating	kl	
(vii)	Total F. Oil Cost for process heating	Rs	
(viii)	Total F. Oil Consumption as fuel	tonnes	

Low Sulphur Heavy Stock (LSHS)

$$Total\ LSHS\ Consumption\ (tonnes) = (Q_{Process\ Heating} + Q_{Power\ Generation})$$

D.2	*Low Sulphur Heavy Stock (LSHS)*	Units	Year
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	tonnes	
(iii)	Quantity used for power generation	tonnes	
(iv)	Quantity used as raw material, if any	tonnes	
(v)	Quantity used for process heating	tonnes	
(vi)	Total LSHS Cost for process heating	Rs	
(vii)	Total LSHS Consumption as Fuel	tonnes	

High Sulphur Heavy Stock (HSHS)

$$Total\ HSHS\ Consumption\ (tonnes) = (Q_{Process\ Heating} + Q_{Power\ Generation})$$

D.3	***High Sulphur Heavy Stock (HSHS)***	Units	Year
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	tonnes	
(iii)	Quantity used for power generation	tonnes	
(iv)	Quantity used as raw material, if any	tonnes	
(v)	Quantity used for process heating	tonnes	
(vi)	Total HSHS Cost for process heating	Rs	
(vii)	Total HSHS Consumption as fuel	tonnes	

Diesel oil

High Speed Diesel (HSD)

$$Total\ HSD\ Consumption(tonnes) = (Q_{Process\ Heating} + Q_{Power\ Generation}) \times \delta ensity$$

E	Diesel oil	Units	Year
E.1	***High Speed Diesel (HSD)***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	kl	
(iii)	Average Density	kg/l	
(iv)	Quantity used for power generation	kl	
(v)	Quantity used as raw material, if any	kl	
(vi)	Quantity used for process heating	kl	
(vii)	Total HSD Cost for process heating	Rs	
(viii)	Total HSD Consumption as fuel	tonnes	

Light Diesel Oil (LDO)

$$Total\ LDO\ Consumption\ (tonnes) = (Q_{Process\ Heating} + Q_{Power\ Generation}) \times \delta ensity$$

E.2	***Light Diesel Oil (LDO)***	Units	Year
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity purchased	kl	
(iii)	Average Density	kg/l	
(iv)	Quantity used for power generation	kl	
(v)	Quantity used as raw material, if any	kl	
(vi)	Quantity used for process heating	kl	
(vii)	Total LDO Cost for process heating	Rs	
(viii)	Total LDO Consumption as fuel	tonnes	

Section D, E Output

Total energy of Liquid fuels is computed as follows:

$$Total\ Energy\ of\ Liquid\ Fuels\ ('000\ kCal) = \sum Quantity\ of\ Fuel\ Used(tonnes)\ \times GCV$$

5.1.5 Gaseous fuels

This section evaluates the energy contained in gaseous fuels used in cement manufacturing. The commonly used gaseous fuels are Compressed Natural Gas (CNG) and Liquid Petroleum Gas (LPG). The gaseous fuel consumption varies depending on the application – Power generation, process heating or transportation.

Compressed Natural Gas (CNG)

*SCM – Standard Cubic Meters

F	Gaseous Fuel	Units	Year
F.1	***Compressed Natural Gas (CNG)***		
(i)	Gross calorific value	kCal/SCM*	
(ii)	Quantity purchased	SCM	
(iii)	Quantity used for power generation	SCM	
(iv)	Quantity used as raw material, if any	SCM	
(v)	Quantity used for transportation, if any	SCM	
(vi)	Quantity used for process heating	SCM	
(vii)	Total cost of natural gas for process heating	Rs	
(viii)	Total CNG Consumption as fuel	SCM	

Liquefied Petroleum Gas (LPG)

F.2	*Liquefied Petroleum Gas (LPG)*	Units	Year
(i)	Gross calorific value (kCal/SCM)	kCal/SCM	
(ii)	Quantity purchased	SCM	
(iii)	Quantity used for power generation	SCM	
(iv)	Quantity used as raw material, if any	SCM	
(v)	Quantity used for process heating	SCM	
(vi)	Total cost of LPG for process heating	Rs	
(vii)	Total LPG Consumption as fuel	SCM	

Section F Output

Total energy of Gaseous fuels is computed as following.

$$Total\ Energy\ from\ Gaseous\ Fuels\ (kCal) = \sum Quantity\ of\ Fuel\ Used\ \times GCV$$

5.1.6 Wastes recovered and used as fuels

Byproducts such as inflammable gases and solid wastes can be utilized in the cement plant as a source of energy.

- G Gas generated as by-product in the plant and used as fuel
- H Solid Waste - Solid waste generated in the plant and used as fuel
- I Liquid Waste - Liquid effluent or waste generated in the plant and used as fuel
- J Gaseous Waste - Gas waste generated in the plant and used as fuel

G	**Gas generated as by-product in the plant and used as fuel**	**Units**	**Year**
G.1	***Name of the Gas***		
(i)	Gross calorific value	kCal/SCM	
(ii)	Quantity Generated	SCM	
(iii)	Quantity used as fuel	SCM	
H	**Solid Waste -** Solid waste generated in the plant and used as fuel		
H.1	***Name of Solid Waste***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Quantity Generated	tonnes	
(iii)	Quantity used as fuel	tonnes	
I	**Liquid Waste -** Liquid effluent/ waste generated in the plant and used as fuel		
I.1	***Name of Liquid Waste***		
(i)	Gross calorific value	kCal/ kg	
(ii)	Average Density	kg/l	
(iii)	Quantity Generated	kl	
(iv)	Quantity used as fuel	kl	
J	**Gaseous Waste -** Gas waste generated in the plant and used as fuel		
J.1	***Name of Gas Waste***		
(i)	Gross calorific value	kCal/SCM	
(ii)	Quantity Generated	SCM	
(iii)	Quantity used as fuel	SCM	
	TOTAL ENERGY_WASTE HEAT	**kCal**	

Section G, H, I and J output
The total energy from wastes (Solid, Liquid and Gas) is computed as following:

$$Total\ Energy_{Waste\ as\ Fuel}('000\ kCal) = \sum (GCV \times Q)_{Soild} + (GCV \times \delta \times Q)_{Liquid} + (GCV \times Q)_{Gaseous}$$

$\delta = density\ of\ the\ Liquid\ fuel\ kg/L$
$Q = Quantity\ of\ the\ Fuel\ (\ tonnes\ or\ kL\ or\ '000SCM)$
$GCV = Gross\ Calorific\ vaue\ of\ the\ Fuel\ type\ (kCal/kg\ or\ kCal/SCM)$

5.1.7 Other Fuel Types

Other fuels not listed above are taken into account as shown below.

K	**Others**	**Units**	**Year**
K.1	***Name of the Fuel***		
(i)	Average gross calorific value	kCal/ kg	
(ii)	Quantity Generated	tonnes	
(iii)	Quantity used for power generation	tonnes	
(iv)	Quantity used for process heat	tonnes	
(v)	Quantity used as fuel	tonnes	
	TOTAL ENERGY_OTHER WASTE	**kCal**	

5.1.8 Energy used in process heating

The total energy for process heating from all types of fuels is calculated using the following equation.

$$Energy_{Process\ Heating}('000\ kCal) = \sum_{Soild}(GCV \times Q) + \sum_{Liquid}(GCV \times \delta \times Q) + \sum_{Gaseous}(GCV \times Q) + Total\ Energy_{Waste\ as\ Fuel}$$

Where,

$\delta = density\ of\ the\ Liquid\ fuel\ kg/l$

$Q = Quantity\ of\ the\ Fuel\ used\ for\ Process\ Heating(\ tonnes, kl\ or\ '000SCM)$

$GCV = Gross\ Calorific\ vaue\ of\ the\ Fuel\ type\ (kCal/kg\ \ or\ \ kCal/SCM)$

5.2 Data Validation

The system of data acquisition and documentation is a significant element of the PAT methodology. Inputs received from energy auditors and reported by the DCs are utilized to compute the baseline SEC.

5.3 Baseline SEC Computation

An accurate estimation of the baseline SEC value is an important step in the PAT methodology. Each DC is dynamic in nature and its performance depends on the technology incorporated and business demand. The baseline SEC could be computed considering the average performance of last three years as it captures variations in manufacturing practices and operating conditions.

Simple SEC is calculated using the formula mentioned below.

$$\text{Specifi}\ \ \text{Energy Consumption (kCal/kg cement)} = \frac{\text{Energy Consumption (MkCal)}}{\text{Production (Mt)} * 1000}$$

Note: In the above formula, energy consumption can be defined as the total energy from all sources that is used for process heating and power generation. Energy generated from waste may not be considered, if the waste has been generated from the initial fuel inputs to the plant.

5.4 Variations in Plant Operating Conditions

A simple calculation of the baseline SEC gives a broad indication of the energy intensity of a plant. However, it is necessary that a robust calculation of the baseline SEC be designed in order to reduce the impact of variations in plant operating conditions. Such normalization factors may be considered based on a few significant plant operating parameters.

1. **Captive Power Plant (CPP):**
   Some plants may have a CPP and may also export surplus power to the grid. When there is change in the share of power that is exported then the baseline SEC of the plant may undergo variations.

2. **Export and Import of Clinker:**
   The clinker output from the pyroprocessing unit is either sent to the grinding unit, or exported to other cement plants or exclusive grinding units. Such clinker exports can cause variations in the baseline SEC.

3. **Product Mix:**

Cement plants typically produce a variety of products in a given year and the product mix could vary from year to year based on market supply and demand conditions. Product changes can cause variations in the energy intensity of a cement plant.

Conversion Factors:

Industries operate in a dynamic market environment and have to manufacture multiple products to suit the prevailing business conditions. For instance, in cement industry, the major products are OPC, PPC and PSC. The conversion factors could be used to convert these to an equivalent major product, which varies from plant to plant. The conversion factors required are the following:

- Clinker to OPC
- Clinker to PPC
- Clinker to PSC

4. **Performance factors**

SEC – Electrical:

Electricity energy is required for different subprocesses such as clinker grinding, mining and the clinkerization process. Therefore, electricity consumption could be estimated in two stages: from mining to clinkerization and for clinker grinding. Total electrical SEC of a plant includes packaging and plant utilities, but excludes power supply to the colony.

SEC – Thermal:

Thermal energy is required for pyro-processing, and calcining. The thermal energy consumption is based on the total quantity of fuel used and the gross calorific values of the fuels used in burning the raw meal. The thermal SEC is the energy (kCal) required to produce one kg of clinker.

5.5 Normalized Baseline SEC

The simple calculation of G2G SEC does not account for variations in plant specific factors such as export and import of clinker, conversion of the product mix to equivalent major product and the CPP's net heat rate and share of power exported to the grid.

As a result, there is a need to include normalization factors and conversion factors to improve the robustness of SEC.

$$Normalized\ baseline\ SEC = f[Simple\ baseline\ SEC, normalization\ factor(s)]$$

6. Baseline Methodology – Application in Sample Plants

In this chapter, the application of the baseline methodology for sample cement plants is illustrated. The results are based on a study of nine sample plants. The study highlights the diversity among the sample plants. The diversity exists in a number of performance factors, operating conditions and parameters such as capacity, product mix, CPP efficiency, conversion factors, energy input mix and import or export of clinker. The simple baseline SEC and the normalized baseline SEC for the sample plants are also compared.

6.1 Industrial Case Studies

A comparative parametric study of nine sample plants is shown in this section. These plants differ from each other across several parameters. A brief description of the sample plants is provided below:

Plant P1

Plant P1 employs a dry process with an annual cement production of 3.383 Mt. The total energy consumption is 2.479 x 10^6 MkCal. About 98% of the final product is PPC, while the rest 2% accounts for OPC. It imported 0.15 Mt clinker and also exported 0.0104 Mt clinker in the same year.

Plant P2

About 1.04 Mt of cement is produced in plant P2 by the dry process. The product profile constitutes 75% PPC, 20% OPC and 5% PSC. The unit also supplies clinker to other cement plants. The total electricity consumed within plant is estimated to be 80.13 Million kWh, while the total energy, electrical and thermal together, is calculated to be 992.44 Billion kCal.

Plant P3

This unit with dry processing technology has produced 2.96 Mt of cement. The total energy consumption is 4.92x10^6 MkCal. The cement variants produced are OPC (30%), PPC (11%) and PSC (24%). One of the key aspects of this unit is the amount of exported clinker (1.107 Mt).

Plant P4

This plant also follows dry processing technology and has produced 0.99 Mt of combined cement variety with an estimated total energy consumption of 1.01x10^6 Million kCal. 86% PPC and 13% OPC are produced. This plant imports clinker (0.059 Mt).

Plant P5

With 77.30% capacity utilization, this unit has produced 4.2 Mt of OPC and PPC varieties. About 20% of the total Clinker produced is exported. A total of 1.10 Mt of clinker is exported and 0.02 Mt is imported. The total energy consumption of this unit is estimated to 6.04x10^6 Million kCal. About 82.309 Million kWh of electricity is exported (highest among 9 plants).

Plant P6:

The cement production is 2.74 Mt. This grinding unit produced only PPC cement with a capacity utilization of 112.96%. Electricity consumption is estimated to be 108.87 Million kWh.

Plant P7:

Combined cement production is 1.36 Mt with 86.33% capacity utilization. The main production is PPC cement (94%). A significant amount of electricity is supplied to the grid. The total energy consumption is 0.989x10^6 MkCal.

Plant P8:
This plant is a grinding unit with a production of 3.06 Mt. The total electricity consumption is 138.8 Million kWh.

Plant P9:
The plant P9 produces 4.42 Mt of cement (OPC and PPC) with an estimated energy consumption of 6.1x10^6 Million kCal. This unit also exports power to the grid.

6.2 Parametric Comparison of Plants

In this section, the plants are compared on the basis of specific parameters which have been described in Form -1. The comparison showcases the diversity that exists between cement plants. The results of this comparison can be utilized to better understand the challenges that the cement industry faces in improving its energy efficiency and in the development of a more robust baseline SEC.

Production and Capacity Utilization

Figure 73 shows the comparative performance of nine industrial units with respect to installed capacity and actual cement produced. The capacity utilization of the sample plants ranges from 37% to 116%.

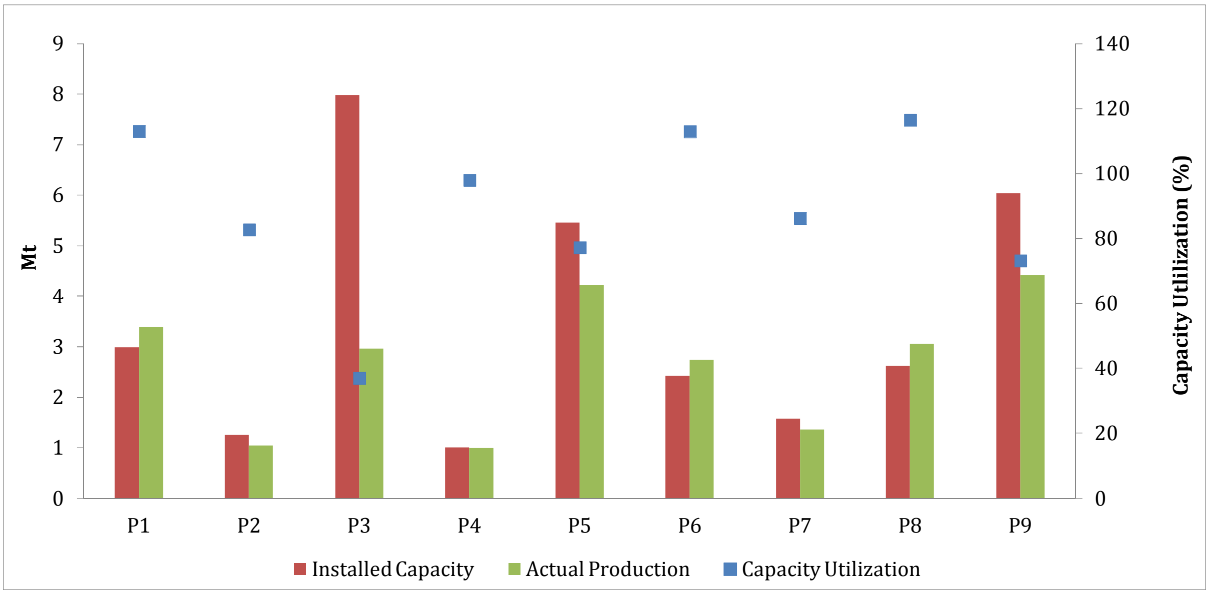


Figure 73. Production and Capacity Utilization across Plants

Electricity consumption

Figure 74 shows the electricity generated and consumed in the sample plants. It is observed that some plants are purchasing electricity from the grid while others generate more than their consumption and export the surplus power to the grid.

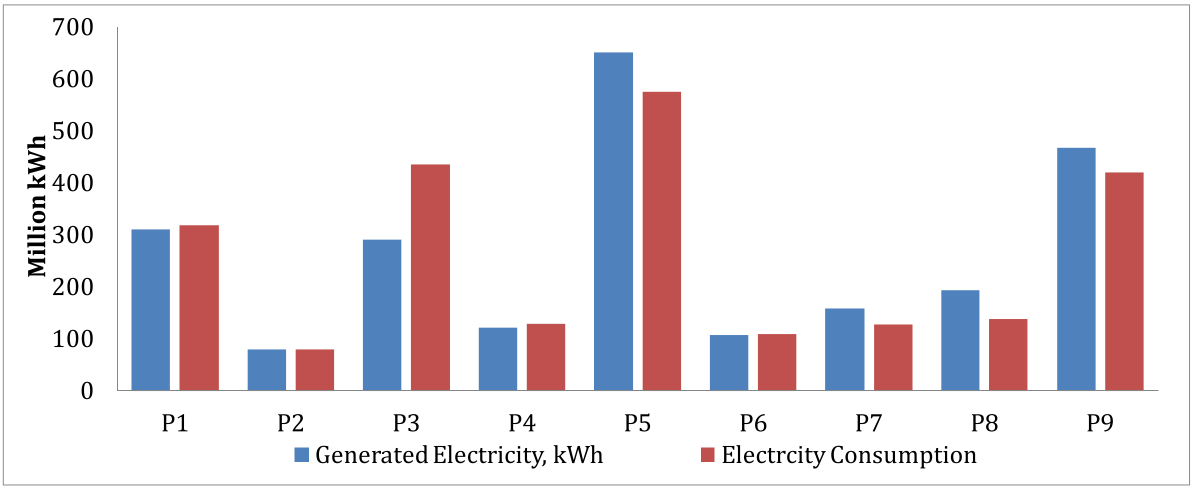


Figure 74. Electricity Generation and Consumption for Illustrative Plants

Solid Fuel Consumption

Coal is the common solid fuel used in the nine plants; however, three units import coal with higher GCV. The GCV of Indian coal ranges between 3412 kCal/kg and 5379 kCal/kg. The GCV of imported coal ranges between 5540 kCal/kg and 6884 kCal/kg. P5 consumes lignite along with Indian and imported coal. Figure 75 shows the total coal consumption in the nine plants and Figure 76 shows the GCV values of the coal consumed.

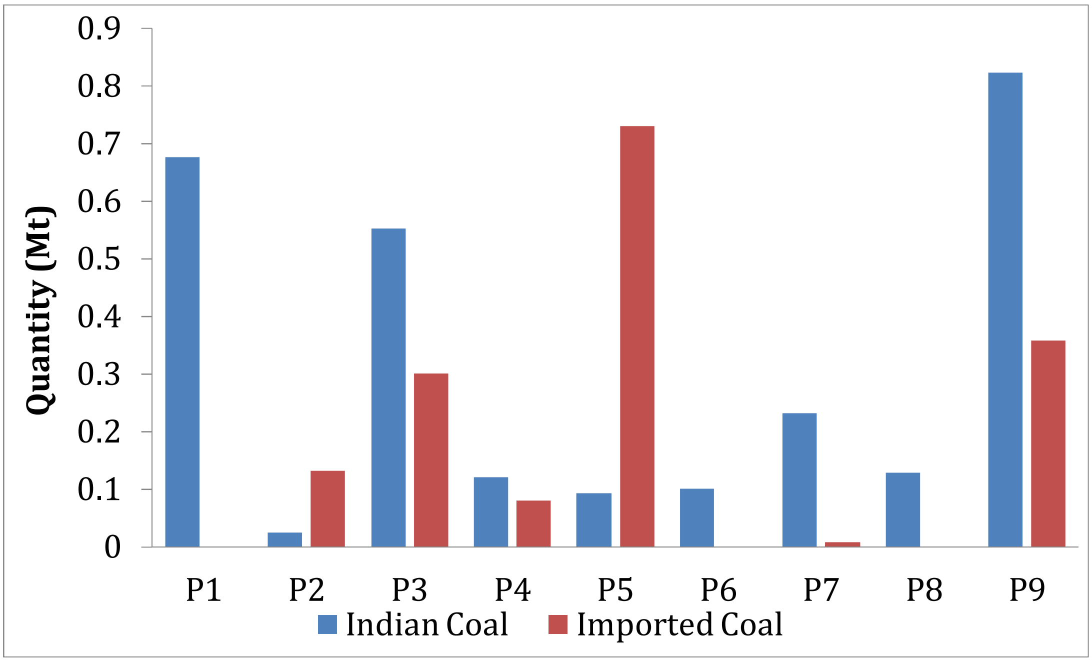


Figure 75. Indian coal and Imported Coal Consumption

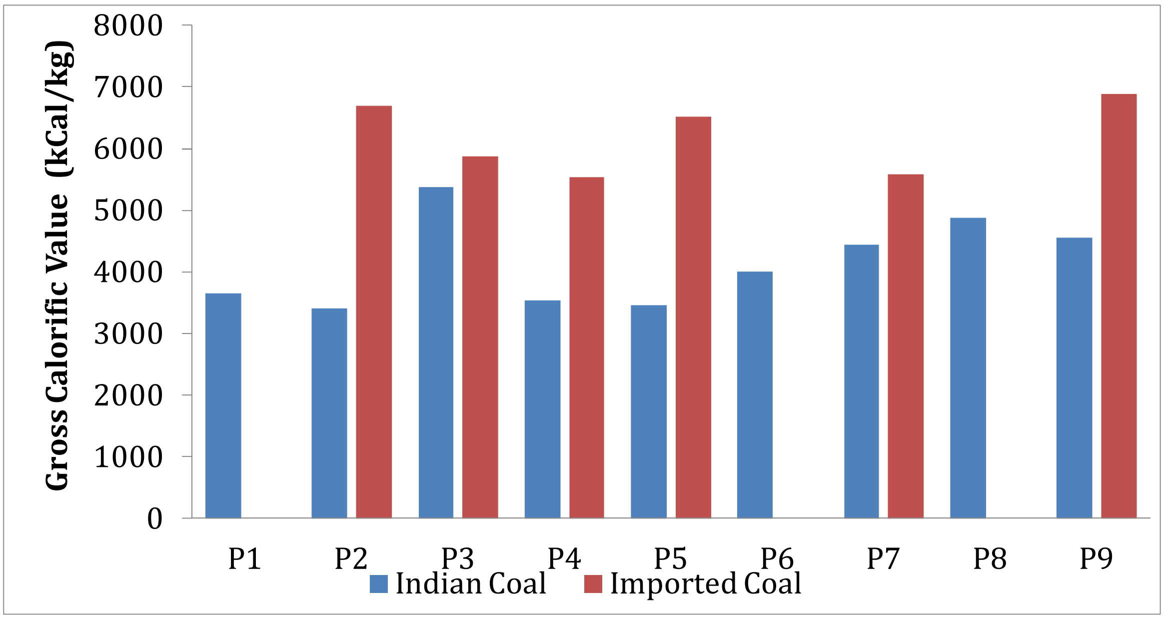


Figure 76. Gross Calorific Value of Indian and Imported Coal

Liquid Fuel Consumption

In this section the nine cement units are analyzed with respect to the quantity of liquid fuels used. Figure 77 shows the GCV of liquid fuels. The energy consumption from liquid fuels is shown in Figure 78. Plant P1 – P5 use a variety of liquid fuels.

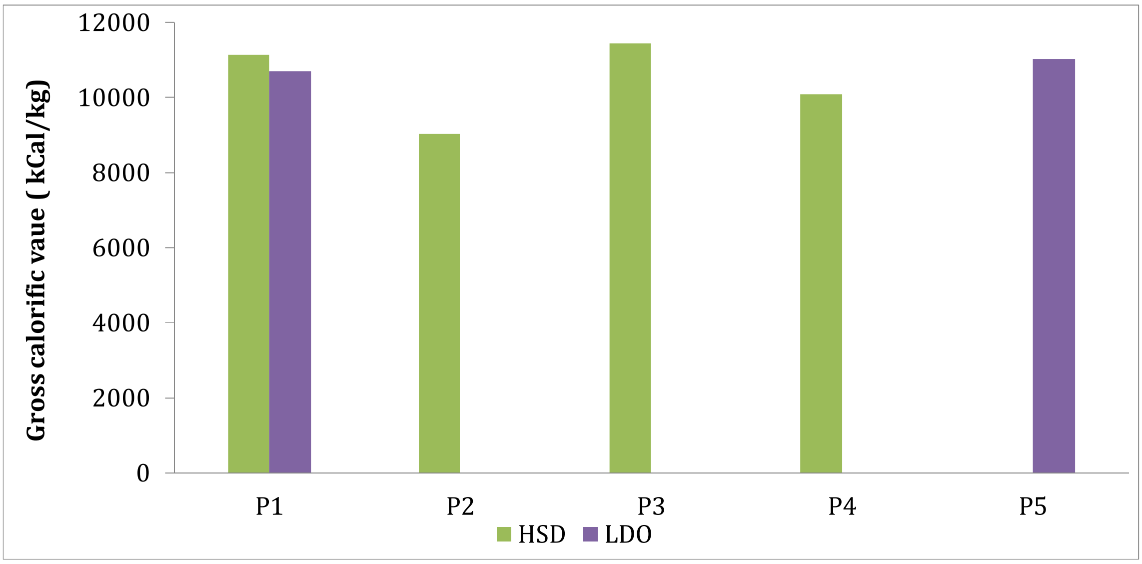


Figure 77. Gross Calorific Value of the Liquid Fuel Types

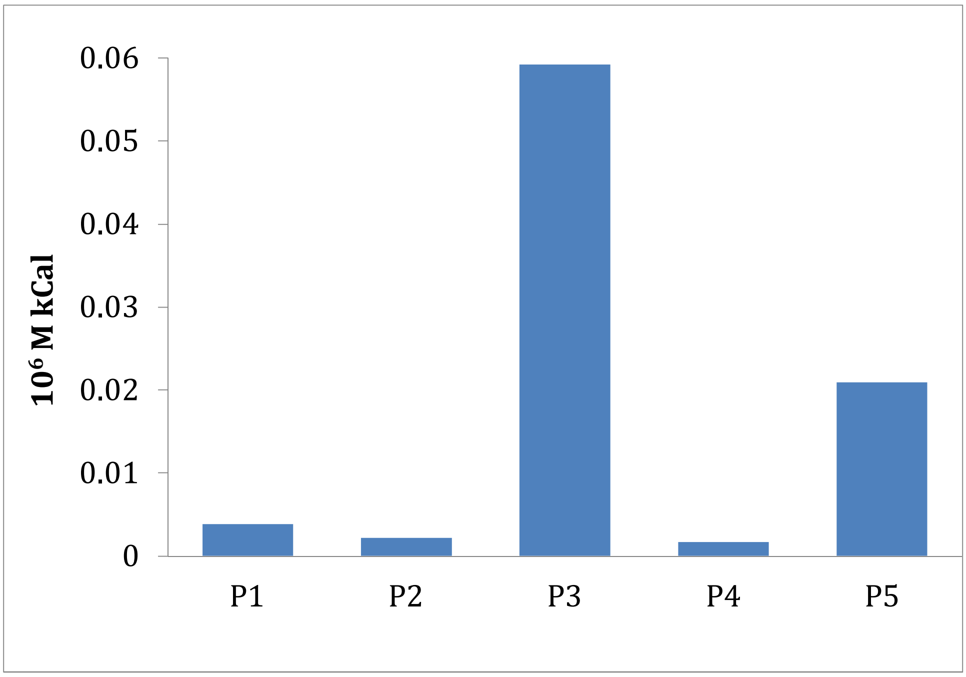


Figure 78. Total Energy from Liquid Fuel Types

Any other fuel

Plants P2, P4 and P5 are utilizing other fuels and the GCVs are 8594, 7875, 8400 kCal/kg respectively.

Total Energy used for Process Heating

Figure 79 shows the energy used for process heating across plants. Plant P5 utilizes more energy for process heating (5 x 10^6 MkCal), while plant P2 accounts for the least (0.59 x 10^6 M kCal).

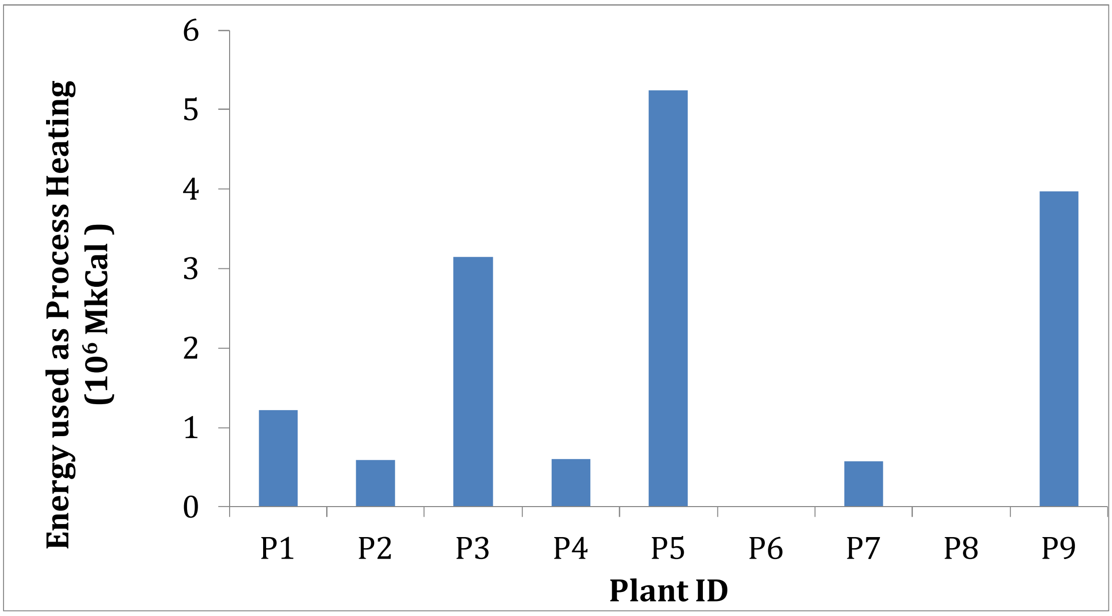
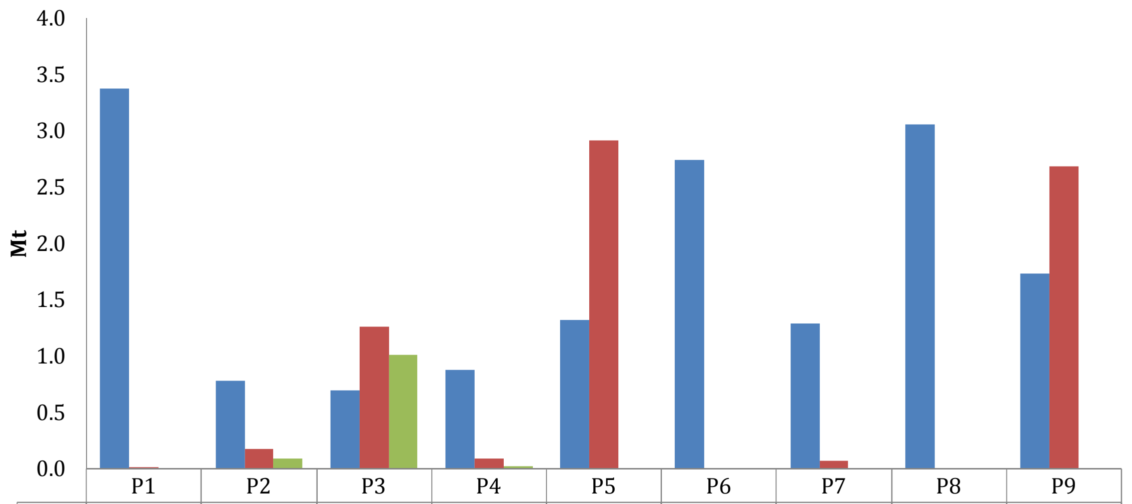


Figure 79. Energy Used as Process Heating across Plants

It is seen in Figure 80 that the product variety differs from plant to plant.



	P1	P2	P3	P4	P5	P6	P7	P8	P9
PPC	3.373	0.783	0.695	0.873	1.314	2.740	1.289	3.059	1.736
OPC	0.010	0.172	1.260	0.089	2.912		0.069		2.681
PSC		0.088	1.009	0.025					

Figure 80. Product variants in Plants

Conversion Factors

The conversion factors used for clinker to final grade of cement is shown in

Table **15**.

Table 15: Conversion factors

2	Conversion Factors (YWA)	P1	P2	P3	P4	P5	P6	P7	P8	P9
(i)	Clinker to OPC	0.965	0.942	0.934	0.908	0.939		0.9243		0.973
(ii)	Clinker to PPC	0.695	0.73	0.719	0.723	0.691	0.6354	0.6826	0.720	0.743
(iii)	Clinker to PSC		0.588	0.628	0.527					

Performance Indicators

Figure 81 shows the comparison of performance indicators across the nine plants. The thermal SEC ranges from 702 – 1045 kCal/kg clinker. The electrical SEC up to clinkerization ranges from 55.5 to 82.1 kWh/t clinker. The electrical SEC for cement grinding ranges from 27.6 – 45.7 kWh/t cement.

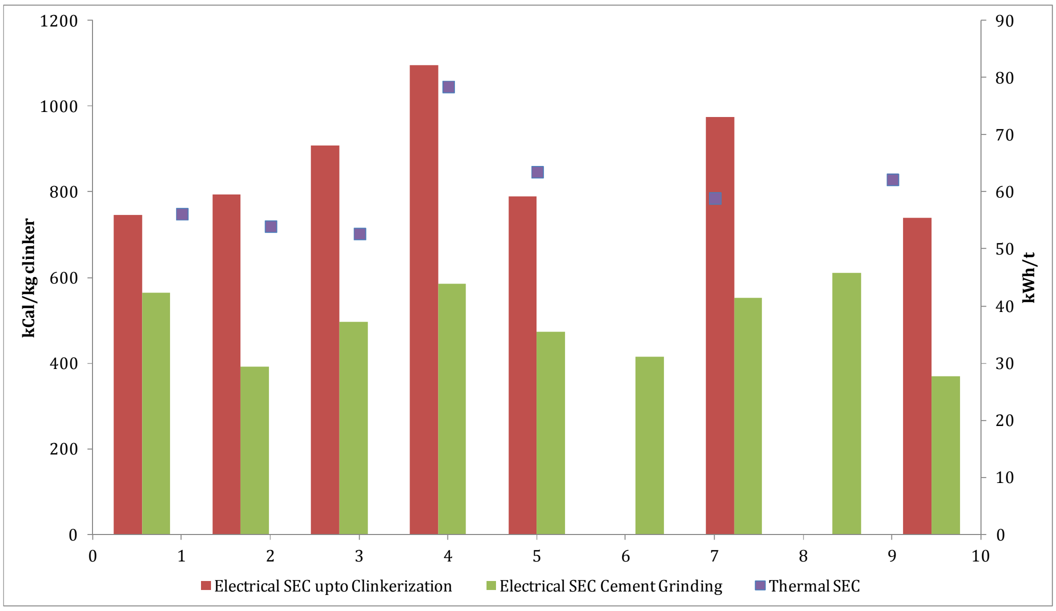


Figure 81. Comparison of Performance Indicators

6.3 Baseline SEC Analysis

Simple baseline SEC is calculated by adding the electrical and thermal energy of the plant and dividing it by the combined cement production.

Total Energy Consumption

The total energy consumed is calculated by adding the total thermal energy and the total electricity consumed in the plant. The electricity purchased from and exported to the grid is multiplied by the standard energy conversion rate (1 kWh = 860 kCal).

Figure 82 shows the total energy consumption across the sample plants and Figure 83 shows the baseline SEC.

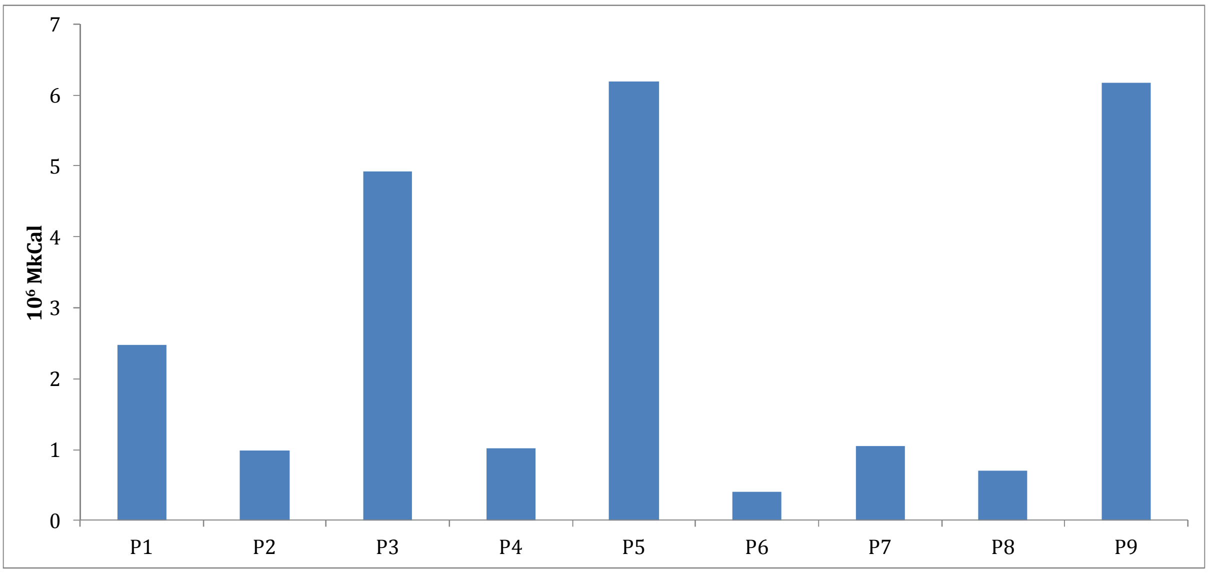


Figure 82. Total energy consumption across sample plants

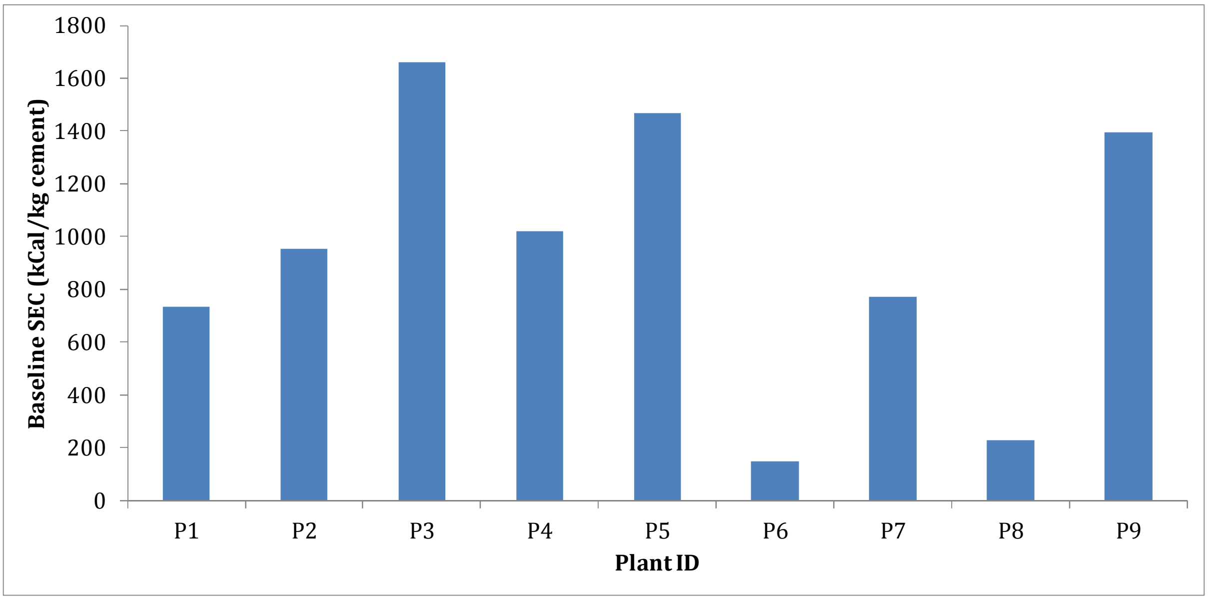


Figure 83. Baseline SEC for sample plants

Equivalent Major Grade Cement

Equivalent major grade cement can be estimated using the cement conversion factors. The amount of OPC, PPC and PSC can be converted to an equivalent major grade cement (among the different grades) using the different conversion factors. The total clinker exported and imported can also be converted to equivalent major grade cement. The total equivalent major grade cement is calculated by adding the above two equivalent grade cements. Figure 84 shows the equivalent major grade cement across the different plants along with the actual combined cement production.

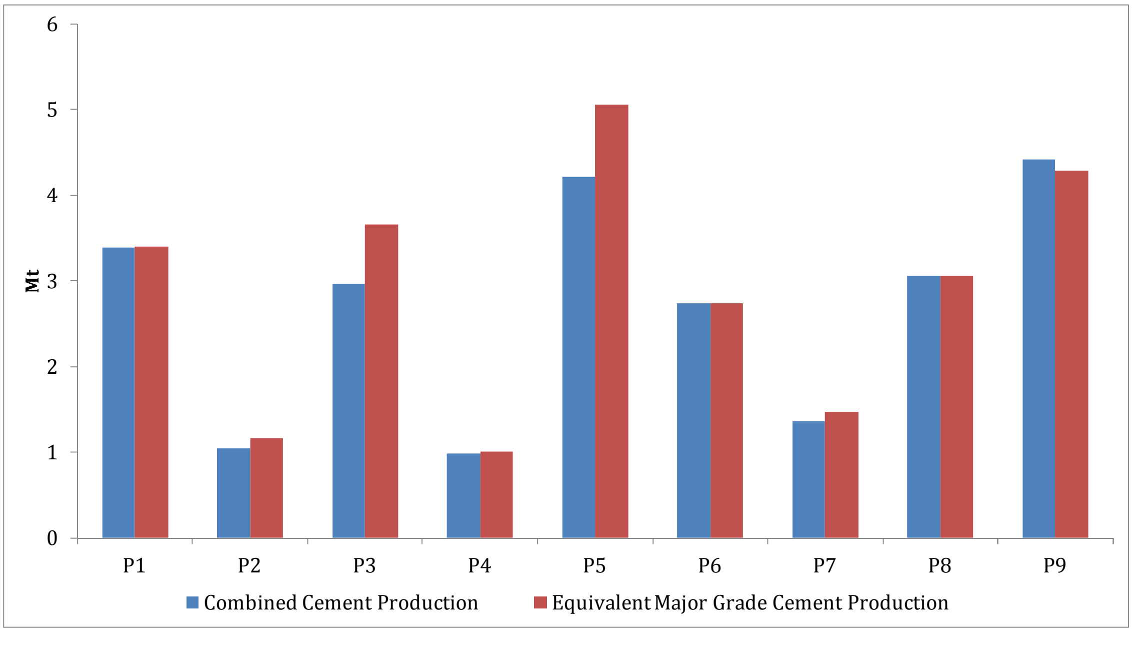


Figure 84. Difference in Equivalent Major Grade Cement Production

The baseline SEC can be normalized based on the factors discussed above. A sample calculation of normalized baseline SEC is shown in Figure 85.

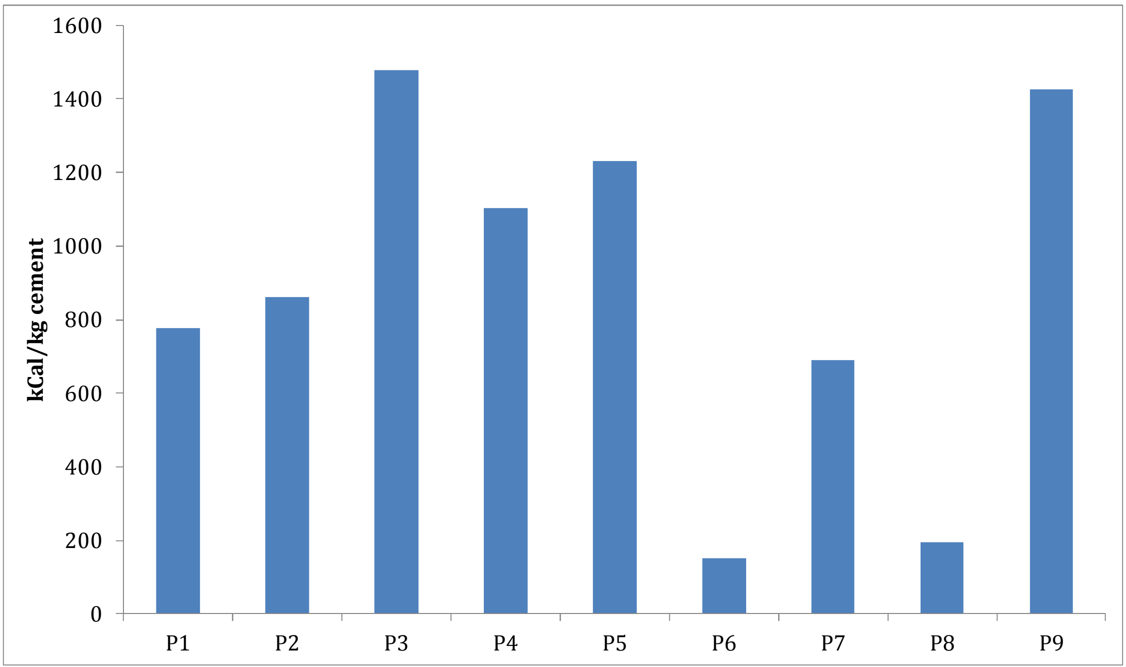


Figure 85. Normalized baseline SEC across plants

A comparison of simple SEC and normalized SEC is shown in Table 16. The percentage change from the simple SEC is also shown.

Table 16: Comparison of simple and normalized SEC

Plant ID	Simple SEC (kCal/kg cement)	Normalized SEC (kCal/kg cement)	% Change
P1	732.839	777.946	6.2
P2	951.848	860.209	-9.6
P3	1660.360	1479.938	-10.9
P4	1021.740	1102.371	7.9
P5	1467.287	1231.593	-16.1
P6	147.982	149.536	1.0
P7	770.386	689.439	-10.5
P8	228.189	195.556	-14.3
P9	1396.745	1426.812	2.2

7. Levers to Improve EE in a Cement Plant

The chapter discusses the levers to improve energy efficiency in a cement plant. It examines the techno-economic options of incorporating EE measures across different subprocesses. The major categories of EE options in a cement plant include technology options, waste heat recovery, blending, alternate fuel resources and increased efficiency of captive power plants. Several EE measures were evaluated based on the financial criteria viz. payback period, Net Present Value (NPV) and Internal Rate of Return (IRR). A technology databank has been created comprising several energy measures that have been adopted (or could be adopted) by the industry.

7.1 Technology Options and EE Measures

A DC's SEC targets could be achieved by adopting energy efficiency measures described in the various sections. However, of all the listed measures, an optimal measure for a cement plant is purely based on the impact parameters. Any parameter that has an impact on the SEC is considered an impact parameter. For instance, in a typical cement plant, the quality of limestone or the moisture content of a limestone may be termed as impact parameters. Table 17 lists some of the key improvement areas to achieve energy savings (17).

Table 17: Key improvement areas across processes

Equipment	Improvement Areas
Kiln	• Use of rotary kiln over any other type • Eradication of wet processes • Kiln firing within the recommended norms
Preheater and precalciner	• Control infiltration of air • Use of low pressure, high efficiency cyclones instead of conventional ones. • Reduction of pressure drop could be achieved by installing an additional cyclone parallel to the existing top stage cyclone • Conventional insulation bricks could be replaced by block insulation • Existing precalciner volume could be increased
Gas cooling	• Replacement of air aided water spray system by high pressure water spray system
Clinker cooler	• Initial rows of first grate could be retrofitted with static high heat recovery efficient plates
Process fans	• Retrofitting high efficiency impeller • Installation of speed regulation devices in fans • Installation of parallel fans instead of inlet dampers
Mills	• Optimization of ball mills by modifying the composition and quantity, arresting the false air entry, gas velocity optimization, operating parameters stabilization etc. • Optimization of vertical mills by arresting the false air, nozzle velocity optimization, optimization of operating parameters, dam ring height adjustment, feed size reduction etc. • Installation of high efficiency separators • Width of the roller tyres can be increased • Inclusion of pre-crusher or pre-grinder • Products of roller press could be used as a feed to the existing ball mill
Material transport system	• Optimal use of compressed air • Inclusion of mechanical transport system like belt conveyor or

	bucket elevators over pneumatic system • Modification of transport route would minimize the travelling distance
Environmental control	• Electro static precipitators or bag filters could be included. • Replacing glass bags by membrane bags • Inclusion of additional chambers with current bag filters

General	• Minimal idle run time
	• Avoiding wastage of resources like water, lubricants, compressed air, etc.
	• Installation of optimization packages like
	    o Kiln optimization system
	    o Refractory management system
	    o Integrated energy management system

Product diversification	• Increased production of blended cement like PPC and PSC

The following subsections describe the energy efficiency measures across the different subprocesses in greater detail.

7.1.1 Ball Mill Replacement by Vertical Roller Mill

Vertical Roller Mill (VRM) is considered to be more energy efficient and require less space than ball or tube mills. The exit gas from kiln or cooler could be used to dry the raw material which is then crushed in the VRMs. The SEC of a VRM is estimated to be between 14-18 kWh/t Raw Material (RM) while a ball mill SEC is in the range of 20-26 kWh/t RM. A 30% reduction in SEC is expected by installing VRMs (18). The chief advantage of the vertical roller mill is in the residence time of grinding being much less with much less heat generation.

7.1.2 Pre-grinding Equipment for Raw Material Grinding

Plants that use tube or ball mill have a potential for efficiency improvement. Incorporating pre-grinding equipment such as roller mill or press improves the grinding quality and production capacity. This system has been installed in various plants and an improvement of 50-100% in production has been observed (Table 18).

Table 18: Effect of implementing raw material pre-grinder (18)

Factor	Units	Before Implementation	After Implementation	Effect
Production Rate	t-RM/h	180	354	97% up
Fineness: 88µm (residue)	%	17	22	
Tube mill power	kW	2550	2650	
Pre-grinder power	kW	-	1120	
Total power consumption	kW	2550	3770	
Specific power consumption of tube mill only	kWh/t – RM	14.2	10.6	25% down
Departmental power consumption rate	kWh/t – RM	34.3	26.6	22% down

7.1.3 Intermittent Charging of Electric Dust Collector

Conventional electric dust collector uses continuous charging method. Intermittent charging uses a waveform (semi-pulse) thinned out from the output of the continuous charging method. This not only saves power but also improves the dust collection efficiency(18).

Table 19: Effectiveness of electric dust collector

		Continuous Charging	Intermittent Charging	Pulse Charging
Power Saving Effect	Relative to continuous charging (%)	100	65	45
Dust Collection Capacity	Relative to continuous charging (%)	100	110	150

7.1.4 Clinker Grinding

The following are some of the techniques that can be engaged during clinker grinding (18):

1. Closed-circuit grinding system
   The open circuit and closed circuit refers to the looping of raw materials to the grinding mill to increase the fineness of the product. The advantage of the closed circuit is that the materials that do not meet the fineness standard are sent back to the grinding mill. The separation of the clinker is done by means of a classifier.

2. Use of grinding aid
   A tube mill loses its efficiency when used for fine grinding. This is because fine particles from ground materials agglomerate and adhere to the mill liners or grinding media as coating, thus reducing the impulsive force of the mill. A grinding aid prevents this agglomeration and improves the grinding efficiency. Di-ethylene glycol is widely used as a grinding aid. A grinding aid is added to the clinkers in the range 0.01-0.03%.

3. Classification liner for the second chamber of tube mill
   The second chamber of a finishing mill is mainly for fine grinding. The grinding efficiency is extremely low in reverse classification, where small balls gather at the inlet of the second chamber and medium sized balls gather at the outlet. To solve this reverse classification efficiency drop, a liner was developed, which is inclined towards the inlet of the mill to set the scraped balls rolling in the direction of the outlet under the influence of rotational force. The specific power consumption is reduced, the optimum circulation ratio becomes smaller than ever, and loads on the separator and the conveyor are reduced.

4. Clinker flow rate regulator for tube mill
   Incorporation of clinker flow rate regulator has the potential to meet the problem of size variations in the mill. The power consumption rate goes down by 2-3kWh/t and the liner life is extended.

5. Improvement of separator
   A separator in a cement plant separates the fine particles from the coarse particles An efficient separator uses centrifugal force to isolate the streams. It prevents over-grinding and the waste of energy that accompanies it. It also keeps the product within specifications by making sure that the correct particle size is achieved. While the first generation of separators was fans, the second generation was cyclone air and the third was rotor blades.

The second and third generation separators have lower circulation of fine particles and higher efficiency, more grinding capacity and consume lesser power in the process. The third generation of separator further boasts of higher efficiency and is compact in structure. It can also control classifying points in a wider range by varying the revolutions per minute. This results in the grinding efficiency improvement of 15-25%.

6. Pre-grinding in roll press system
   The ground material is made to pass through a roller press and fed into a tube mills to crush the materials to 50% fineness. This is done to reduce the load on the finish mill and also to improve the grinding capacity of the mill, thereby resulting in reduced SEC.

7. Automatic run control of tube mill
   This reduces efficiency drops by using advanced automated control systems.
   The filling factor is kept constant by automatic control of power, mill acoustics, mill vibrations and fuzzy control.

8. External materials circulating system to cement grinding vertical mill
   Similar to raw mill grinding, adapting external circulation system to VRM reduces the energy consumption in the mill fan. Uncrushed large size materials pop out from the grinding table and are collected by the external circulating system installed below the mill.

7.1.5 Motors

Motors consume around 75% of the total electrical energy consumption. In this section we focus on how motors can be made more energy efficient in order to reduce SEC. Further, two case studies have been included highlighting the difference in design and operation of two different motor configurations for the same load.

Table 20 shows the differences in operation and energy savings while using a motor of higher efficiency. Although the cost of an efficient motor is higher, it can be observed that the payback time is under a year whereas the energy savings are higher throughout the lifetime of the motor(19).

Table 20: Comparison between motors of different efficiencies (19)

Motor Output	Price of eff2	Price Difference (eff1-eff2)	eff2 efficiency	eff1 efficiency	eff1 is higher by	Annual energy savings	Annual energy savings	Price difference is recovered in
kW	Rs	Rs	%	%	%	kWh	Rs	Months
0.37	3,447	517	66.0	73.0	7.0	263	1,184	5.2
1.5	4,613	692	78.5	85.0	6.5	715	3,219	2.6
5.5	10,742	1611	85.7	89.2	3.5	1233	5,548	3.5
11	20,025	3004	88.4	91.0	2.6	1741	7,833	4.6
18.5	35,213	5282	90.0	92.2	2.2	2401	10,806	5.9
30	50,648	7597	91.4	93.2	1.8	3103	13,966	6.5

Some of the measures that could be incorporated to reduce the losses and improve the efficiency of the motor have been presented in Table 21.

Table 21: Measures to improve motor efficiency (19)

Losses			Measures
Copper losses	I^2R	55-60%	Proper selection of copper conductors
Stator	W_s		
Rotor	W_r		Copper cage rotors or specially designed ; Al die-cast rotors
Core loss	W_c	20-25%	Low Watt Loss Material Thinner Laminations Ensuring reduced Burr Height
Mechanical losses		8-14%	
Friction	W_{fr}		Properly selected bearings
Windage	W_{wind}		Optimally designed fans or Unidirectional fans for very large machines.
Stray load loss	W_l	4-5%	Optimum slot geometry Minimum Overhang length

7.1.6 Blending of Raw Materials

Three types of blending of raw materials are practiced in the industry. These are as follows (18):

Mechanical System

It consists of multiple storage silos, each of which is provided with regulated withdrawal facilities. Blending is achieved by an orderly withdrawal of materials at variable rates from all silos. While this type of mixing consumes less power, the system requires a great deal of material handling which increases power consumption. In addition, the required number of silos is more than in other systems. As a result, this type of system is not widely in use in the cement industry.

Pneumatic fluidization,

A fluid like behavior is created by the air passed from the bottom of the silo. The agitation method is known to provide high blending efficiency for dry materials. But at the same time, plants using this method consume excess power.

Gravity approach

Gravity approach to homogenize has been conceived only with the compulsion of achieving reduced power consumption. This system is quite similar to the mechanical system. However, multiple silos are not used here.

Energy Efficiency Measures in Blending systems

The primary issues that surface during the blending of raw materials are high power consumption, regular maintenance, difficulty in supplying clean air and high cost of installing oil free air compressors. The energy efficiency of the process could be achieved by the following:

Blending and coal firing system optimization

- Optimizing the blending systems by improving the blending efficiency in silos would result in 2.5kCal/kg clinker reduction in thermal energy consumption
- Installation of solid flow meter based coal firing system would result in a reduction of 5kCal/kg clinker in thermal energy consumption

7.1.7 Pyro-processing

Pyro-processing section in a cement plant comprises of pre-heater, rotary kiln and clinker cooler. Pyro-processing section is considered to be the heart of a cement plant since the clinker formation happens in the kiln. With the introduction of pre-calciners in 1980's, the size of cement plants has increased considerably. The size of the plant in 1980s was 3300 tpd (increased to about 12000 tpd currently) (20).

Preheater

A variety of preheaters with different design of precalciners have come into existence. Preheaters can be classified into the following five categories: (20)

a) Preheater without calciner

b) Inline calciner with air passing through the kiln

c) Inline calciner with external tertiary air duct

d) Separate line calciner

e) Separate line calciner with inline calciner

Cyclones

Cyclones are basic units in a pre-heater system. Pressure drop and change of temperature of gas across each stage determines the efficiency of cyclones. Introduction of Low Pressure drop (LP) cyclones has brought the pressure drop across each stage to around 50 mm water gauge (WG) from around 150 mm WG in conventional cyclones. This has resulted in more and more plants adopting 5 or 6 stages of pre-heater. A typical 6-stage pre-heater with LP cyclones will have a pre-heater exhaust gas temperature of around 250°C and draught of around 500 mm WG. This in turn led to reduction in pre-heater fan power consumption. The reduced temperatures at the pre-heater exhaust contribute to environmental performance (20).

The burners also play an important role in determining the thermal efficiency of the pyro-processing system. (There has been a continuous effort on operating the burners with the least possible primary air.). Multi-channel burners (taking only 5% primary air) are being installed in many plants giving a direct thermal energy saving of 15 kCal/kg clinker. Apart from saving thermal energy, the modern burners also enable easy flame control.

Cooler

Clinker cooler is a critical component and the size of clinker cooler sometimes becomes a bottle-neck for increasing production from the rotary kiln. The clinker cooler has more than two functions in a cement plant. It reduces the temperature of the clinker to a level that is acceptable for further transport and recovers energy from the hot clinker. Thus, thermal efficiency of clinker cooler is very important in deciding the type of the cooler. Two types of clinker coolers are used at present in the cement industry. They are

- Grate cooler
- Planetary cooler

Convention grate coolers are widely in use in the existing plants. These coolers have lower recuperation efficiency, occupy more space and need more cooling air. In spite of these draw backs, grate coolers are more widely used than planetary coolers primarily due to relative higher thermal efficiency. There have been a number of design improvements in grate coolers in recent times, mainly on grate plate to improve the efficiencies simultaneously reducing the cooling air intake. The specific load of clinker on grate plate can be as high as 50 tpd/m^2. These modern coolers are compact in size. High efficiency coolers operate on the principle of

Horizontal aeration. More and more cement plants with conventional grate coolers are retrofitting the coolers with high efficiency coolers.

By installing high efficiency coolers, it is possible to reduce the cooling air to about 1.8 m^3/kg clinker from the conventional value of more than 3 m^3/kg clinker. This has resulted in lower electrical energy consumption in cooling air fans and also in cooler ID fan. Thus high efficiency coolers give rise to both thermal and electrical energy conservation.

7.1.8 Cost of a Typical Cement Plant

The cost estimation for a new cement plant and major upgrades is explained in this section. The cost of a typical cement plant for different tonnages is examined using data from North American Cement Manufacturers Market. The section also provides a break-up cost of the different components of the cement plant (21).

The details are applicable for a cement plant capacity of 3,175 TPD. A quarry includes one limestone crusher and one additive crusher. The raw grinding, with a capacity of 280 tph, comprises of a roller mill, a main baghouse, couple of fans (<10% H_2O) and a silo that can store 6,000 t. The pyro section has a pre-heater, kiln and cooler, with fans and cooler vents. The finish mill has a throughput of 170 tph. However, land, taxes, permits, unusual infrastructure, quarry preparation and trucking are not included in the cost estimation.

Table 22: Cost of a 3,175 TPD production capacity cement plant

Processes	Equipment Cost (Million $)	Installation Cost (Million $)	Total Cost (Million $)	% of total cost
Quarry	3.5	4	7.5	5.00
Raw Storage/Reclaim	7	9	16	10.67
Raw Grinding System	10	13	23	15.33
Blend/Kiln feed system	2.5	3	5.5	3.67
Coal Handling/Firing	3	3.5	6.5	4.33
Preheater/Kiln/Cooler	16	19	35	23.33
Clinker Handling/Storage	2	6	8	5.33
Finish Mill System	10	12	22	14.67
Cement Transport/Storage/Shipping	3	12.5	15.5	10.33
Control Room/Workshop/Office	3	4	7	4.67
Infrastructure, Roads, Water	1.5	2.5	4	2.67
TOTAL	**61.5**	**88.5**	**150**	**100**

Figure 86 shows the variation of production capacity with capital cost of the cement plant. We observe that as the production capacity increases the cost per tonne of capacity of the plant decreases.

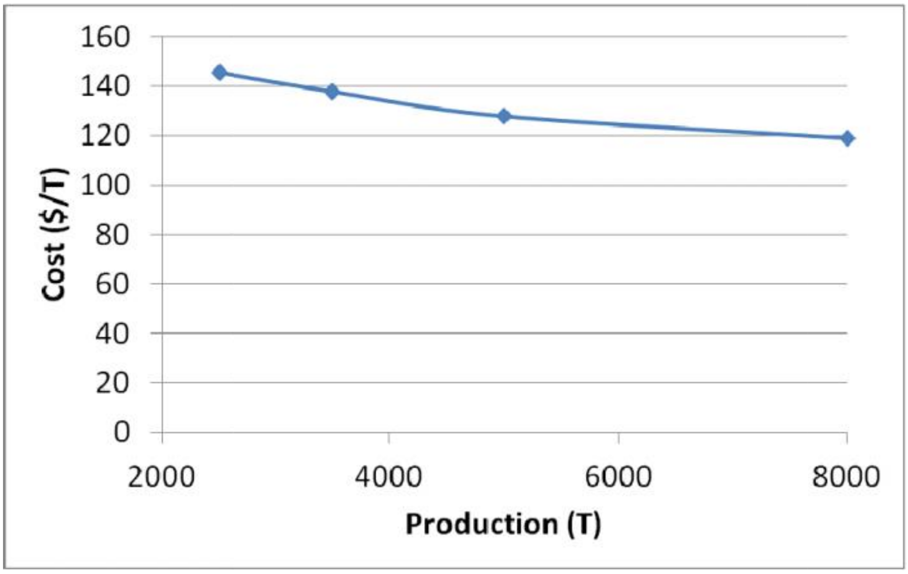


Figure 86. Cost per tonne for different plant capacities

Pyro System (Upgrade Dry Process)
Since large amounts of energy are being consumed in the pyro-processing of cement plants, upgradation of sub processes requires critical attention. One such scenario is the upgradation of an existing pre-heater kiln, without pre-calciner, to a kiln with pre-calciner. This option can be improved by appending a pre-heater string and clinker cooler. However, spatial arrangement would be the foremost challenge for these plants. Savings that could be incurred by implementing this improvement would offset the inclusion of the second pyroline. Needless to say, plants should be ready to consider a down time cost due to a transitory pause in production. The cost comparison for an upgrade from 2,268 TPD to 4,536 TPD would be $21.5 Million. However, a new pyroline with a capacity of 2,268 TPD would cost $27 Million (21).

It is to be noted that the maintenance cost would go up when one kiln line is extended to two. On the other hand, if a complete new line of 4,536 TPD is considered, the total cost would be in the range of $45 Million (21).

Finish Milling (Upgrade vs. New)
The milling section of a plant can be upgraded by way of incorporating a pre-grinding system with a roller press of vertical roller mill or install a new finish mill. The total cost of finish mill of a capacity of 91 TPD is estimated to be $17 Million, which includes $7.5 Million for process and auxiliaries and $9.5 for structural erection (21). On the contrary, a modified grinding system with a two stage grinding would cost $15 Million that includes $6.5 Million from process and auxiliaries and $8.5 Million from structural erection. This improvement seems viable considering the cost savings and the energy savings associated with it.

7.2 Waste Heat Recovery System (WHR)

Different sources of waste heat from the cement industry are as follows:

- Kiln Exhaust Temperature (280–350 ^{0}C)
- Cooler Exhaust Temperature (250-300 ^{0}C)
- DG set Exhaust Temperature (350 ^{0}C)

WHR Boilers (WHRB) can be installed at pre-heater and clinker cooler exit points. Waste heat can be utilized in the following ways:

1. Power – Steam Rankine Cycle
2. Power – Organic Rankine Cycle
3. Integration with Captive Power Plant
4. Fly ash drying

Currently pre-heater exhaust gas is partly utilized for raw meal/coal drying. Cooler exhaust is generally not utilized in the Indian cement sector. In recent times, a few plants have started using the latter for slag drying.

Waste heat could also be recovered by extracting heat from the surface of kilns. Here, a secondary shell is fitted around the rotating hot kiln and air is passed through the annulus. The air carries heat along with it and can be used at different sections of the plant (22).

Working Principle of WHRB

The exhaust gases emanating from the *pre-heater cyclone tower* and *clinker cooler* are at a high temperature. The enthalpy of the exhaust gases can be utilized to meet the heat requirements of the cement plant.

The pre-heater and clinker cooler exhausts are made to pass through heat exchangers to generate steam. The steam generated from each section is collected and used to run a turbine to generate electricity.

The following are the technologies available for producing power from exhaust gases of cement plant.

- Rankine Cycle
- Organic Rankine Cycle
- Kalina Cycle

The potential for WHR from both PH & cooler exhaust is 1.5-4 MW depending on capacity of the plant.

Case Studies

A study has examined three plants and has identified the source of WHR and the technology used to utilize it. The details are given in Table 23.

Table 23: Details of WHR in three plants (23)

Plant/Parameter	Plant 1	Plant 2	Plant 3
Power Cycle	Organic Rankine Cycle	Steam Rankine Cycle	Waste Heat Recovery Boiler
Clinker Production	2.5 Million TPA	0.5 Million TPA	1 Million TPA
Source	Clinker cooler losses	Pre-heater and clinker cooler	Pre-heater
Gross Power Generation	4 MW	2.3 MW	5 MW

WHR Potential of a Model Plant

A cement plant of kiln capacity of 2400 tpd with five stage preheater has been considered in this study. The cement plant operates for 330 days. The temperature of the gas exiting the preheater and cooler is approximately 300 °C and 290 °C respectively. The basic data and assumptions for estimating the WHR potential are shown in the table below (23).

Table 24: Basic data for WHR calculations

Symbol	Description	Quantity	Units	Remarks
P_{cap}	Kiln capacity	2400	tpd	
P_{No}	No of stages in the preheater	5	numbers	
m_{PH}	Preheater exit gas volume	1.5	m^3/kg clinker	Preheater Exit gas details with average molecular weight taken that of CO_2
$M_{PHexitgas}$	Average Molecular weight of exit gas	44	kg/kmol	
$\rho_{PHexitgas}$	Density of Preheater exit gas based on NTP conditions	1.830	kg/m3	
$C_{P\ PH}$	Specific heat capacity of Preheater Exit Gas	0.36	kCal/kg °C	
T_{PH1}	Preheater exit gas Temperature	300	°C	
m_C	Cooler exit gas Volume	1	m^3/kg clinker	
$M_{Cexitgas}$	Average molecular weight of cooler exit gas	28.84	kg/kmol	Average molecular weight of air
$\rho_{Cexitgas}$	Density of Cooler exit gas based on NTP conditions	1.200	kg/m^3	
C_{PC}	Cooler exit gas specific heat capacity	0.317	kCal/kg °C	
T_{C1}	Cooler Exit Gas Temperature	290	°C	
LM	Limestone moisture content	2	%	
N_R	Raw mill running hrs	22	hrs/day	
N_{days}	Kiln running days per annum	330	days/annum	
EFF_{WHR}	Heat Transfer efficiency of WHR boiler	0.6		
EFF_{AQC}	Heat Transfer efficiency of Air Quenching Cooler (AQC) boiler	0.7		
EFF_{TG}	TG system efficiency	0.33		
Q_{cl}	Specific heat consumption	700	kCal/kg clinker	
M_{coal}	Raw coal moisture	15	%	
F_{m-cl}	Raw meal to clinker factor	1.55		
Q_{RM-CM}	Heat requirement for moisture in raw mill & Coal mill	950	kCal/kg water	
Q_{coal}	Calorific Value of fine coal used	5000	kCal/kg coal	
N_{CM}	Coal mill running hours per day	20	hrs/day	
T_{PH2}	PH gas temperature at WHRB outlet	240	°C	
T_{C2}	Cooler exit temperature at AQC boiler outlet	120	°C	
T_R	Reference temperature	25	°C	

Heat available from the preheater exhaust is given by mCpΔT where m represents mass of the exhaust gas, Cp is the heat capacity of the gas and ΔT represents temperature difference between the gas entering and leaving the WHR boiler. Similarly, heat available from the cooler exhaust is calculated. Total recoverable heat is calculated by multiplying the heat available from WHR and Air Quenching Cooler (AQC) by their respective efficiencies and adding them. The total recoverable heat multiplied by the corresponding kWh conversion factor and the efficiencies of the turbine and generator yields the power which could be recovered from the waste heat and the cooler exhaust gases. The analysis finds that the estimated power generation from WHR plant is 3.1 MW. The following table describes parameters that are used in estimating WHR based power generation from PH and cooler exhaust gases.

Table 25: Calculation for power generated from the WHR model plant

Symbol	Description	Quantity	Units
Q_{PH}	Heat available in the preheater gas	296.5	kCal/kg clinker
RM_{cap}	Raw mill capacity	1.69	kg/kg clinker
M_{RMflow}	Moisture flow rate in raw mill	3.45	Tonnes/hr
$M_{RMratio}$	Moisture in raw mill per kg clinker	0.035	kg moisture/kg clinker
Q_{RM}	Heat requirement for raw mill	32.78	kCal/kg clinker
SCC	Specific Coal Consumption	0.14	kg coal/kg clinker
CM_{cap}	Coal Mill capacity	16.8	TPH
$M_{evap\text{-}CM}$	Moisture evaporation in coal mill	2.97	TPH
Q_{CM}	Heat requirement for coal mill	28.17	kCal/kg clinker
$Q_{PHexcess}$	Excess heat available for Preheater	235.54	kCal/kg clinker
Q_C	Heat available in the cooler exit gas	110.28	kCal/kg clinker
Qtotexcess	Total excess or waste heat available	345.82	kCal/kg clinker
Q_{WHRB}	Heat available from PH-WHR boiler	59.29	kCal/kg clinker
Q_{AQC}	Heat available from the Air Quenching Cooler	64.65	kCal/kg clinker
Q_{power}	Recoverable heat in steam for power generation	80.83	kCal/kg clinker
$Q_{generation}$	Power generation possible	3101.65	kW

Challenges

There are several technical challenges in establishing WHR systems. Exhaust gas comprises of dust which is abrasive and sticks to the PH boiler. The dust needs to be separated and collected before sending it to WHR system. The 5-6 stage PH is located at high elevation and the WHR system is installed along with it. Thus the placement poses its own challenge both technical as well as in its maintenance. Exhaust gas temperature not being high enough to produce superheated steam, wide variation in temperature of the cooler gas and high installation cost are some of the prominent barriers faced by plants in adopting WHR technology (24).

7.3 Blending

Clinker when mixed with fly ash/slag is called blended cement. Fly ash or blast furnace slag replaces the amount of clinker that would be added to OPC grade cement. Blending leads to both decrease in the electrical and thermal energy consumption. It also helps in conserving limestone and reduces release of greenhouse gas (GHG) emissions. Increasing the blending percentage decreases the SEC of a plant. The following sections discuss the blending material in greater detail.

Fly Ash
Fly ash is a fine powder resulting from the combustion of coal in a thermal power plant. When mixed with lime and water, the fly ash forms a cementitious compound with properties very similar to that of Portland cement. Because of this similarity, fly ash can be used to replace a portion of clinker in the cement. India generates around 130 Mt of fly ash per annum (25). Around 30% of the fly ash is recycled out of which the cement industry accounts for 75%.

Blast Furnace Slag
As per the BIS standards, only 65% of blast furnace slag can be added to the clinker. The following improvements are noted when cement in blended with BF slag:

1. Better concrete
2. Easier finish
3. Higher compressive and flexural strengths
4. Lower permeability
5. Improved resistance to aggressive chemicals
6. More consistent plastic and hardened properties
7. Lighter color

Current Status
The status of blending in Indian cement industry is shown in Figure 87. In 2009, PPC contributed more than 66% followed by OPC with 25% and PSC at 8% of the total production (4).

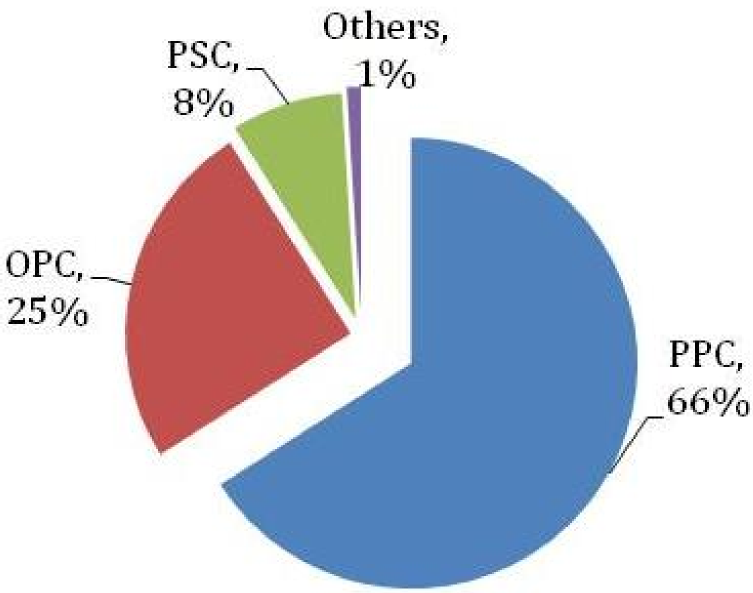


Figure 87. Various Types of Cement Products in India in 2009

Energy Savings and GHG Reduction in a Model Plant
In the following sections, the study examines a model cement plant with respect to reductions in energy consumption and CO_2 emissions by varying the portion of blended cement production. Certain parameters of a model cement plant have been used and are presented in Table 26

Table 26: Data of a model cement plant

Symbol	Description	Value	Units
C	Cement production	1.000	Mt
Cl	Clinker production	0.930	Mt
X	cement to clinker factor	1.0753	
X_{PPC}	PPC	0.000	
X_{PSC}	PSC	0.000	
X_{OPC}	OPC	1.000	
G	Gypsum addition	0.050	
fi	Filler addition in OPC	0.020	
S	Slag addition in PSC	0.500	
y	Fly ash in PPC	0.250	
SEC_{Th}	Thermal SEC	710.000	kCal/kg clinker
SEC_{El}	Electrical SEC	82	kWh/t cement
E_f	Emission factor of coal	0.00040	kg CO_2/kCal
G_f	Grid emission factor	0.90	kg CO_2/kWh
G_c	Process emissions due to calcination	525	kg CO_2/t clinker
G_{fuel}	Emission due to fuel consumption in kiln	285.420	kg CO_2/t clinker
G_p	Emission due to power consumption	73.800	kg CO_2/t cement
T_1	Overall CO_2 emission	827.491	kg CO_2/t cement
E_1	Overall energy consumption	730.820	kCal/kg cement

Scenarios
The study examines two scenarios for energy savings and CO_2 emission reduction. In one scenario the amount of blended cement produced by the plant is increased as a percentage of total cement production. In the second scenario the percentage of flyash within PPC and percentage of slag with in PSC are increased.

Scenario I: Increasing the Portion of Blended Cement

The portion of blended cement is increased from 0% to 70% while keeping other parameters constant. The fly ash, slag and gypsum composition are maintained as shown in Table 26.

Increasing the blending portion from 0% to 40%PPC, 30%PSC & 30%OPC
Currently, the model plant does not produce blended cement. Hence, there is a scope to increase the blended cement production. The composition of different grades of cement is depicted in Table 27.

Due to blending, there is an increase in cement production. The clinker production remains the same because of the installed capacity of clinker production in the plant. The cement to clinker factor varies due to blending. Therefore the energy consumption per unit mass of clinker is same before and after blending.
(Energy consumption/t cement)*(t cement/t clinker) before blending= (Energy consumption/t cement)*(t cement/t clinker) after blending

The reductions in energy and CO_2 emission are shown in Table 27.

Table 27: Energy Savings and CO_2 reduction by increasing the portion of blended cement (40%PPC, 30%PSC & 30%OPC)

Symbol	Description	Value	Units
X	Cement to clinker factor for 0% blended cement	1.075	
X_B	Cement to clinker factor for 70% blended cement	1.441	
	Reduction in energy consumption	185.45	kCal/kg cement
	Reduction in CO_2	209.99	kg CO_2/t cement

X, X_B are the cement to clinker factor before and after blending respectively. As mentioned earlier, the cement to clinker factor increases by increasing the blending percentage. The reduction in energy consumption and CO_2 emissions by increasing the blending percentage from 0% to 70% are 185.45 kCal/kg cement and 209.99 kg CO_2/t cement respectively as shown in Table 27.

Increasing the portion of PPC (0% to 70%)

The composition of PPC in the model is increased to 70% in this case. The reduction in energy consumption and CO_2 emissions by increasing the portion of blended cement (70%PPC), are shown in Table 28 and are 126.518 kCal/kg cement and 143.25 kg CO_2/t cement respectively.

Table 28: Energy savings by increasing the Portion of blended cement (70%PPC)

Symbol	Description	Value	Units
X	Cement to clinker factor for 0% blended cement	1.075	
X_B	Cement to clinker factor for 70% blended cement	1.300	
	Reduction in energy consumption	126.52	kCal/kg cement
	Reduction in CO_2	143.25	kg CO_2/t cement

Increasing the portion of PSC (0% to 70%)

The reduction in energy consumption and CO_2 emissions by increasing the portion of blended cement (70%PSC), are shown in Table 29. The values are 264.04 kCal/kg cement and 298.96 kg CO_2/t cement respectively.

Table 29: Energy savings by increasing the portion of blended cement (70%PSC)

Symbol	Description	Value	Units
X	Cement to clinker factor for 0% blended cement	1.075	
X_B	Cement to clinker factor for 70% blended cement	1.684	
	Reduction in energy consumption	264.04	kCal/kg cement
	Reduction in CO_2	298.96	kg CO_2/t cement

Figure 88 and Figure 89 compare the energy savings and CO_2 reduction potential by increasing the blending composition in cement manufacturing. The highest energy savings and CO_2 reduction are observed for cement production with the highest ratio from PSC blended cement.

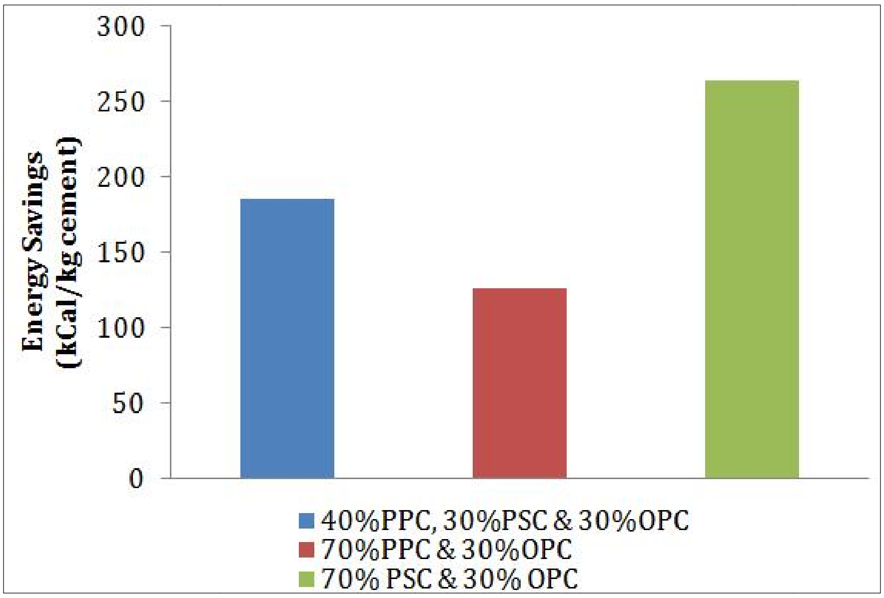


Figure 88. Energy savings from different types of blended materials

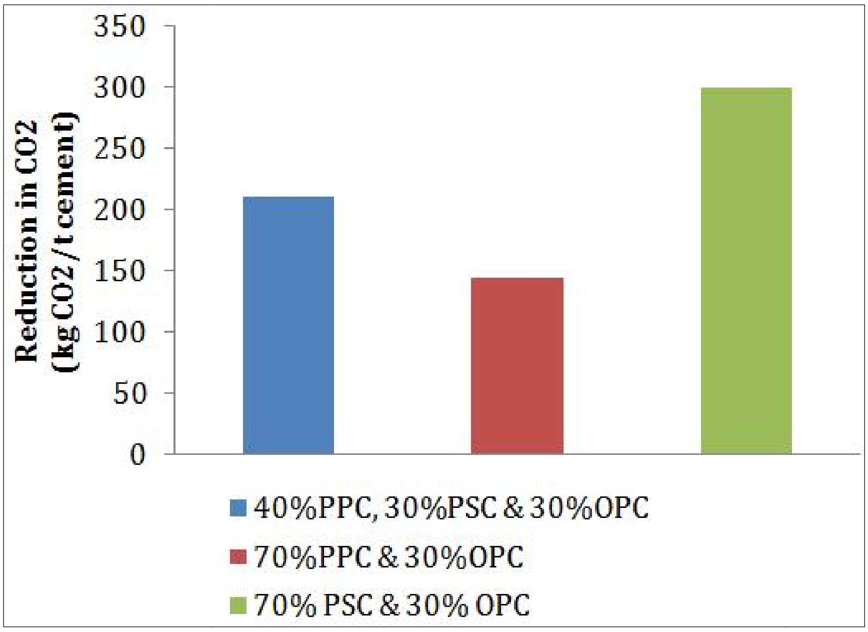


Figure 89. CO_2 reduction from different types of blended materials

Scenario II: Increasing the Composition of Fly Ash and Slag in Cement

Increasing the composition of fly ash in PPC from 7% to 35%

The portion of blended cement is 40% PPC, 30% PSC and 30% OPC. According to BIS, the maximum permissible fly ash percentage in PPC is 35(26). We have considered different compositions of fly ash in PPC and studied the variation of energy consumption and CO_2 reduction potential. Table 30 shows the variations in cement to clinker factor with respect to fly ash composition in PPC. The cement to clinker factor increases with increase in fly ash composition.

Table 30: Variation of GHG and reduction in energy consumption with increasing fly-ash percentage

Symbol	Description	% fly ash in PPC					Units
y	Fly ash composition in PPC	7.00	14.00	21.00	28.00	35.00	
X	cement to clinker factor for 0% blended cement	1.075	1.075	1.075	1.075	1.075	
X_B	cement to clinker factor for different fly ash content	1.305	1.355	1.408	1.466	1.529	
E_1-E_2	Reduction in energy consumption	128.9	150.9	172.9	194.9	216.9	kCal/kg cement
T_1-T_2	Reduction in CO_2	145.9	170.8	195.8	220.7	245.6	kg CO_2/t cement

Figure 90 and Figure 91 show the energy savings and corresponding CO_2 emissions for various compositions of fly ash in PPC. It is observed that the addition of fly ash results in increased energy savings. An increase (%) in fly ash results in larger (%) reduction in CO_2 emissions.

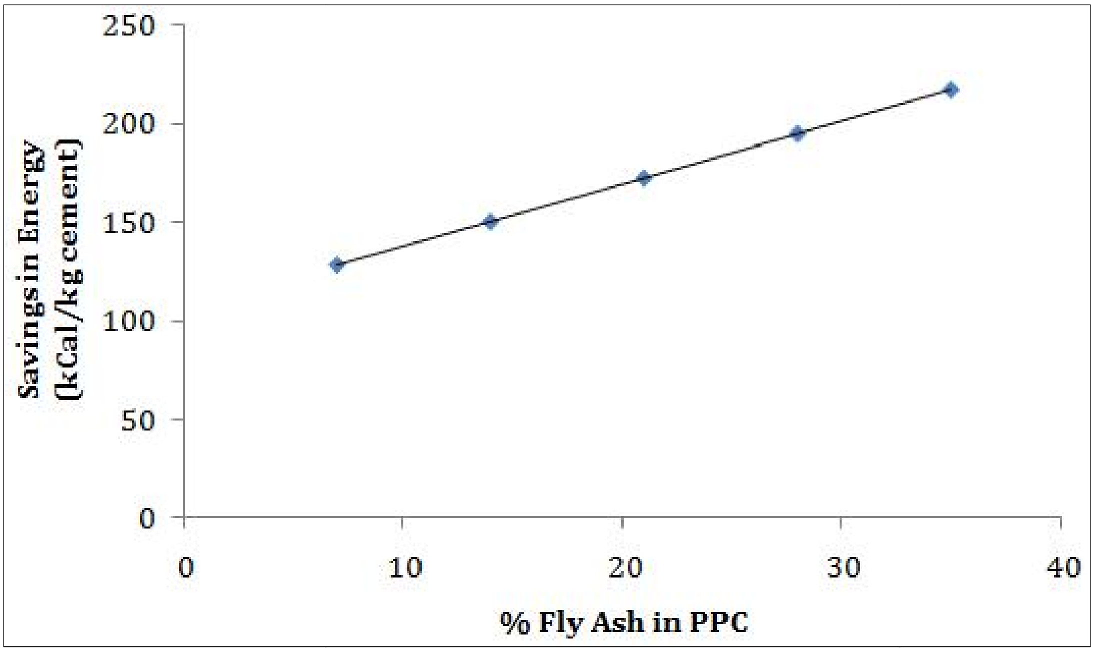


Figure 90. Energy savings from different composition of fly ash in PPC

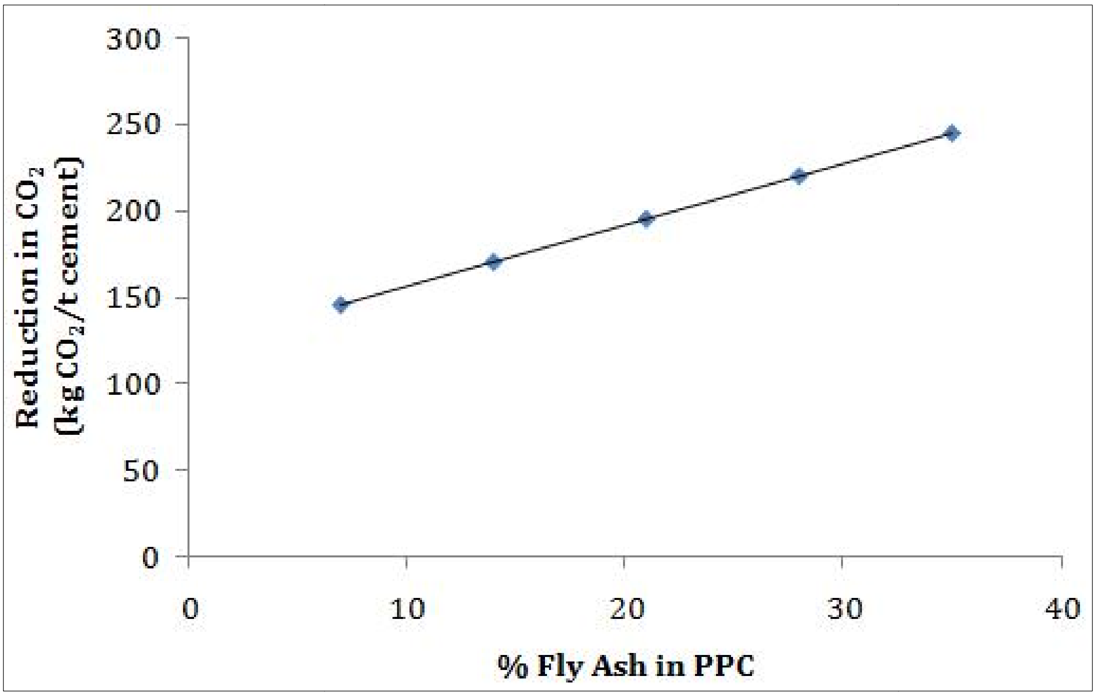


Figure 91. CO_2 reduction potential from different composition of fly-ash in PPC

Increasing the composition of slag in PSC from 10% to 50%

According to a CII-GBC report, the slag percentage in PSC is in the range 25%-65% (20). We have considered different composition of slag in PSC and studied the variation of energy consumption and CO_2 reduction potential.

Table 31 shows the variation in cement to clinker factor with respect to slag composition in PSC. The cement to clinker factor increases with increasing amounts of slag in PSC.

Table 31: Variation of GHG and reduction in energy consumption with increasing slag percentage

Symbol	Description	% Slag in PSC					Units
S	Slag composition in PSC	10.00	20.00	30.00	40.00	50.00	
X	Cement to clinker factor for 0% blended cement	1.075	1.075	1.075	1.075	1.075	
X_B	Cement to clinker factor for 70% blended cement	1.229	1.276	1.326	1.381	1.441	
E_1-E_2	Reduction in energy consumption	91.16	114.73	138.31	161.88	185.46	kCal/kg cement
T_1-T_2	Reduction in CO_2	103.21	129.91	156.60	183.29	209.99	kg CO_2/t cement

Figure 92 and Figure 93 show the energy savings and corresponding CO_2 emissions for various compositions of slag in PSC. It is observed that the addition of slag results in energy savings and corresponding emissions reduction.

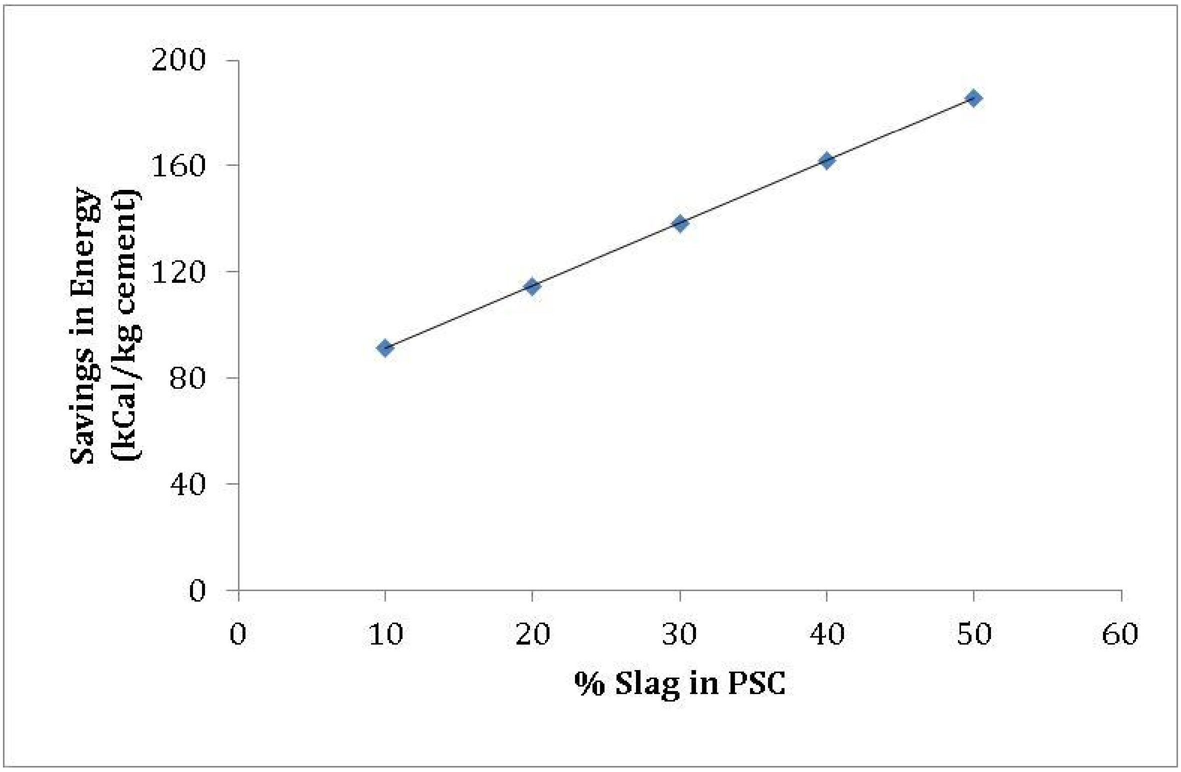


Figure 92. Energy savings from different composition of slag in PSC

Increasing limestone content in OPC from 2% to 10%
The OPC available in the market contains 2% limestone (4). The reduction in energy consumption and corresponding GHG emission by increasing the portion of limestone from 2% to 10% is shown in the table below. 204.32 kCal/kg cement and 231.34 kg CO_2/t cement of energy savings and CO_2 reduction is obtained. Table 32 summarizes the result.
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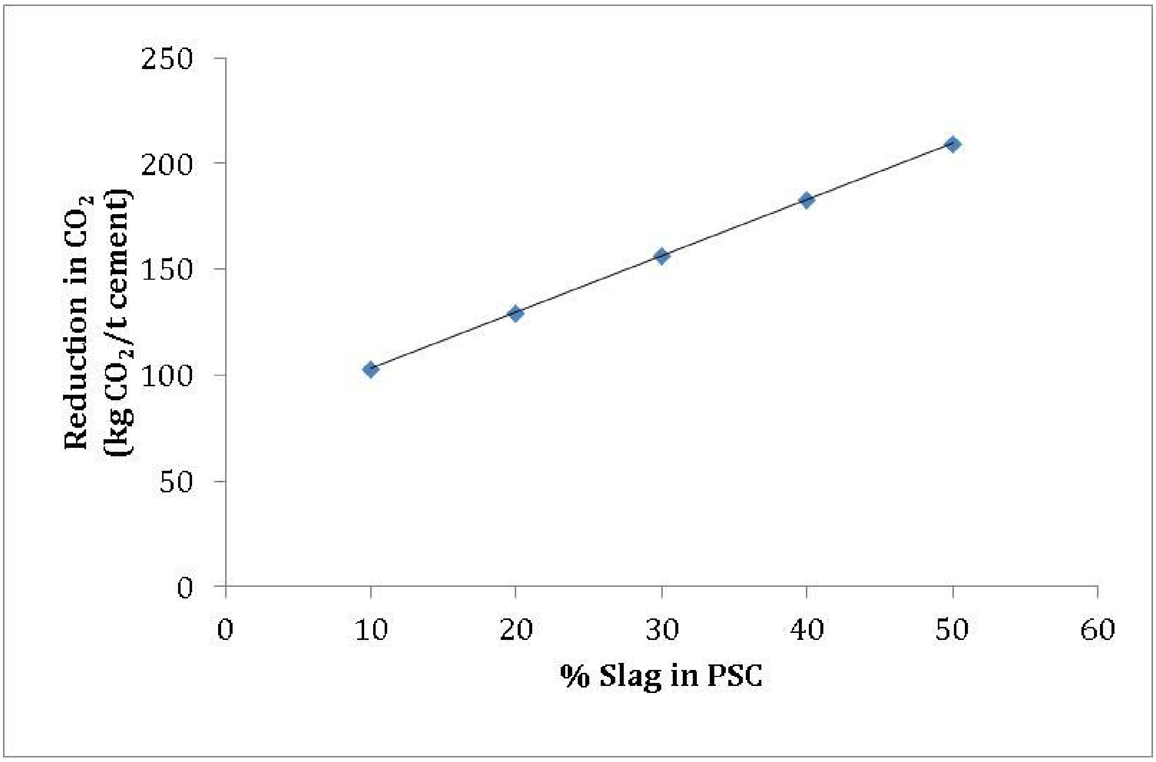


Figure 93. CO_2 reduction potential from different composition of slag in PSC

Table 32: Energy savings by increasing portion of limestone in OPC

Symbol	Description	Value	Units
$OPC_{limestone}$	Limestone in OPC	0.100	Fraction
X	cement to clinker factor for 2% filler in OPC	1.075	Fraction
X_l	cement to clinker factor for 15% filler in OPC	1.493	Fraction
	Reduction in energy consumption	204.32	kCal/kg cement
	Reduction in CO_2	231.34	kg CO_2/t cement

7.4 Alternative Fuel Resources (AFR)

Cement production is characterized by an extremely high-temperature combustion process (up to 2000^{o}C flame temperature), necessary for heating and fusing the raw materials. The most commonly used traditional fossil fuels in this combustion process are coal, heavy fuel oil or gas. Substitution of these fossil fuels by alternative, waste derived fuels is a common practice in the cement industry in many parts of the world. The nature of the production process makes it eminently suitable for this purpose - by ensuring full energy recovery from various wastes under appropriate conditions. Any solid residue from the waste then becomes a raw material for the process and is incorporated into the final cement clinker. Sometimes, waste can also be used to substitute raw materials in the process, thereby also conserving the natural resources generally used in the manufacture of cement.

Importance to Cement Industry

Waste is an important issue for society - as an example, Europe alone generates more than 350 million waste tyres per annum. Recycling and disposal options for many waste materials and industrial by-products are often limited - used tyres is but one example. Where recycling is not possible, incineration or landfill is the most common disposal practice available for many wastes. However, by using waste as an alternative fuel or raw material in the cement-making process, there are benefits for society as well as the cement maker. For any cement industry it represents an attractive business opportunity because it reduces fuel costs and CO_2 emissions. By dealing safely with wastes that are often difficult to dispose of in any other way, we are trying to provide an important service to society.

Key Challenges and Motivation

The key challenge facing the cement-making industry is the efficient use of natural resources. Cement industry should therefore be committed to using secondary materials (waste and industrial by-products) in place of natural resources wherever possible. However, this strategy is not without its challenges. Not every waste is suitable. In addition, one should ensure that using a particular waste does not increase the atmospheric emissions, nor impact product quality. At the same time, a key objective of AFR use is to achieve reductions in CO_2 emissions.

Meanwhile, stakeholder debate continues over the use of AFR in cement kilns. Some stakeholders are concerned about potential health or environmental impacts from the handling and combustion of alternative fuels. Others are concerned that product quality could be compromised. It has also been claimed that the use of waste and by-products as fuels actually perpetuates the production of these wastes, by offering a legal, cost-efficient solution to disposal. However, other stakeholders are pleased by the dual possibilities of cutting GHG emissions and disposing of wastes by using AFR. It is therefore a challenge for regulatory authorities to manage stakeholder expectations and provide assurances to demonstrate the use of waste materials (27).

Alternate Raw Materials (ARM)

The waste materials which are used in cement manufacturing or as a substitute for clinker are often referred as Alternate Raw Materials (ARM). This practice benefits both cement industry and society, since it reduces operating costs as well as CO_2 emissions. In some cases, cement companies can earn revenues through waste recovery services.

ARM can be used to replace the traditional raw materials extracted from quarries, such as clay, shale and limestone. Examples of ARMs include contaminated soils, wastes from cleaning roads, wastes from iron, aluminum production, coal ash, blast furnace slag and sewage sludge. The chemical suitability of ARM is important to ensure that they provide the necessary constituents in the formation of clinker (28).

Such a practice provides numerous benefits including a receded need for quarrying and an improved environmental footprint of such activities. Substitution for clinker in cement will be an example of the positive contribution to Indian cement industry both in terms of resource management and environmental impact (28).

Classification and Constituents

Raw materials applicable in cement manufacture are mainly substances found in nature, such as limestone, lime marl, clay, sand, or calcium sulfate. Alternative raw materials having SiO_2, Al_2O_3, Fe_2O_3, and/or CaO as their main constituents can be combined with natural raw materials in such a way that they comply with the requirements, both for clinker quality and environmental protection, and operational reliability, if their distribution is homogeneous. The demand for alternative materials primarily depends on the prevalence of raw material. The decisive factor is the quality of the extractable deposits of limestone and lime marl, respectively. The materials used include several substances of the calcium group and corrective materials, such as iron oxide agents or substances providing sulfur and fluorine, respectively. Table 33 shows the possible alternative raw materials according to their constituents.

Table 33: Group classification of alternative raw materials with examples for individual materials(29)

Ca-Group	Industrial lime Lime sludge
Si-Group	Used foundry sand
Fe-Group	Roaster pyrite Synthetic haematite Red mud
Si-Al-Ca-Group	Fly ash Slag Crushed sand
S-Group	Gypsum from flue gas desulfurization Chemical gypsum
F-Group	CaF_2 filter mud

Case Study

Madras Aluminum Company (MALCO) has identified a breakthrough technology of using red mud as one of the raw materials in the cement manufacturing. Red mud as by product is generated out of Bayer's process for alumina production from bauxite ore. The solid waste is currently dumped as in the back yard of alumina refinery. Presence of alumina and iron oxide in red mud compensates for the deficiency of the same components in limestone. One of the qualities that makes red mud special is the presence of soda in which when used in clinker production neutralizes the sulfur content in pet coke which is used for burning clinker and adds to the cement's setting characteristics(30).

The following is the composition of the Dry Red Mud used in cement manufacturing.

Table 34: Composition of red mud from MALCO and its properties

Component	Weight (%)	In Limestone (%)	In Gypsum (%)	In Fly Ash (%)
Al_2O_3	20-22	13.5	2	60
Fe_2O_3	40-45	1.5		27
SiO_2	12-15	1.0		8
TiO_2	1.8-2.0	47.0	2	2.5
CaO	1.0-2.0	0.5		0.5
Na_2O	4-5	36.5		2.5
$CaSO_4.2H_2O$			96	

A comparison of composition of the MALCO Red Mud and the Low Grade Bauxite (LGB) from its mines are shown in Table 35. From this, it is evident that red mud can be used as a substitute for LGB Bauxite in Cement production, but in varying ratios.

Table 35: Comparison of constituents of red mud and low grade bauxite

Component	Red Mud %	In LGB %
Al_2O_3	20-22	<30
Fe_2O_3	40-45	>35
SiO_2	10-12	10-25

The cement industry uses pet coke for burning clinker in the rotary kilns. Pet coke contains sulfur of about 3% found to react with the residual soda (contained in Red Mud). The reaction leads to the formation of sodium sulfide which enables the setting characteristics of cement. The property of cement comprising red mud and without red mud is shown in Table 36.

Table 36: Properties of cement produced without red mud and with red mud

Parameters of Cement	Specification as per BIS 43 Grade OPC	Cement Produced without Red Mud	Cement Produced with Red Mud
Compressive strength at 28 days	Min: 43 MPa	59.8 MPa	59.9 MPa
Fineness	Min: 225 m^2/kg	310 m^2/kg	310 m^2/kg
Setting Time			
Initial	Min: 30 mins	120 mins	110 mins
Final	Max: 600 mins	190 mins	180 Mins

It can be seen from the table that the Red Mud does not affect the cement properties; it improves the cement quality by reducing the setting time (15). Some other benefits of using red mud are as follows:

- Raw mix cost is reduced by Rs 10/t, since the cost of red mud is half of bauxite
- Red mud could increase the alkali content by 0.28% in the raw mix
- Titania contained in the bauxite is supposed to produce clinker with less hydraulic properties resulting in long setting cement. By eliminating the usage of bauxite, the Titania intake to the clinker is reduced yielding high hydraulic clinker.

Limitations of Alternate fuels and Raw Materials

Although, technically cement kilns could use up to 100% of alternative fuels or use greater amount alternate raw materials to increase productivity, there are some practical limitations. The physical and chemical properties of most alternative fuels and raw materials differ significantly from those of conventional fuels and materials. These are related to low calorific value, high moisture content, or high concentration of chlorine or other trace substances. For example, volatile metals (e.g., mercury, cadmium, and thallium) must be managed carefully, and proper removal of cement kiln dust from the system is necessary. This means pre-treatment is often needed to ensure more uniform composition and optimum combustion. However, the achievement of higher substitution rates has stronger political and legal barriers than technical ones:

- Waste management legislation significantly impacts availability. Higher fuel substitution only takes place if local or regional waste legislation restricts land-filling or dedicated incineration, and allows controlled waste collection and treatment of alternative fuels.
- Local waste collection networks must be adequate.
- Alternative fuel costs are likely to increase with high CO_2 costs. It may then become increasingly difficult for the cement industry to source significant quantities of biomass at acceptable prices.
- Level of social acceptance of co-processing waste fuels in cement plants can strongly affect local uptake. People are often concerned about harmful emissions from co-processing, even though emissions levels from well-managed cement plants are the same with or without alternative fuel use. In addition, alternative fuel use has the potential to increase thermal energy consumption, for example when pre-treatment is required as outlined above(29).

7.5 Captive Power Plant (CPP)

CPP, including a generation set, is a power plant established to meet a manufacturer's electricity requirement. A typical CPP is similar to a normal thermal power plant, which can consume not only coal but also biofuels or any other type of fuel to generate electricity.

The Plant Load Factor (PLF) of CPPs in India varied from the lowest value of 29% to a maximum value of 41% over the years from 1971 to 2008. Figure 94 also shows the generation of 90,477 GWh of energy by CPPs in 2006.

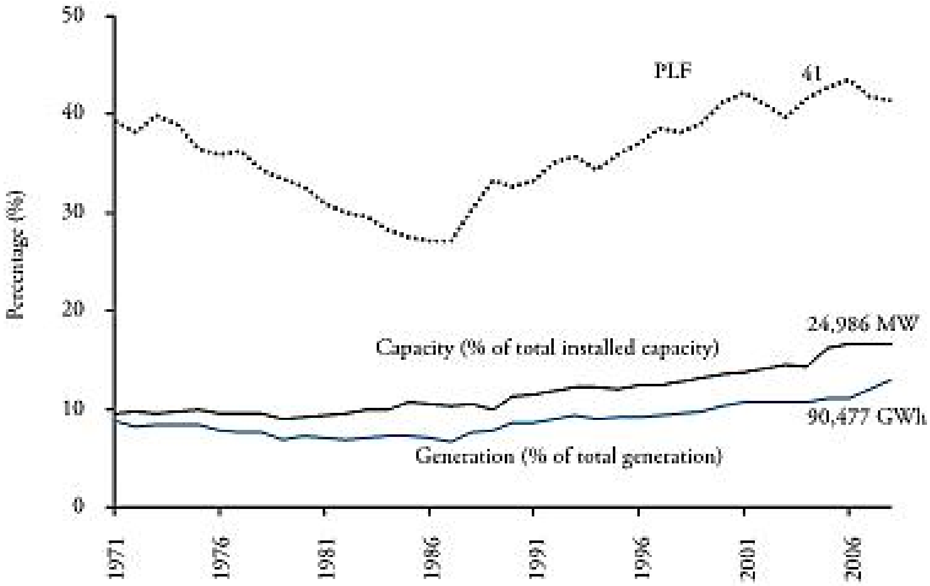


Figure 94. Captive capacity, generation and efficiency in 2008

The capacity of CPP for each sector is given in the following Figure 95 (31). The Chemical sector has the highest capacity followed by Iron and Steel. Cement plants had an installed capacity of around 2250 MW in 2007.

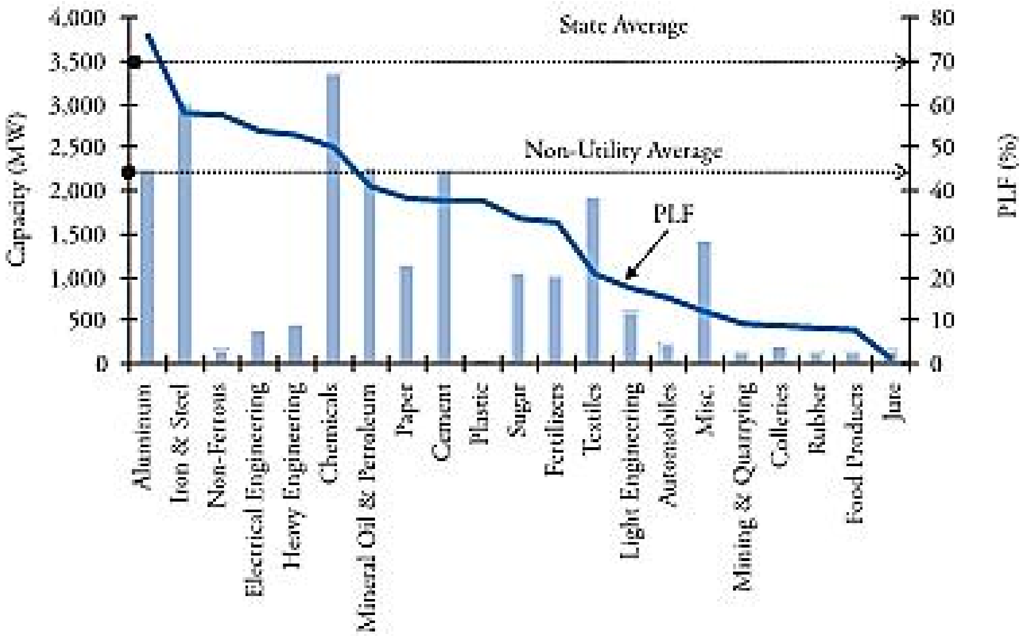


Figure 95. Sector wise installed capacity and PLF of CPP

General diagram of a captive power plant

The general diagram of a CPP is shown in Figure 96. Fuel along with the stoichiometric amount of air is fired in the boiler system producing heat. Water is pumped using a boiler feed water pump through tubes in the boiler system. The heat that comes from combustion of fuel is transferred to the water in tubes to raise superheated steam at a typical temperature and pressure specified (as per the Rankine cycle or other combustion cycle). The steam is collected in a steam drum and passed on to a steam turbine generator to generate electricity (kW). The condensate from the steam turbine is collected in a de-aerator to remove any non-condensable gases inside the condensate. The condensate from the de-aerator is passed through a condenser where it is cooled by water. The condensate is then collected in the boiler feed water drum. The boiler feed water pump will be subjected to erosion if there is any vapor content in the condensate. The level in the boiler feed water drum is kept constant by adding "make up" water. This cycle is repeated continuously to generate electricity. The electricity generated by the CPP is supplied to the CPP auxiliaries, plant utilities and the excess amount is supplied to the grid.

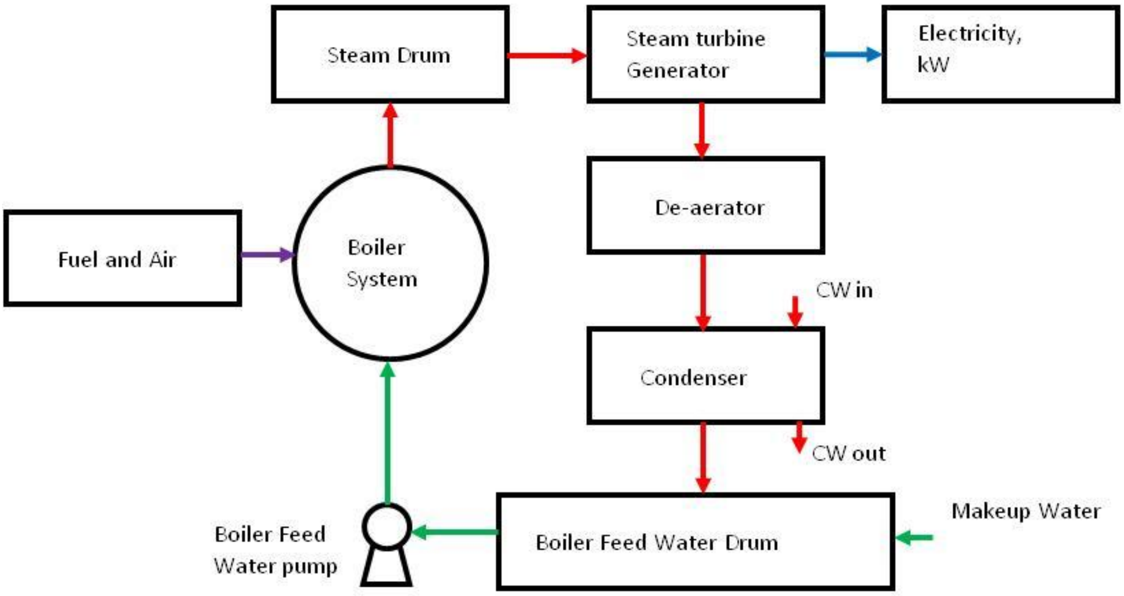


Figure 96. General process flow diagram of CPP

CPPs can be divided into the following types: (32)

1. Extraction cum – condensing steam turbine based cogeneration plant
2. Gas turbine based co-generation plant and
3. Reciprocating engine based co-generation plant

Heat Rates

Heat rate is defined as the heat that is to be supplied in kCal by the fuel to generate 1 kWh of electricity. Heat rates in general are of two types-

1. Gross heat rate
2. Net heat rate

Gross heat rate is the power generated per unit of fuel consumed including the auxiliary power consumption in the power plant. Net heat rate is estimated after excluding the auxiliary power consumption.

A typical gas fired power plant consumes around 2900 kCal/kWh for open cycle and 2000 kCal/kWh for closed cycle (33). Open and closed cycles are two types of technologies used for power generation. A typical coal or lignite based thermal power plant has an operating station heat rate of 2861 kCal/kWh (33).

The primary factors affecting heat rate are as follows:

1. Depending upon the quality of fuel used, deposits are formed on the external surface of the tubes inside the boiler. The deposits lead to the increase of resistance to heat transfer between the products of combustion and water flowing inside the tubes. This leads to a decrease in boiler efficiency.
2. The quality of water used is very critical. If the water quality varies from the specifications, it will result in the formation of scales on the inner surface of the tubes. These scales result in the increase of resistance to heat transfer, which ultimately reduces boiler efficiency.

The heat rate of thermal power plant is also defined as follows: (34)

$$\text{Gross heat rate} = \frac{\text{Gross Turbine heat rate}}{\text{Boiler efficiency}}$$

The following explanation is applicable for a power plant with a rated capacity of 250 MW. For every 1°C temperature drop in steam from the designed value of 537°C, the increase in the heat rate will be 0.67 kCal/kWh. Every 1 kg/cm^2 drop in steam pressure (design pressure 150kg/cm^2) at the turbine inlet results in a loss of 1.31 kCal/kWh.

The following are the few measures for heat rate reduction (35)

1. Modification in steam turbines such as replacement of rotors, blades, nozzles, seals and inner and outer casings.
2. Modification in boilers
3. Control systems (digital, online performance monitoring, etc.)
4. Variable Frequency Drive (VFD) motors on all major rotating equipment (usually improves efficiencies at partial load).

Heat Rate Reduction – Case Studies

Case 1

The heat rate reduction was studied for the case of a 250 MW Pulverized Coal plant. The following are the measures taken for the improvement in the heat rate (35)

1. A decrease in the excess O_2 concentration involving neural network system with combustion control module led to a heat rate reduction of 6.3 kCal/kWh.
2. Reducing the flue gas temperature to the design value by installing new air heater with additional surface area reduced the heat rate by 23.18 kCal/kWh.
3. Changes in the steam turbine with a new rotor and stationary blades will result in an increase of 2-3 MW power by High Pressure (HP) cylinder, 2–3 MW for the Intermediate pressure (IP) cylinder and 1–2 MW for the Low Pressure cylinder. The reduction in heat rate is expected to be around 64.26 kCal/kWh.
4. Reducing steam leakage between shaft and casing results in a heat rate reduction of 3.78 kCal/kWh.
5. Improvement in steam condenser by installing new stainless steel tubing heat exchanger with an online cleaning system, to reduce degradation on the surface of the steam condenser.
6. Changing the boiler feed water pump to steam driven results in the reduction of heat rate by 9.32 kCal/kWh.

Case 2

In this case, the reduction in heat rate is studied for a CPP with a rated capacity of 850 MW (35). The following improvements are observed:

1. Overhaul of the steam turbine to reduce leakage and solid particle erosion resulted in a heat rate reduction of 9.57 kCal/kWh.
2. Air leakage at the primary air heater was arrested resulting in a heat rate reduction of 5.29 kCal/kWh.
3. Optimization of combustion by reducing excess O_2 by 2.3% resulted in a heat rate reduction of 16.32 kCal/kWh.

Energy savings in auxiliary power consumption

The following are the measures for optimization of auxiliary power consumption (36):

- ID Fans can be provided with VFD and speed can be varied according to the furnace draft auto logic. The suction & delivery damper need to be kept in open condition.
- Chimney height optimized to reduce the load on Induced Draft (ID) fan
- Forced draft fan can be provided with VFD and speed can be varied according to the wind box pressure and oxygen level in flue gas auto combustion logic. The suction and delivery damper needs to be kept in open condition
- Primary Air (PA) fan can be provided with VFD and operated manually
- Air Cooled Condenser (ACC) fan can be provided with VFD and operated manually

The following are the key areas for the reduction of power consumption (36)

1. Boiler feed water pump
2. Condensate extraction pump
3. Air cooled condenser fan
4. Boiler primary air fan
5. Auxiliary cooling water pump
6. Cooling tower fan
7. Hot well pump and
8. Air compressor

In the following sections initial conditions of the components are mentioned and then the changes in performance after implementing an energy efficiency measure have been described.

Boiler Feed Water Pump

Initially, the operating conditions of the boiler feed water pump (BFP) (36) were as follows:

1. BFP was running at 100% capacity and the control station maintained the water flow to the drum level.
2. Pressure drop across the control valve was 40 kg/cm^2 and valve was kept opened 25% to 30%.

The modifications that were done for BFP to reduce the energy consumption are:

- Speed was reduced using VFD to auto mode with closed loop control
- Pressure drop across the valve was reduced to 10 kg/cm^2 and the valve opening was maintained at 50 – 55%
- The BFP discharge pressure is to be kept 9.75 kg/cm^2 more than the drum pressure

Table 37 shows the change in parameter values after modification (36)

Table 37: Effect of EE measures in BFP

Variable	Before implementation of auto logic	After implementation of auto logic	Units
Pump Speed	2980	2630	rpm
Discharge Pressure	130	100	kg/cm^2
Power consumption	373	292	Units/hr

Power consumption decreased from 373 to 292 units/hr, amounting to 22% electricity savings. Reduction of differential pressure across feed control valves reduced the usage of 13A/6.6V rating pump.

Condensate Extraction Pump

A Condensate Extraction Pump (CEP) is used to pump the condensate water from condensate storage tank to the de-aerator through ejector, gland steam condenser and LP heater (36).

Initially, the operating conditions of the CEP were as follows:

1. CEP was running at 100% speed and the controller was maintaining the de-aerator level
2. Pressure drop across the control valve was 12 kg/cm^2 and the valve opening is at 15–20%.

The following modifications were done:

Speed was reduced by using VFD in auto mode with closed loop control. The pressure drop across the valve was reduced to 3 kg/cm^2 and the valve opening of 45% to 50%. CEP discharge pressure was maintained at 9 kg/cm^2 to ensure proper heat transfer and maintain vacuum in ejector. This modification is shown in Figure 97.

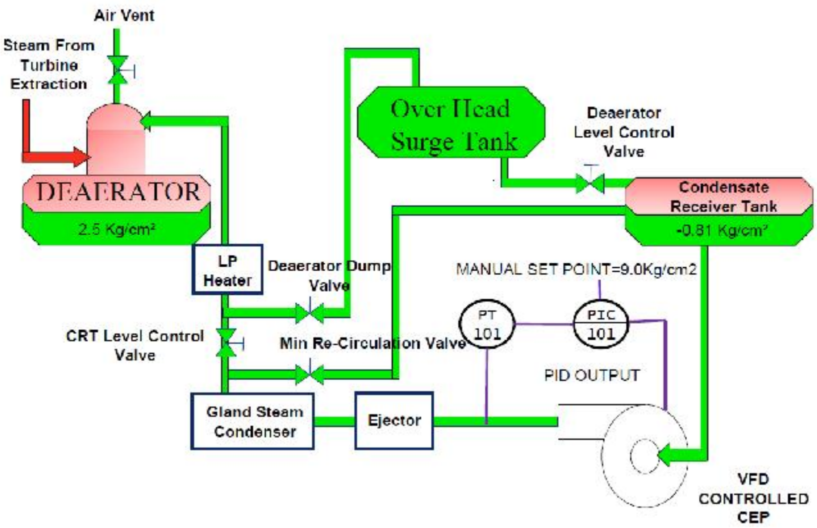


Figure 97. Auto logic for VFD controlled condensate extraction pump (36)

Table 38 shows the parameter values that were observed after modification, which reduced the power consumption from 76 units/hour to 40 units/hour.

Table 38: Effect of EE measures in CEP

Variable	Before Implementation of Auto logic	After Implementation of Auto logic	Units
Pump speed	2980	2150	rpm
Discharge Pressure	18.8	9	kg/cm^2
Power consumption	76	40	Units/hr

Air Cooled Condenser Fan

Air Cooled Condenser (ACC) fans are used to force the air to the condenser to condense the exhaust steam from the turbine (36). Initially ACC fan speed was controlled manually to maintain the vacuum pressure. It was modified by reducing the fan speed using VFD in auto mode with closed loop control. This modified control system is shown in Figure 98. The steam condensate pressure was used for controlling the speed of the fan.

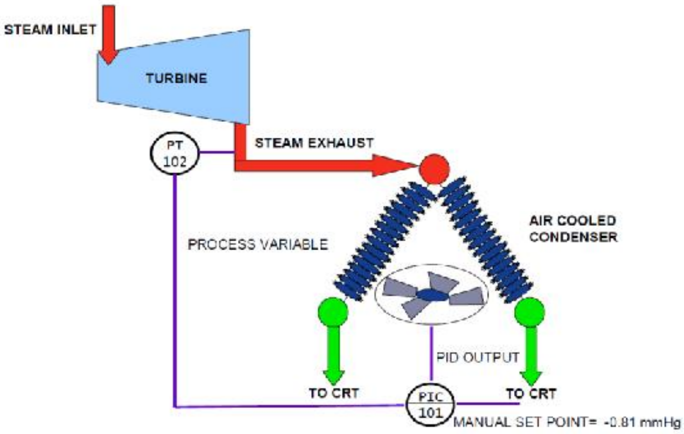


Figure 98. Auto logic for VFD controlled air-cooled condenser fan (36)

Table 39 shows the changes in the parameters that were observed after modification.

Table 39: Effect of EE measures in ACC

Variable	Before Implementation of Auto logic	After Implementation of Auto logic	Units
Fan speed	Manual mode	Auto mode	
Power consumption	50	42	Units/hr

Primary Air Fan

Primary Air (PA) fans are used to transport the fuel from surge hopper to boiler furnace. Initially the PA fan speed was controlled manually to maintain PA header pressure. It was modified by reducing the fan speed using VFD in auto mode with closed loop control. This modified control system is shown in Figure 99 (23). Table 40 shows the parameters that were observed after modification.

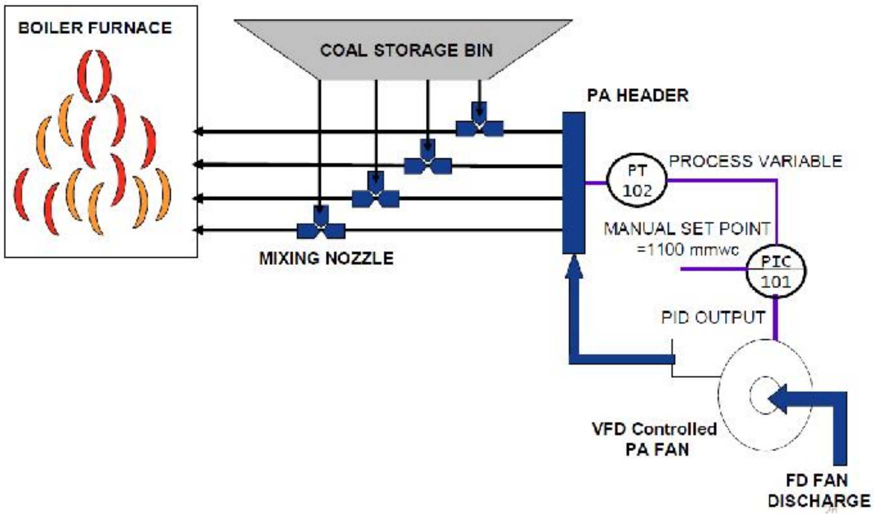


Figure 99. Auto logic for VFD controlled primary air fan (36)

Table 40: Effect of EE measures in primary air fan

Variable	Before Implementation of Auto logic	After Implementation of Auto logic	Units
Fan speed	Manual mode	Auto mode	
Power consumption	55	51	Units/hr

Auxiliary Cooling Water Pump

Auxiliary cooling water (ACW) pump is used to pump the cooling water to turbine oil cooler, generator air cooler and BFP pump-bearing cooler (36). Initially the pump was operated at 100% capacity and header pressure was maintained by regulating the discharge manual control valve. It was modified by reducing the pump speed using VFD. This modified control system is shown in Figure 100. The header pressure of the cooling water pipes of generator and lube oil cooler is used to control the speed of the VFD in Figure 100.

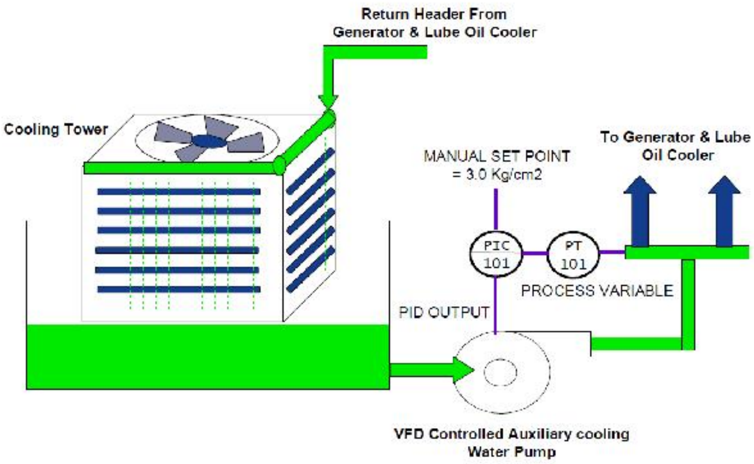


Figure 100. Control system of the auxiliary cooler water Pump (36)

Table 41 shows the parameters that were observed after modification. From this table, it is observed that almost 50% of the energy consumption is saved after implementing the control system of auto logic.

Table 41: Effect of EE measures in auxiliary cooling water pump

Variable	Before Implementation of Auto logic	After Implementation of Auto logic	Units
Pump speed	1480	1180	rpm
Discharge Pressure	5	3	kg/cm^2
Power consumption	48	24	Units/hr

Cooling Tower Fan

Cooling tower fan is used to extract vapor from the cooling water (36). Initially there is no linkage between the return header water temperature and the cooling tower fan. This was modified by starting and stopping of cooling tower fan depending upon the header water temperature. This control system is indicated in Figure 101. The control system works by sensing the return water header temperature and then comparing with higher and lower temperature values. If the temperature is within the range, the fan will be in operating mode. The higher and lower temperatures are indicated as HH and LL in Figure 101. If the temperature is more than HH, then the fan starts and stops if the temperature is lower than LL as there is no need to further decrease the temperature of water coming from the return header.

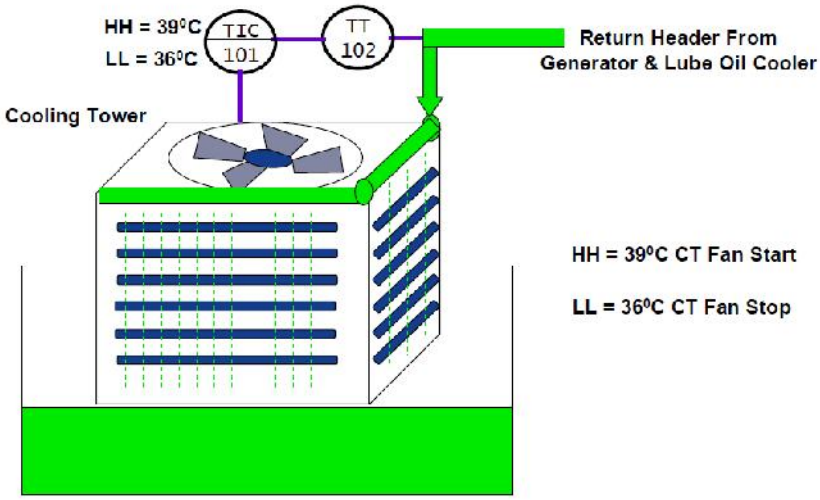


Figure 101. Control system of the cooling tower fan (36)

Table 42 shows the effect of the modification.

Table 42: Effect of EE measures in cooling tower fan

Variable	Before Implementation of Auto logic	After Implementation of Auto logic	Units
Power consumption	5	5	Units/hr
Running hours	24	14	hrs/day
Total power consumption	120	70	Units/day

Hot Well Pump

A hot well pump is used to pump the low pressure (LP) heater condensate and turbine drains to condensate storage tank (36). The hot well pump runs continuously and the hot well level is controlled by the valve. It was modified by opening the control valve completely and then the pump either starts or stops depending on the hot well level. The modification is shown in Figure 102. Table 43 shows the parameters that were observed after modification.

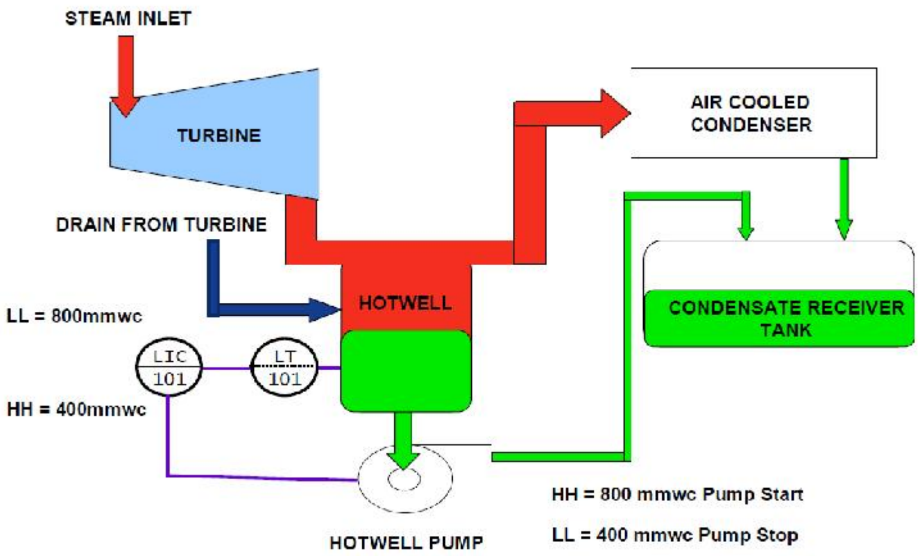


Figure 102. Control system of the hotwell pump (36)

Table 43: Effect of EE measures in hot well pump

Variable	Before Implementation of Auto logic	After Implementation of Auto logic	Units
Power consumption	2.7	2.7	Units/hr
Running hours	24	4.5	hrs/day
Total power consumption	64.8	12.15	Units/day

Air Compressor

Screw type air compressor is used for plant control instruments and ash conveying system (36). Initially air pressure was running at a design value of 7 kg/cm^2 with 21 loading hours and 3 unloading hours. It was modified by reducing the air compressor discharge pressure to 6 kg/cm^2 as per process requirement. Table 44 shows the modification in the air compressor.

Table 44: Effect of EE measures in air compressor

Variable	Before reducing the pressure	After reducing the pressure	Units
Unloading pressure	7	6	kg/cm^2
Loading pressure	5.5	5.5	kg/cm^2
Power consumption	50	45	Units/hr

Potential Economic Savings

Boiler feed water pump seeks an investment of Rs 25.3 lakhs provides annual savings of Rs 32 lakhs with a payback of 10 months. Similarly, the summary of savings for the different equipments used in the power plant is given in Table 45 (36).

Table 45: Energy and rupees savings after implementing EE measures in CPP's auxiliary systems

Equipment Modified	Power Savings, Units per hour	Power Savings, Units per day	Power Savings, Units per year	Savings (at Rs. 4.5/unit), Rs. Lakhs	Capital Cost, Rs. Lakhs	Payback Period, Months
Boiler Feed Water Pump	81	1944	7,09,560	31.9	25.3	10
Condensate Extraction Pump (CEP)	36	864	3,15,360	14.2	5.9	3
Air Cooled Condenser Fan (ACC)	8	192	70,080	12.6/fan		
Primary Air Fan	4	96	35,040	1.5		
Auxiliary Cooling Water Pump	24	576	2,10,240	9.5	2.7	4
Cooling Tower Fan		50	18,250	0.8		
Hot Well Pump		52	18,980	0.85		
Air Compressor	5	120	43,800	1.95		

The following list provides a summary of the scope for energy reduction in different equipments engaged in auxiliary power consumption in CPP (37).

1. Air & Flue Gas Cycle
    - Power consumption in ID and FD fans can be reduced by optimizing excess air
    - VFD for ID and FD fans
2. Steam, Feed water and Condensate cycle
    - Optimizing level set points of LP and HP heaters.
    - Installation of VFD for various pumps helps in reducing the power consumption
3. Fuel and Ash Cycle
    - Using washed coal as fuel compared to high ash coal
    - Optimizing idle running of crushers and conveyors in the system
    - Using dry ash evacuation system compared to wet system
4. Electrical and Lighting system
    - Using CFL, replacement of mercury vapor lamp with metal halide lamp, auto timer for switching on and off of lights etc.
5. Compressed air system
    - Optimizing discharge air pressure
    - Use of screw compressor instead of reciprocating compressor
6. Improving cooling water tower performance

7.6 Financial Analysis of EE Options

The study examined several energy efficiency measures for which the Net Present Value (NPV) and Internal Rate of Return (IRR) were calculated. The following were assumed for the analysis:

1) Discount rate of 10%
2) Corporate tax rate of 30% with a surcharge of 3%
3) End of Life (EoL) of 10 years
4) Minimum Alternate Tax (MAT) of 18% and carry forward of MAT credits as applicable u/s 115JAA of the IT Act, 1961
5) Carry forward of operating losses as applicable under the provisions of IT Act, 1961
6) Book depreciation by engaging straight line method
7) Income tax depreciation at 80% and 20% for the first and second years, respectively.

Energy savings, payback period and investment levels of each energy efficiency measure were obtained from CII (38).

The Present Value (PV) of each year's net profit is calculated using the following formula:

$$Present\ value(PV) = \frac{Net\ Profit_i}{(1+r)^n}$$

Where,

i = year at which the net profit was achieved

r = discount rate

n = Number of years to the EoL

High efficiency preheater fans and Star delta star starters are two case studies reported in this study.

Case Study 1 – High Efficiency Preheater Fan

High efficiency preheater fans blow the kiln exit gases into the preheating chamber and enhance system thermal efficiency by increasing the heat exchange rates(38). The savings, NPV and IRR are depicted in Figure 103.

Installation of High Efficiency fan for Pre-heater fan

All figures in Millions of Indian Rupees

Annual Savings	1.10		Payback	22	months		Depreciation Rate - First Year	80%
Investment	2.00		Life of Equipment	10	years		Depreciation Rate - Second Year	20%
Discount Rate	10%							

Income Tax Depreciation

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Income		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Expenses		-									
EBITDA		1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Book Profit											
Depreciation (Straight Line Method)		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Profit Before Tax (PBT)		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
IT Profit											
Deprecation (Written Down Value)		1.60	0.40	-	-	-	-	-	-	-	-
PBT		-0.50	0.70	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Tax (@Normal rate)	**30.90%**	-	0.06	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
MAT Credit		0.16	0.26	0.08							
Calculated Tax		-	-	-	0.26	0.34	0.34	0.34	0.34	0.34	0.34
Tax (@ MAT rate)	**18.00%**	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Effective Tax		0.16	0.16	0.16	0.26	0.34	0.34	0.34	0.34	0.34	0.34
Profit After Tax (PAT)	-2.00	0.94	0.94	0.94	0.84	0.76	0.76	0.76	0.76	0.76	0.76

IRR	**43.26%**
NPV	**3.17**

Figure 103. Annual energy savings for the installation of high efficiency PH fan

The annual savings incurred by the investment is equal to Rs. 1.10 Million for a total capital cost of Rs. 2 Million. The higher annual savings result in payback of 22 months and an IRR of 43.26%. Figure 104 shows the present value of annual energy savings. We observe that higher depreciation rates (in the first two years) result in larger annual savings in the first two years. Further, the steep decrease in the present value (in the later years) can be explained by the higher discount rate employed in the analysis.

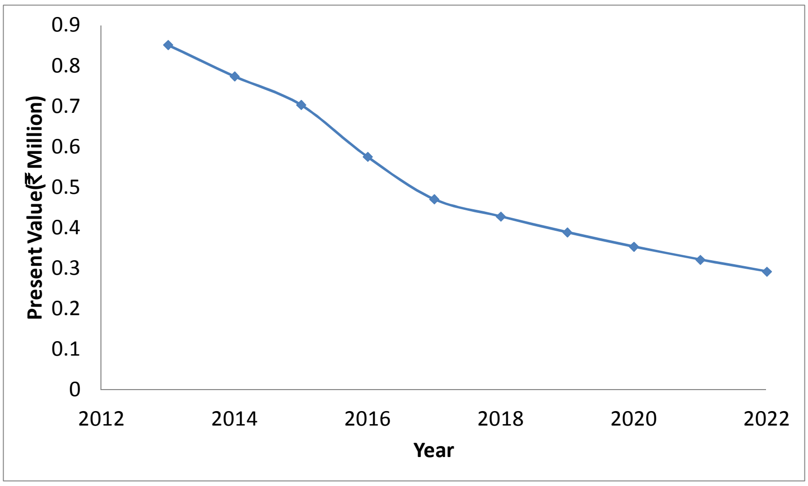


Figure 104. Present value of annual energy savings

Case Study 2 – Star Delta Star Starter

Star delta star starters allow the motors in the conveyors to start in the STAR mode and then switch to DELTA mode once sufficient speed has been attained in order to continue running at full torque and speed(39). This increases the electrical energy efficiency of the plant by reducing the electrical SEC. The investment required for the measure is around Rs 0.12 Million. The annual savings obtained are Rs. 0.28 Million resulting in a 5 month payback for the investment. Figure 106 shows the different calculations used in the analysis. Figure 105 shows the present value of annual energy savings

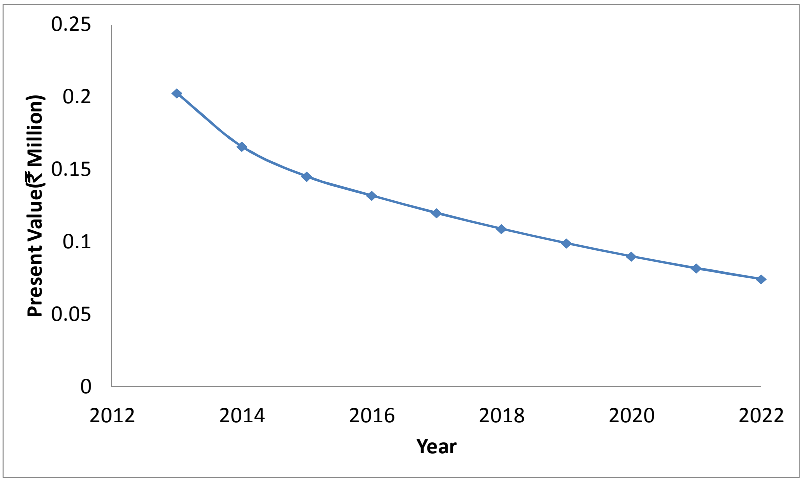


Figure 105. Present value of annual energy savings

Automatic Star Delta Star Starters for Belt Conveyors

All figures in Millions of Indian Rupees

Annual Savings	0.28
Investment	0.12
Discount Rate	10%

Payback	5	months
Life of Equipment	10	years

Income Tax Depreciation

Depreciation Rate - First Year	80%
Depreciation Rate - Second Year	20%

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Income		0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Expenses		-									
EBITDA		0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Book Profit											
Depreciation (Straight Line Method)		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Profit Before Tax (PBT)		0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
IT Profit											
Deprecation (Written Down Value)		0.10	0.02	-	-	-	-	-	-	-	-
PBT		0.18	0.26	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Tax (@Normal rate)	**30.90%**	0.06	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
MAT Credit											
Calculated Tax		0.06	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Tax (@ MAT rate)	**18.00%**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Effective Tax		0.06	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Profit After Tax (PAT)	-0.12	0.22	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

IRR	**178.49%**
NPV	**1.10**

Figure 106. Annual energy savings for the installation of automatic star delta star starter for belt conveyors

Table 46: Consolidated list of EE measures

Measure ID	Measure Undertaken	Payback Period	Net Present Value(NPV)	Internal Rate of Return(IRR)	Investment	Annual Savings
		Months	₹ Millions	%	₹ Millions	₹ Millions
EM1	Coal Mill Ventilation Fan Speed Reduction	1	0.565	1875.646%	0.005	0.13
EM2	Idle Operation of Equipments in Packing	2	3.112	539.922%	0.10	0.75
EM3	Reduce RPM of CF Silo Aeration Blowers by 10%	3	0.385	345.012%	0.02	0.09
EM4	Lower Inlet Suction Pressure Drop in Identified Fans	3	3.498	316.349%	0.20	0.86
EM5	Optimize Ventilation Air Slag Circuit	4	1.074	204.533%	0.10	0.27
EM6	Automatic Star Delta Star Starters for Belt Conveyors	5	1.102	178.494%	0.12	0.28
EM7	Optimization of Blow Hard Fan Power	6	8.371	164.842%	1.00	2.14
EM8	Install New Cooler Vent Fan with Higher Efficiency	7	22.878	152.284%	3.00	5.90
EM9	Increase Grinding Chamber by 0.5 M (by Shifting Diaphragm)	8	2.708	117.452%	0.48	0.72
EM10	Install New Correct Head Fan for ESP Exhaust	10	4.365	94.617%	1.00	1.20
EM11	Optimal Utilization of Compressors - 37 kW compressor with 30 % loading	11	0.214	93.097%	0.05	0.06
EM12	Install Correct size Fan for Coal Mill Vent Fan	13	0.317	72.905%	0.10	0.09
EM13	Improving PF of Generator	13	5.183	78.174%	1.50	1.48
EM14	High level control system for kiln operation	16	9.773	59.466%	4.00	3.00
EM15	Install High Efficiency Fan for Cooler	16	0.977	59.466%	0.40	0.30
EM16	Transport GCT & Kiln ESP dust to Cement mills	16	9.346	57.484%	4.00	2.90
EM17	Improve Overall PF and Reduce MD	18	3.259	54.440%	1.50	1.03
EM18	Installation of High Efficiency fan for Pre-heater fan	22	3.170	43.264%	2.00	1.10
EM19	Install GRR/Variable Fluid Coupling for ESP fan	22	1.072	53.910%	0.50	0.34
EM20	Replace old motors with Energy Efficient Motors	22	4.071	44.092%	2.50	1.40
EM21	Replacement of Inefficient Compressor at Pneumatic Conveyor	24	1.109	39.417%	0.80	0.40
EM22	Transport cooler ESP dust to cement mill outlet (using compressed air)	24	1.370	39.104%	1.00	0.50
EM23	Replacement of the Air - lift with Bucket Elevator for Raw meal transport to the silo	29	5.412	31.821%	5.40	2.24
EM24	Usage of High Efficiency crushers as a pre-grinder before the cement mill	32	33.185	28.314%	40.00	15.00

Summary

Several other energy efficiency measures have been analyzed for different components of a cement plant. NPV, IRR and payback periods have been calculated. Highest investment of Rs. 40 million is indicated on a high efficiency crusher as a pre-grinder before the cement mill. The highest NPV was obtained for high efficiency crusher as a pre-grinder before the cement mill as it offered the highest annual savings. Coal mill ventilation fan speed reduction yielded the lowest payback period (1 month) and the highest IRR. These are depicted in the following figures (Figure 107 - Figure 109) and Table 46.

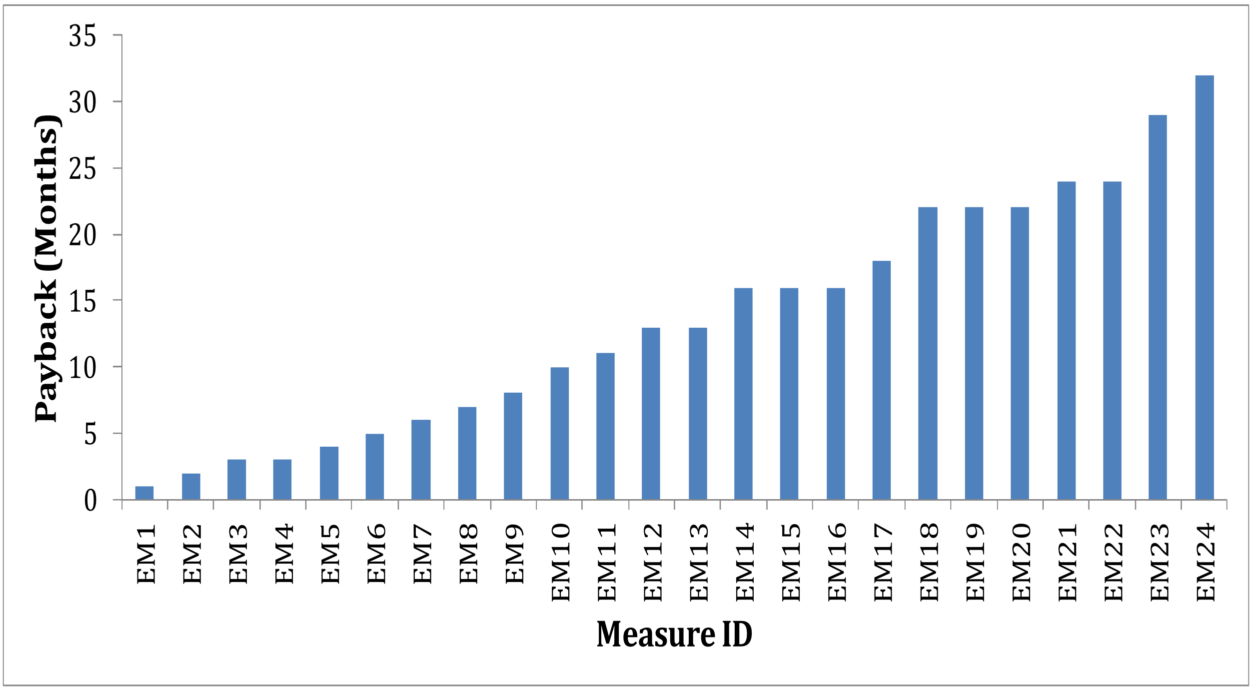


Figure 107. Payback period of different EE measures

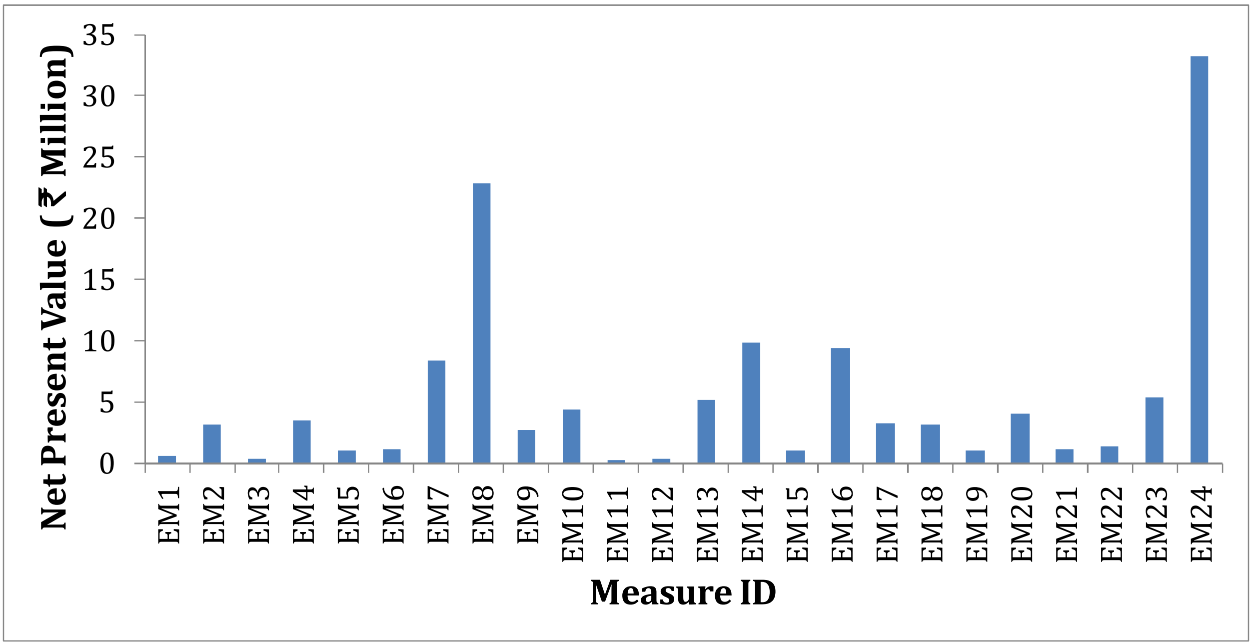


Figure 108. NPV of EE measures

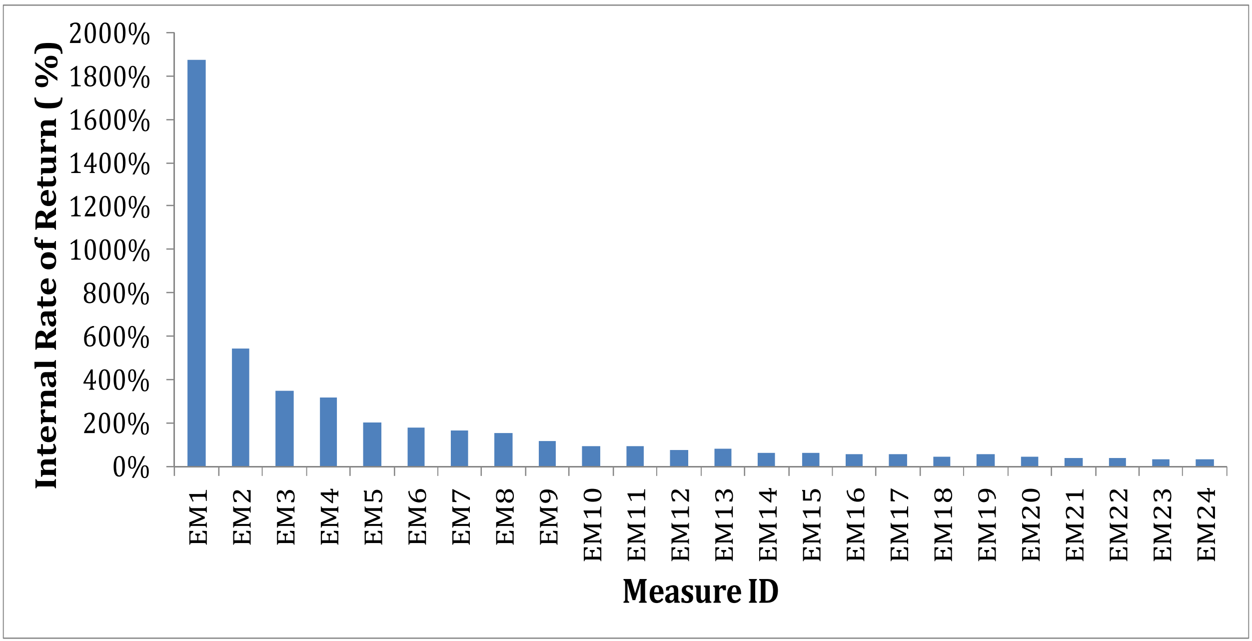


Figure 109. IRR of EE measures

Various case studies involving different EE measures for the different subprocesses are considered here. The executable measures are considered, with their corresponding investment, payback and annual savings. The Internal Rate of Return (IRR) and Net Profit Value (NPV) are calculated.

The financial analysis performed for each measure along with the expected payback offers an approximate validation on possible return. These together with the energy savings (in J or kWh) or SEC reduction potential of each measure offers policy makers a valuable tool to make decisions.

7.7 Technology Databank

The concluding section collates the different EE technologies manufactured by various product or equipment manufacturers. The table below shows the names of the equipment, advantages of the equipment and the corresponding energy rating for one major subprocess. Similarly, several technologies for other subprocesses have been tabulated in Appendix I.

Cement Grinding, Silo and Gears(40)

Name of the equipment	Advantages
Startup Aeration System for powder coolers	Reduces the problem associated with crash stops and plugging
	Minimizes the downtime and avoids costly cleanout delays
	Easy retrofit to existing coolers
Ball Mill UMS, TMS and TUMS	120 mill sizes with capacity ranging from 1000 to 10000 kW
Barring Device	Allows stopping the mill at any position
	Facilitates Mill Servicing, turns the mill at about 2% of normal speed
Controlled Flow Inteverted Silo	SPC is kept low by aerating only two sections at the same time

Controlled Flow Storage Silo	SPC is kept low by aerating silo bottom sector by sector
Hydraulic Roller Press	In high-pressure roller press combinations the feed material is exposed to very high pressure for a short time. The high pressure causes formation of micro cracks in the feed particles and generates a substantial amount of fine material.
OK Vertical Roller Mill	OK vertical roller mills use 30-50% less energy than ball mill systems
	For a typical Cement plant, Ball Mill consumes 37.4 kWh/t of cement. While the roller mill's SPC is 24.5 kWh/t of cement
O-Sepa Separator	Wear protection targets specific abrasion mechanisms for each separator component
	Circulating oil lubrication system promotes exceptional bearing life
Powder Cooler	FLS coolers are available with capacities up to 180 tons material per hour.
	FLS Cylindrical Coolers are ideal for reducing the temperature of the hot pulverized material discharged directly from a mill circuit.
Sepax Separator	Highly effective nibs extraction minimizes clogging of mill grates, thus enabling long-lasting
	Practically eliminated nibs recirculation reduces maintenance work and downtime caused by clogged mill grates.
Symetro Gear Unit	Optimized teeth contact through profile and lead (helix angle) corrections as well as end relief.
	Allows minor settlement of gear and/or mill foundations

8. PAT Focussed Scenario Analysis

The likely scenarios for sample cement plants are studied in this chapter. It is assumed that each plant has a certain baseline SEC and is required to reduce its SEC by a specific percentage. It would be useful for the energy managers, operation personnel and the senior management to have a detailed analysis of the possible scenarios that are likely to occur. These scenarios can be used to better understand the impact of the required SEC reduction in the context of the various choices that are available to a plant. The calculations include an estimation of the amount of energy that a plant is required to have saved in a given period of about three years. It is assumed that a plant may be able to reduce its SEC beyond the given norm or may not be able to reduce its SEC sufficiently in order to achieve the norm. In case a plant exceeds the given norms it would have saved energy beyond what is required while there would be an energy savings shortfall otherwise. In both cases the likely cost of the energy savings or shortfall is estimated based on low-cost and high-cost scenarios.

8.1 Scenario Description

Scenario analyses for selected plants (P1-P9) based on the reduction target percentage are shown. Savings are calculated based on the Baseline (BL) SEC and target SEC. Their corresponding energy savings or shortfalls are computed for two cost scenarios.

Table 47: Baseline data, SEC reduction target and estimated cost

PERFORMANCE ASSESSMENT		P1	P2	P3	P4	P5	P6	P7	P8	P9
Baseline Production - BL Prod	Mt	3.40	1.17	3.66	1.00	5.05	2.74	1.47	3.06	4.28
Baseline Energy - BL Energy	10^6 MkCal	2.65	1.00	5.41	1.11	6.22	0.41	1.01	0.60	6.11
Baseline SEC - BL SEC	kCal/kg eq cement	777.9	860.2	1479.9	1102.3	1231.5	149.5	689.4	195.56	1426.8
SEC Reduction Target	%	-5								
Target SEC	kCal/kg eq cement	739.0	817.2	1405.9	1047.2	1170.0	142.0	654.9	185.78	1355.4

Each scenario is synthesized with the following structure:

- BL Energy: The energy consumed by the plant during the baseline year.
- Actual SEC Reduction Percentage: A set of actual reduction percentage is assumed for every plant: -7,-5,-3, 0, 3 and 5.
- Actual SEC: The actual SEC is computed based on the baseline SEC and the set of actual SEC reduction percentage.
- Actual Energy at BL Production: Actual Energy at BL Production is calculated by multiplying the above calculated Actual SEC and Baseline Production.
$$Actual\ Energy\ at\ BL\ Production = Actual\ SEC \times BL\ Production$$
- Target Energy at BL Production: Target Energy at BL Production is calculated by multiplying the target SEC and Baseline Production.
$$Target\ Energy\ at\ BL\ Production = Target\ SEC \times BL\ Production$$
- Energy saved at BL Production: Energy saved at BL Production is the difference between Actual Energy at BL Production and Baseline Energy
$$Energy\ saved\ at\ BL\ Production = BL\ Energy - Actual\ Energy\ at\ BL\ Production$$
- Energy saved beyond target: The difference between actual energy at BL production and target energy at BL production is calculated as energy saved beyond target.

$$\text{Energy saved beyond Target} = \text{Target Energy at BL Production} - \text{Actual Energy at BL Production}$$

- Low Cost Scenario
  - Savings at BL Production: The savings at BL Production, in rupees, is calculated by multiplying the energy saved at BL Production by low cost assumption of energy price.

$$\text{Savings at BL Production in LC Scenario} = \text{Energy Saved at BL Prod} \times \text{low cost price of energy}$$

  - Savings beyond target: The savings beyond target, in rupees, is calculated by multiplying the energy saved beyond target by low cost assumption of energy price.

$$\text{Savings beyond target in LC Scenario} = \text{Energy Saved beyond target} \times \text{low cost price of energy}$$

- High Cost Scenario
  - Savings at BL Production: The savings at BL Production, in rupees, is calculated by multiplying the energy saved at BL Production by high cost assumption of energy price.

$$\text{Savings at BL Production in HC Scenario} = \text{Energy Saved at BL Prod} \times \text{high cost price of energy}$$

  - Savings beyond target: The savings beyond target, in rupees, is calculated by multiplying the energy saved beyond target by high cost assumption of energy price.

$$\text{Savings beyond target in HC Scenario} = \text{Energy Saved beyond target} \times \text{high cost price of energy}$$

8.2 Results of Scenario Analysis

The results of scenario analysis on the sample plants are shown in this section. The scenarios I-VI imply an actual SEC reduction percentage of -7,-5,-3, 0, 3, 5 respectively. Based on these scenarios the energy saved by a plant when compared to the baseline energy consumption is estimated. In addition the energy saved by a plant beyond the required target SEC at the end of a PAT cycle is estimated. The estimate of the value of the energy savings in monetary terms is done by considering two cost scenarios as described earlier.

The results are shown later in this section and provide a guidance for the implication of different SEC performance of the sample plants at the end of the first PAT cycle. Such analysis would be very helpful to cement plant operators and senior management to make informed decisions regarding the implementation of the various EE measures and options in a specific plant.

It is observed that the various plants save energy compared to the baseline in the scenarios in which the actual SEC is lower than the baseline SEC. However, for a plant to save energy beyond the targeted energy consumption, it is necessary for a plant to decrease its actual SEC lower than the target SEC. Therefore it is observed from the results that there is a shortfall in energy savings beyond the target in both energy and monetary units in scenarios where the actual SEC is higher than the target SEC. Such a shortfall provides an indication of the potential that needs to be exploited by plants in order to achieve maximum benefits under a mechanism such as PAT.

Savings at BL Production under Low Cost Scenario

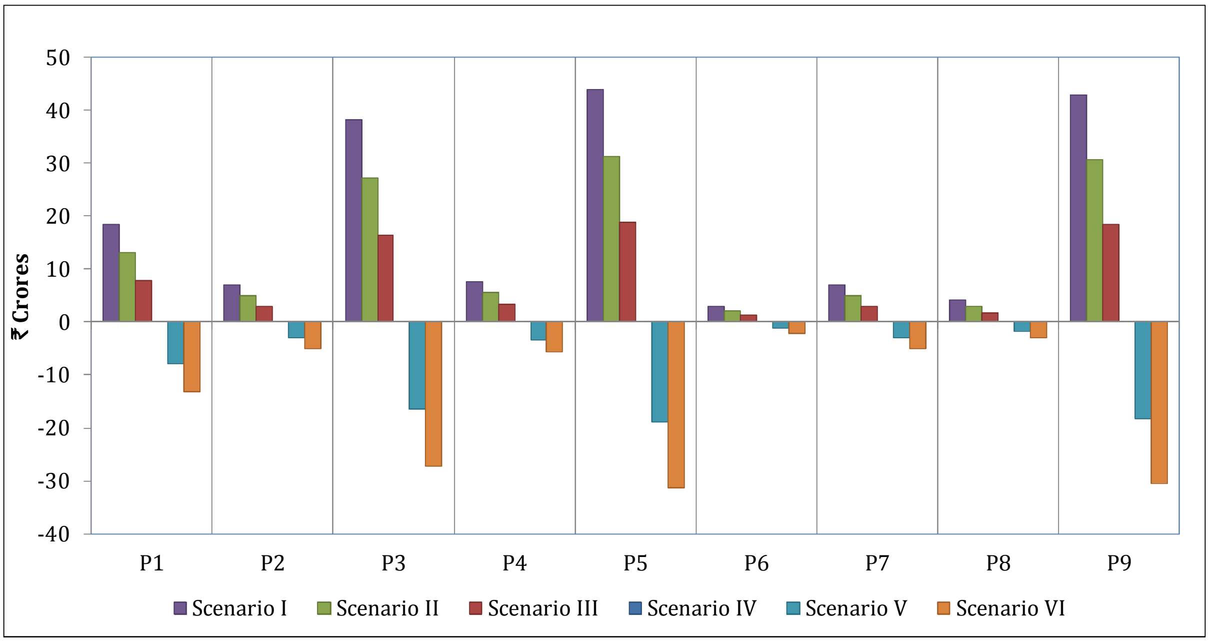


Figure 110. Scenarios based on estimated low cost

Savings at BL Production under High Cost Scenario

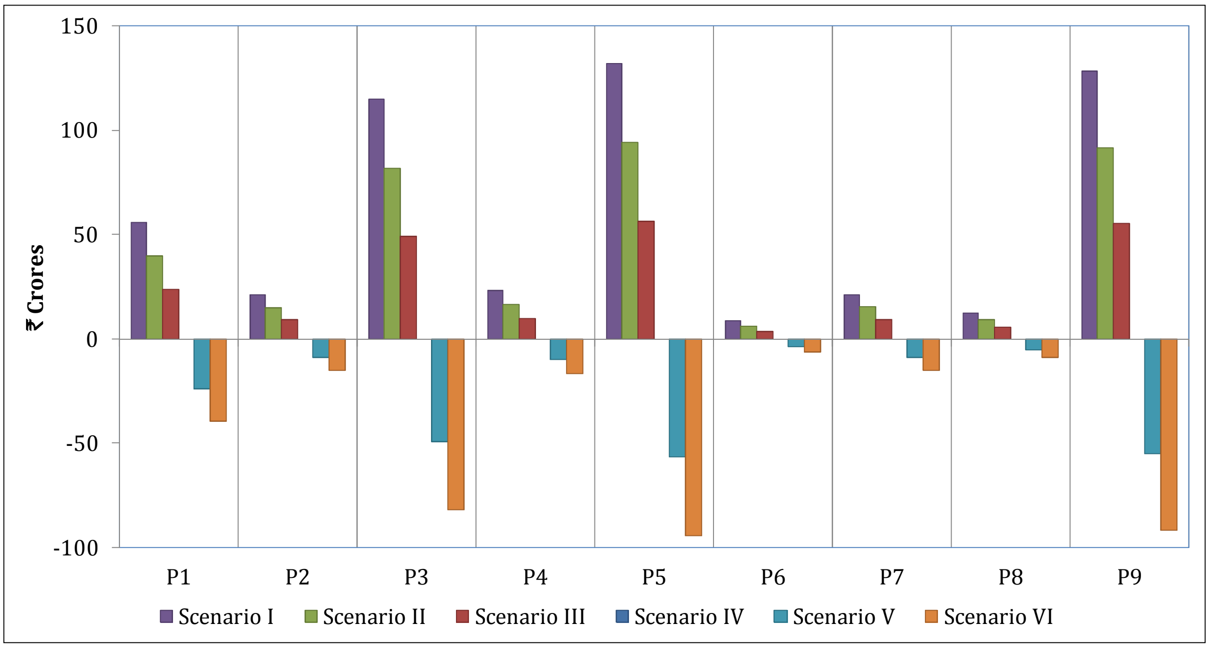


Figure 111. Scenarios based on estimated high cost

Savings beyond target under Low Cost Scenario

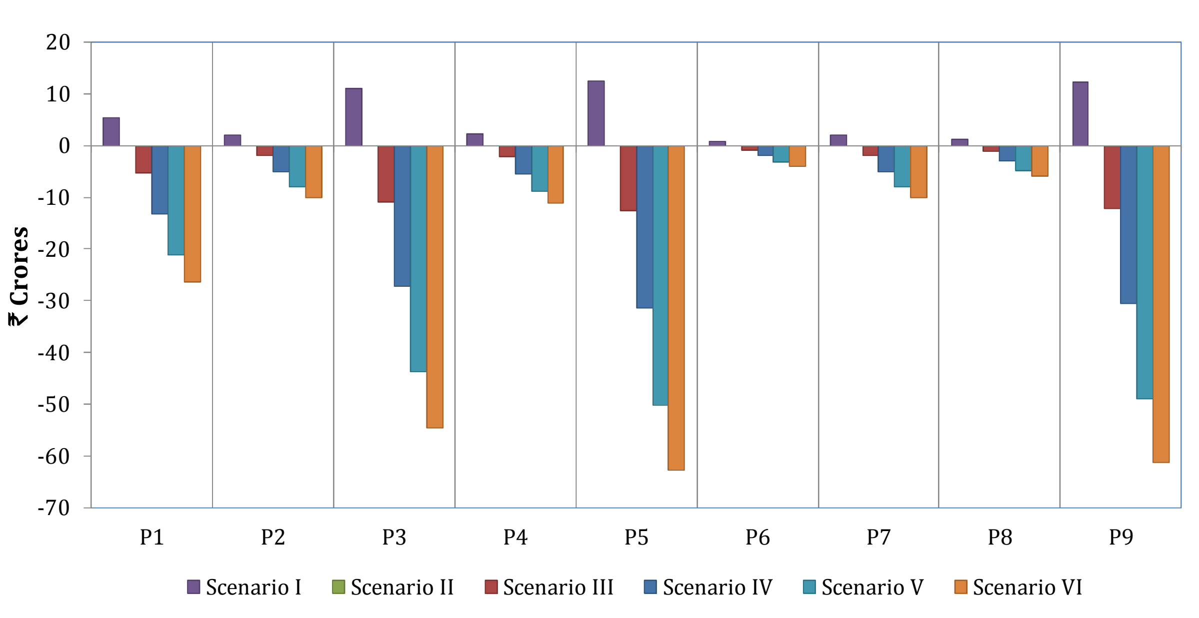


Figure 112: Savings beyond target under low cost scenario

Savings beyond target under High Cost Scenario

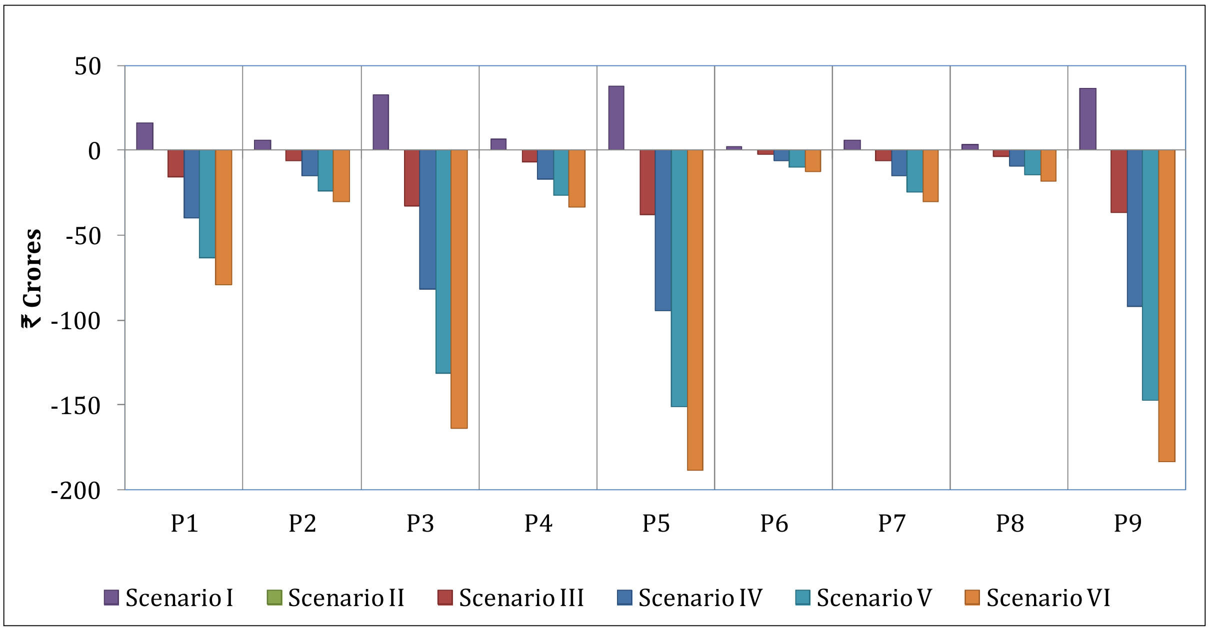


Figure 113: Savings beyond target under high cost scenario

Energy saved at BL Production for different Scenarios

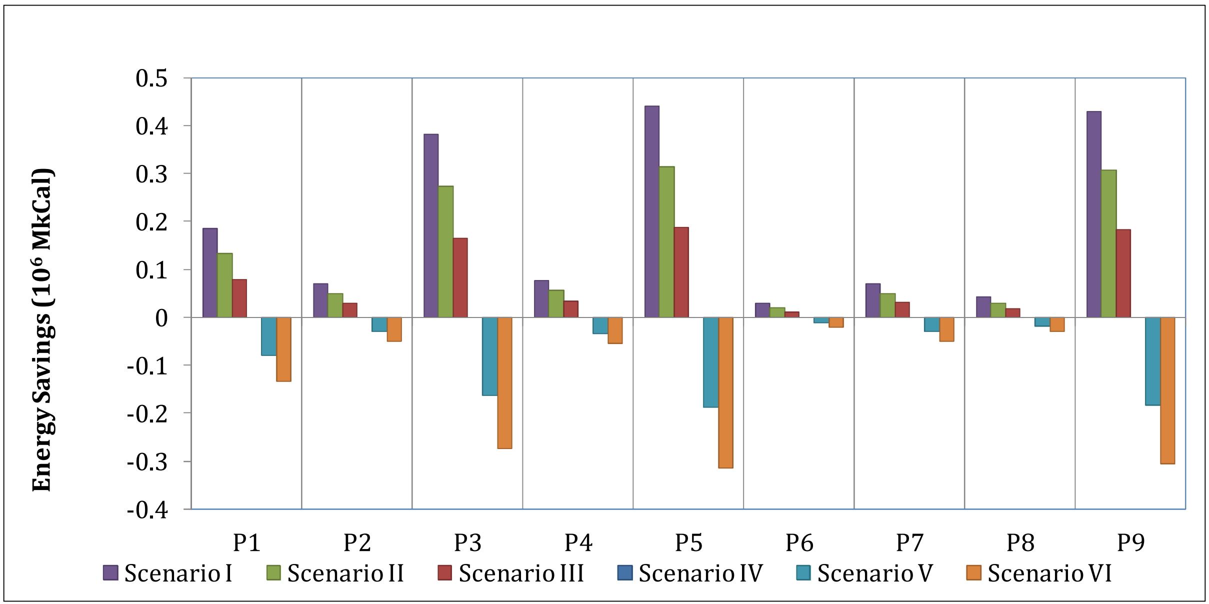


Figure 114: Energy Saved at BL production for various scenarios

Energy saved beyond target for different Scenarios

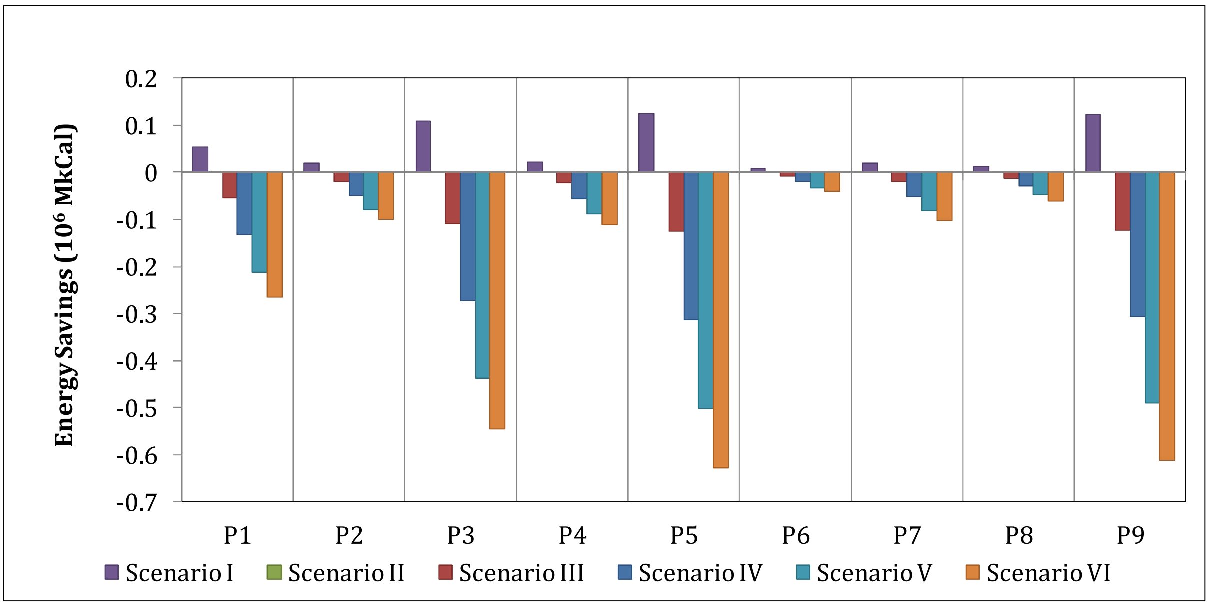


Figure 115: Energy saved beyond target for different Scenarios

8.3 Agent Based Model for PAT

In this section, a preliminary simulation to visualize the behavior of DCs using agent based modeling has been performed. Agents are used to represent plants (DC) and the regulatory authority that sets norms for DCs. Given the technology to upgrade and SEC Reduction (%), the performance of the plant is visualized. The figures used and generated here are illustrative.

8.3.1 Introduction to agent based model

Agent-based computing represents a synthesis both for Artificial Intelligence (AI) and more generally, Computer Science. It has the potential to significantly improve the theory and the practice of modeling, designing, and implementing complex systems. There has been little systematic analysis of what makes an agent such an appealing and powerful conceptual model. Moreover, even less effort has been devoted to exploring the inherent disadvantages that stem from adopting an agent-oriented view (41).

The first step in proposing an agent-oriented approach to software engineering is to precisely identify and define the key concepts of agent-oriented computing. Here the key definitional problem relates to the term "*agent*".

"An agent is an encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet its design objectives"(42)

There are a number of points about this definition that require further explanation. Agents are:

- Clearly identifiable problem solving entities with well-defined boundaries and interfaces;
- Situated (embedded) in a particular environment—they receive inputs related to the state of their environment through sensors and they act on the environment through effectors;
- Designed to fulfill a specific purpose— they have particular objectives (goals) to achieve;
- Autonomous—they have control both over their internal state and over their own behavior;
- Capable of exhibiting flexible problem solving behavior in pursuit of their design objectives—they need to be both reactive (able to respond in a timely fashion to changes that occur in their environment)and proactive (able to opportunistically adopt new goals)

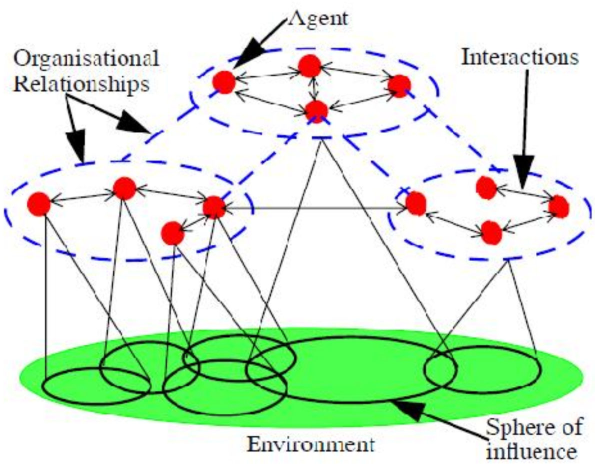


Figure 116. Canonical view of an agent-based system (41)

In most cases, agents act to achieve objectives either on behalf of individuals/companies or as part of some wider problem solving initiative. Thus, when agents interact, there is typically some underpinning organizational context. This context defines the nature of the relationship between the agents e.g. they may be peers working together in a team or one may be the manager of the other agents. In any case, this context influences an agent's behavior. Thus it is important to explicitly represent the relationship. In many cases, relationships are subject to ongoing change: social interaction means existing relationships evolve and new relations are created. Drawing these points together (Figure 116), the essential concepts of agent-based computing are: agents, high level interactions and organizational relationships.

8.3.2 Agent Based Model for PAT

The PAT scheme is basically a market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that could be traded. The preliminary model described in this section helps in understanding the effectiveness of the PAT scheme. The proposed institutional framework to implement the above mechanism is simulated, and will allow the user to study the policies and parameters of the mechanism.

8.3.3 Preliminary Design

The model has five agents of type 'firm' (each firm representing a plant in cement sector) and one agent of type 'policy regulator' (PR). A PR reads a firm's current SEC and sets a target SEC. The model simulates the behavior of a firm for the compliance period (3 years). The Compliance behavior is dependent on parameters such as cost and time of technology up gradation, current capital, firm's investment behavior & target SEC. The PR issues certificates or collects penalties based on difference between targets SEC and achieved SEC reduction.

Objective of the model

The objective of the model is to increase the overall energy efficiency within an industrial sector through certain mechanisms, which will incentivize the firms within that sector to upgrade their technology, thereby improving their energy efficiency. The objective of each firm within this model is to meet a Specified Energy Consumption (SEC) target within a given time period, failing which it is penalized. If a firm exceeds the SEC, it benefits by receiving Energy Saving Certificates (ESCs) which it can either trade with other firms or save for future use. A firm failing to meet the SEC can both buy ESCs from another firm, and use those certificates to lessen the penalty which it has to pay or pay penalty only. Firms can keep paying penalty or buying ESCs, but the design of this model has to ensure that it is beneficial for a firm to upgrade their technology and exceed the SEC target reduction rather than pay a penalty.

Model Architecture

The model has several agents which simulates the real entities like firms in the industrial sector and PR. Each agent has a given set of attributes and behaviours, and each agent reacts to certain situation according to the behaviour. Simulation shows the interaction between different agents at different points of time in the graphs that follow and in the end shows the cumulative result in the form of tables. The figure below shows the architectural diagram of the model. The different agents and their parameters are described below:

Firm

Each firm is represented by an agent in the system. Firms have a number of attributes,

- **Name:** Name of the plant.
- **Production Capacity (Maximum Value):** This indicates the maximum amount which a firm can produce, based on its technology and currency. Every firm produces some percentage (depending upon capacity utilization) of maximum amount that it can, irrespective of the number of orders, raw material etc. The supply chain within the industrial sector has not been modelled.
- **Capacity Utilization:** This value indicates what percentage of maximum capacity a firm can produce.
- **Capital**: The amount of operating capital which a firm has, it includes all inflows and outflows of cash.

- **Current SEC:** Current specific energy consumption of the firm.
- **Target SEC**: Firm specific targets set by the monitoring agency (PR).
- **ESCerts**: Number of energy savings certificates held by firm at any given time.
- **Possible Technology Up gradations**: List of technology options available with a firm for reducing SEC. It includes other details such as cost of technology, time to upgrade, amount of reduction in energy achieved etc.

Policy Regulator (PR)

PR is represented by an agent in the system. PR has mainly two behaviours:

- **Calculate target SEC:** This behaviour is to set target SECs for individual firms based on their current SECs.
- **Calculate penalty**: This behaviour is to calculate penalty at the end of the compliance period, based on the amount of energy savings shortfall.

Goal Planning

Agent PR reads the current SEC of each firm and based on its saving potential it sets a target SEC. At present the target is set as a percentage (3% to 5%) of the initial SEC.

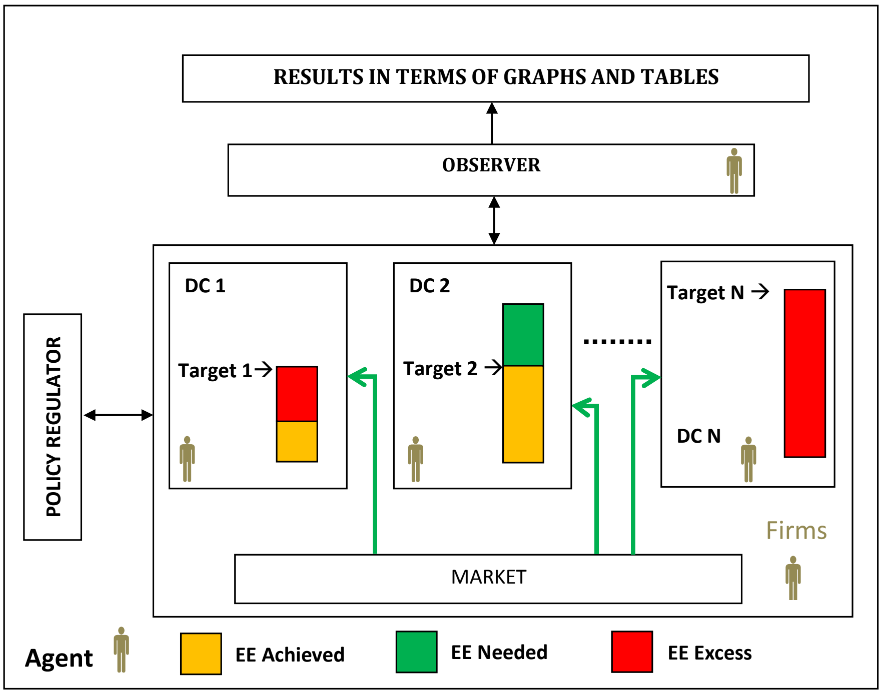


Figure 117. Agent based model architecture diagram

Compliance Behaviour

Each firm agent behaves differently during the compliance period. Based on certain criteria such as current capital, cost of up gradation to new technology, time required upgrading to new technology; a firm plans its strategy. Based on the strategy decided by any firm, compliance behaviour is bound to fall into one of the following categories:

- A firm decides to upgrade to a new technology in the first year of compliance period.
- A firm decides to upgrade to a new technology in the second year of compliance period.
- A firm decides to upgrade to a new technology in the third year of compliance period.
- A firm takes no energy efficiency measures and decides to pay penalty.

Penalty & Trading

A firm may be penalised or benefited in terms of ESCs on the basis of the amount of energy saved. The amount of energy saved can either be equal, less than or greater than the amount of energy savings expected from an individual firm. Depending on the condition, the authorized body will take respective action:

- **Achieved SEC = target SEC**: Firms which come under such cases are exempted from paying penalty. At the same time no ESCs will be issued to them.
- **Achieved SEC < target SEC:** Firms coming under this category will be awarded with ESCs which can further be used for trading or for meeting energy saving targets in next compliance period.
- **Achieved SEC > target SEC:** Firms which are not able to achieve their target but are successful in taking some measures towards energy efficiency come under this category. They have two options available with them:
    - Buy certificates to meet their targets
    - Pay a penalty for the amount of energy savings shortfall.

Scope & limitation

The current model is implemented for five firms but can be increased up to 500. The trading of certificates is not yet implemented. The term 'capital' used in the simulation is ambiguous. The extent of inclusion of this term needs to be explicitly mentioned. At present, the graph does not display the behaviour of the agent if there are no feasible technological options available to upgrade.

8.3.4 Case studies

Case Study 1
In this case, three dry plants are used along with two wet plants. The available technology to upgrade for dry plants would be dry+6ph, while the wet process can be upgraded to dry process.

Firm Name	kCal/kg cement	% decrease required	Production(t)	Technology
Plant-1	700	3	500000	Dry
Plant-2	850	3.7	1000000	Dry
Plant-3	900	4.2	1500000	Dry
Plant-4	1000	3.1	2000000	Wet
Plant-5	1100	5.0	2500000	Wet

Case Study 2
Two wet and dry plants are used in this case study. As discussed above, a dry unit can upgrade themselves to dry+6ph and wet can be upgraded to dry. Plants that employ dry+6ph technology could not upgrade since we have not considered any other better technologies for them. The intent behind this assumption is to visualize the performance of a plant that does not upgrade. This behavior can be observed in the dashboard in which Plant-2 does not perform, unlike other plants that decrease their specific energy consumption over a period of time.

Firm Name	kCal/kg cement	% decrease required	Production(t)	Technology
Plant-1	750	3	500000	Dry
Plant-2	900	3.5	1000000	Dry +6PH
Plant-3	1050	5	1300000	Wet
Plant-4	850	4.5	750000	Dry
Plant-5	1200	4.3	1200000	Wet

Case Study 3

Firm Name	kCal/kg Cement	% decrease required	Production(t)	Technology
Plant-1	800	3.4	600000	Dry +6PH
Plant-2	950	3.8	1000000	Dry
Plant-3	1100	4.8	2100000	Wet
Plant-4	1210	5	1000000	Wet
Plant-5	860	3.9	800000	Dry

Case Study 4

Firm Name	kCal/kg Cement	% decrease required	Production(t)	Technology
Plant-1	1100	4.75	1200000	Dry
Plant-2	1250	4.98	1500000	Wet
Plant-3	980	3.87	2100000	Dry
Plant-4	870	3.25	1800000	Dry+6PH
Plant-5	1020	4.3	950000	Dry

Case Study 5

Firm Name	kCal/kg Cement	% decrease required	Production(t)	Technology
Plant-1	950	3.85	1850000	Dry
Plant-2	980	4.15	1250000	Dry
Plant-3	1250	4.85	2500000	Wet
Plant-4	1100	4.35	2900000	Wet
Plant-5	890	3.75	1200000	Dry+6PH

Figure 118 shows the behaviour of Case 1 in the model with time and how parameters like production, SEC, and target SEC vary over time in the PAT cycle. The model also shows how the likely investments along with the production and SEC vary over the duration of the PAT cycle.

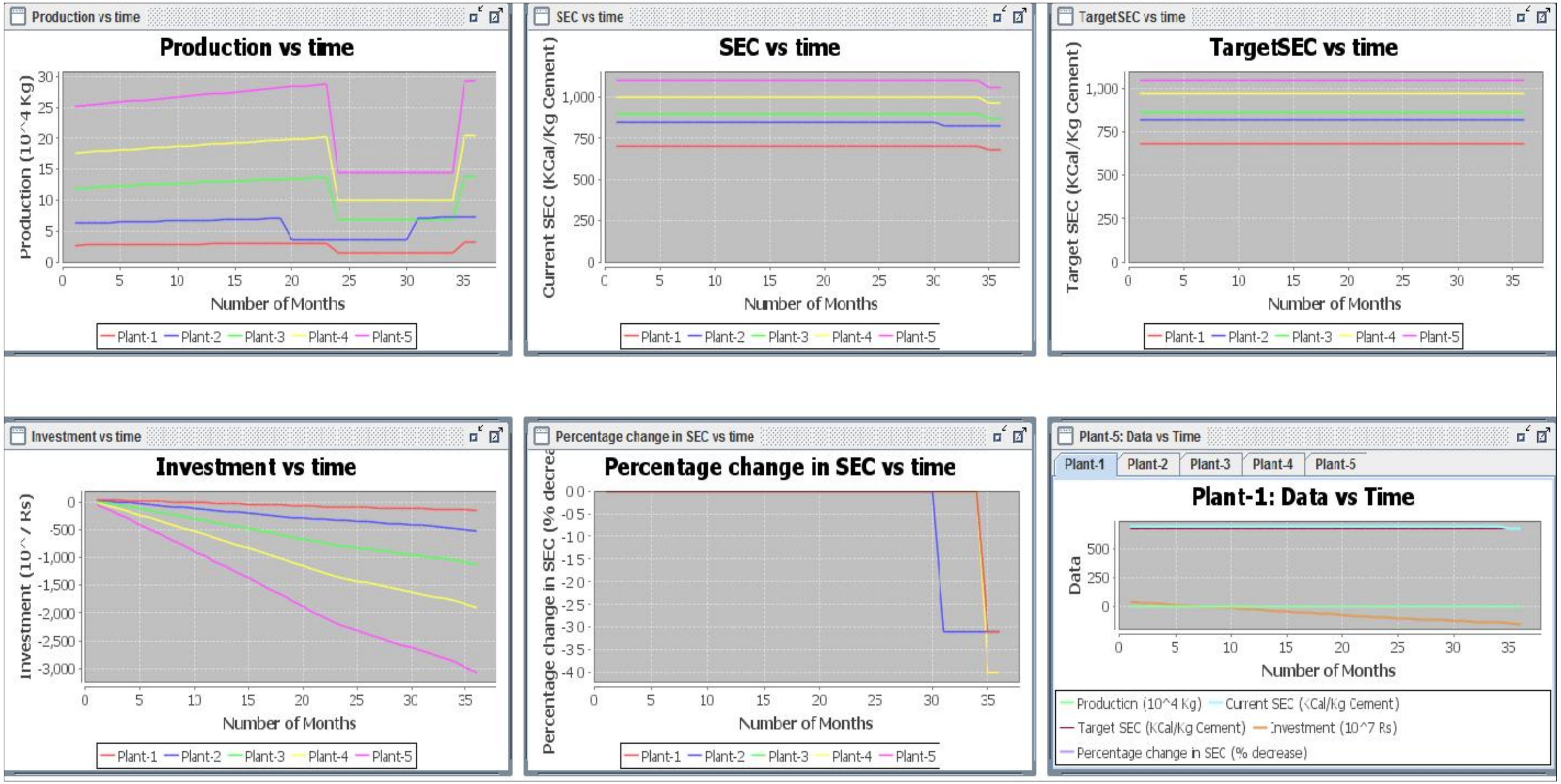


Figure 118. Behavior of agents during a three year period

9. Eco-Friendly Cements

This section of the report deals with cleaner varieties of cement being innovated in the niche markets. One tonne of cement production leads to about 0.84 tonnes of CO_2 being emitted into the atmosphere. Therefore efforts should not only be made to reduce energy consumption but also to reduce GHG emissions to the maximum possible extent. Extensive research is being carried out all over the world and brief descriptions of some of the important developments are described in this chapter.

9.1 Green cement

Alinite Cement

Based on the chemistry of alinite, researchers at the Tata Research Development and Design Center (TRDDC), Pune, have successfully developed processes for converting a wide variety of fly ash and other mineral, industrial and municipal waste materials into a new class of hydraulic setting alinite (43). Large quantities of solid waste, some of which are toxic, hazardous and/or voluminous are generated during the extraction of metals and materials from minerals. The prodigious rate of generation of solid waste cannot be sustained indefinitely unless technologically sound and economically viable ways and means are found to manage them. Due to high rates of consumption, building materials are perhaps the most attractive option for recycling and utilization. The practice of blending fly-ash and blast furnace slag in cement production is used worldwide and extensively in different grades of pozzolana cements. Also mining wastes and fly-ash are routinely used in the production of bricks, building blocks, filters, aggregates, glass ceramics and zeolites (43).

It is evident that a preferred solid waste management strategy should be based on a benign technology solution that has low energy consumption and minimal environmental impact for producing a value added product for mass consumption. It turns out that a class of hydraulic setting cements could meet these stipulations.

Noudelman et al. (44) showed that the alinite phase belongs to CaO-SiO_2-MgO-Al_2O_3-$CaCl_2$ system. The characteristic feature of alinite is that oxygen ions are partially substituted by chlorine and silica is substituted by alumina. This is similar to alite - the well-known di-calcium silicate C2S phase of Portland cement.

The following three studies were carried out:

- Alinite cement was made from fly-ash obtained from captive power plants and steel plant wastes which comprised of limestone fines, mill scales (Fe_2O_3) and magnesite ($MgCO_3$) dust.
- Utilization of tailings from gold ore processing plants with low grade limestone available locally along with calcium chloride as a flux. The alinite cement produced in this way proved to be an excellent substitute for Portland cement.
- Alinite cement was also produced from chlorine rich municipal incinerator fly ash and bottom ash with lime stone and siliceous gravel ore as a source of silica.

In all three cases, significantly lower temperatures of the order of 1150^{o}C are sufficient to achieve the desired proportion of alinite phase in the final product, as compared to the temperature of about 1450^{o}C required in the manufacturing of OPC. Incorporation of gypsum during clinker grinding invariably has a beneficial effect on the quality of cement produced. The alinite technology offers a considerable potential for energy savings, both at the clinkering stage (because of lower temperature employed) and at the grinding stage (due to highly friable nature of the alinite clinker). Table 48 shows a comparison of Portland cement with alinite cement. The alinite cement proved better with respect to lime index and compressive strength when compared to OPC (experiments over 3, 7 and 28 days). Blaine of the alinite cement was 2 times better than OPCs. The estimated saving is expected to be around 50-80% in electrical and 30-60% savings in thermal energy consumption.

Table 48: Comparison of OPC with alinite cement (43)

Material	Ordinary Portland Cement	Alinite cement with Fly Ash	Alinite cement with Tailings	Alinite cement with Municipal Incinerator ash
Composition (by % wt)				
CaO	62-67	45-55	55-60	60.5
SiO_2	18-24	13-19	18-21	17.8
Al_2O_3	4-8	9-12	2-5	2.3
Fe_2O_3	0.5-4	1-10	4-6	2.9
MgO	1.5-4.5	4-10	4-7	2
$CaCl_2$	-	6-18	4-9	8.6
Gypsum (by % wt)	5	8	8	8
Calcareous component (by % wt)	75-90	60-70	72-73	65
Raw materials	Limestone and clay	Fly ash, limestone, mill scale magnesite dust and calcium	Tailings, sand, limestone and calcium chloride	Incinerator fly ash and bottle mash, limestone, calcium chloride
Lime saturation factor	0.66-1.02	~0.7	~0.7	~0.7
Lime index	>2	1.5-2.0	1.5-2.0	2.7
Clinkering temperature °C	1400-1500	1100-1200	1100-1200	1100-1200
Major Phases	C3S, C2S, C3A, C4AF	Alinite Alite , C3S	Alinite Alite , C4AF	Alinite , C11A7$CaCl_2$C2S
Blaine cm^2/g	2000-3200	4000-7000	4000-7000	6000
Compressive strength kg/cm^2				
3 days	>160	145-420	100-260	207
7 days	>220	200-475	160-330	263
28 days	>330	300-500	235-450	402
Energy Consumption				
Electrical kWh/t cement	110-135	Estimated savings 50-80%		
Thermal kCal/t clinker	800-1100	Estimated savings 30-60%		

Novacem Cement

Novacem, UK, has manufactured a cement using magnesium oxide that emits less carbon di-oxide during its production. This has evoked interest among those exploring low carbon production options in the cement industry.

Novacem cement is considered to be carbon negative in that more carbon dioxide (CO_2) is absorbed than emitted. The cement is based on magnesium oxide (MgO) and hydrated magnesium carbonates. The production process uses accelerated carbonization of magnesium silicates. The carbonate produced is heated at low temperatures (700 °C) (45).This allows the use of fuels with low energy content or carbon intensity (i.e. biomass), thus further reducing carbon emissions. The production of 1 tonne of Novacem cement absorbs up to 100 kg more CO_2 than it emits, making it a carbon negative product. Table 49 highlights the difference between OPC and Novacem cements.

Table 49: Comparison between OPC and Novacem cement

Ordinary Portland Cement	Novacem
Carbonate feedstock (Mining and Processing Limestone. (400kg of CO_2 released from limestone per tonne of cement	Non-Carbonate feedstock
High temperature process (1450^{o}C) requires fossil fuels.	Lower temperature process (700^{o}C), can better utilise biomass fuel. 0-420kg CO_2 /t cement is released depending on fuel mix used and choice of feedstock.
No absorption of CO_2.	Cement composition includes a carbonate created during production process by absorbing CO_2. 30-100 kg CO_2 absorbed per tonne of cement.
Total emissions: +800kg CO_2/t cement	**Total emissions: -100kg to +320kg CO_2/t cement**

Magnesium Based Cement

Magnesium based cement requires less energy for production and does not emit as much CO_2 as compared to Portland cement manufacturing. The phosphates typically used to combine with the magnesium can be sourced from animal wastes or fermented plants. These cements develop considerably greater compressive and tensile strengths as compared to Portland cement. Another advantage of magnesium-based cements is that they have a natural affinity for cellulosic materials, such as plant fibers or wood chips. Portland cement repels cellulose. Therefore, utilization of wood chips serves to achieve lighter weight and better insulative properties.

MgO when combined with clay and cellulose creates cements that breathe water vapor. Hence the product never rots, as it can expel moisture. MgO cements do not conduct electricity, nor absorb or emit heat/coldness, and hence are used as tiles of radar stations and hospital operating rooms.

'AirKrete' is a natural MgO mineral-based blown-in insulation that combines the advantages of MgO cement with aeration and spray in place. It is non-toxic, resists mold growth even in high humidity, fire proof and sound proof, re-absorbs CO_2 as it cures, has an R-value of 3.9 per inch and does not shrink as it dries.

Magnesium oxide is also available from several other sources. These recipes require either liquid fertilizer or special brine "reactors" to harden into concrete and are especially useful for binding, non-load-bearing straw/clay and woodchip/clay mixes for building construction (46).

CALERA Cement

Ocean chemistry involves the gradual absorption and mineralization of carbon. Over time, vast amounts of CO_2 are naturally absorbed into the oceans and converted into stable minerals, such as limestone. Calera's technology is based on these processes. Both the conversion of CO_2 into bicarbonate and the subsequent conversion of bicarbonate to carbonate occur more rapidly in solutions with high pH. Hence maintenance of a high pH environment is important to Calera's process

The technology focuses increasing the speed and scale of gas absorption in the solution and then increasing the speed and scale of conversion into minerals so that large volumes of gas can be continuously captured.

Process
CALERA process uses technology associated with carbon capture and its conversion to stable solid minerals. The process known as Mineralization via Aqueous Precipitation (MAP) involves contacting gas from the power plant with water. A process diagram highlighting the working principle of CALERA is shown in Figure 119. The water chemistry is controlled such that the carbon dioxide in the power plant gas is absorbed in water and reacts to form solid mineral carbonates and bicarbonates. This is the key step in the MAP process i.e. the conversion of carbon dioxide (CO_2) to carbonate (CO_3) and binding it to minerals such as calcium and magnesium. The water contains carbon dioxide that would have been emitted into the air. These materials produced us removed from the water and processed to produce high reactive cement (47).

The outputs of the process are clean air, fresh water and solid materials that can be sold as an aggregate or Supplementary Cementitious Material (SCM) like fly-ash or blast furnace slag. The process also captures other emissions, including sulfur dioxide, particulate matter, mercury and other metals. The schematic diagram Figure 119 shows the CALERA process to convert CO_2 to carbonates (48).

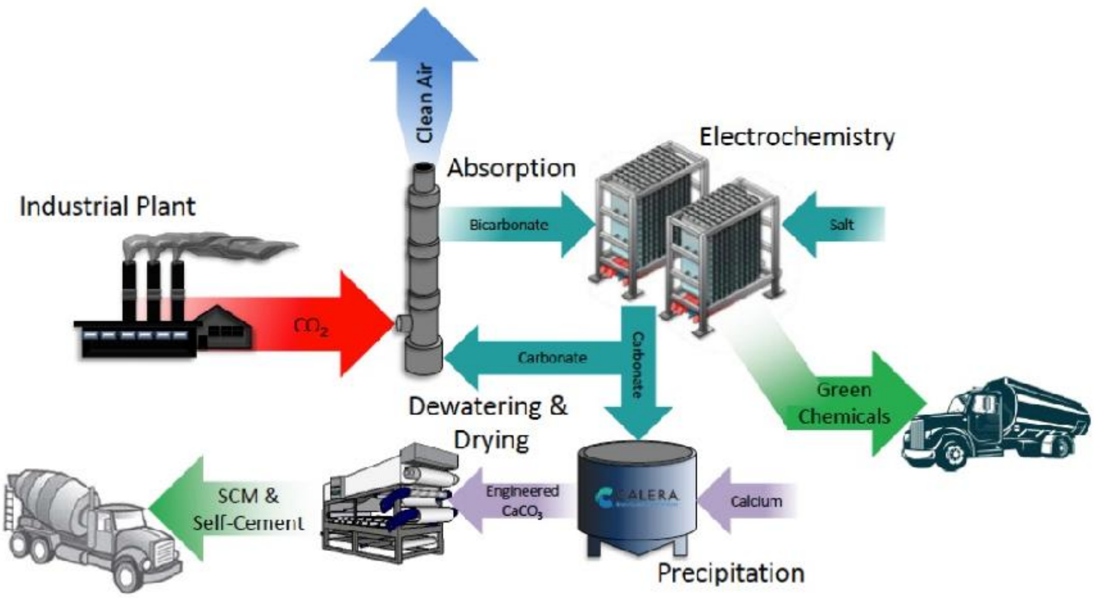


Figure 119. Schematic diagram of CALERA process

Calix Technology
Calix technology uses Catalytic Flash Calcination (CFC) reactor to heat a mineral within seconds and change its chemical properties. The calcined minerals may include dolomite, magnetite, kaolin, bauxite or limestone. The process is illustrated in Figure 120. The ground dolomite feedstock is injected into the calciner tube (in blue) by a stream of superheated steam. The dolomite solids are centrifuged onto the hot walls of the heat chamber (orange).

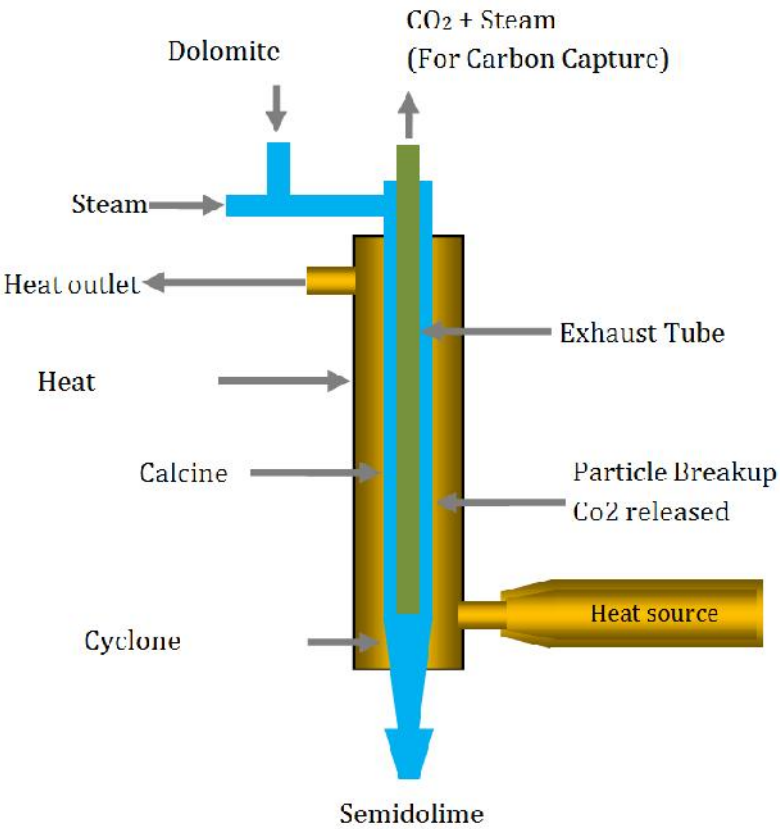


Figure 120. Calciner System for Semidolime Production

The steam breaks-up the particles and leads to the calcination reaction. The thermal energy used in the process is extracted from the walls of the calciner tube, heated by an external heat source. The process solids are separated with the aid of an industrial cyclone separator. The residue primarily comprises of semidolime (which can replace cement using calcined dolomite) which is directed onto the cyclone wall by the centrifugal action. The final product is then collected from the base of the reactor. The gas, comprising of CO_2 and steam, is ejected from the cyclone by forming a counter-circulating vortex which rises upwards through the exhaust tube and can be captured for sequestration or re-utilization. The process produces less CO_2 emissions and semidolime can be used as a good binding agent (49).

9.2 Standards in Cement Industry

9.2.1 BIS Standards for Cements

BIS standards for the OPC 53, PPC 33 and PSC 33 grade cements are given in Table 50-90, respectively. OPC 53 grade cement has the highest compressive strength of 53 MPa after 28 days of curing time.

Table 50: BIS standards for OPC 53 (9)

Particulars	BIS specification
Fineness (m^2/kg)	Minimum 225
Soundness	
Le Chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.27.0
7 days	Min.37.0
28 days	Min. 53.0

Table 51: BIS standards for PPC 33 (9)

Particulars	BIS specification
Fineness (m^2/kg)	Minimum 300
% Fly ash in PPC	15-35
Soundness	
Le Chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.16.0
7 days	Min.22.0
28 days	Min. 33.0

Table 52: BIS standards for PSC 33 (9)

Particulars	BIS specification
Fineness (m^2/kg)	Minimum 300
% Slag in PSC	25-65
Soundness	
Le Chatelier expansion (mm)	Max. 10
Auto-clave expansion (%)	Max. 0.8
Setting Time (Mins)	
Initial	Minimum 30
Final	Max. 600
Compressive Strength (MPa)	
3 days	Min.16.0
7 days	Min.22.0
28 days	Min. 33.0

9.3 Emissions Intensity

The emissions during cement manufacturing can be classified into fugitive emissions and stack emissions. According to United States' Environmental Protection Agency (US-EPA), fugitive emissions are any solid particulate matter that becomes airborne by natural or man-made activities, excluding particulate matter emitted from an exhaust stack (which is referred as stack emission) (50). The fugitive emissions are further sub-divided into primary, secondary and tertiary emissions based on generation.

The different points of emission in cement manufacturing are shown in Figure 122 (51). The numbers highlighted in red are fugitive emissions. Stack emissions are marked by numbers in violet color. The figure also shows the processes along with the types of emissions.

According to CMA, the industry emitted 152 Mt of CO_2 eq. in 2007. This corresponded to 6.8% of the total emissions in India and 32% of all the industrial sectors' emissions.

In 2000, approximately 99 Mt of CO_2 eq. was emitted by the industry. The Compound Annual Growth Rate (CAGR) of CO_2 eq. emissions was 6.4%. Figure 121 describes the trend. The specific emission of the industry has been decreasing from 0.96 to 0.89 t CO_2 eq./t cement resulting in a CAGR of -1.2%.

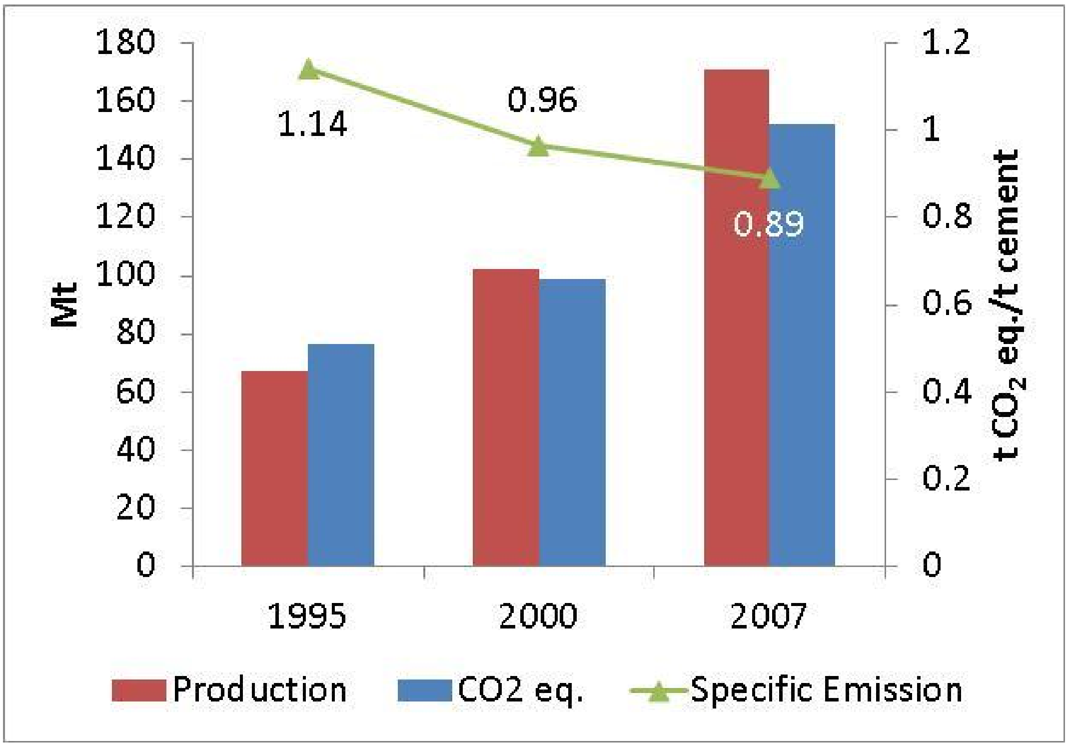
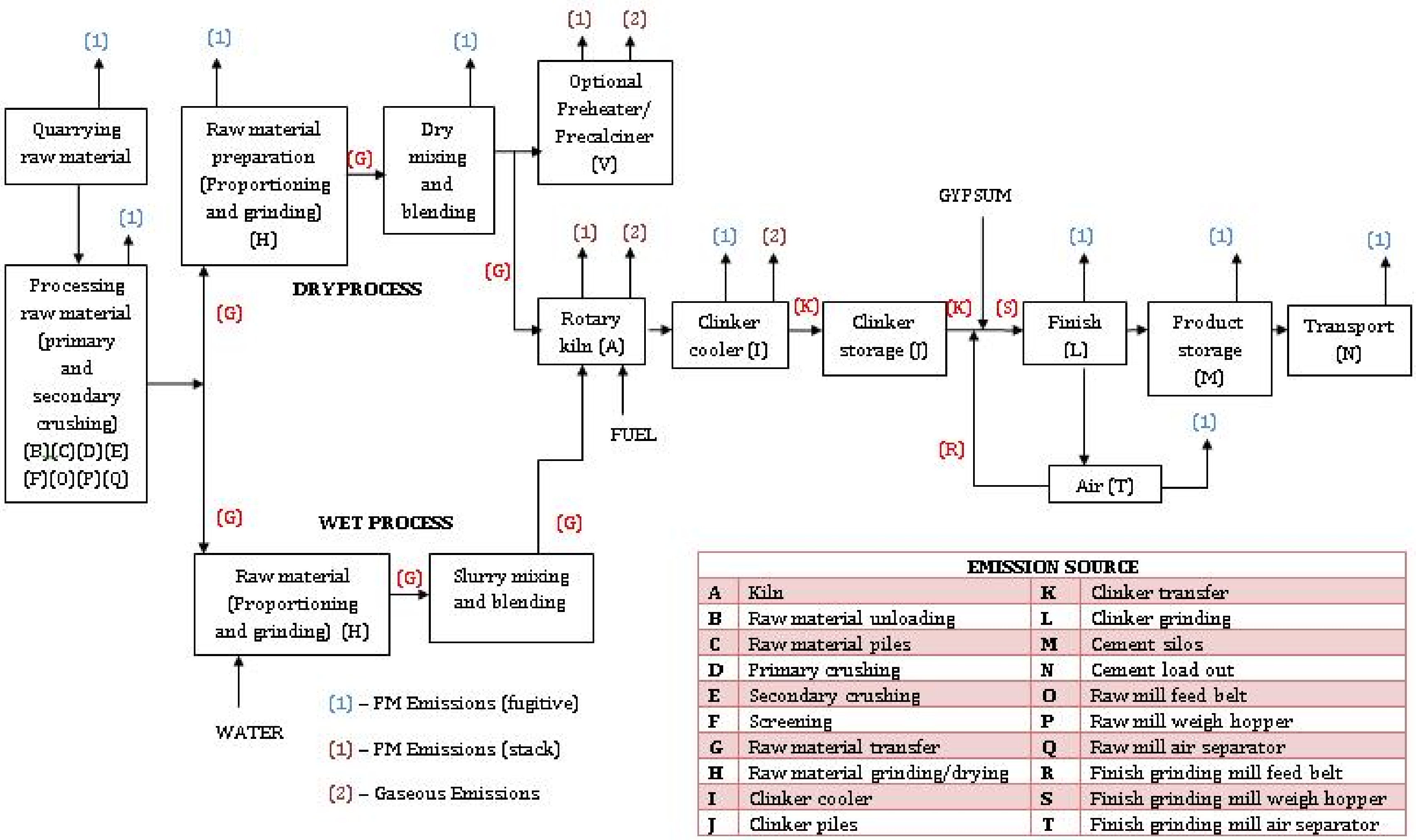


Figure 121. Specific emission intensity of cement sector



EMISSION SOURCE			
A	Kiln	K	Clinker transfer
B	Raw material unloading	L	Clinker grinding
C	Raw material piles	M	Cement silos
D	Primary crushing	N	Cement load out
E	Secondary crushing	O	Raw mill feed belt
F	Screening	P	Raw mill weigh hopper
G	Raw material transfer	Q	Raw mill air separator
H	Raw material grinding/drying	R	Finish grinding mill feed belt
I	Clinker cooler	S	Finish grinding mill weigh hopper
J	Clinker piles	T	Finish grinding mill air separator

Figure 122. Process flow diagram of cement manufacturing showing emission points

9.3.1 CO_2 Emission from Sample Plants

This section presents the result of the study of the CO_2 emissions for the nine sample plants. The emissions from the plants are classified from four sources as follows:

1. Grid Electricity
2. Raw Material (Calcination)
3. Captive Electricity Generation
4. Process Heat

Emission from Grid Electricity – Total electricity consumed by the plant from the grid is used to calculate the emission from grid electricity. A grid emission factor of 0.82t CO_2/MWh has been assumed (52). Emission from the grid electricity is given by:

$$Total\ electricity\ consumed\ from\ the\ grid\ (MWh)\ \times 0.82\ (\frac{tCO_2}{MWh})$$

Emission from Raw Material (Calcination) – A plant requires about 1.5 tonnes of raw material to produce one tonne of clinker (53). From the total clinker produced by each plant, this study estimates the amount of limestone utilized. Calcium carbonate, in pyro-processing, is reduced to calcium oxide and carbon dioxide. One kg of calcium carbonate is reduced to 0.56 kg of calcium oxide and 0.44 kg of carbon di-oxide(54). The total emission from raw material is calculated as follows:

$$Total\ limestone\ utilized\ (tonnes)\ \times 0.44$$

Emission from Electricity Generation– Most of the cement plants have captive power plants. These are either Diesel Generator (DG) sets or coal based steam turbine plants. The emission factors of diesel and coal are 74.1 and 95.81 t CO_2/TJ respectively (1).

$$Emission\ from\ Electricity\ Generated\ by\ DG\ sets\ (Tonnes\ of\ CO_2) \\ = Total\ Electricity\ Generated\ (TJ)\ \times 74.1\ (tonne\ of\ CO_2/TJ)$$

$$Emission\ from\ Electricity\ Generated\ by\ Steam\ Turbine\ plant\ (Tonnes\ of\ CO_2) \\ = Total\ Electricity\ Generated\ (TJ)\ \times 95.81\ (tonnes\ of\ CO_2/TJ)$$

Emission from Process heat– Most plants use three types of fuel viz. solid, liquid and gaseous. Solid fuel sources are Indian coal, imported coal, lignite and biomass. Other purchased solid fuels include baggase, rice husk etc. Liquid fuels include furnace oil, Low sulphur heavy stock and high sulphur heavy stock. High Speed Diesel (HSD) and Light Diesel Oil (LDO) are some other types of fuel used for process heating.

Thus total emissions from the four sources are as follows:

$$\begin{aligned} Total\ Emission(Tonnes\ of\ CO_2) \\ &= Emission\ from\ Grid\ Electricity \\ &+ Emission\ from\ Raw\ Material\ Calcination\ + Emission\ from\ DG\ sets \\ &+ Emission\ from\ Steam\ Turbine\ Plants\ + Emission\ from\ Indian\ Coal \\ &+ Emission\ from\ Imported\ Coal\ + Emission\ from\ Furnace\ Oil \\ &+ Emission\ from\ High\ Speed\ Diesel\ + Emission\ from\ Light\ Diesel\ Oil \end{aligned}$$

Specific emission is calculated by dividing the total emission of the plant by its corresponding cement production. The emission intensity for the sample plants is depicted in Figure 123. It is observed that Plant 9 (wet process) has the highest specific emission.

The emission intensities of the grinding units are 0.046 and 0.059 kgCO_2/kg cement, while the emission intensity range of integrated cement plants is from 0.666 to 1.155 kgCO_2/kg cement.

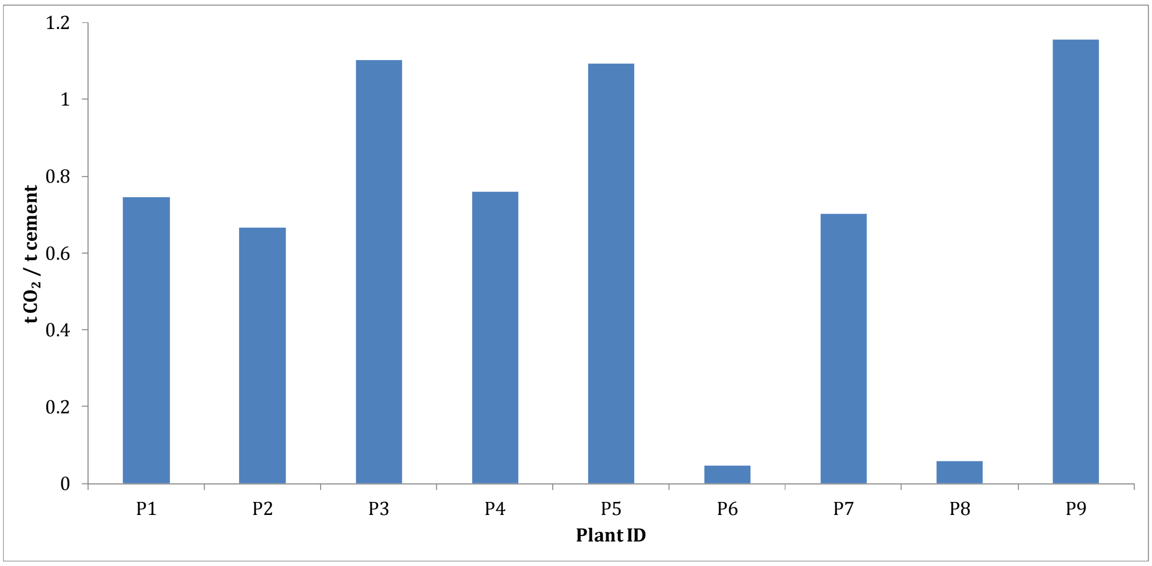


Figure 123. Emission intensity across selected plants

Comparison of Emission Intensity and SEC

Figure 124 shows the trend in emission intensity and SEC. It is observed that as the SEC increases, the emission intensity tends to increase. However, there may be some variation to this trend due to high clinker export, high percentage of PPC production and high percentage of PSC production in P2, P3 and P4.

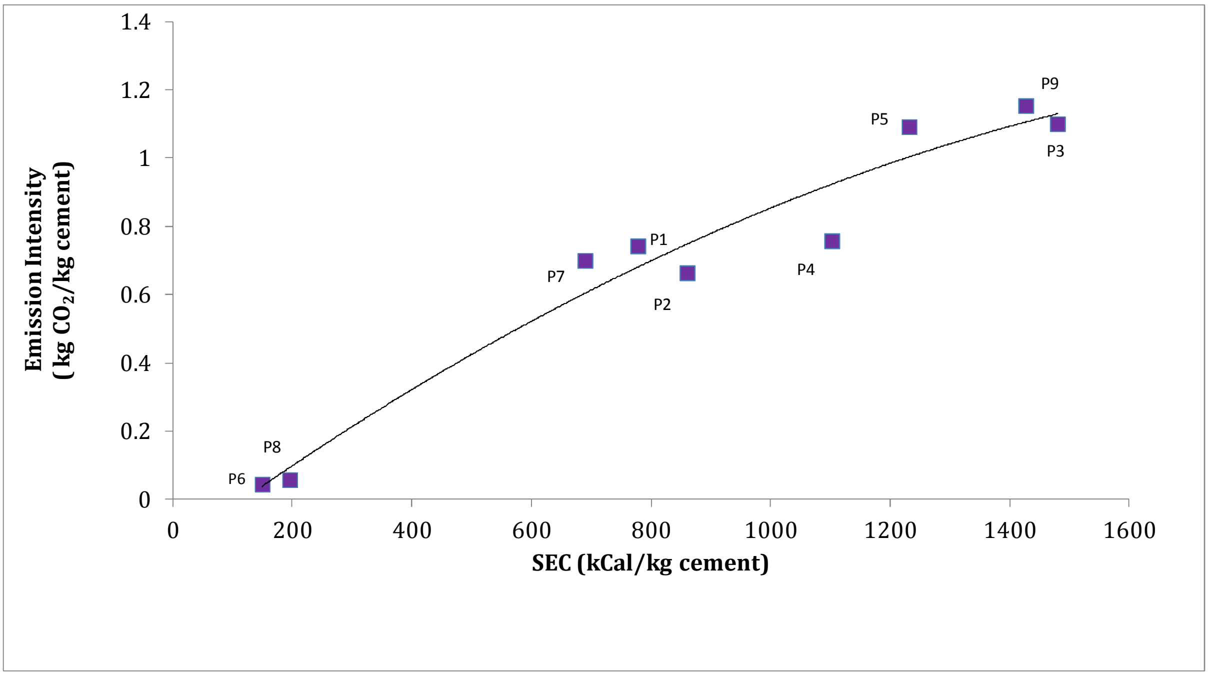


Figure 124. Emission intensity vs. SEC trend for nine plants

Innovative technologies are being incorporated in cement manufacturing processes all over the world which lead to lower emission intensities in the industry. The Indian cement sector can continue to encourage the deployment of these technologies into the inherent processes and reduce its GHG emissions, thereby contributing to national and global sustainability.

10. Challenges and Policies for Cement Industry

PAT is an innovative market based mechanism that aims to reduce the energy consumption of DCs in India. Since it is in a nascent stage with the first cycle coming into effect shortly, adequate management and policy measures need to be undertaken for it to be implemented across industries. This chapter of the report looks at the challenges faced by the cement industry relating to the improvement of energy efficiency of cement DCs and how policy regulations can play a part in addressing them. It also describes certain policy measures to facilitate the financing of different EE measures.

10.1 Fly Ash Consumption

According to the Ministry of Commerce, the Indian cement industry consumed 35 Mt of fly- ash during 2008-09(55). However, the total fly-ash generation was 130 Mt (56). This shows that the potential of fly-ash utilization is yet to be completely exploited.

Problems associated with fly-ash include (57):

(a) Requirement of large area of land for disposal and

(b) Toxicity associated with metals percolated to groundwater

Fly-ash is considered a major waste and a source of air and water pollution. The quality of fly-ash is determined by the quality of coal used. Indian coal possesses high ash content (in the range of 35%-45%), with a low calorific value of 3500 kCal/kg to 4000 kCal/kg. With increasing power demand, coal shall continue to play a major role in the power generation and fuel mix. As a result of high coal utilization, the fly-ash expected to be generated is also high. By 2012, the fly-ash generation is anticipated to increase to about 200 Mt.(57). Applications of fly-ash include:

a) Cement and Concrete industry – accounts for 28% of fly-ash utilization
b) Low Lying Area Fill (17%)
c) Roads and Embankments (15%)
d) Dyke Raising (4%)
e) Brick Manufacturing (2%)
f) Safe disposal in paint industry, agriculture etc.

Fly-ash is broadly classified into two major categories: Class F and Class C fly-ash. Class F fly-ash is produced by old anthracite and bituminous coal, and contains less than 10% of lime i.e., CaO. Class C fly-ash is produced from the combustion of lignite and sub bituminous coal. This fly-ash possesses more than 20% of lime.

The problem that could be faced by the cement industry is that fly-ash can follow a transitional path to becoming a commodity in the future. As the demand for fly-ash increases, it might not be seen as a mere waste product of industries. Instead it might be treated as a resource whose price will be determined by market conditions. Policies may be considered to regulate the price of fly-ash in the future so that it continues to be a useful waste product.

10.2 Slag Consumption

Slag is a by-product generated during the manufacturing of pig iron and steel. The slag is crushed, pulverized and screened for use in various applications, particularly in cement production because of its pozzolanic characteristics. Different types of slags find different uses in the industry. Granulated BF slag is used as a pozzolanic material for producing Portland slag cement. The component materials, viz. clinker, granulated slag and gypsum, are ground together in specified proportions for obtaining BF slag cement.

According to the Ministry of Commerce, the Indian cement industry consumed 7.5 Mt of slag in 2008-09.(55). Table 53 shows an overview of blast furnace slag produced across plants and the price at which it is being sold. Utilization of blast furnace slag in the cement industry has the same barriers or problems as fly ash. Similar policy and regulations will need to be made in order for greater absorption of blast furnace slag in cement industry.

Table 53: Price of Blast Furnace Slag (58)

Cement Plant	Price (Rs/tonne)	Source of Supply
Plant A	259.1	Bhilai Steel Plant, Durg, Chhattisgarh
Plant B	355.6	Bhilai Steel Plant, Durg, Chhattisgarh
Plant C	570.5	Visakhapatnam Steel Plant, Visakhapatnam, Andhra Pradesh(AP)
Plant D	721	Visakhapatnam Steel Plant, Visakhapatnam, AP
Plant E	496.3 450	i)JSW Steel Ltd., Bellary, Karnataka ii)SJK Steels, Tadipatri, AP
Plant F	250	Ispat Industries Ltd., Raigad, Maharashtra
Plant G	696 (Road) 706 (Rail) 371.9 (Rail)	i) JSW Steel Ltd., Bellary, Karnataka ii) VISL, Bhadravati, Karnataka
Plant H	500	JSW Steel Ltd., Bellary, Karnataka

10.3 Industrial Waste Usage

According to Central Pollution Control Board (CPCB), the identified potential industrial wastes that can be utilized in cement manufacturing are.

- Fly-ash
- Granulated Blast Furnace Slag
- Steel Slag
- Red Mud
- Lime Sludges
    - Paper Sludge
    - Sugar Sludge
    - Carbide Sludge
    - Chromium Sludge
    - Phospo Chalk
    - Soda Ash Sludge
- Phospo Gypsum
- Jerosite
- Lead-Zinc Slag & Phosphorus Furnace Slag
- Kimberlite
- Mine Rejects

Holcim group and GTZ have defined the potential group classification of alternative raw materials which is shown in Table 54(59). The compounds extracted from various waste materials are listed along with the industrial sources from which the wastes were generated.

For these resources to have increased utilization in the cement industry, policies need to be formulated which induce DCs to include them in the manufacturing process of their cement plants either as blending material or alternate fuels.

Table 54: Group classification of ARM

Compounds	Waste Material	Industrial sources
Clay Mineral/Al_2O_3	Coating Residues Aluminum recycling sludge	Foundries Aluminum Industry
Limestone / $CaCO_3$	Industrial Lime Lime Sludge	Neutralization process Sewage Treatment
Silicates / SiO_2	Foundry Sand Contaminated Soil	Foundries Soil remediation
Iron-oxide / Fe_2O_3	Roasted pyrite Mechanical Sludge Red Sludge	Metal Surface treatment Metal Industry Industrial waste water treatment
Si-Al-Ca-Fe	Fly Ash Crushed Sand	Incinerator Foundries
Sulfur	Gypsum from Gas Desulphurization Chemical Gypsum	Incineration Neutralization Process
Fluorine	CaF_2 Filter Sludge	Aluminum Industry

10.4 Corporate Responsibility for Environmental Protection

According to the CPCB, the action points framed for Corporate Responsibility for Environment Protection (CREP) to the cement industry are listed below(60):

1. The new cement kilns to be accorded No Objection Certificate/Environmental Clearance if they meet the limit of 50 mg/m^3 for particulate matter emissions.
2. CPCB will evolve load based standards.
3. CPCB and NCBM will evolve SO_2 and NO_x emission standards.
4. The cement industries will control fugitive emissions from all the raw material and products storage and transfer points. However, the feasibility for the control of fugitive emissions from limestone and coal storage areas will be decided by the National Task Force (NTF).
5. CPCB, NCBM, BIS and Oil refineries will jointly prepare the policy on use of petroleum cokes as fuel in cement kiln.
6. After performance evaluation of various types of continuous monitoring equipment and feedback from the industries and equipment manufacturers, NTF will decide feasible unit operations/sections for installation of continuous monitoring equipment.
7. Industries will submit the target date to enhance the utilization of waste material.
8. NCBM will carry out a study on hazardous waste utilization in cement kiln.
9. Cement industries will carry out feasibility study and submit target dates to CPCB for co-generation of power

Note: Non complying units shall give bank guarantee to respective SPCBs.

10.5 Other Major Policies

The interstate transportation of hazardous waste, as per the national hazardous waste management policy, is summarized in this section. CPCB has notified the norms for managing hazardous waste and their use in cement kilns through incineration. The potential use of hazardous waste is discussed in this section.

10.5.1 Interstate Transportation of Hazardous Waste

Based on mutual consultation and agreement between the state governments, interstate movement of hazardous waste could be permitted, in particular, to take care of difficulties faced by some states in development of Treatment, Storage and Disposal Facilities - such as not having viable quantities of hazardous waste.

The Pollution Control Boards or Pollution Control Committees could introduce on-line tracking system for movement of hazardous waste from generation to the disposal, recovery or recycle stage(61).

10.5.2 Use of Cement Kilns for Hazardous Waste Incineration

Field trials conducted by CPCB indicate that use of hazardous waste (such as effluent treatment plant sludge from textile units, tire pieces, paint sludge, tar residue and refinery sludge) as alternative fuels in cement kilns, could be promoted. The use could be in compliance with notified emission norms for hazardous waste incinerators, Reuse of hazardous waste, however, for instance paint sludge after reconditioning as primer/ coating, is a preferable option over incineration. Such alternative options to reuse the wastes and sludge could be explored and encouraged.

The safer alternative to consider is incinerating the high calorific value hazardous waste in cement kiln as compared to conventional incineration. Prior to the incineration, the wastes must be subjected to suitable processing. Given the vast spread of cement plants across the country, the aforementioned option seems attractive. Sludge from petrochemical industry, oil refinery and paint industry as well as residues from pesticide and drug industries are particularly suitable for this purpose as they possess high calorific value. In the cement kilns, the high flame temperature of around 2000°C, high material temperature of around 1400°C and large residence time of around 4-5 seconds ensures that the material incinerates completely. The non-combustible residue including heavy metals gets mixed into the clinker. To avoid such occurrence, it is advisable to blend and process the metallic waste before introducing them into the cement kiln. It is indicated from the field trials, conducted by CPCB that monitoring hazardous air pollutants followed by a compliance notification of emission norms for hazardous waste use, needs to be promoted.

10.6 Shortage of Raw Material and Substitutes

The primary raw materials used to produce cement are limestone, gypsum and silica. During the visit of committee of Ministry of Commerce to the cement plants, many companies shared their concerns about the diminishing lime stone reserves in India. They also mentioned that at this rate, the current reserves may last only for 15-20 years. Further, gypsum an important additive is being imported from other countries. On the other hand, natural sand, which is also known as silica is obtained from mining which leads to soil erosion and degradation.

It is clear that research on materials that could replace limestone (if not fully but partially) needs to be undertaken in order to sustain the industry (62).

10.7 Availability of Coal

Coal acts as a major source of fuel for manufacturing cement. Therefore, it is of paramount importance that the availability of proper quality of coal exists for a longer period of time. According to the 95th performance of Cement Industry report, Coal India Limited (CIL) and Singerani Colleries Co. Ltd (SCCL) are the major suppliers of indigenous coal for the cement industry. It is learnt that in 2008-09, against a consumption of 29.58 Mt, CIL and SCCL supplied 14.29 Mt, meeting only 48% of the total requirement. Around 15.28 Mt was procured from other sources like open market purchases, import, use of pet coke, etc., at a higher cost, to meet the requirements. Other reasons for this deficit is delay in signing the Fuel Supply Agreements (FSAs) by the cement and coal companies (62).

The report also mentioned that as per the notification issued by the New Coal Distribution Policy (NCDP) in 2007, the FSAs would be signed only for the 75% of the requirement based on the norms, resulting in an initial shortage in the allocation of coal.

Some of the suggestions provided by the Ministry of Commerce committee are as follows.

- Government should intervene to ensure the supply of coal at regular basis.
- FSAs should be signed without further delay.
- It is important that 80% or more coal of total requirement should be provided through linkages. This would restore the confidence of the investors.

10.8 Factors Attributed to High Retail Cost of Indian Cement

Some of the factors that are attributed to the high retail cost of Indian cement include:

- High cost of Raw Material
- High Power Cost
- High Transportation Cost
- Dependence on Road Transport for moving Clinker
- Variation in Freight Charges

The associated economics need to be analyzed and avenues for alleviation of finances should be explored by concerned authorities. Systemic evaluation of the components and their linkages will address the shortcomings and identify the areas of improvement.

10.9 Environmental Pollution Norms

With any industrial activity, generation of waste and by-products is expected. In the case of cement manufacturing, the associated process lead to pollution in the following ways (62) :

- Dust generation in specific sections of cement plants (crushers, raw mill, coal mill, kiln, clinker cooler, cement mill)
- Sulphur dioxide (SO_2) emissions arising from oxidation of sulphur containing compounds present in raw materials and fuel
- Nitrogen oxide (NO_X) emissions from the plants (in the range of 400-1300 mg/m^3)
- Carbon dioxide (CO_2) emissions arising from calcination of limestone (50-55%), combustion of fossil fuels (40-50%) and electricity consumption (0-10%)
- CO_2 intensity of the cement sector is 0.85kg CO_2/kg cement produced. For the quantity of cement produced, 0.234 g of particulate matter, 1.5 g of SO_2 and 3 g of NO_X are generated as by-products or pollutants

The cement industry has taken the following steps to curb environmental pollution:

- Fly ash and BF slag have substituted clinker to a certain extent and this has led to reduced emissions of pollutants per tonne of cement produced
- Out of 130 Mt of fly ash generated in power plants per year, 34 Mt are utilized in the cement sector
- Out of the 13 Mt of BF slag generated by steel plants per year, 8 Mt are utilized in cement plants

10.10 Financing to Meet the EE Goals

PAT has set realistic goals and strives to drive the nation's industrial economy towards a more energy efficient one. Some of the measures that can be taken to ensure sound financing of EE measures in the cement industry are listed below:

- Soft loans to the industry for specific energy efficiency improvement measures.
- Interest subsidies can be provided in case of standard loans availed by DCs from financial institutions
- Partial Risk Guarantee funds such as those designed under the NMEEE.

10.11 Monitoring and Validation

Monitoring and Validation (M&V) is one of the most important aspects of a program and is a key indicator to measure the success or failure of a program. Any M&V schema requires a clear elucidation of goals which should then be periodically measured. Ideally, the program(s) should be flexible enough to allow mid-course corrections.

The M&V protocols comprise of determining baseline, verifying energy conservation savings and M&V implementation procedures and protocols.

A project specific M&V plan could address the following (63):

- Describe the project site and the project; include information on how the project saves energy and what key variables affect the realization of savings.
- Describe the M&V method to be used.
- Indicate who will conduct the M&V activities and prepare the M&V analyses and documentation.
- Define the details of how calculations will be made.
- Specify what metering equipment will be used, who will provide the equipment, its accuracy and calibration procedures. Include a metering schedule describing metering duration and when it will occur, and how data from the metering will be validated and reported. Include data formats. Electronic, formatted data read directly from a meter or data logger are recommended for any short- or long-term metering.
- Define what key assumptions are made about significant variables or unknowns. Define how any baseline adjustments will be made.
- Describe any sampling that will be used, why it is included, sample sizes, documentation on how sample sizes were selected, and information on how random sample points will be selected.
- Indicate how quality assurance will be maintained and replication confirmed.

10.12 ISO 50001 initiative

International Organization for Standardization (ISO) 50001: 2011 also known as Energy Management Standards (EMS) is a voluntary international standard developed by ISO(64). It enables organizations to establish the systems and processes necessary to improve energy performance. The incorporation of these standards should yield reductions in energy consumption, energy costs and greenhouse gas emissions (65). It is designed to integrate with other management standards, especially ISO 14001 on environmental management and ISO 9001 on quality management.

ISO 50001 specifies requirements for factors affecting (66):

- Energy supply, use and consumption
- Measurement, documentation and reporting
- Design and procurement practices for energy using equipment, processes, system and personnel

ISO 50001 is based on the ISO management system. The system is recognized worldwide with standards such as ISO 9001 (quality management), ISO 14001 (environmental management) and ISO 22000 (food safety). ISO 50001 follows the **Plan-Do-Check-Act** (PDCA) process for improvement of the energy management system over time based on the best available data to the organization.

The **planning** process involves conducting the energy use assessment, establishing the baseline, energy performance indicators (EPIs), objectives, targets and action plans necessary to deliver results that will improve energy performance (measurable results related to energy efficiency, use and consumption) in line with the organization's energy policy. Implementation of energy management action plans is a critical component of the **doing** process. Monitoring and measurement of the results and the key characteristics of operations that determine energy performance against the energy policy and objectives, and reporting the results is the **checking** process. The **acting** aspect involves steps to continually improve energy performance and the energy management system (66). The salient components of the PDCA process are depicted inFigure 125. The integration of standards such as ISO 50001 in a suitable form with an appropriate M&V procedure could enable the increased realization of benefits under an industrial EE program for industrial stakeholders.

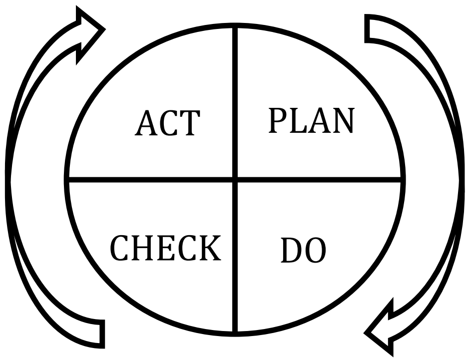
Management		Technical
Plan • Policy/goals/ targets • Resources	 	**Plan** • Energy review • Energy baseline • Energy Performance Indicators
Do • Training • Communication • Documentation • Operational Control		**Do** • Design • Energy purchasing
Check • Internal audit • Corrective/ Preventive action		**Check** • Monitoring • Measurement • Verifying action plans results
Act • Management review		**Act** • Energy performance and Energy performance indicators review

Figure 125. Essential Components of the PDCA Process (66)

11. Conclusions

This report has examined the status of energy efficiency in the Indian cement industry. A comprehensive study of the cement manufacturing process, the material and energy flows, process modeling and financial analysis of several measures in a range of cement plants has been carried out. A study of the diversity of plant operating conditions and performance parameters for several sample plants has been presented. This study will be useful in examining the significance of various factors in order to normalize the baseline SEC of a cement plant. A preliminary agent based model was utilized to simulate the response of various industrial units to a specific SEC norm. Emission intensities and a scenario analysis of the impact of SEC norms on a range of sample plants have been provided.

Energy audit studies have estimated 5-10% energy savings in thermal and electrical energy consumption in cement plants by adopting different energy conservation measures. It is estimated that saving of 5 kCal/kg clinker of thermal energy and 1 kWh/t cement of electrical energy will result in total savings of about Rs 6 Million per annum in a typical 1 Mt capacity plant.

The key levers for improving EE in a typical cement plant are:

EE Technologies: A variety of efficient technologies can be utilized in order to contribute to energy savings in the thermal energy and electrical energy consuming equipment.

Using waste heat recovery (WHR) systems: The waste heat available in the exhaust gases can be recovered and converted into useful form as required by the cement plant.

Blending: Approximately 20-30% of fly-ash and 45-50% of blast furnace slag is added to the clinker which could be increased further.

Alternative Fuel Resources (AFR): Currently only a small percentage of the industry uses AFR. There is a large scope of increasing the percentage of alternative resources such as industrial wastes, bio waste, rice husk etc.

Captive Power Plant (CPP): The station heat rate reduction, energy savings from auxiliary power consumption and using recovered waste heat in CPP are some of the ways to reduce energy consumption.

The cement industry in India is second largest in the world and has plants which are among the most efficient globally. The cement industry has been playing a vital role in the development of the Indian economy and has been overcoming various challenges while doing so. Various policy issues related to ameliorating these challenges have been discussed in this report.

It is observed that focused effective mechanisms such as PAT can contribute to an accelerated mitigation of the energy intensity of the Indian cement sector when accompanied by a framework to support the financing of EE projects. Such mechanisms can contribute to reducing the projected energy consumption of the cement industry and of the country while lowering GHG emissions, thereby mitigating global warming and climate change.

Energy efficiency in India is a national priority given that large sections of rural households do not have access to energy. The Indian cement industry and energy policy implementing agencies such as the BEE are vital enablers on the country's roadmap for low-carbon inclusive growth.

References

1. **MoEF.** *India: Greenhouse Gas Emissions 2007.* 2010.

2. **Planning Commission.** *Low Carbon Growth - Interim report.* 2011.

3. **IEA.** International Energy Agency. [Online] 2010. http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=IN.

4. **CII.** *Low Carbon Roadmap for Indian Cement Industry.* Hyderabad : CII - Green Business Centre, 2010.

5. **Dr.S.K.Handoo.** *CII-GBC.* [Online] 2011. http://www.greenbusinesscentre.com/site/ciigbc/viewprest.jsp?eventid=272083&event=272083&event=dd&dated=218662.

6. **IEA.** *Energy Transition For Industry India And The Global Context.* 2011.

7. **BEE.** *PAT Consultation Document.* s.l. : BEE, 2011.

8. **Taylor, Harold F.W.** *Cement Chemistry.* London : Academic Press, 1990. ISBN 0 - 12 - 683900 - X.

9. **CII-GBC.** Cement formulae handbook. s.l. : CII, 2010.

10. **FLSmidth.** Preheater brochure. [Online] July 27, 2011. http://www.flsmidth.com/~/media/Brochures/Brochures%20for%20kilns%20and%20firing/preheater_lores.ashx. C 03-11 400-12 -ENG.

11. **Deolalkar, S P.** *Handbook for Designing Cement Plants.* Hyderabad : s.n., 2008. 978-81-7800-145-4.

12. *Chemistry and Engineering of The Production Process: State of The Art.* **Francois, Sorrentino.** 616, s.l. : Elsevier Limited, 2011, Vol. 41.

13. **Mohanty, Brahmanand.** *Technology, Energy Efficiency and Environmental Externaities in the Cement Industry.* s.l. : Asian Institute of Technology, 1997.

14. Energy Efficiency Asia. *IndustrySectorsCement Draft Report.* [Online] 2005. http://www.energyefficiencyasia.org/docs/IndustrySectorsCement_draftMay05.pdf.

15. **McCabe, Smith and Harriott.** *Unit Operations of Chemical Engineering.* Singapore : Mc Graw Hill, 1993. ISBN 0-07-112738-0.

16. **Peray, Kurt E.** *The Cement Manufacturer's Handbook.* New York : Chemical Publishing Co., Inc., 1979.

17. **V.K.Batra, P.N.Chhangani, Dinesh Satija and R.B.Garg.** *Capacity Enhancement and Energy Conservation in Cement Plant.* s.l. : Holtec Consulting Private Ltd, Gurgaon, 2004.

18. **Cement Task Force.** *Asia-Pacific Partnership.* 2006.

19. *High Efficiency Motors.* **Haridkar, Prasad.** Pune : AEEE, 2011. Workshop on Energy Efficiency in Rotating Equipment.

20. **BEE.** Energy Managagement Training. [Online] 2009. http://www.energymanagertraining.com/Journal/Technological%20Trends%20in%20Cement%20Industry.pdf.

21. **H.Conroy, Geoffrey.** *Cement Plant Expansion Cost Evaluation for New and Upgraded Installations.* s.l. : KHD. Georgia, 1998.

22. *Energy Auditing and Recovery for Dry Type Cement Rotary Kiln Systems.* **al, Tahsin Engin et.** s.l. : Elsevier, 2004, Vol. 46.

23. **CII-GBC.** *Manual on Waste Heat Recovery in Indian Cement Industry.* s.l. : CII, 2009.

24. **Banthia, S.** Waste Heat Recovery System. *Green Cementech 2011.* Hyderabad : s.n., 2011.

25. **Cement Manufacturers Association.** *Annual Report 2009 - 10.* s.l. : Cement Manufacturers Association, 2010.

26. UNFCCC. *UNFCC-CDM.* [Online] 2011. http://cdm.unfccc.int/Projects/DB/DNV-CUK1149496574.99/ReviewInitialComments/EJ4AQTXS14IOL5Q6Z6DWI74PDR22AV.

27. **Holcim.** Fact Sheets. [Online] 2008. http://www.hcb.ch/holcimcms/uploads/CORP/Holcim_FactSheet_AFR_2008.pdf.

28. **CEMBUREAU.** [Online] http://www.cembureau.be/sites/default/files/Sustainable%20cement%20production%20Brochure.pdf.

29. **WBSCD.** *Environmental Compatability of Cement and Concrete – Manufacture, Application and Use of Alternative Materials.* s.l. : wbcsd, 2011.

30. **S.Balasubramaniam, R.Vasantha Kumar.** *Waste into Wealth.* s.l. : The Minerals, Metals and Materials Society, 2008. p. 4.

31. **Tirthankar.** Captive generation in India. [Online] 2011. www.idfc.com/pdf/report/Chapter-12.pdf.

32. **DECPL.** *BEE Code Cogeneration.* Vadodara : s.n., 2006.

33. **CEA.** *Annual Report.* 2009 - 10.

34. **Singh, Braj Nandan.** *Energy Efficiency in Thermal Power Plants.*

35. **Sargent, Lundy.** *Coal Fired Power Plant Heat Rate Reductions.* Chicago : s.n., 2009.

36. **Ganeshan, V.** CII - GBC. *http://www.greenbusinesscentre.com/site/ciigbc/viewprest.jsp?eventid=272083&event=272083&event=dd&dated=218662.* [Online] May 6, 2011. [Cited: August 10, 2011.]

37. **Taneja, Vivek.** CII - GBC. [Online] May 6, 2011. [Cited: August 10, 2011.]

38. *Investors Manual for Energy Efficiency in Small and Medium Scale Enterprises.* s.l. : Confederation of Indian Industry, 2006.

39. *Advanced training programme on energy management.* **Confederation of Indian Industry - Green Business Center.** Vijayawada : CII, 2010.

40. **FL Smidth.** [Online] www.flsmidth.com.

41. *Agent-Based Computing: Promise and Perils.* **Jennings, Nicholas R.** s.l. : University of London, 1999.

42. **Wooldridge.** Agent-based software. *IEE Proc Software Engineering.* 1997, Vols. 144:26-37.

43. *Manufacture of Eco friendly and Energy Efficient Alinite Cements from Flyash and other Bulk Wastes.* **Pradip and Kapur, P.C.** 1, Pune : Tata Research Development and Design Center, 2004, Resources Processing, Vol. 51.

44. *Structure and Properties of a Finite and Alinite Cements.* **B Noudelman, M Bikbaou, A Sventsitski, V Ilukhine.** s.l. : 7th International Congress on the Chemistry of Cement, 1980, Vols. Vol 3 V169-174.

45. **Novacem.** The Novacem solution. *Novacem - Carbon Negative Cement.* [Online] 2012. http://novacem.com/technology/novacem-technology/.

46. **Hart, Kelly.** Magnesium Based Cement. *Green home Building.* [Online] 2010. http://www.greenhomebuilding.com/articles/ceramicrete.htm.

47. **CALERA.** Our Process. *CALERA.* [Online] 2012. http://calera.com/index.php/technology/.

48. **ARB.** *Air Resources Board, California Environmental Protection Agency.* [Online] 2009. http://www.arb.ca.gov/cc/etaac/meetings/102909pubmeet/mtgmaterials102909/basicsofcaleraprocess.pdf.

49. **Calix.** Proven Flash Calcination Technology. *Calix.* [Online] 2011. http://www.calix.com.au/technology.html.

50. **EPA.** Fugitive and Stack emissions. *Environmental Protection Agency.* [Online] 1998. http://www.epa.gov/osw/nonhaz/industrial/special/ckd/ckd/ckdp0101.pdf.

51. **PCB.** *Assessment of Fugitive Emissions & Developement of Environmental Guidelines for control of Fugitive Emissions in Cement Manufacturing Industries.* s.l. : Central Pollution Control Board, MoEF, 2007.

52. **CEA.** *CO2 Baseline Database For the Indian Power Sector - User Guide.* New Delhi : Central Electricity Authority, 2011.

53. **Galitsky, Ernst Worrell and Christina.** *Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making.* s.l. : Environmental Energy Technologies Division LBNL, 2008.

54. *Emission Reduction of Greenhouse Gases from the Cement Industry.* **C.A.Hendriks, E.Worrell,D.de.Jager,K.Blok and P.Riemer.** s.l. : GHG Control Technologies Conference, 2004.

55. **Commerce, Ministry of.** *Ninety Fifth Report on Performance of Cement Industry.* New Delhi : Rajya Sabha Secretariat, 2011.

56. **Pankaj Dewangan, Manoj Pradhan, Naval Kishore.** Utilization of Fly Ash as a Structural Fill Material for Safe and Sustainable Development: Need of the Hour. *The IME Journal.* [Online] 2008. [Cited: January 19, 2012.] theimejournal.com/aug/134_139.pdf.

57. *Fly Ash Utilization in Different Sectors in Indian Scenario.* **Alam, J and Akhtar, M. N.** s.l. : International Journal of Emerging trends in engineering and development, 2011, International Journal of Emerging trends in Engineering and Development.

58. **Indian Bureau of Mines.** Slag-Iron and Steel. [book auth.] Indian Bureau of Mines. *Indian Minerals Yearbook 2009.* Nagpur : s.n., 2011.

59. **GTZ-Holcim Public Private Partnership.** *Guidelines on Co-processing Waste Materials in Cement Production.* s.l. : Holcim Group Support Ltd and GTZ, 2006.

60. **Central Pollution Control Board.** *Corporate Responsibility for Environment Protection.* s.l. : Central Pollution Control Board, 2003. Chapter on CREP.

61. **MoEF.** Hazardous Substances Management Division. *Ministry of Environment and Forest.* [Online] 2012. [Cited: January 20, 2012.] moef.gov.in/divisions/hsmd/NationalHazardous.pdf.

62. **Rajya Sabha Secretariat.** *Ninety Fifty Report on Performance of Cement Industry.* New Delhi : s.n., 2011.

63. **AEP Efficiency.** *Measurement and Verification (M&V) Guidelines: Retrofit, Commercial Program Manual.* 2011.

64. **ISO.** *ISO 50001 and its benefits.* 2011.

65. **Huang, E.G.T.** Understanding the requirements of the energy management system certification. *SGS.* [Online] 2011. http://www.sgs.com/sgs-energy-management-white-paper-en-11.pdf.pdf.

66. *ISO 50001: Energy Management Systems Standard.* **Chakaravarti, K.K.** New Delhi : DRDO, 2011.

67. **KHD.** [Online] www.khd.com.

68. **ThyssenKrupp Polysius.** [Online] www.polysius.com.

Appendix I

A comprehensive list of technology options from various manufacturers is provided here.

FL Smidth (40)

Raw Meal, Coal and Cement Grinding, Silo and Gears

Name of the equipment	Advantages
Startup Aeration System for powder coolers	Reduces the problem associated with crash stops and plugging
	Minimizes the downtime and avoids costly cleanout delays
	Easy retrofit to existing coolers
Ball Mill UMS,TMS and TUMS	120 mill sizes with capacity ranging from 1000 to 10000 kW
Barring Device	Allows stopping the mill at any position
	Facilitates Mill Servicing, turns the mill at about 2% of normal speed
Controlled Flow Inteverted Silo	SPC is kept low by aerating only two sections at the same time
Controlled Flow Storage Silo	SPC is kept low by aerating silo bottom sector by sector
Hydraulic Roller Press	In high-pressure roller press combinations the feed material is exposed to very high pressure for a short time. The high pressure causes formation of micro cracks in the feed particles and generates a substantial amount of fine material.
OK Vertical Roller Mill	OK vertical roller mills use 30-50% less energy than ball mill systems
	For a typical Cement plant, Ball Mill consumes 37.4 kWh/t of cement. While the roller mill's SPC is 24.5 kWh/t of cement
O-Sepa Separator	Wear protection targets specific abrasion mechanisms for each separator component
	Circulating oil lubrication system promotes exceptional bearing life
Powder Cooler	FLS coolers are available with capacities up to 180 tons material per hour.
	FLS Cylindrical Coolers are ideal for reducing the temperature of the hot pulverised material discharged directly from a mill circuit.
Sepax Separator	Highly effective nibs extraction minimizes clogging of mill grates, thus enabling long-lasting
	Practically eliminated nibs recirculation reduces maintenance work and downtime caused by clogged mill grates.
Symetro Gear Unit	Optimized teeth contact through profile and lead (helix angle) corrections as well as end relief.
	Allows minor settlement of gear and/or mill foundations

Crushers and Raw Materials Stores

Name of the equipment	Advantages
Apron Feeder	Blending and crushing in one installation
	Easy installation and replacement
Clinker crushers	Facilitation in accessing internal component
EV Hammer Impact crusher	Reduction ratio up to 1:100
	Adjustable outlet grate and durable
EV Crusher Retrofit	Hydraulic tool for changing of hammers
	Hydraulic Openings for crusher housing

Hammer crushers without inlet grate	Adjustable crushing plates
Hammer Mill Driers	Moisture content of the raw materials is reduced to 1-3%
	At the same time gas stream is cooled down to a temperature between 100-150°C
	Maintenance cost is low
MCH Twin Shaft Breaker	Crushes soft and sticky materials
	Low power consumption
	Stable and trouble free operation
	Easy Install, Adjust and maintenance
Roller Crushers	Designed for Soft chalk and clay
Stacker and Recalimer	Suitable for Raw materials in the cement, coal, pulp and paper, mining and others
	Also used in the Power plant
	Available methods are chevron, windraw, Windraw open pile, Continuous chevron
	Cone shell. Touch view graphical Flatplate in operator cabin
	Homogenous storage

Kilns and Firing

Name of the equipment	Advantages
ABC Air Blast Controlled cooler inlet	Prevents dead zones Ensures uniform clinker distribution Introduces flexible control of air blasting Based on well-proven Mechanical Flow Regulator (MFR) system Suitable for both new coolers and for retrofitting
Air-to-Air Heat Exchanger	Stabilized kiln operation Improved cooler vent system control Reduced power consumption Reduced filter maintenance
Utilise the power of alternative fuels	Market-leading products, solutions and services that help you reduce fuel costs and cut CO2 emissions
ATOX Coal Mill	High-efficiency mill grinding coal, lignite pet coke, anthracite, etc. Dynamic rotary separator ensures high-grade end product. Compact design minimizes space requirement. Segmented roller and table wear parts prolong service life and facilitate installation. Large rollers permit coarser feed and ensure a thick grinding bed. No auxiliary drive needed. High flexibility ensures stable operation, even during low production load. Optimized air distribution reduces pressure loss.
Kiln Gas Bypass Systems	Dual layer dip tube Quench air inlet flap valve Control scheme for maximum stability Special lining design in transition pipe section Constant force support system Multiple layout possibilities
Cast central pipe for cyclones	Improves cyclone efficiency Minimizes clogging tendency Easy to install and maintain Readily available from stock
CIS/MFR fixed inlet cooler retrofit	Customized Mechanical Flow Regulator (MFR) pattern Constant and self-regulated air-flow to each grate plate Air-blaster channels maintain constant clinker flow
CONDITIONING TOWERS, LYR	Conditioning towers in the cement industry are used for cooling exhaust gases from the kiln before they are conveyed to the

	electrostatic precipitators
Coolax Grate Cooler	Fuel savings of 30-40 kcal/kg clinker 30% less cooling air and 40% less air to be dedusted Low overall power consumption Effective and consistent cooling of clinker More stable high capacity kiln and cooler performance due to Less dust circulation and no blowing through of cooling air Low maintenance costs due to minimum wear on grate plates and movable parts Less red river tendency due to the Controlled Flow Grate system Less snowman tendency Less falling through of clinker Small overall dimensions due to high specific grate load (up to 60 t/m2 per 24 hours).

Co-processing of waste	Reduction of fuel costs
	Environmental benefits
	Saving of fossil fuel resources
Dry process kiln systems	Highly reliable
	Low emission levels
	Efficient energy utilization
DUOFLEX	Improved heat economy
	Widely adjustable flame shape
	Easy change-over between fuels
	Suitable for alternative fuels
Grate Cooler CFG-Retrofit	Upgrading existing grate coolers with the
	CFG system offers:
	Fuel savings of 25-40 kcal/kg clinker
	Less cooling air consumption and reduction of air to be deducted
	Reduced overall power consumption
	Effective and even cooling of clinker
	More stable high capacity kiln and cooler performance due to less dust circulation and no blowing through of cooling air
	Low maintenance costs due to minimum wear on CFG grate plates and movable parts
	Less red river tendency due to the Controlled Flow Grate system
	Less snowman tendency
	Less falling through of clinker
	Short payback period.
GUNNAX co-processing of waste	To reduce the generation of waste at source.
	To increase recovery of waste.
	To dispose of the waste in a satisfactory way.
HOTDISC technology	Simple to operate
	Lumpy waste derived fuel
	Efficient combustion
	Reduced operational cost
HRB · Heavy-duty Roll Breaker	Maximum availability
	Unique position of shafts allows adjustment of gaps
	Large coatings easily broken down
HRB MF Heavy-duty Roll Breaker Modular Frame	Maximum reliability
	Low maintenance
	Unique shaft arrangements
	Modular design
Kiln Inlet Lamella Seal	Some of the advantages of
	Extremely flexible Sealing between kiln and preheater
	independent of kiln rotation
	Insulation incorporated to protect the lamella spring effect

	Scoop arrangement included
	Rapid and easy maintenance
	High-rated, secure sealing effect
	Straightforward Installation even on non-FLS equipment
	10,000 - 20,000 service hours for wear parts (dependent on the process conditions)
	Extremely flexible sealing between kiln and cooler
	Independent of kiln rotation
	Insulation incorporated to protect the lamella spring effect
	Material return arrangement to either first grate or external drag chain
	Rapid and easy maintenance
	Straightforward installation even on non-FLS equipment
	Dust retention curtain incorporated
	7,000 - 14,000 service hours for the wear parts (dependent on the process conditions)

Multi-Movable Cross-Bar Cooler	Proven, reliable technology
	Flexible, horizontal modular design
	Reduced, predictable maintenance
	Consistently high thermal efficiency
RTKM Separator - for coal grinding ball mills	Dynamic separator for old and new installations
	15% more energy-efficient than static separators
	Steeper particle size distribution curve
SF Cross-Bar Cooler	Mechanical air-flow control
	No moving grates
	Optimized air distribution
	Reduced installation time and costs
Selective Non-Catalytic Reduction (SNCR) Systems	Minimized NOX emission
	High ammonia utilization
	Complete solutions
	Full process and service support
Tire Gunnax	Compact Design
	For Firing Whole Tyres in the Kiln
	Efficiently Reduces NOx Emissions
	Optimized Tire Placement and
	Controlled Substitution

Material Handling

Name of the equipment	Advantages
Bucket Elevators	The fast-running FLS bucket elevators can handle lumps up to 50 mm in size and can withstand temperatures up to 350oC.
	The FLS fast-running elevator is designed for centrifugal discharge.
CFI silo	Controlled Flow Inverted cone Silo
	System of several outlets for highly reliable extraction
	More free space under inverted cone
CFMI silo	Controlled Flow Multi-compartment storage silo with Inverted cone
	Two or more compartments
	Facilitates compact plant layout
CFS silo	Controlled Flow Storage silo
	Simple layout and low cost installation
	Low air and specific power consumption
CF silo	Controlled Flow silo for continuous blending and storage
	Ensures stable kiln operation

	High blending efficiency
Change-over valve	For conveying of raw meal, cement, precipitator dust, coal meal
	Reliable and efficient in pneumatic systems
	Designed for easy maintenance
Dosimat Feeder	Cost Effective system
	Extraction/proportioning of sticy/abrasive and coarse materials in one unit
	Online calibration
	Less than +/- 0.5 deviation from normal feed rate
	Automatic adjustment for variations in bulk density
	Frequency regulated AC or Hydraulic drive.
Drag chain Conveyors	Can withstand temperatures up to 350oC, and up to 400oC if fitted with special chains. 400- 500oC is allowed for a short period
Fluxo filling device	Movable bulk loader for trucks or wagons makes filling easy and swift
	Highly flexible conveying system from silo outlet to loading point
Fluxo Pump retrofit	Higher conveying capacity
	More stable operation
	Less maintenance and greater availability
	Lower power consumption
Large pneumatic ship unloaders	Ship sizes from 9,000 to 40,000 DWT
	Unloading capacity up to 600 tph
	Pneumatic unloading direct to storage
	Stationary or mobile units
	Diesel or electrically driven
Rubber Belt conveyors	
Screw Conveyors	FLS Serew Conveyors are designed for inclined transport (up to 8o') of material with temperatures below 300oC. They have a conveying capacity up to 550 m3/h and are manufactured up to 60 m length.
Large mechanical ship-unloaders	Efficient and dust-reducing
	Ship sizes up to 70,000 dwt
	Standard unloading capacity from 200 tph to 2000 tph
FLSmidth Terminal Solutions	Complete project capability
	Mechanical and pneumatic shipunloaders
	Storage silos and domes
	Floating terminals

Name of the equipment	Advantages
Pneumatic transport for the fly ash Management Industry	3-in-1: blender, storage, efficient discharge
	No moving parts, low maintenance
	No mechanical wearing parts, low noise
	Gentle blending action
	Storage and blending combined into one vessel
	Can be effectively used to overcome bridging or funnel flow when discharging silos
	Rapid and total discharge capability
Bucket Elevators	
Central pulse filter	
Change over Valve	
Drag chain	
Filtax jet pulse filter	
Fluxo Pump retrofit	
Fluxo Slides	
Gas control valve	
Haf Fans	

KHD(67)

Major division	Name of the Equipment	Advantages
Burners	High pressure jet burners for multi-fuel scenarios The PYROSTREAM	The advantage of this configuration was a strong suction effect, which mixed clinker dust into the flame cone together with the fuel rich flame base creating a strong radiant flame. The result was superior heat transfer compared to low pressure gas burners. Since this development, the jet nozzle concept has been the most outstanding feature of all KHD kiln burners.
Grinding	COMFLEX Grinding System	Roller Press with Swing Frame for easy and fast roller service Tailor -made separating unit to separate, dry and convey materials Efficient product collection system
Rotary Kilns	Compact and Efficient Rotary Kilns	Investment costs approx. 15% lower than three station kilns. The lower space requirements and lower weights lead to more favorable construction costs. Mechanical overloading is impossible. This results in higher levels of operational reliability and lower maintenance costs. Lower consumption of refractory lining. The reduced required power and lower radiation losses reduce energy costs. The tire at the kiln discharge is outside the sintering zone.
KHD Separators	VSK Separator	Relieving the dynamic classifier of coarse material by pre-classifying. Mixing feed and recycled material before entering the roller press. Deglomeration of RP discharge by impact action of the cascade. Drying / cooling. High efficiency classifying. Cut size between 25 and 150µm. Effective wear protection and Minimizing of bucket elevator capacity
Grinding	Tube mill with slide shoes and INTEGRAL DRIVE	Extremely compact arrangement No foundation for the gear reducer No complicated drive adjustments The motor can be installed separately from the gears Does not need to be run in Low staffing level for operation monitoring Environment-friendly due to light sealing, No grease required High availability High efficiency level as no coupling required on the mill side

ThyssenKrupp Polysius(68)

Major division	Equipment	Advantage
Material Handling	Circular Stock Pile	
	Cole store with cone-shell stacking method	
	Circulate blending bed for limestone	
	Longitudinal stockpile	
	Bridge scraper	
	Longitudinal stockpile for additives	
Conveyor /Feeds	Conveyor Belts	
	Flow regulation bins	
	Apron Conveyors	
	Weigh belts	
	Rotary Air blocks	
Grinding and Drying	QUADROPOL® roller mill	The compact QUADROPOL® is designed for drive powers of up to and above 12 MW while assuring high plant availability. With its automatic changeover from 4 to 2-roller operation, the mill provides high adjustment flexibility within a range of approx. 30 - 100% for adaptation to changes in raw meal requirement.
	DOROL® roller mill	For Raw Materials grinding
		.
	Tube mill Air-swept mill	Air swept mill
		tube bill
	POLYCOM® high-pressure grinding roll	OLYCOM® units are used for throughput rates in excess of 2,000 tph. The mill feed material can be dry or moist with a largest feed grain size of up to 60 mm. If necessary, the material can be pre-dried.
Separating and Collecting	High efficiency Cyclone	
	High efficiency separator	
	Dust Collection Filter	
Pre heater	DOPOL® '90 cyclone preheater	Polysius offers preheater/calciner concepts that are innovative and nevertheless technically mature for the production of white and grey cement; for new plants as well as plant conversions, and tailored to the desired production capacity - no matter whether this is less than 1,000 or more than 10,000 tonnes per day.
	PREPOL® calcining system	This system permits the use of un-reactive fuels and simultaneously reduces the nitrogen oxide emissions.
Kiln	POLRO® 2-support kiln	The POLRO® rotary kiln has a statically determined support configuration on only two roller stations and has a direct drive system. The kiln shell with its splined tyres rotates on self-aligning rollers, which automatically adjust themselves to the momentary running conditions.
	POLFLAME® Burner	Variable burner adjustment possibilities

		Complete combustion of the different fuels within the clinkering zone
		High rate of standard fuel substitution by secondary fuels
		Constant flame stability at different burner settings
		Easy operability
		Reproducible setting of the flame shape depending on kiln operating conditions and type of fuel
		Modular nozzle design
Cooling	POLYTRACK®	Ideal transverse distribution of the clinker, with the effect of uniform, efficient cooling of all grain size fractions over the entire width of the cooler
		Extremely low construction height
		Very high thermal efficiency
		A robust, low-wear and easy to maintain design, with resultant outstanding availability and
		A consistently modular design.

List of Acronyms	
ACC	Air Cooled Condenser
AFR	Alternate Fuels Resources
Al_2O_3	Aluminum oxide
ARM	Alternate Raw Material
B/E	Bucket Elevator
BAU	Business As Usual
BEE	Bureau of Energy Efficiency
BFP	Boiler Feed water Pump
BH	Bag House
BIS	Bureau of Indian Standards
BM	Ball Mill
C2S	Belite
C3A	Tri Calcium Aluminate
C3S	Alite
C4AF	Alumino ferrite
$CaCO_3$	Calcium carbonate
CAGR	Compounded Annual Growth Rate
CaO	Calcium oxide
CEA	Central Electricity Authority
CEMBUREAU	Cement Bureau
CEP	Condensate Extraction Pump
CF	Capacity Factor
CFC	Catalytic Flash Calcination
CII	Confederation of Indian Industry
CM	Cement Mill
CMA	Cement Manufacturers Association
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CPP	Captive Power Plant
DC	Designated Consumer
DC drive	Direct Current drive
DEPCL	Diamond Engineering Private (Chennai) Limited
DG set	Diesel Generator set
D_{pa}	Mesh size(mm) where 80% of feed pass through mesh
D_{pb}	Mesh size(mm) where 80% of product pass through mesh
EE	Energy Efficiency
EEFP	Energy Efficiency Financing Platform
EoL	End of Life
ESC	Energy Saving Certificate
ESP	Electro Static Precipitator
Fe_2O_3	Ferrous oxide
FEEED	Framework for Energy Efficient Economic Development
FGD	Flue Gas Desulphurization

G2G	Gate to Gate
GBC	Green Business Center
GBH	Glass Bag House
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GHG	Green House Gas
GHR	Gross Heat Rate
HP	Horse Power
HSD oil	High Speed Diesel oil
HSHS	High Sulfur Heavy Stock
I^2R	Copper losses
ID fan	Induced Draft fan
IEA	International Energy Agency
IRR	Internal Rate of Return
K/F	Kiln feed
LBNL	Lawrence Berkeley National Laboratory
LDO	Light diesel oil
LP	Low pressure
LPG	Liquefied Petroleum Gas
LSFO	Low Sulfur Furnace Oil
LSHS	Low Sulphur Heavy Stock
MAP	Mineralization via Aqueous Precipitation
$MgCO_3$	Magnesium carbonate
MgO	Magnesium oxide
MoEF	Ministry of Environment and Forests
MTEE	Market Transformation for Energy Efficiency
NG	Natural Gas
NHR	Net Heat Rate
NMEEE	National Mission on Enhanced Energy Efficiency
NPV	Net Present Value
OPC	Ordinary Portland Cement
PAT	Perform, Achieve and Trade
PC	Precalciner
PCB	Pollution Control Board
PH	Preheater
PLF	Plant Load Factor
PM	Particulate Matter
PNG	Pipeline Natural Gas
PPC	Portland Pozzolana Cement
PPM	Parts Per Million
PSC	Portland Slag Cement
PV	Present Value
RDF	Refuse Derived Fuel
RM	Raw Material
RP	Roller Press
SCM	Supplementary Cementitious Material
SCR	Selective Catalytic Reduction

SEC	Specific Energy Consumption
SiO_2	Silicon dioxide
STP	Standard Temperature and Pressure
TDF	Tire Derived Fuel
TRDDC	Tata Research Design and Development Center
UHR	Unit Heat Rate
US-EPA	United States Environmental Protection Agency
VFD	Variable Frequency Drive
VRM	Vertical Roller Mill
WBCSD	World Business Council for Sustainable Development
W_c	Core Loss
W_{fr}	Frictional loss
W_{fr}	Frictional loss
WHR	Waste Heat Recovery
WHRB	Waste Heat Recovery Boiler
W_i	Work Index
W_I	Stray Load Loss
W_r	Rotor losses
W_s	Stator losses
W_{wind}	Windage loss

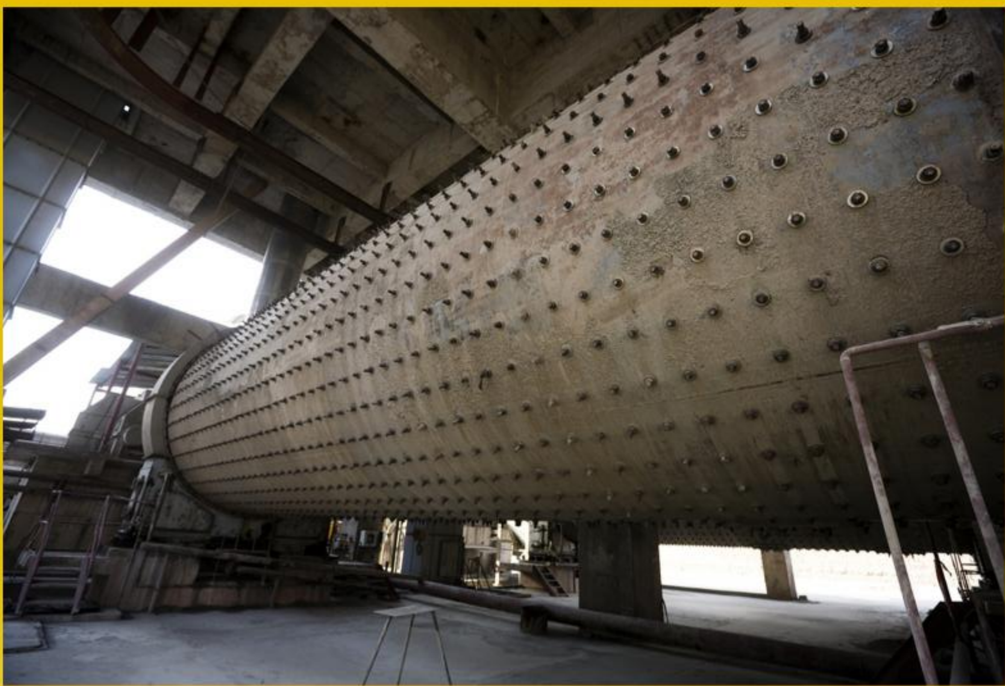
List of Units	
A	Amperes
V	Voltage
pH	negative logarithm of hydrogen ion concentration
SCM	Standard Cubic Meter
RPM	Rotation Per Minute
TJ	Tera Joules
kWh	kilo watt hour
m^3/kg	cubic meters per kilogram
kW	kilo watt
^{0}C	Degree Celsius
hr	Hour
kCal/h/m^2	kilocalorie per hour per square meter
K	Kelvin (Temperature scale)
kCal	kilocalorie
kCal/kg	kilocalorie per kilogram
kg	kilogram
kJ	kilo joule
kPa	kilo Pascal
kWh/t	kilo watt hour per tonne
m	Meter
Min	Minute
kg/s	kilogram per second
^{0}	degree
kg/min	kilogram per minute
MW	Mega watt
mBar	millibar (Pressure)
m^3/s	cubic meters per second
m^2	square meters
kCal/kWh	kilocalories per kilo watt hour
Rs.	Rupees
cm	centimeter
cm^2	square centimeter
cm^2/gm	square centimeter per gram
kW/m	kilo watt per meter
mm.Wg	millimeter water gauge
Mt	Million tonnes
tpd/m^2	tonnes per day per square meter
GCal	Giga Calorie
PJ	Peta Joule
toe	metric tonne of oil equivalent
Mtoe	Million tonne of oil equivalent
µm	micro meter
tpa/TPA	Tonnes Per Annum

tpd/TPD	Tonnes Per Day
tph/TPH	Tonnes Per Hour
Pa	Pascal
MPa	Mega Pascal
STPD	short tonnes per day
kg/kmol	kilogram per kilo mole
kmol	kilo mole
kWh/t Eq. cement	kilo watt hour per tonne of equivalent cement
kCal/kg ^{0}C	kilocalorie per kilogram degree Celsius

Units Conversion	
1toe	10^7 kCal
1kWh	860 kCal
1 kWh	36×10^5 J
1Mtoe	41.87 PJ
1kWh	3.6 MJ





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