7.1 Introduction

The cement industry is one of the oldest and core industrial sector in India. It is a highly capital and energy intensive industry. It is also an air polluting process due to the evolution of considerable amount of CO₂. Energy consumption by the cement industry is estimated about 2% of the global primary energy consumption, and almost 5% of the total global industrial energy consumption (WEC, 1995). In cement plants, carbon dioxide is generated by three means: consumption of thermal energy due to primary use of carbon intensive fuels, consumption of electrical energy generated by thermal power stations and calcination of limestone in the clinker making process. With the above configuration, a large capacity dry process cement plant (> 3500 tonnes of clinker per day) consumes about 715 kcal/kg clinker and 80 – 90 kWh/tonne while producing ASTM Type I and Type II cement (Ordinary Portland Cement or OPC) respectively. In a cement plant with commonly used modern technology and equipment, carbon dioxide generation should be in the order of about 0.825 kg CO₂ per kg of OPC. Out of the total CO₂ emissions, the contribution from thermal energy consumption, electrical energy consumption, and process of
calcination are about 28%, 9% and 63%, respectively. Improving energy efficiency in a cement plant should be approached from several directions.

Recently, there is a growing interest in the use of both the energy analysis and exergy analysis assessments for energy utilization to save energy and thereby achieve financial savings. The exergy method of thermodynamic analysis is based upon both the first and the second laws of thermodynamics together, while the energy analysis is based upon the first law only. It is a feature of the exergy concept to allow quantitative assessment of energy degradation. In this study, the energy analysis of the typical cement plant was conducted to examine the various energy losses in the important areas like raw mill and the kiln system and proposed a waste heat recovery system to recover heat from the exhaust gas from the kiln system. The exergy analysis indicates the important areas in which energy degradation occurs in the production process.

In order to understand the natural factors which affect the change in CO₂ emissions from the cement industries in India, a decomposition analysis was conducted. The plant data from the important selected cement industries in India were collected for the period 2001 - 2010. By analysing the data it was found that CO₂ emissions from these industries increase every year due to the increase in the rate of cement production. For decomposition analysis, the selected cement industries are grouped into A, B and C according to the specific thermal energy consumption. Among the different decomposition methods, the complete decomposition approach was selected for the study, due to the inherent characteristics of equal distribution of the residual term. The natural predetermined factors selected for the decomposition model includes pollution effect, energy intensity effect, structural effect and activity effect.
A model has been developed based on system dynamic approach in order to forecast cement production and related CO₂ emissions from the ten years data of the selected cement industries in India. The credibility of the model was tested with historical data. Finally the model is modified and applied to predict cement production and CO₂ emissions in India under different scenarios up to 2030. Energy management scenario was also performed in the model to find out the reduction in CO₂ emissions.

7.2 Conclusions

The following conclusions were made based on the research work

- The energy and exergy analysis of the raw mill of the typical cement plant indicates that exergy utilisation was even worse than energy utilization. This process represents a big potential for increasing the exergy efficiency. It is clear that a conscious and planned effort is needed to improve exergy utilization in the raw mill.

- The energy analysis of the kiln emphasised the need for identifying the areas of energy saving opportunities. There are areas of serious energy losses, which lead to the drop of thermal performance of the kiln system.

- The conservation technique for improving efficiency was proposed. Waste heat recovery steam generation and secondary shell energy conservation measures were studied. Waste heat recovery steam generation unit can generate up to 7 MW of electricity.
The secondary shell concept can save up to 6.9% of thermal energy, which is equivalent to percentage margin and energy efficiency of the unit increased by 3 to 4%.

The above measures increase the available amount of energy or, in other words can decrease the fuel consumption considerably and thus decrease of CO₂ emissions.

The waste heat recovery and secondary shell concept shows a relatively remarkable improvement over the existing system. It has been suggested that waste heat recovery system must also be incorporated in the design of new industries to minimize energy consumption, manufacturing cost and improve the product quality.

The exergy analysis accounts for the operation indicating the location of energy degradation in the process. The main cause of irreversibility in the process was due to conversion of chemical energy of fuel to thermal energy in the kiln system.

It may also be concluded that the energy and exergy analysis reported in this study will provide the investigators with knowledge about how effectively and efficiently a sector uses its energy resources.

The result of decomposition analysis reveals that CO₂ emissions of Indian cement industries depend mainly on economic activity. An increase in economic growth is vital for the development of a country. The major factors that can be controlled to reduce CO₂ emissions in Indian industries are energy intensity effect and pollution coefficient effect.
Energy savings in the cement sector are possible by energy efficiency improvement and by increased use of blended cements, thereby reducing the demand for energy-intensive clinker. Blending cement with additives reduces the consumption of energy intensive clinker. However, saving potentials are very much determined by indigenous availability of resources commonly used to blend cement, such as blast furnace slags, fly ash, natural pozzolanes, etc. In order to reduce greenhouse gases emissions and to meet uncomprimissable objective of developments we need to concentrate on developing new energy policies. In this context, one policy in terms of reducing CO₂ emissions would be to enhance technical improvement that would enhance energy efficiency. Whenever feasible, energy conservation and reduction of output share of energy-intensive sectors are also important strategies for reducing energy intensity.

The forecasting analysis examined CO₂ emissions reduction potential in India’s cement industry through analysis of different scenarios of future cement output and carbon reductions. The CO₂ emissions from cement plants are dependent on many interrelated variables viz population and GDP growth rate, cement demand and production, clinker consumption and energy utilised.

The base model for projection of CO₂ emissions for the selected cement industries in India was developed and validated the model with hystorical data. The sensitivity analysis of the forecasting model was conducted and found satisfactory. Then the base model was modified and applied to project CO₂
emissions from cement production in India for a span of 21 years with different scenarios.

- For the baseline scenario the model projected that the cement production in India will reach 1106.54 MT by the year 2030. The CO₂ emissions are estimated to reach 985.38 MT by the year 2030. Cement demand projected for the year 2030 is 376.66 MT and this value is comparable to that of 387 MT in 2031 (Monica and Mukherjee, 2010).

- In the scenario-1 the population would stabilize by the year 2030. The cement demand will then be 343.19 MT, a reduction of 8.7% of the baseline scenario. It is found that the cement production decreased to 937.68 MT for the year 2030 and the CO₂ emissions reduced to 15.22% (835.42MT) compared to baseline scenario.

- In the scenario-2 the population would stabilize by the year 2020 and remain constant. It is found that cement production is projected to reach 780.35 MT by the year 2030 and the CO₂ emissions reduced to 29.44% (695.26MT) compared to baseline scenario.

- In the energy management scenario, the effect of 38% thermal energy recovered from waste heat streams and 25% of electrical energy supply to the cement plants replaced by renewable energy revealed that the CO₂ emissions in 2030 declines to 915.47 MT (7.1%) for baseline scenario, 744.15 MT (10.9%) to scenario-1 and 617.64 MT in scenario-2 (11.16%).
The combined scenario with population stabilization by the year 2020, 25% of contribution from renewable energy sources of the cement industry and 38% thermal energy from waste heat streams can reduce CO₂ emissions from Indian cement industry to approximately 37% in the year 2030. This could be a substantial lowering of greenhouse gas load to the environment.

The cement industry will remain one of the critical sectors for India to meet its CO₂ emissions reduction target. India’s cement production will continue to grow in the near future due to its GDP growth. The control of population is one of the best options to mitigate CO₂ emissions from Indian cement industries. India’s CO₂ emissions from the cement industry will rise with increased cement production, especially if there is no significant efficiency improvement in the cement production process not taken into consideration. Use of renewable energy in place of electricity is another option to reduce CO₂ emissions from Indian cement industry.

Apart from the conventional options, CO₂ capture and storage is more efficient and technologically feasible approach to further mitigate the CO₂ emissions generated during cement manufacturing process.

Significant energy savings and CO₂ emissions reduction potential of India’s cement industry is mainly attributed to the large quantity of cement production.
7.3 Scope for Future Work

- The exergy analysis of the cement plant identifies areas in the process where irreversibility exists and allows the quantification of work that result from irreversibility. If economic environment is introduced by establishing prices for these losses at various places in the process, the researchers can concentrate on the areas that are important economically as well as thermodynamically in a single step.

- It was found that around 2/3 of the CO\textsubscript{2} from a cement process comes from the actual decomposition of the raw materials. Cement processes require a high temperature energy source to drive the chemical reactions to form cement clinker. This produces an excess of energy at low temperature and results in significant sensible heat within the flue gases. This excess heat could be balanced with the sensible heat required for regenerating the solvent within a potential carbon capture plant. So researchers are recommended to make a study to forecast CO\textsubscript{2} emissions from the cement industries in India with integrated carbon capture and compare it with the results for the option without carbon capture.

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