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CO_2 emission reduction using blast furnace slag for the clinker manufacturing in Cement Industry

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The cement plant is a major CO_2 emitter during the clinker manufacturing process. CO_2 is mainly emitted at Calciner and Kiln due to calcination of raw materials and burning of fossil fuel. Worldwide several technologies and various measures have been taken for the reduction of CO_2 in cement plant i.e. efficiency improvement of thermal and electrical energy by using alternative materials etc. In India, mainly three types of cement are produced i.e. Ordinary Portland cement (OPC), Portland pozzolana cement (PPC) and Portland slag cement (PSC) and percentage clinker for OPC, PPC and PSC are 90–95%, 30–35%, 50–70%, respectively. Chemical conversion takes place during the clinker production. Limestone ($CaCO_3$) is converted into lime (CaO), $MgCO_3$ is converted to MgO and carbon dioxide (CO_2) is emitted during clinker manufacturing and burning of fossil fuel. Blast furnace slag is a waste of steel industries and it contains CaO, MgO and silicates etc. The CO_2 emission reduction and energy efficiency improvement of the clinker manufacturing unit are investigated (M/s Emami Cement Limited, Village-Risda, Suhela Road, Baloda Bazar, Chhattisgarh) during the clinker manufacturing are around 2–4% of total raw feed. Blast furnace slag is used as elective raw materials which are fed into the kiln inlet with the help of winch machine. It is converted into the clinker and reduces the CO_2 emission and fuel consumption. Blast furnace slag is already calcined due to high temperature in the furnace. The authors have investigated the CO_2 emission reduction using blast furnace slag as alternative raw material for clinker manufacturing at the earlier mentioned cement plant to conserve natural resources and also suggested the alternatives for the emission reduction using the process integration approach.

Keywords: Clinker production, CO_2 emissions, alternative raw materials, Global warming.

Introduction

Cement is widely used material and essential ingredient that can fulfil the basic requirement in our life. The cement production plants are the world's biggest greenhouse gas emitter. Worldwide cement industries contribute the largest CO_2 emissions and cause climate change. Kyoto protocol is the first international agreement about climate change in the world and last climate change summit, United Nation has decided a goal to achieve at least 50% reduction of global CO_2 emissions by 2050[1]. CO_2 contributes highest percentage for global warming phenomenon. Main strategies are to reduce the carbon dioxide emissions in cement plant in terms of fuel and energy saving, use of alternative materials, carbon capture and storage technique. Fuel and energy saving target have been achieved by the process modification or process integration and waste heat recovery system. Similarly, utilization of alternative materials can be done by the conservation of the natural resources through raw material substitute, fossil fuel substitute or use of renewable energy and the carbon capture and storage are possible by the plantation in industrial area for capturing, storing of CO_2 released from industries[2]. A huge quantity of the thermal energy required during the calcinations process results large amount of CO_2 emission. Integration for the utilization of waste is significant and effective pathway for the CO_2 emission reduction. Thus, the raw material substitute from the wastage materials enhances the thermal and electrical energy efficiency in the cement industries. This plays a vital role of energy conservation and CO_2 emission reduction. Some new policies and framework have been formed to the latest direction in the energy and environment rules. At a European level, various direction are renewed by directive 2008/98/EC[3,4]. Use of raw material substitute being already calcined in the blast furnace process reduces the virgin material requirement and greenhouse gas emission which are the main purposes of our study. Worldwide various processes for clinker manufacturing are available and among them dry process is popular etc. Manufacturing process of the cement needs 3.2–6.3 GJ amount of energy[5,6]. Cement plant is a higher energy consumption industry and demand of thermal energy is approximately 25% of the total production cost. Worldwide emissions of CO_2 were approximately 35.9 Gt in 2014. Cement plant contributes 6% of total global CO_2 emission[7,8]. A guideline of the Intergovernmental Panel on Climate Change for evaluating CO_2 emission provides emission factor and default values for all industries. At the time of clinker production scenario, CO_2 emissions are calculated by two ways: one is traditional cement production (without raw material substitute) called baseline scenario and other is with alternative raw material substitute called as alternative material scenario[9]. Various studies have been done by the scientists for CO_2 emissions in the cement plants. Some of them have shown the decreases in CO_2 emission by using alternative raw materials and fuels. Carbon budgeting have also been proposed for the whole integrated cement plant[10]. However, the energy analysis is the fundamental concept for the efficiency improvement of clinker/cement manufacturing industries and energy reduction is directly proportional to emission reduction[11]. In this investigation, the carbon dioxide emissions during the clinker production are calculated by two ways: one is traditional cement production and other is with alternative raw material substitute. CO_2 emission was reduced using blast furnace slag which remains already calcined during the blast furnace process and using alternative raw material for clinker manufacturing process to conserve natural resources[12]. Authors have also suggested reduction of greenhouse gases using the process integration approach. This research is focused on emission reduction, utilization of waste, minimization of energy requirement through the concept of conservation of natural resources.

Process description

Clinker manufacturing unit is located at Village-Risda, Suhela Road, Baloda Bazar, Chhattisgarh. It consists of preheater with cyclone, raw mill, crusher, calciner and kiln, cooler etc. It's capacity is 3200000 metric ton per year of clinker production. Raw material is sent by covered mechanical conveyors by measurement and control of feed rate to the raw mill for the preparation of raw mix and sent to the homogenising silo, then preheater tower. In this pathway, the raw materials come into contact with flue gases where moisture removal happens and then enters into the calciner. The calciner is fitted at various firing points. Flue gases of the preheater get utilized for electricity generation. Finally, exit flue gases are discharged through the stack equipped with the bag house (BH). Fig. 1 shows the clinker manufacturing plant located at Village-Risda, Suhela Road, Baloda Bazar, Chhattisgarh. Around 3 to 4% of total raw feed, blast furnace slag as alternate raw material are fed into the kiln inlet by winch machine. Blast furnace slag is already calcined due to passed in high temperature at the furnace, it is converted into the clinker. The clinker cooler recuperates heat from the hot clinker, and used for electricity generation[13]. Waste thermal energy investigations and recoveries by overall system also play the important role of CO_2 emission reductions[14,15].

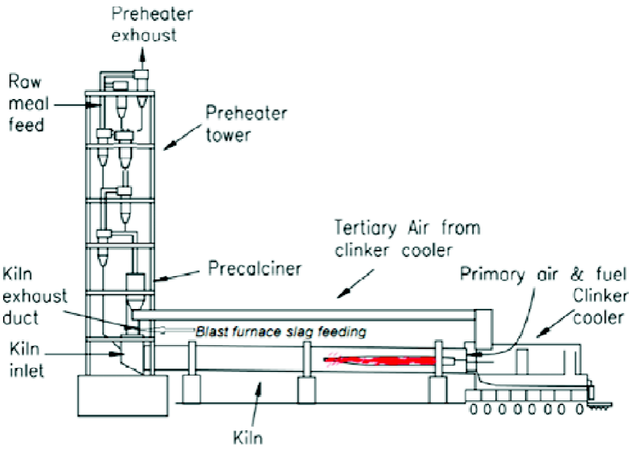

Fig. 1. Configuration of clinker manufacturing plant (Emami Cement Limited, Village-Risda, Suhela Road, Baloda Bazar, Chhattisgarh).

Methodology

Clinker manufacturing process traditionally and with alternative material are divided into 4 stages, i.e. mining with transportation, electricity consumption during raw material preparation, calcinations and transportation of slag.

(a) CO_2 emission assessment by traditional clinker manufacturing process:

(i) Emissions from clinkerization:

Carbon dioxide is mainly emitted during chemical conversion procedure. The Revised 1996 IPCC guidelines provide a common route to evaluate carbon dioxide emissions from the process. $CaCO_3$ is heated and finally lime and carbon dioxide are generated. The stoichiometric is as follows:

$CaCO_3 + \text{Heat} \rightarrow CaO + CO_2$

The emission factor for clinker is as follows:

$EF_{clinker}$ = fraction of CaO×(44.01 g/mole CO_2/56.08 g/mole CaO)

$EF_{clinker}$ = fraction of CaO×0.785

As per Intergovernmental Panel on Climate Change, fraction of lime into clinker is 64.6%. This results in an emission factor of 0.507 tons of carbon dioxide/ton of clinker, as illustrated below:

$EF_{clinker} = 0.646 \times 0.785 = 0.507$

However, one day clinker production is 10883 tons.

$PE_{clinker}$ = 0.507×10883 tons of carbon dioxide/day

$PE_{clinker}$ = 5517.68 tons of CO_2/day

Therefore,

CO_2 emissions from clinkerization are 5517.68 tCO_2/day.

(ii) Emission from mining activity:

During the mining activity for quarrying and transportation, heavy machinery/vehicle are used and it consumes the large quantity of diesel as a fuel of vehicle. Therefore, CO_2 emissions from mining activity are estimated by combustion of diesel and estimated as follows:

$PE_{Mining} = EF \times DC$

where,

PE_{Mining} = (tCO_2/day) – Emissions by combustion of diesel (tCO_2/day)

EF = 2.6972 tCO_2/liter – Emission factor for diesel

DC = 9.644 KL/day – Diesel consumption (KL/day)

Therefore,

PE_{Mining} = 26.011 tCO_2/day

(iii) Emission from the electricity:

Emissions by electricity consumption (grid) during the process are estimated by UNFCCC methodology "Tool to calculate emissions from electricity consumption" and calculated by using the following formula:

$PE_{grid} = EC \times EF \times (1 + TDL)$

where: PE_{grid} **=** (tCO_2/day) – CO_2 emission from electricity

EC = 325.16 MW, electricity consumed in Megawatt (MW) from the process.

EF = 0.82 tCO_2/MW [Central Electricity Authority India, CO_2 emission factor for grid]

TDL = 4.85% [Average losses by grid/day/year]

So,

PE_{grid} = 279.56 tCO_2/day

(b) CO_2 emission assessment during clinker manufacturing using blast furnace slag:

(i) Emissions from clinkerization:

Emission factor of clinker,

$EF_{clinker}$ = 0.507 tCO_2/ton of clinker

One day clinker production is 10883 tons. Blast furnace slag is used as alternate raw material which contains 1–2% moisture and it is already calcined due to passed in high temperature at blast furnace process, directly fed into the kiln inlet with the help of winch machine and converted into the clinker. One day slag used quantity is 219 tons, after less the moisture it is around 215 tons. So CO_2 emission in the form of clinker production 10883 – 215 = 10668 ton.

$PE_{clinker}$ **=** 0.507×10668 tons of CO_2/day

$PE_{clinker}$ = 5408.67 tons of CO_2/day

Therefore, CO_2 emissions from clinkerization are 5408.67 tCO_2/day.

(ii) Emissions from mining:

Clinker manufacturing approximately requires 156% limestone, so for 10883 tons clinker manufacturing, approximately 16975 tons limestone is required. But by using of the blast furnace slag, it is less by 215 ton×1.56 = 335 ton/day. So total limestone requirement is 16640 tons, then the diesel consumption is also less. Total diesel consumption is 9.46 KL. The CO_2 emissions are estimated:

$PE_{Mining} = EF \times DC$

where,

Table 1. The CO_2 emissions from both the processes

Sr. No.	Stage (Emissions from)	CO_2 emission by traditional clinker manufacturing (tCO_2/day)	CO_2 emission during clinker manufacturing using blast furnace slag (tCO_2/day)
1.	Clinkerization	5517.68	5408.67
2.	Mining	26.01	25.52
3.	Electricity consumption	279.56	274.12
4.	Transportation	–	1.36
5.	Total	5823.25	5709.67

EF = 2.6972 tCO_2/ltr – Emission factor for diesel

DC = 9.46 KL/day – Diesel consumption (KL/day)

Therefore,

PE_{Mining} = 25.52 tCO_2/day

(iii) Emissions from electricity consumption:

Using blast furnace slag as alternate raw material, consumption of the electricity is less during crushing, Stacker and Reclaimer, conveying, raw mill grinding etc. Grid emission factor formula is:

$$PE_{grid} = EC \times EF \times (1 + TDL)$$

where,

PE_{grid} **=** (tCO_2/day) – CO_2 emission from electricity

EC = 319.14 MW – Electricity consumed by process

EF = 0.82 tCO_2/MW [Central Electricity Authority India, CO_2 emission factor for grid]

TDL = 4.85% [Average transmission and distribution losses in the grid/day or/year]

Therefore,

PE_{grid} = 274.12 tCO_2/day

(iv) Emission from transportation:

As blast furnace slag is transported from Siltara Industrial Area, Raipur (Chhattisgarh) to Emami Cement Limited, Village-Risda, Suhela Road, Baloda Bazar (Chhattisgarh), it travels distance up and down approx. 170 KM and for 220 tons slag transportation, 505 liter diesel is consumed. Transportation involves burning of fuel, resulting CO_2 emissions and emissions are estimated as follows:

$$PE_{Transportation} = 2.69 \times 0.505 = 1.36 \ tCO_2/day$$

Table 1 shows the CO_2 emissions from both the process.

Results and discussion

Limestone is the best source of $CaCO_3$ for clinker manufacturing. Limestone represents about 156% of the clinker composition by mass. The cement plant is the major greenhouse gas emitter in the world. The potential advantage of using blast furnace slag as substitute raw material for clinker manufacturing allows remarkable savings of CO_2 emissions and conservation of the natural resources. A comparison of CO_2 emission during the both process shows the 113.58 tCO_2/day saving using slag as alternate raw material. It also represents 0.01 tCO_2/ton of clinker saving. In Emami Cement Limited, clinker manufacturing capacity is 3200000 ton/year. Traditionally in clinker manufacturing process, 1712248 tCO_2 is emitted, but by using blast furnace slag as alternate raw material, CO_2 emission is reduced to 1678852 tCO_2. So, total CO_2 emission reduction is 33396 tons per year. Fig. 2 shows the CO_2 emission using blast furnace slag.

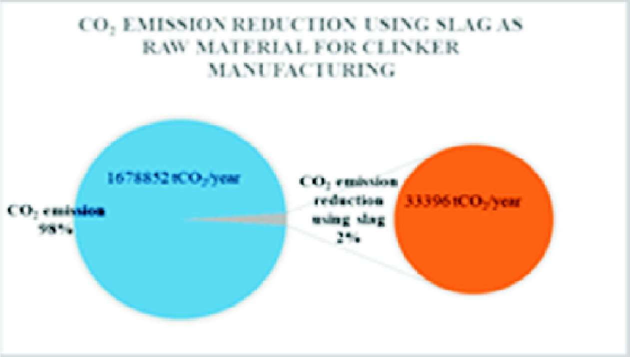

Fig. 2. CO_2 emission using blast furnace slag.

The virgin material requirement becomes also less by using slag for clinker manufacturing and also helps the utili-

Table 2. The environmental benefits comparison

Parameters	Traditional clinker manufacturing	Clinker manufacturing using blast furnace slag	Total savings/year
CO_2 emission	1712248	1678852	33396 tCO_2
Virgin material	4992000	4836250	155750 tons
Electrical energy	95561 MW	94091 MW	1470 MW
Utilization of waste	0	63220	63220 tons

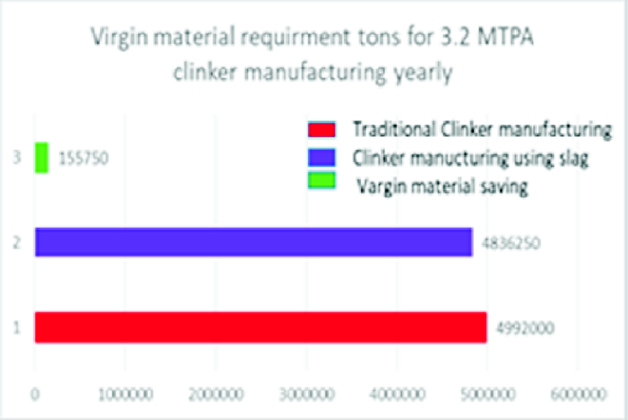

Fig. 3. Virgin material requirements and saving during clinker manufacturing.

zation of waste and conservation of natural resource. Fig. 3 shows the virgin material requirements and saving during clinker manufacturing. Table 2 shows the environmental benefits comparison.

Conclusions

Cement production has the global impact of greenhouse gas emission, the higher thermal energy demand and virgin material requirement. The total CO_2 emission reduction was found as 33396 tCO_2/year by using slag as raw material substitute yearly. This also reduces the electrical energy consumption and virgin raw material requirement. In addition, the overall 155750 ton per year of limestone mining saving (conservation of natural resources) was done and also utilization of waste of the blast furnace slag was made, which directly get converted into the clinker through kiln and it is the part of Portland cement. Also quality of clinker does not change as per the BIS norms. 63220 ton per year of blast furnace slag waste is utilized for the clinker manufacturing in Emami Cement Limited. The calcined blast furnace slag is input to the kiln as raw material substitute for clinker manufacturing. This study efficiently showed the CO_2 reduction through process optimization and utilization of waste.

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