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Thermal energy consumption and its conservation for a cement production unit

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Abstract

The manufacturing of cement is an energy-intensive industrial process which requires huge amount of heat to be supplied at a higher value of temperature. In this paper, use of the thermal energy at different sections of clinker manufacturing in cement industry, losses and thermal energy savings have been reviewed and presented. A detailed analysis of pre heater, kiln & clinker cooler was done and possible approaches of heat recovery from major losses have been discussed for technological opportunities to maximize use of waste heat recovery. The amount of CO_2 emission reduction has been presented along with the payback period for energy saving measures. The energy efficiency during clinker formation was 58.67%. Unidentified losses of 5.74% were observed for the system. The energy of 16.34% was conserved by using the waste heat recovery system for electricity generation and 1.15% was conserved by using the pyro jet burner and gunning castable of 250 mm as per our design data for the cement production unit. Overall, 75.17% of heat was utilized during the process and 24.83% was lost through stack and other activities.

Keywords: Clinker, Cement production, heat losses, thermal energy conservation

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1. Introduction

Cement is essential ingredients that can fulfil the basic requirement in our day to day life [1] Cement requirements include the construction of housing and infrastructure crucial to mankind and play an essential role in the global construction industries [2]. The cement production is accompanied by the higher consumption of energy (thermal and electricity), calls for the need for large quantities of resources and thus, causes significant impact on the environment [3]. About 11% of total energy consumption in the industries is accounted only for the cement industry [4]. A large amount of energy is consumed in the cement manufacturing plant especially during the calcination process [5]. As a result, the substantial amount of carbon dioxide (CO_2) emits through the calcination process [6]. Again, the major part of the energy is utilized in the cement production as waste heat.

Therefore, the integration of the utilization and recovery of waste heat is an essential and effective way for the reduction of the energy that is required to capture CO_2 [7]. Thus, the heat recovery from the waste heat can improve the energy utilization efficiency in cement industries [8]. This phenomenon does not only play a vital role in the conservation of energy, but also the reduction of the CO_2 emission. Accordingly, some new scenario and policies have been formed as a result of the latest trends in environment, energy and waste legislations. At a European level, the fundamentals and the definitions regarding pollution control were renewed by the waste framework directive 2008/98/EC [9].

The increase in the efficiency of the energy and the reduction in the emission of greenhouse gas are the key objectives of our study. The cement production unit has a higher potential of managing all these tendencies as an integrated system to save energy, the reduction in the emission of greenhouse gas and the recovery of the waste materials. That leads the sector of the cement production unit to focus on the diversification of the energy sources. The manufacturing process of cement is very complex consisting of the raw materials of varying properties, several methods for the pyro-processing and different variety of resources. Approximately, the process needs 3.2-6.3 GJ amount of energy and near about 1.7 tons of raw materials (mainly limestone) per ton of the clinker generated [10]. Being an energy-intensive industry (cement production), the demand for thermal energy can be approximately about 20-25% of the total cement production cost [11]. The kiln used in the cement industries has a lifetime of 30-50 years [12]. The few kilns have been rebuilt to meet the needs of the European Union (EU) on the emission of the pollutants and the technical standards [13].

The consumption of the energy in the cement plant is mainly due to raw mill, cooler, pre-heater and rotary kiln [14]. The total energy loss of the plant is generally accounted for about 35-39% of the total energy input [15]. This energy loss is due to the loss from the exhaust gas, cooler and the radiation heat transfer from the kiln cell. Thus, the main focus should be given on improving the rate of energy utilization in the cement industry [16]. Many research works have been investigated by the scientists to propose some theoretical methods for the analysis of the reduction of energy loss in the cement plants. Some of them have shown decrease in the energy consumption of the raw mill by increasing the ambient temperature and decreasing the moisture content of the materials [17]. Some researchers have used heat recovery device on the surface of the kiln and used waste heat for the pretreatment of raw materials [18]. Consequently, the cement industry requires the proper management of energy and saving measures. Energy auditing measures has also been proposed in the published work of literature. Those include the replacement of the lower efficiency types of equipment with the efficient one, the reduction in the heat losses from the kiln cell, preheater, clinker cooler and cyclones [19].

Moreover, the energy analysis is the basic approach which can be used for the improvement in the energy efficiency of the cement industry [20]. In this study, the thermal energy losses from the kiln, preheater and the clinker cooler were calculated to investigate the energy efficiency of the cement production unit. The configuration of the existing cement production unit of Emami Cement Limited, Baloda Bazaar, Chhattisgarh was used for this study, having a clinker production of about 32,00,000 tons per year and 30,00,000 tons per year for cement. This investigation aimed at the utilization of waste heat through the concept of energy conservation.

2. Process Description

The reference cement plant is the Emami Cement Limited, Baloda Bazar (Chhattisgarh), India. It is based on the dry kiln process, which consists of a six-stage cyclone preheater, calciner with tertiary air duct, rotary kiln and clinker cooler. The raw material is transported to the kiln feed from the homogenising silo. From the kiln feed bin, the materials get transported through the mechanical conveyors with the measurement and control of the kiln feed rate. The pre-heating of the equipment comprises of the multi-stage cyclone system connected with gas ducts and mill chutes, the down comer duct and the induced draught (ID) fan. In cyclone pre-heater system, an efficient heat transfer takes place to finally disperse the raw material particles, when they come into contact with the hot gases from the kiln.

The raw materials, which are fed into the top stage gas duct, carried by the hot gas stream into the cyclone. The material gets separated from the gas in cyclones and then travel downwards through the mill, the chute is discharged into the next lower stage gas duct. In this way, the material comes into contact with the high-temperature gases, gets pre-heated and partially calcined and then enters to the pre-calcinator. The calciner will provide sufficient residence time for the efficient combustion of the convection coal/pet coke. The calciner is equipped with the multi firing points for the above-said requirements. The preheater is equipped with the ID fan for ensuring counter-current heat transfer from the kiln through the calciner and the series of cyclones. The exit hot gas from the preheater gets utilized for the waste heat energy recovery system, further drying of raw material takes place in raw mill and drying of coal / pet coke happens in coal mill. Fig. 1. shows the configuration of the cement manufacturing plant (Emami Cement Limited, Baloda bazar (C.G).

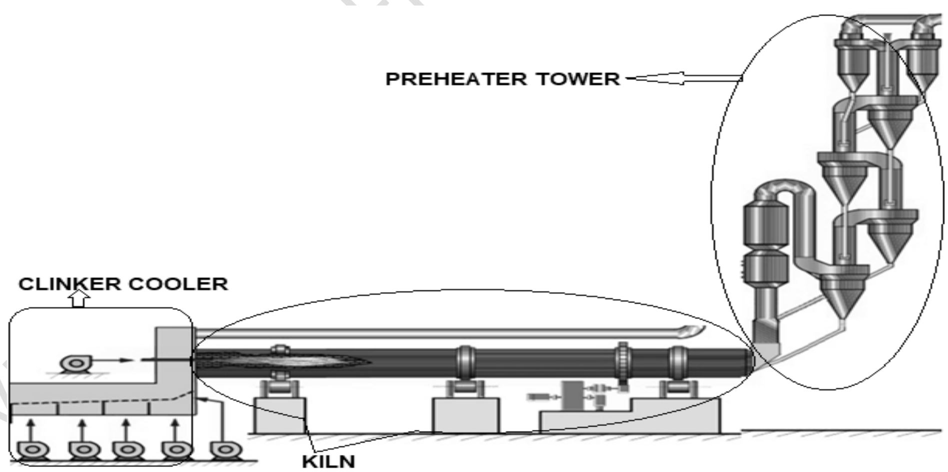

Fig. 1. Configuration of the cement manufacturing plant (Emami Cement Limited, Risda, Baloda Bazar, Chhattisgarh, India).

In the pre-calcinator, further calcination takes place by firing pulverised coal/pet coke to provide the necessary heat in the kiln and the pre-calciner located at the bottom of the pre-heater. The calcined material (93 to 94%) from the bottom stage of the cyclone is fed to the kiln. The feed travels down as the kiln rotates. The complete chemical reaction takes place when the material reaches the burning zone and cement clinker is formed.

The clinker cooler recuperates heat from hot clinker, which reduces the consumption of fossil fuel and other fuels required for the cement clinker making. It is a spillage-free and high-efficiency third-generation clinker cooler with roller crusher, ESP (electrostatic precipitator) including fan and stack.

The vital part of this study is to develop an understanding of the cement production plant. This understanding extends to the various types of equipment used during the process. The authors have estimated thermal energy losses, which would lead to the further utilization of waste energy. The heat losses through the preheater, calciner, kiln, tertiary air duct and kiln cooler were investigated in detail using the available resources in Emami cement plant.

3. Materials and Methods

Thermal energy balance in cement plant is a practical method to determine the energy use during the process by various equipment operational activities with the source of losses, considering design parameters of the cement plant by keeping adequate safety factors of calculation and the physical properties of equipments can be found in Perrys hand book. It covers the following points:

(1) Normal heat consumption by different equipments

(2) Are heat balance are normal in operation?

(3) Measures in order to improve the heat economy for its conservation

Thermal energy balance does not only include calculation part. Its determination includes the following steps.

3.1. Preparation

A careful planning and preparation are recommendable

(1) What has to be measured with the location of sampling points

(2) Duration of test

(3) Frequency of measurement

(4) Log sheet for manual and electronic recordings

(5) Calibration and checks of instruments

(6) Flow information among the test team

(7) Instruments i.e. Pitot tube, U-tube manometer, mobile thermometer, thermocouple, radiation pyrometer, orsat / gas analyzer, sampling equipment for gas, sampling equipment for solids (eg. clinker, dust etc.)

3.2. Execution

For a good test, it is important that the plant is in smooth operation during the test. Variation in the operating parameters should be avoided. It is recommended to check all the necessary parameters during the test before going for test and evaluation.

3.3. Methods of Calculations

Assumptions: Following assumptions are made during the test

(1) Raw materials / fuel properties, composition & feed rate are constant.

(2) The system is assumed to be in steady state condition.

(3) Kinetic & potential energy changes of input or output materials are negligible.

(4) Calculation for the heat is $Q = m*Cp*\Delta \mathbf{T}$.

Where Q = Heat energy (Joules), m = mass of substance (Kg), Cp = Specific heat constant, and ΔT= temperature difference. Radiation and convection heat loss in pre-heater with calciner, kiln, tertiary air duct etc. are calculated as follows.

Radiation losses are calculated by Stefan – Boltzmann law, Radiation loss = $\sigma *\varepsilon*A*\Delta T^4$

Where, σ = Stefan – Boltzmann constant, $5.67*10^8$, ε = emissivity of metal, A = surface area (m^2) and ΔT = Temp difference.

Convection loss = $h_a*A*\Delta \mathbf{T}$, **w**here h_a = convective heat transfer coefficient, A = surface area, $\Delta \mathbf{T}$ = temperature difference

4. Results

4.1. Radiation and Convection Heat Losses

4.1.1. At pre-heater and calciner

In the preheater and calciner, the prepared raw mixture consisting of limestone, iron ore, bauxite, etc. gets dried with the internal passage of the flue gases. The prepared mixture was passed through the six-stage cyclone preheater (from A to F) and the calciner. The flue gases were generated with the burning of fossil fuel in the calciner and kiln. As a result, the heat is lost through the preheater and calciner via the radiation and convection heat transfer. At various points of the surface of the cyclone & calciner, temperature was measured with the help of the pyrometer. Oxygen content in the flue gas was measured at the inlet & outlet of the pre-heater with the help of Orsat / gas analyzer. Fig. 2. indicates the radiation and convectional heat losses with respect to the surface area along the preheater and calciner.

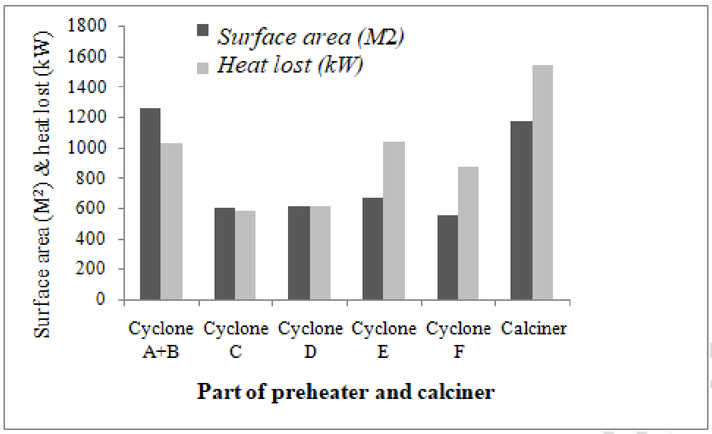

Fig. 2. Heat losses with respect to the surface area along the preheater and calciner.

From the Fig. 2, it was found that the value of the energy losses becomes less in case of the cyclone than the calciner. The thermal energy losses are not uniform and vary concerning the surface area of both the preheater and the calciner [21]. The radiation and convection heat losses are less in the case of cyclones from A to F due to the preheating of the raw mixture. The actual burning of the coal/fuel takes place in the calciner. That is why the radiation and convection energy losses are more from calciner and nearby equipments (cyclone A and B). The majority of the used fuel is consumed in the calciner using the advancement of the recent technology. The raw mix can be calcined 93 to 94% in the calciner before reaching to the kiln inlet. This result in the lower consumption of the energy per ton of the clinker produced in the cement production unit [22]. In general, the pyroprocessing section is considered as the nucleus of the cement production unit and nowadays, the designs of the variety preheater and diverse precalciners have come into the reality.

4.1.2. At kiln

In the kiln, hot raw mixture comes from the pre-heater and calciner. It again gets heated by the energy produced from the burning of the fuel, resulting in more energy losses in the form of radiation and convection. These thermal energy losses can be observed from the walls of the kiln which is about 86 m long. The energy losses were studied at a distance of every 1 m along the wall of the kiln. Temperatures were measured outside the surface of the kiln with the help of pyrometer. After the test, losses are calculated with the help of Stefan-Boltzmann law and convection law formula. Fig. 3. Shows the radiation and convection heat loss profile along the kiln.

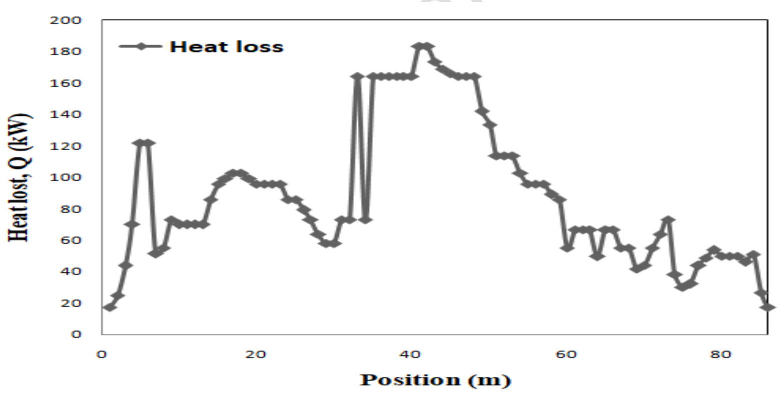

Fig. 3. The radiation and convection heat loss profile along the kiln.

Initially, the thermal energy losses inside the kiln are more because of the more intensity of the flame generated. Further, the losses of energy get reduced along the length of kiln due to the possibility of the reduction in the thickness of inside coatings/quality. The cement production consists of different processes such as crushing and grinding of the raw materials, their mixing and burning in a kiln at a temperature of 700^{o}C to 1,450^{o}C [23].

The decomposition reactions, transformation and formation of the new phases occur during the heating up and burning process in the kiln. Around 70-80% of the overall energy in the form of thermal energy is consumed in the cement production plant. The residual (20-30%) energy is in the form of electrical energy. Moreover, the thermal energy represents about 90-95% of the required energy while the electrical energy counts only for 5-10%. This is the reason that the potentials for the reduction of the specific heat consumption in the cement production plant deserve the priority. From Fig. 3, it can be concluded that the heat loss profile is not uniform along the total length of the kiln. It was found to vary with the increase in the length of the kiln. The heat loss was more at a distance of 40 m. Again, it was decreased with the increase in the length of the kiln cell.

The warm surface of the kiln is the main source for the recovery of the waste heat, in which the thermal energy loss takes place by convection and radiation, which is around 15-16% of the total input energy. The utilization of the secondary cell on the surface of the kiln can efficiently reduce this loss. This can further reduce the consumption of the fuel and enhance the overall system efficiency by 5% approximately [24].

Previously, the kiln used to be operated for 9,700 tons per day with the consideration of 330 days running. It means that it is capable of producing 3.20 million tons of clinker per annum. Further, the kiln throughput has been increased to a value of 11,400 tons per day, to enhance the clinker capacity. Following process optimizations, modifications were carried out in order to achieve this without impacting the life of plant and machinery. To reduce the requirement of air, the low primary air burner (pyrojet burner) has been installed for the reduction of the total Volume of air requirement by increasing the pressure of 400 to 900 mbar which leads to increase in the rate of clinker production.

It can also reduce the consumption of the specific coal by producing the sharp flame at an increased production of clinker. To increase the total effective volume of the cooler, the industry has started to apply the gunning castable of 250 mm. 250 mm brick along with 100 mm insulation was used previously in the cement production unit. This increases the effective volume of the clinker cooler which increases the kiln productivity. The heat input from the fuel for the production of clinker (9,700 tons per day) is 2,912 kJ/kg of clinker as per the design considerations. But, the value for the heat input from the fuel for the production of 11,400 tons per day of clinker was found to be 2,879 kJ/kg of clinker. This information is very important and interesting to explain the reduction of thermal energy losses across the system. Energy efficiency of 1.15% was calculated as per our design data for the cement plant unit. Around 54.5 KJ/kg of clinker of thermal energy was lost at kiln surface through radiation & convection, so secondary shell system with thermal insulation has been proposed to reduce the losses.

4.1.3. At tertiary air duct

In tertiary air duct, there is a need to supply the additional hot air (tertiary air), which comes from the clinker cooler [25]. Sometimes, the clinker particles in air settle inside the duct. Thus, it is necessary to understand the processes that take place in the kiln for the optimization of operating conditions. The thermal energy also exits along the tertiary air duct at a varying temperature. Temperatures of the outside surface of tertiary air duct were measured. Inlet and outlet of the duct gas temp were also measured. Radiation & convection losses were calculated by the above formula. Fig. 4. shows the heat loss profile along the tertiary air duct.

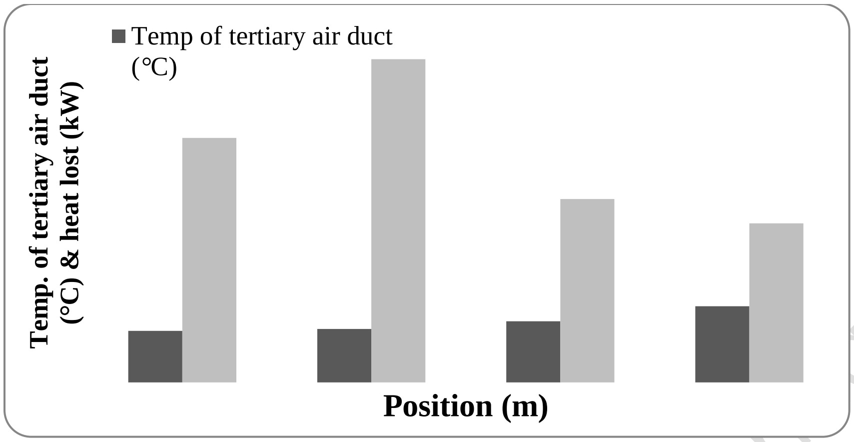

Fig. 4. The heat loss profile along the tertiary air duct.

The heat loss was found to be more at a position of 63 m, while it got decreased further at a relative value of the temperature. The thermal energy losses from the different sections of the system affect the consumption of the fuel by different degrees.

4.1.4. Clinker cooler

The maximum recovery of the energy from the clinker cooler demands the air quantities for combustion from a cooler to have the highest possible temperature [26].

It is needed for the clinker to remain in the cooler for a specific length of time to get a maximum clinker cooling with the lowest cooling volumes of the air. The specific consumption of heat is the main indicator for the measurement of the thermal energy consumed in the generation of the clinker and for the optimum performance of the cooler [27]. The analysis of the energy allows the identification of the heat losses in the clinker cooler of the cement production unit [28]. Determination of losses involves the ambient air temp, measurement the value of the total cooling air, false air supplied to the system as input and secondary air output, tertiary air inclusive dust, cooler middle air etc. From the obtained results, the total heat input was 1585.2 kJ/kg clinker whereas the heat output value is less by 11.5 kJ/kg of clinker. It results in the generation of 0.7% of losses while studying the heat input and heat output across the clinker cooler.

4.1.5. Overall radiation and convectional thermal energy losses in the cement production unit

Fig. 5. shows the overall radiation and convectional heat losses of the cement production unit.

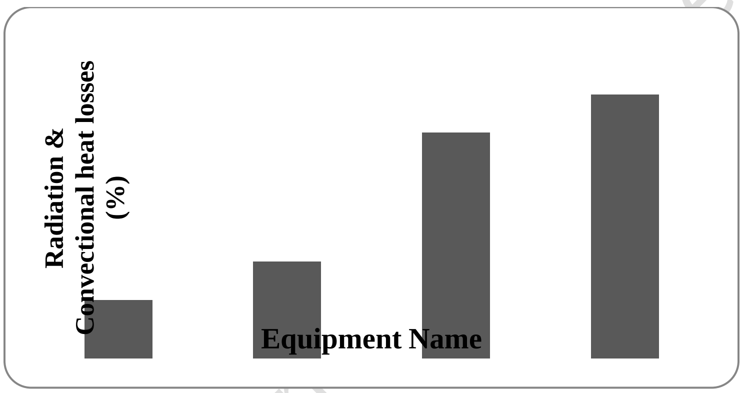

Fig. 5. Overall radiation and convectional thermal energy losses of the system.

From the observed results, it was concluded that the percentage of the heat losses was more from the kiln surface comparing to the heat losses from the six-stage preheater, clinker cooler and the tertiary air duct. In case of our studies, 4.5% of total thermal energy losses were found through radiation and convection, where 41% from the surface of the kiln, 35% from the pre-heater, 15% from the cooler and around 9% from the tertiary air duct.

4.2. Thermal Energy Balances Across The Cement Production Unit

Following equations were used to calculate the heat balance.

Heat input

(1) From the fuel, Q = CV*X, Where CV is net calorific value and X is fuel consumption.

(2) From cooling air, kiln feed, primary air and Sensible heat in fuel, all were calculated as per the following formula, $Q = m*C_p*\Delta\mathbf{T}$, Where, m is mass or amount, C_p is specific heat coefficient and $\Delta\mathbf{T}$= temperature difference

Heat output

(1) Heat for clinker formation of four clinker phases such as tricalcium silicate (C_3S), di calcium silicate (C_2S), tri calcium aluminate (C_3A) & tetra calcium alumina ferrite C_4AF were calculated based on Bouge calculation using the clinker analysis data of the plant and the heat used was estimated for the clinker formation.

(2) Heat for moisture removal was calculated as Q = m*L, where m is mass and L is moisture content. Heat for others purpose were calculated by $Q = m*C_p*\Delta\mathbf{T}$.

Whole system was investigated to calculate the energy efficiency of the plant. The heat input for the whole system was calculated as 2,965.6 KJ/kg of clinker. Unidentified losses of 5.74% were found as the heat output value, less by 170.20 KJ/kg of clinker produced. Therefore, the overall energy efficiency was calculated as η=100*(clinker formation energy/total input energy). It has been calculated as 58.67%.

Table 1. Thermal Energy Balances Data for The System

	Heat, KJ/kg of clinker	% of the total heat
Input		
Heat input from the fuel	2881.8	97.17
Heat input from cooling air	30.4	1.03
Heat input via kiln feed	48.1	1.62
Heat input from primary air	1.9	0.06
Sensible heat in fuel	3.4	0.11
Total	**2965.6**	**100.00**
Output		
Heat of clinker formation	1740	58.67
Heat output via kiln exhaust gas	441.7	14.89
Heat output via hot clinker temp.	94.3	3.18
Heat output via cooler middle air	369.6	12.46
Heat loss due to incomplete combustion	5.2	0.18
Heat output from kiln feed water evaporation	4.6	0.16
Heat output via dust loss	7.2	0.24
Heat output through radiation and convention	132.8	4.48
Unidentified losses	170.2	5.74
Total	**2965.6**	**100.00**

Table 1 shows the thermal energy of 1.15% conserved by using the pyro jet burner and gunning castable of 250 mm as per our design data for the cement production unit.

Thermal energy of 696 Kcal/kg or 2,912 KJ/kg is required for the running full capacity of plant, but 688 Kcal/kg or 2,879 KJ/kg is consumed during the operation. Total 8 Kcal/kg or 33 KJ/kg thermal energy are saved/kg of clinker manufacturing. Total 11,400 ton clinker manufacturing per day amounts to 37,62,000,00 KJ/d or 8,99,13,957 Kcal/d thermal energy saving.

Coal as fuel was used and its calorific value is approximate 4500 Kcal/kg, around 20 MT of fuel was saved.

Cost of the coal is Rs. 4000/MT, cost saving is around Rs. 80000/d.

So every year saving is = 80000*330 or 26400000 or 2.64 crore/year

4.3. Waste Heat Recovery System for Electricity Generation

Exit heat from the clinker cooler and kiln, preheater exhaust gas utilized with the help of waste heat recovery boiler (AQC and SP boiler) for the electricity generation is called waste heat recovery (WHR) system. The exhaust gas from the kiln, preheater is at 257^{o}C and the temperature released from the clinker cooler is 422^{o}C, are passed through waste heat recovery boiler (WHRB), where water is circulated in the tubes.

The latent heat of the hot gases is transferred to the water and converted into steam. Then steam is fed to the turbine through pipeline and rotates at high speed, drive the generator to rotate and finally electricity is generated. Table 2 shows the thermal energy balances of the waste heat recovery boiler for electricity generation.

Table 2. Thermal energy balance across the waste heat recovery boiler for electricity generation

System	**Heat output (KJ/Kg)**	**Heat used for WHRS for power generation (KJ/Kg)**	**Heat lost through stack (KJ/Kg)**	**% of the total waste heat recovery**
Kiln exhaust gas	441.7	208.8	232.9	43.08
Cooler middle air	369.6	275.9	93.7	56.92
Total	**811.3**	**484.7**	**326.6**	**100.00**

By waste heat recovery system, 13.14 MW/h of electricity has been generated.

Power generation through waste heat = 13,100 Kwh*24 h*330 running days per every year = 103,752,000 Kwh/year.

Unit price in Chhattisgarh state of India is Rs. 5 /Kwh. So, total of 51,87,600,00 Rs./year or Rs. 51.876 crore/year can be saved.

Cost of the WHRS of 15 MW Power plant is Rs. 10 Crore/MW and installed WHRS power plant capacity is 15MW, so total cost is Rs. 150 crore.

So pay back of system was estimated as follows:

Payback period = Implementation cost / Cost of saving

Payback period = 150/ 51.876 = 2.89 or 2.9 years or 35 months.

Total energy conservation cost (Rs.) means energy was conserved by using the pyro jet burner and gunning castable of 250 mm as per our design data for the cement production unit and through waste hear recovery power plant is 2.64 + 51.876 = 54.5 crores/year

The input heat energy is 2965.6 KJ/kg to the overall system. Table 3 shows the thermal energy utilized and not utilized across the whole system.

Table 3. Thermal Energy Used (Heat utilization) Across The Whole System

	Heat, KJ/kg of clinker	**% of the total heat**
Heat Used		
Heat of clinker formation	1740	58.67
Heat used at kiln exhaust gas form waste heat recovery boiler power generation	208.85	7.04
Heat used at cooler middle air form waste heat recovery boiler power generation	275.95	9.3
Heat output from kiln feed water evaporation	4.6	0.16
Total	**2229.4**	**75.17**
Heat lost and Unidentified loss		
Heat out through kiln stack	232.88	7.85

Heat out through cooler stack	93.68	3.16
Heat output via hot clinker temp.	94.3	3.18
Heat loss due to incomplete combustion	5.2	0.18
Heat output via dust loss	7.2	0.24
Heat output through radiation and convention	132.8	4.48
Unidentified losses	170.2	5.74
Total	**736.26**	**24.83**

4.4. CO_2 Emission Reduction From Waste Heat Recovery System for Ericity Generation and Their cConsumption for Various Cement Manufacturing Processes

Emission occurs by electricity consumption by grid during the manufacturing process.

The emission factor for grid:

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

Where, PE_{grid} = (tCO_2 / year), CO_2 emission from electricity.

EC = 13.1MW/h, Electricity generated and consumed by process

EC = 13.1MW*24 h*330 d running d/year, EC = 1,03,752 MW/Year

EF = 0.82 tCO_2/MW, CO_2 emission factor for grid, (CEA, Default value for India)

TDL = 4.85 %, avg. Transmission & Distribution losses in the grid/year.

Therefore, PE_{grid} = 89,202.85 tCO_2/year.

Generated power from WHR system is used instead of grid, so the total CO_2 emission can be reduced by using waste heat recovery. Otherwise power plant is needed for electricity generation and its consumption for various cement manufacturing process which can emit 89,202.85 tCO2/year.

5. Discussion

5.1. Overall Radiation and Convection Thermal Energy Losses.

Engin and Ari (2005) [29] reported the possible approaches for the heat recovery of dry type cement production unit. It was found that the total energy loss of a cement production unit was approximately 40% of the total heat input. Around 19.15% of the heat losses were from the hot flue gas, 15.11% is due to the heat loss from the surface of the kiln and 5.61% from the cooler stack [29]. But, it is possible to recover 15.6% of the heat using the design of the proper heat recovery. In case of our studies, 4.5% of total thermal energy losses were found through radiation and convection, where 41% from the surface of the kiln, 35% from the pre-heater, 15% from the cooler and around 9% from the tertiary air duct. All these data were collected while working in the Emami Cement Limited, Baloda Bazar, Chhattisgarh, India. Sogut et al. (2010) [30] developed a mathematical model for examining the efficiency of a heat recovery unit for the rotary kiln. From the observations, it was concluded that 73% of the waste heat can be recovered with the use of proposed geometry of the heat exchanger. Karamarkovic et al. (2013) [31] observed the heat losses from the rotary kiln, exhaust gases and it was found to be 26.35% and 18.95% of the total input energy to the system. According to them, the heat losses can be reduced with the use of the annular duct type of the heat exchanger [31].

The implementation of such a heat exchanger in the system can reduce the fuel consumption of the kiln by 12% and enhance the energy efficiency to 3.81%. Luo et al. (2014) [32] proposed a unit of thermoelectric waste heat recovery for the production of the electricity using a temperature difference between the surface of the kiln and the ambient temperature. The hot surface of the kiln is another source for waste heat recovery system. The use of secondary shell on kiln surface can significantly reduce this loss. This will reduce the fuel consumption and increase the overall system efficiency and also can be used for waste heat recovery based electricity generation [35].

The waste heat in a rotary kiln can be recovered by using a predicted model of possible power generation with dimensions of 5.5 m in diameter and 86 m long. Approximately 300 kW of electricity will be produced for the proposed unit which nearly corresponds to 30-35% of the heat loss from the surface of the kiln.

5.2. Waste Heat Recovery Based Power Plant

Thermal energy which was wasted through pre heater tower and clinker cooler are captured and utilized for pre heating and waste heat recovery based electricity generation system. This is a very cost effective process and environmental benefit too. Thermal energy waste through pre heater tower and clinker cooler was converted into electricity and reduces the electrical energy demand of the plant [34]. Heat can be captured and utilized for preheating & electricity generation, the thermal energy losses were captured by WHRS for power generation. This system converts the available waste thermal energy to electricity, which in turn reduces the demand of electrical energy of plant by grid. At waste heat recovery based power plant, 13.14 MW/hr of electricity was generated by the WHR System with simple payback period of 35 months.

5.3. Thermal Energy for Clinker Formation

The overall energy efficiency for the clinker manufacturing was calculated as 58.67%. Clinker manufacturing system operating at full capacity gives an efficiency of 55% based on the dry process methodology. The overall efficiency of the clinker manufacturing through process optimization was good and improved by recovering losses [35].

Thermal energy of 1.15% was conserved by using the pyro jet burner and gunning castable of 250 mm as per our design data for the cement production unit. This will lead to saving of cost around Rs. 2.6 crores through the process in every year.

5.4. CO_2 Emission Reduction

IPCC guidelines for evaluating CO_2 emission provide emissions factor and default values for all industries. Many reports have been investigated by the scientists for the investigation of CO_2 emissions in the cement plants. Energy analysis is the basic approach to improve the efficiency and its conservation is directly proportional to CO_2 emission reduction [36].

CO_2 Emission reduction by waste heat recovery system for electricity generation was calculated as 89,202 tones CO_2/year and it shows good agreement for greenhouse gas emission reduction.

6. Conclusions

The method of the cement production and the thermal energy losses across the preheater tower, kiln and clinker cooler etc. has been studied for the reference cement plant (Emami cement). The total thermal energy losses were found as 4.5% through radiation and convection, whereas 41% from the surface of the kiln, 35% from the pre-heater, 15% from the cooler and around 9% from the tertiary air duct. At kiln surface, secondary shell with thermal insulation has been proposed to reduce the losses. The percentage unidentified loss of 0.73% was of 0.73% was found on studying the heat balances across the clinker cooler. The energy efficiency of 99.27% was calculated for the clinker cooler.

This study aimed at determination of thermal situation during the clinker manufacturing in cement plant, possible energy conservation measures and financial saving potentials. The overall energy efficiency of the system during clinker formation has been measured as 58.67%. The major thermal energy losses at pre heater exhaust gas and clinker cooler vent air system were saved by waste heat recovery power plant saving potential of 13.1 MW/h with simple payback of 35 months. The thermal energy cost plays the major role for clinker production in cement plant. Total energy saving cost of around Rs. 54.5 crores/year was calculated at Emami cement limited.

The distribution of the input heat energy to the overall system showed the good agreement between the total input and output energy Waste heat recovery power plant can reduce the CO_2 emission of 89,202.85 tCO_2/year.

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Author Contributions

Y.K.V. (Ph.D. Student) wrote the article with the help of Supervisor, Co-Supervisor and group teachers. P.G (Ph.D.) and B.M. (Ph.D.) gave suggestions and authoritative points to write the article.

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