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Research Article: MECHANICAL ENGINEERING

Thermal energy audit of Kiln system in a cement plant

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Abstract: A successful energy management programme requires energy auditing as one of the important procedure. Energy audit of kiln system in a cement plant, which uses the data measured from cement plant, is the main theme of this research paper. The possible approaches of heat recovery from some major heat loss sources are discussed by making a detailed analysis of kiln, raw mill, and coal mill and grate cooler. To improve the production process, increase the productivity, decrease energy consumption of the plant certain technological opportunities are also identified.

Keywords: *Coal Mill, Raw Mill, Rotary Kiln,grate cooler, Energy audit, Waste heat recovery.*

1. INTRODUCTION

The main discussion of today's world is the conservation balance and management of energy and emerging topic. In order to reveal the detailed information needed for determining the possible opportunities for energy conservation energy auditing is used because it provides an accurate account of energy consumption and energy usage analysis of different components. Developing countries like India are having extreme significance for energy balance in industries. Cement industry is considered as an important energy intensive industry. Cement manufacturing uses dry process which includes the use of a rotary kiln, that consume large amount of energy to burn coal and the working of the blower which is used to suck the heated air to the other end of the rotary kiln. Theoretically it requires a minimum of 1.6 GJ heat (Liu et al., 1995) for producing one ton of clinker. In India the thermal energy consumption in cement industries varies from 2.95 GJ to 4 GJ/ton of clinker. Harder raw material and poor quality of fuel is one of the reasons for the higher specific energy consumption

The energy saving methods and potentials for German Cement Industry is described and the energy consumption values are given in scheuretal. (1992). Electrical and thermal energy saving methods are the main themes of the research. Energy flow diagram represents the results drawn .The research on energy balance in a cement industry is conducted in shaken et al. (2002). The data used by them is from the existing plant in India with a production capacity 1MT per annum. It is found by the author that about 35% of the input energy was lost with the waste heat streams. In order to recover heat from the steams using a waste heat recovery steam generator a steam cycle was used and it was estimated that about 4.4 MW of electricity could be generated.

Caudal et al. (2004) carried out energy and energy analysis for a dry system rotary burner with pre-calcinations in a cement plant of an important cement producer in Turkey using actual operational data. It was founded that energy and energy efficiency values for rotary burner were 85% and 64% respectively. An energy audit analysis of a dry type rotary kiln system with a capacity of 600 ton clinker working per day was performed by Engine and Ari (2005) in a cement plant in Turkey. They found that about 40% of the total input energy was being lost through hot flue gas (19.15%), cooler stack (5.61%) and kiln shell (15.11%) convection plus radiation. A waste heat recovery steam generation system was proposed which recovered 1 MW energy for the heat loss through hot flue gas and cooler exhaust

Result et al. (2005) conducted a research base data from Indonesian Portland cement plant. They presented a simple model to evaluate the thermal performance of the cement industry.

- Mass, energy as well as energy balance is used as the main aspects for building the developed model. The results obtained were:
- burning efficiency was 52.7%,
- cooler efficiency was 45%,
- Heat recovery efficiency was 51.2%.

Due to convection and radiation there was a high heat loss at the cooler of 19%

Heat recovery from rotary kiln for a cement plant in Turkey was examined by so gut at el.(2009). It was determined that 5% of the waste heat could be utilized with the heat recovery

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exchanger. Domestic-coal and natural gas consumption can be decreased by (51.55% and 62.62% respectively) through installing this system.

Energy audit of kiln system in a cement plant is conducted by; using data measured from a typical cement plant in Coimbatore, India and this is the main theme of the paper. The possible approaches of heat recovery from some major heat loss sources are discussed by making a detailed analysis of kiln, grate cooler, raw mill and coal mill.

2. PROCESS DESCRIPTION

Mines

At about a distance of 6.5kms from plant the plant is having its own mining facility. For convenient transportation the mined limestone is crushed into small sizes with the help of primary and secondary crusher in the mines itself. Through aerial ropeways the crushed limestone is transported to plant and using tertiary crusher it is further crushed into small particles.

Raw mill

The plant has one raw mill capacity of120TPH. Raw milling involves mixing the extracted raw materials to obtain the correct chemical configuration, and grinding them to achieve the proper particle-size to ensure optimal fuel efficiency in the kiln and strength in the final concrete product.

Lime Stone, sweetener and latrine are the main raw materials and they are grounded proportionately in the mill. Blending & Storage silos are used to store the mill output product as raw meal. To remove the moisture content from meal hot gas from PH section is used. Material moisture is 4% in Inlet whereas after mill the moisture content in raw meal is 0%.

Coal mill

At the plant there are three coal mills of capacity varying from 3.3 TPH to 15TPH. The coal that is to be burnt in the kiln and Precalciner section is dried and finely grounded. It is from the storage silos that the fined coal is fed to Kiln burner and Precalciner section. While entering the mill the moisture content in the coal is around 10% whereas it becomes 2% at the outlet.

Pyroprocess

Through four stages two strings are installed in the preheater section. In preheater the raw meal fed from top of the string will preheated by the hot exit gas coming from kiln, and in the precalciner combustion is taking place for calcining (a heating process in which calcium oxide is formed) the raw meal. After this for burning (sintering process) in the kiln the calcined raw meal is fed into the kiln, and this is the final process in pyroprocessing. The raw meal fed into the kiln comes out as clinker at the end of this process.

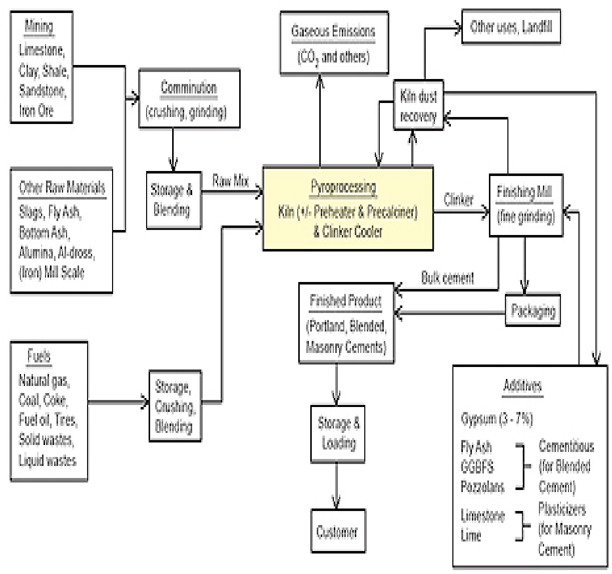

Fig 1. process flow diagram of the cement plant

Grate cooler

Inorder to preserve the ideal quality and for maneuver by conveyors the clinker has cooled to 70-100^{0}C after the clinker formation. . In cooler, clinker cooling is taking place with the help of ambient air supplied by cooler fans to recover the heat from clinker, after taking heat from clinker one part of hot air is supplied into kiln as secondary air for complete combustion and one part is supplied to precalciner as tertiary air and remaining will be vent through ESP and ID fan. Six fans are used in the cooler section for clinker cooling of varying flow rates. The clinker is conveyed and stored in yard for the next process after cooling it at a desired temperature.

Cement mill

This is the final stage in the process of cement making. There are two mills installed in the plant for cement grinding with capacity of 35 TPH and 65 TPH for Ordinary Portland Cement (OPC).To convert cement into a fine powder it is grinded with other materials like slag, gypsum etc(which impart special characteristics to the finished product) in the cement mill. To separate the materials that has not been completely grinded is sent back into the mill and after it gets separated in separator. The output of the mill is then sent to cement storage silos where it is stored and sent to the packing units which are consisting of manual as well as electronic packers.

3.OBSERVATION AND ANALYSIS

Raw mill

Average production rate of mill is varying from 115 – 120 TPH. As per plant data moisture content present in raw material IN and OUT of Raw mill is 4% and 0% respectively. The total power consumption of the raw mill system is constant throughout the logging period and it is 1150KW. Average specific energy consumption is 26.9 kWh / Tons of material. Pressure drop between cyclones, Separator, ESP are as follows119, 200, 68mmWC.

- Air ingress across duct from PH fan to Mill separator is 15%.
- Air ingress across separator and cyclone is 18%.
- Air ingress across cyclone and ESP outlet is 10%.

Air ingress at different locations as mentioned above is on the higher side, reducing the air ingress would reduce power of raw mill fan and raw mill ESP fan.

Coal mill

Three mills are used for plant installation, in which two mills (CM-1&5) are of ball mill type and other one is vertical roller mill (CM-3). The design capacity of the mill is 3TPH, 5 TPH and 15 TPH (with higher fineness) respectively. The typical coal mill circuit diagram with temperature, pressure, oxygen percentage and flow of fans at various locations is given below.

- Average production rate of CM-1 is 1.4 TPH, CM-5 is 3.05 TPH and CM-3 is 4.7 TPH.
- Moisture content present in raw material IN and OUT of Coal mill is 7-12% and 2.2-3.5% respectively as per plant data.

In CM-1 and CM-5 the power consumption of coal is almost constant and it consumes 69 kW and 116 kW respectively. Power consumption of CM-3 (VRM) is varying between 78 – 90 kW. 60.1 kWh is consumed in average for per Ton of material. From PH fan to coal mill booster fan air ingress across duct is 20%.

- Air ingress across Coal mill booster fan and VRM cyclone is 26.5%.
- Air ingress across VRM cyclone and bag house outlet is 6%. Air ingress at different locations as mentioned above is on the higher side, reducing the air ingression would reduce power of mill fans and Bag house fan.

4.PYROPROCESSING SECTION

There are 4 stages for Preheated and Precalciner, the preheated section consists of dual streams (preheated and precalciner).The raw meal after gets grind in raw mill stored in storage silo is fed into the preheated section through the first cyclone which gets heated up by the upcoming hot gas in both streams.

Fuel (coal) is conveyed through compressed air for firing in kiln and precalciner. The preprocessing section of the cement plant is shown in figure 2

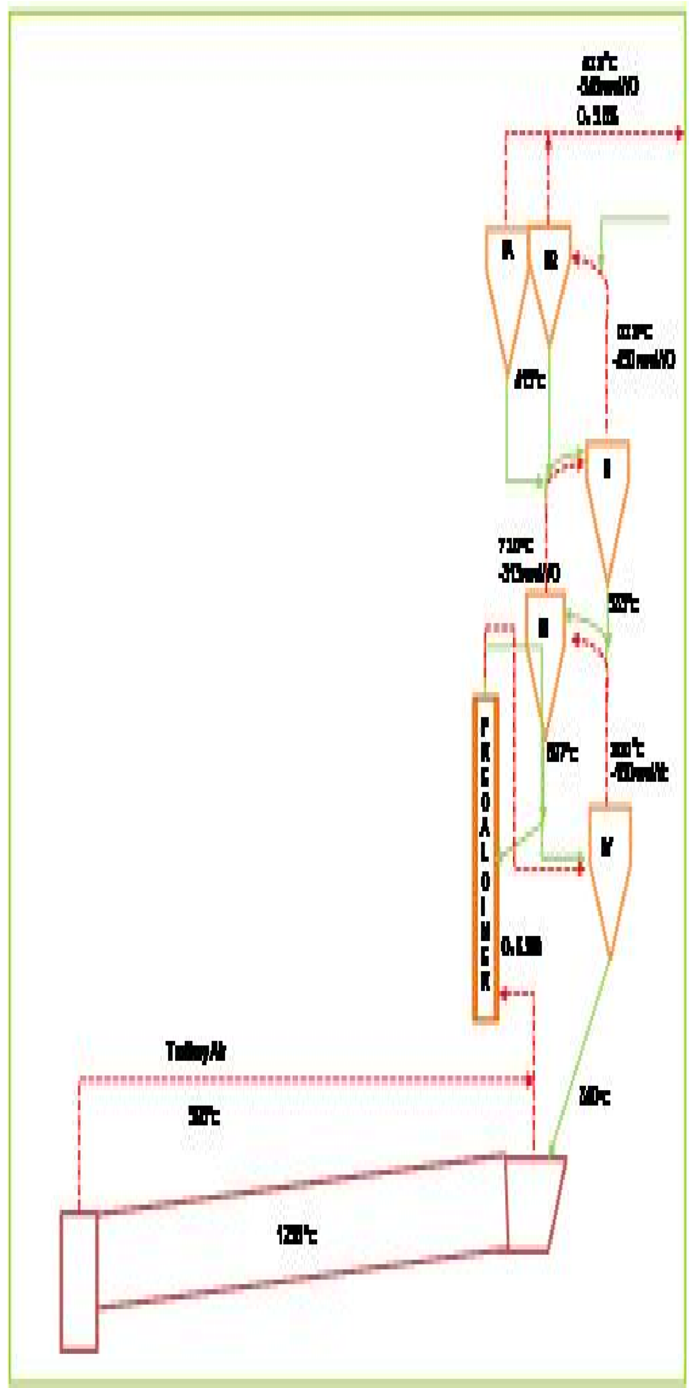

Figure 2: Pyroprocessing Section

5. PARAMETERS OBSERVED IN CYCLONES

1. The temperature of hot gas and material temperature,
2. static pressure at cyclone IN & OUT,
3. Oxygen content in flue gas at the exit

	Kiln Exit	Precalciner Stream Exit	GCT Outlet	ESP Outlet
Oxygen %	3.2	9.5	10	11.7

Table 1: Flue Gas Analysis of Preprocessing Section

Pressure drop across cyclone 2 & 3 are found high. Possible material clogging that needs to be cleaned was checked. The resulting reduction is observed in power consumption of preheated fan through the reduction of pressure drop. It was found that there is ambient air infiltration into the Preheated and Precalciner from the flue gas analysis which is the ducting system that increases the work load of PH fan and Kiln ESP fan. Oxygen percentage in kiln discharge is satisfactory. At present air infiltration percentage is 15.5%, so the specific air flow in preheated section is 2.47 NM^3/kg of clinker which is on the higher side compare to the standard 1.6 NM^3/kg of clinker. The air infiltration must be reduced to 8 % to reduce specific air flow to 2.31 NM^3/kg of clinker. Since only one string is in operation this is on higher side.

Grate cooler

Grate cooler is installed in the plant to cool the hot clinker which comes out from the kiln after calcinations process. The design parameters of cooler is the Capacity- 1250 TPD of clinker and Grate area – 52.92 m^2. The plant is running on partial load with one string operation in preheater section during the study.The clinker coming in to the cooler is reduced by half in one string operation, but during this time also grate speed is at its design 3.5 Strokes/min. The specific air flow of cooler is calculated from our measurements and it is found to be 5.22 NM^3/kg of clinker which is on higher side compared to its standard of 1.8 NM^3/kg of clinker. The main reasons for this is the Kiln is running with 50% load so clinker coming in to the cooler is less than the rated and cooler fans are running at full speed. The bed thickness would be thin and uneven since Grate speed is also at its rated/full load speed.

Heat balance

Following assumption are made in order to analyze the heat balance of the Rotary kiln and Grate cooler.

- Steady state working condition
- Change in ambient temperature is neglected
- Cold air leakage into the systems is negligible

Rotary kiln

One Rotary Kiln with production capacity of 1250 TPD is installed by the plant. The present Kiln speed is 1.2 rpm. To control the flame shape the kiln is installed with one centrifugal fan for swirl air and one root bowler for axial air and the same air is acting as primary air for combustion.

Coal is conveyed through compressed air into the kiln. During study various operating parameters have been observed and measured and the important data collected is given below:

1. The average coal consumption of main kiln burner is 3 TPH coal.
2. The average kiln feed is 74.5 TPH and clinker production is 52 TPH.

To reduce kiln surface heat losses in its interior surface is covered with refractoriness of alumina bricks with 200mm thickness. The measured average surface temperature of kiln is 181^{0}C. During the audit the kiln drive power consumption was taken and the average power consumption is 40 kW.

The heat balance is done based on coal firing quantity, measured air flow rates and temperature. The following parameters are considered as the basis for the analysis:

1. Ambient air temperature is 34^{o}C.
2. Clinker production at kiln discharge is 52 TPH.
3. Assumed clinker temperature at kiln discharge side is 1270 ^{0}C.

Proximate analysis of coal (Fixed carbon-39%, Ash-29%, Volatile matter-27.7%, Moisture-2.44%) and ultimate analysis of coal (Carbon-54.62%, Hydrogen-3.54%, Nitrogen-1.54%) The Gross Calorific value of coal(GCV) can be calculated by using Dulong's formulae as

$$GCV = ([35.5\times C+114.8\times H+9.5\times S-14.5\times O] = 23422.212 \text{ kJ/kg.}$$

Composition of clinker is SiO_2-20.90%, Al_2O_3-5.25%, Fe_2O_3-2.93%, CaO-62.11%, MgO-5.82%.

Heat of reaction of clinker (H_R) = $(4.11\times Al_2O_3) + (6.48\times MgO) + (7.646\times CaO) - (5.11\times SiO_2)-(0.59\times Fe_2O_3)$

= 1779.50 kJ/kg of clinker

TABLE 2. Input and Output energy

INPUT ENERGY						
	Equation	Mass, m (Kg/Kg of clinker)	Temp C	Cp (KJ/Kg)	Result (KJ/Kg of clinker)	%
Coal combustion in kiln (Q1), GCV= 23422.212 KJ/Kg	m*GCV	0.094			2201.68	41.14
Coal combustion in precalciner (O2), GCV= 23422.212 KJ/Kg	m*GCV	0.1345			3150.28	58.86
TOTAL HEAT INPUT					5351.96	100

OUTPUT ENERGY							
1	Heat required for Clinker formation(O3), Hr=1779.50KJ/ Kg of clinker	m*Hr	1			1779.50	33.24
2	Quantity of heat used in Raw mill(O4)	m*Cp(T1-T2)	1.1670	T1= 420 T2= 75.1	1.01574	408.83	7.63
3	Quantity of coal used in coal mill (Q5)	m*Cp(T1-T2)	0.2891	T1=420 T2= 73.1	1.01573	101.86	1.9
4	Heat carried away by raw mill ESP fan vent (Q6)	m*Cp(T1-T2)	1.9699	T1=75 T2=34	1.0241	82.70	1.54
5	Heat carried away by coal mill bag filter fan vent (Q7)	m*Cp(T1-T2)	1.58	T1=73 T2=34	1.0241	63.401	1.184
6	Heat carried away by clinker from grate cooler (Q8)	m*Cp(T1-T2)	1	T1=110 T2=34	0.7774	59.08	1.103
7	Heat carried away by cooler vent air (Q9)	m*Cp(T1-T2)	5.88	T1=180 T2=34	1.01574	871.95	16.29

TABLE I

8	Heat losses due to hot gas flowing out from kiln ESP fan vent (Q10)	m*Cp(T1-T2)	4.162	T1=139 T2=34	0.9990	436.56	8.15
9	Heat losses in GCT section (Q11)	m*Cp(T1-T2)	2.55	T1=420 T2=34	1.0241	1008.02	18.83
10	Heat loss due to moisture in coal (Q12)	(L+(Cps+(T1-T2)*M)	Mkiln=0.0943 Mpc=0.1049	T1=840 T2=34	1.881	26.25	0.49
11	Radiatio loss from kiln surface (Q13)	M×N×A×(Ts4-TO4),Akiln =1272.34m2		Ts=181 T_=34		89.53	1.67
12	Convection heat loss from kiln surface (Q14)	2.32×Akiln ×(Ts-TO)1.25×0.86, Akiln=1272.34m2		Ts=181 T_=34		89.82	1.68
13	Heat losses by surface convection and radiation from cooler (Q15)	{[0.548×(T1/55.55)4-(T2/55..55) 4+ 1.957 (T1-T2)1.25] ×0.86} ×Acooler, Acooler=310.2m2		T1=328K T2=307K		8.51	0.16

TOTAL OUTPUT ENERGY	5026.011	94.26
UNACCOUNTED HEAT LOSS	325.98	6.9

6.RESULTS AND DISCUSSIONS

Instal waste heat recovery syst

For generating steam by boiler recovered waste heat was used. To generate power, Boiler is coupled with steam turbine. GCT can be avoided, water sprayed into the GCT will be saved, power consumed by GCT pump and LSQ pump is also saved through installing this. So inorder to utilize the heat from the gas coming to Gas Conditioning Tower it is better to install a waste heat recovery boiler. The proposed waste heat recovery system for the plant is shown in figure 3.

This formula can be used to calculate the total heat that could potentially be recovered:

$$Q = V\times\rho\times Cp\times\Delta T\times\eta$$

Flow rate (V) of gas inlet to gas conditioning tower in m^3/hr

Density of gas(ρ) corresponding to the gas temperature in kg\m^3

Specific heat (Cp) of gas corresponding to the temperature in kcal/kg°C.
Combined(η) of waste heat recovery boiler and turbine

Change in temperature(ΔT) in °C

$$Q = 2,32{,}962 \times 0.5576 \times 0.24 \times (360-185) \times 0.18 = 982041/860.4/1000$$

$$= 1.14\text{MW}$$

Investment- Rs 1500Lakhs

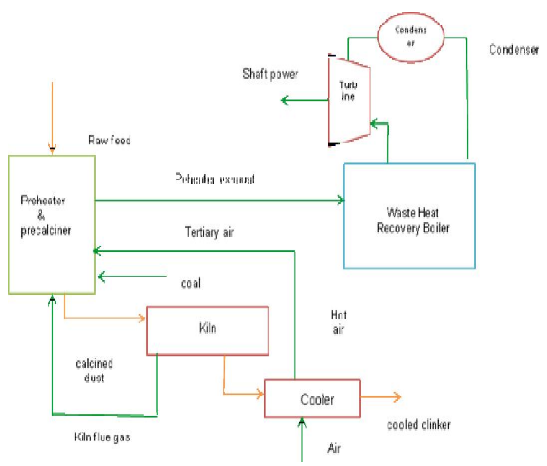

Fig. 3. Proposed waste heat recover system

7. SUMMARY AND CONCLUDING REMARKS

The main aim of this study was to determine energy situation in cement plant and to find out the possible energy conservation measures and financial saving potentials. The energy efficiency value for the kiln system was found to be 41.83%. The major heat losses for the system were identified as the preheater exhaust gases (GCT) and heat carried away by cooler vent air(grate cooler). The preheater exhaust gas carries about 232962 m^3/hr, which indicate the total energy recovery from these waste gases of (16.48%). A waste heat recovery steam generation system was selected showing the energy saving potential of 1.14 MW from the waste heat streams with simple pay back of 48 months.

Thermal energy conservation study is carried out in a cement industry as the energy cost plays a major role in production cost of the cement. The total investment required to implement all proposals will be Rs 1534 Lakhs, which gives an overall payback period of 37 months.

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