Waste Heat Recovery in Cement plant

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***Abstract*— Cement production has been one of the most energy intensive industries in the world. In order to produce clinker, rotary kilns are widely used in cement plants. To achieve effective and efficient energy management scheme, thermal energy audit analysis was employed in the Dalmia cement plant. Reduction of the production cost and consumption cost is very much important because of that waste heat recovery is implemented in the cement industry. The waste heat recovery reduces the Green house gas emissions and enhances the overall system performance. The aim of this work is to determine the Power Generation by utilizing the waste exit gases from the Pre-heater, Grate cooler. By using the various Energy Auditing instrument the exhaust gas temperature, Dust concentration , Surface temperature, Velocity were identified. A detailed analysis of Grate cooler, Preheater are done and the possible approaches of heat recovery from some major heat loss sources.**

***Keywords*-Energy audit; Heat loss; Preheater; Cooler; Heat recovery; Clinker; Steam cycle;**

I. INTRODUCTION

Waste heat recovery from the hot gases in the system can be considered as a potential option to improve energy efficiency in industrial processes. The Waste heat is heat, which is generated in a process by way of fuel combustion or chemical reaction, and then dumped into the environment even though it could still be reused for some useful and economic purpose. The essential quality of heat is not the amount but rather its temperature of the waste heat gases and the economics involved. Large quantity of hot flue gases is generated from Boilers, Kilns, Ovens and Furnaces. If some of this waste heat could be recovered, a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. Waste heat Recovery means allowing the waste heat to leave the process, but converting into electricity before it is discharged at lower temperature level to the environment. Therefore, after the efficiency of a cement plant has been driven to the economic optimum, the remaining waste heat is converted into electricity. 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. In addition to the plan of reducing of energy consumption in cement production process, the recovery waste heats can be achieved in order to produce the electrical energy by utilization cogeneration power plant. This means no additional fuel consumption and thus, reducing the high cost of electrical energy and the emissions of greenhouse gases. In cement plant the exit gases from Rotary kilns, pre-heater and Calciners are used to heat the incoming feed material and gases are cooler around 300 to 350 °C in 4 stage pre-heater and then exhausted to the atmosphere.

II. SYSTEM DESCRIPTION AND DATA SOURCE

The cement industry has an important role in the economy based on its production. During the production of Cement natural resources are consumed in large amounts. The most important raw materials for the manufacture of cement are limestone ($CaCO3$) and clay or calcareous clay in which both Components are already naturally mixed. The components are milled and dried with flue gases from the clinker kiln. Depending on the type of cement to be produced, the following product may be added to the dried limestone subsequently: Pyrite ash, fly ash from coal fired power plants, sandy clay and filter ash from the electrostatic precipitator present. The mixture obtained is ground and subsequently fired in a rotary furnace to cement clinkers. For heating, various fuels and other combustible materials, for example coal dust, petroleum coke, etc., are used. Depending on the type of preheating of the material, it is differentiated between grate and cyclone preheating, whereby the starting materials are preheated to 700 to 800°C. The raw materials pass through the rotary furnace towards the flame. In the hottest zone, the material being fired reaches temperatures of around 1450°C.The cement plant considered is Dalmia Cement—Unit 2, Trichirapalli, India. A schematic of the plant (Fig. 1) shows the flow of various streams and the components of the plant. The plant runs on dry process with a four stage suspension preheater and an inline Calciners. The production capacity is 3018 tonne per day. It is the pyroprocessing unit that includes the preheater, the Calciners, the kiln and the clinker cooler. The streams into the system are the raw material, the air into the cooler and the coal fired into the kiln and the Calciners. The streams leaving the system are clinker out from the cooler, the exhaust gases from the preheater and the hot air out from the cooler.

III. MASSBALANCE AND ENERGY BALANCE

A. Mass balance

The average compositions for dried coal are shown in Fig. 1 Based on the coal composition, the net heat value has been found to be 30,600kJ/kg-coal. The stream data obtained from the plant is used to perform a mass balance over the system. It is usually more convenient to define mass/energy data per kg clinker produced per unit time. The mass balance of the kiln system is summarized in Fig. 3. All gas streams are assumed to be ideal gases at the given temperatures.

B. Energy balance

In order to analyze the kiln system thermodynamically, the following assumptions are made

1. Steady state working conditions.
2. The change in the ambient temperature is neglected.
3. Cold air leakage into the system is negligible.
4. Raw material and coal compositions do not change.
5. Averaged kiln surface temperatures do not change.

Based on the collected data, an energy balance is applied to the kiln system. The Datum Temperature is taken as 20˚C. Based on the collected data, an energy balance is applied to the kiln system. The Datum Temperature is taken as 20˚C. The pertinent equations used in evaluating the different Heat transfer components of the systems energy balance are shown inTable1.The Relevant data and constants are obtained from on site measurements, plant records Peray [8].The result presented in Table 1, shows that fuel combustion generate 97.3% (780 kJ/kg clinker) of the total heat input to the unit. The sensible heats with the raw materials, fuel and air entering the coolers heat content are very small. The total sensible heats with streams are about 0.2% of the total heat input to the unit. Therefore, total heat input of 801.9 kJ/kgclinker is required to maintain Clinkerization reactions temperatures for the clinker formation. The total heat input is generated from combustion heat and total sensible heat with the total heat input to the unit. The total heat input is generated from combustion heat and total sensible heat with the material streams. During clinker formation, 413.2 kJ/kgclinker of heat is released, about 51.5% of the total heat input. This percentage gives a measure of the thermal efficiency of the kiln systems. The overall efficiency can be improved by recovering some of the heat losses. The recovered energy can then be used for several purposes, such as electricity generation. There are few major heat losses that would be considered for recovery. Theseare heat losses by Preheater exhaust gas (24.4%), from cooler stack (12.8%) and Radiation and convection losses (6.1%).The overall system efficiency can be defined by $Q_5/Q_{total\ input}$ = 413/801.9= 0.515 or 51.5% which can be regarded as low. Some kiln system operating at full capacity would declare an efficiency of 55% based on dry process methodology. The overall efficiency of the system can be improved by recover some of the heat losses.

IV.WASTEHEAT RECOVERY AND POWER GENERATION

There are opportunities that exist within the plant to capture the heat that would otherwise be wasted to the environment and utilize this heat to generate electricity. The most accessible and, in turn, the most cost effective waste heat losses available are the clinker cooler discharge and the kiln exhaust gas. The exhaust gas from the Preheater is, on average, 361˚C, and the temperature of the air discharged from the cooler stack is 268˚C.The hot gases from the preheater and cooler are passed through the waste heat recovery boiler. Water is circulated through the WHRB. Latent heat from the hot gas is transferred to the water and it is converted to steam. The steam is expanded in the turbine and then it is condensed and the condensed water is passed through the WHRG and the process repeats.The electricity generated would offset a portion of the purchased electricity, thereby reducing the electrical demand.

Power generation

Generally the waste heat recovery efficiency is 22.7%.The total heat available for power generation is 9.92Mcal/hr.

Gross power generation

= Total heat available for power generation*WHR efficiency*1000

= 9.92 * 0.227 * 1000/860

Assuming 8000h usage, we find

Energy saved = power generated * Hour usage

= 2620 * 8000

= 20960000 Kwh/year

Cost savings = Unit price of electricity * Energy saved

= 3.75 * 20960000

= 78,600,000 Rupees/year

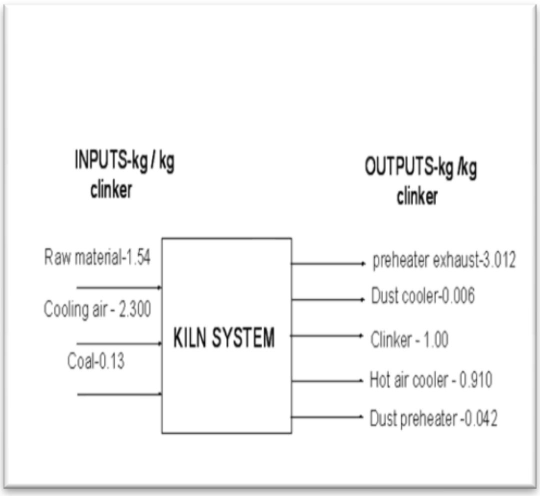

Fig2. Mass balance of the system

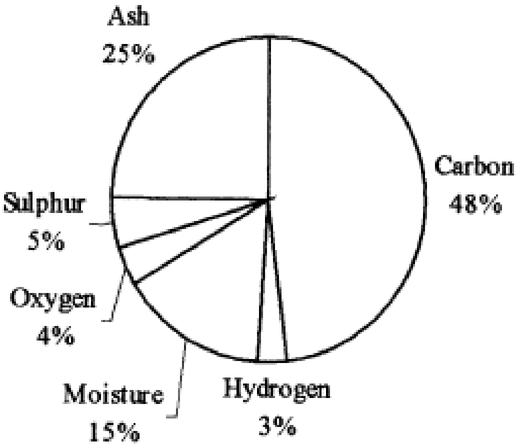

Fig 1.Composition of coal

An additional cost will be required for maintenance of the power generation unit. For the whole system shown in fig 3, based on our calculations, we were able to determine a budget estimation of 136400000 rupees/year. We can make a rough estimate for a simple payback period.

Simple payback period = (Implementation cost)/(Cost savings)
= 136400000/78600000
= 1.73 years

Operational approach for thermal energy saving opportunities

Potential opportunities for improving energy efficiency of the pyroprocessing unit could be achieved from the following operational approach

- Upgrading existing equipments in the pyroprocessing unit

Table 1 Heat balance of the kiln system

Heat Input

Description	Equation used	Data	Results(kcal/kgclinker)
kiln Feed	$Q_1=mC_p(T_2-T_1)$	m=0.2155kg/kg clinker, C_p=215kJ/kg˚C,T_1=20˚C,T_2=60˚C	15.1(1.9%)
Cooling air	$Q_2=mC_p(T_2-T_1)$	m=1.816kg/kg clinker, C_p=0.31J/kg˚C,T_1=20˚C,T_2=29˚C	5.1(0.6)
Coal dust sensible heat	$Q_3=mC_p(T_2-T_1)$	m=1.816kg/kg clinker, C_p=0.31J/kg˚C,T_1=68˚C,T_2=20˚C	1.70(0.2%)
From fuel(By difference)	Q_4	-	780(97.3%)
Total Heat			801.9(100%)

Heat Output

Description	Equation used	Data	Results(kcal/kgclinker)
Heat of formation	$Q_{5=}$ (4.11*Al_2O_3)+(6.48*Mgo)+(7.646*CaO)+(-5.1165*SiO_2)+(-0.59*Fe_2O_3)	Al_2O_3 = 5.630 Mgo = 0.850 CaO= 64.870 SiO_2 = 21.160 Fe_2O_3 = 5.340	413.2(51.5%)
Kiln feed moisture temperature	Q_6=kilnfeed rate*Moisture in kilnfeed*540/clinker production	Kilnfeedrate = 215TPH Moisture in kiln feed = 0.5% Clinkerproduction =125.73TPH	4.6(0.6%)
Coal dust moisture temperature	$Q_{7=}$Fuel rate*moisture in coaldust*540/clinker production	Fuel rate = 15.3 Moisture in coal dust = 3.310% Clinkerproduction =125.73TPH	2.2(0.3%)
Heat through Preheater exhaust gas	$Q_8 = mC_p(T_2 - T_1)$	m=1.621 kJ/kg clinker, C_p=0.354kJ/kg˚C,T_1=20˚C,T_2=361˚C	195.7(24.4%)
Heat through dust entrained in Preheater exhaust gas	$Q_9= mC_p(T_2 - T_1)$	m=1.621 kJ/kg clinker, C_p=0.100kJ/kg˚C,T_1=20˚C,T_2=361˚C	12.8(1.6%)
Heat through cooling vent air	$Q_6= mC_p(T_2 - T_1)$	m=1.307 kJ/kg clinker, C_p=0.317kJ/kg˚C,T_1=20˚C,T_2=268˚C	102.78(12.8%)
Heat through Clinker	$Q_7= mC_p(T_2 - T_1)$	m=1kg/kg clinker, C_p=0.189kJ/kg˚C, T_1=20˚C,T_2=135˚C	21.7(2.7%)
Radiation and convection losses (cooler, kiln, preheater, Duct)	—	—	48.8(6.1%)
Total Heat loss	—	—	801.9(100%)

Table 2 Heat utilization

Description	Equation used	Data	Results(Mcal/hr)
Preheater heat available from exhaust gas	$Q_1 = mC_p(T_2 - T_1)$	m=0.34kg/kg clinker, C_p=204 kJ/kg˚C, T= 380 ˚C	26.36
Cooler Heat Available from Exit Gases	$Q_2 = mC_p(T_2 - T_1)$	m=0.34kg/kg clinker, C_p=204 kJ/kg˚C, T= 380 ˚C	18.97
Preheater Heat available for Raw mill and Coal mill at WHRS Outlet	$Q_3 = mC_p(T_2 - T_1)$	m=0.34kg/kg clinker, C_p=204 kJ/kg˚C, T= 361 ˚C	25.04
Preheater Heat available for boiler	$Q_4 = mC_p(T_2 - T_1)$	m=0.354 kJ/kg clinker, C_p=204kJ/kg˚C,T_1=361˚C,T_2=380˚C	1.32
Total heat from Cooler mid tap for boiler	$Q_5 = mC_p(T_2 - T_1)$	m=99kg/kg clinker, C_p=0.317 kJ/kg˚C, T= 400 ˚C	12.29
Useful cooler heat available at 120 ˚c exit temp for cooler mid tap boiler	$Q_6 = mC_p(T_2 - T_1)$	m=99 kJ/kg clinker, C_p=0.31kJ/kg˚C,T_1=120˚C,T_2=400˚C	8.59
Unused heat vented to atm at 120˚Cfrom cooler midtap boiler	$Q_7 = mC_p(T_2 - T_1)$	m=99 kJ/kg clinker, C_p=0.31kJ/kg˚C,T_1=120˚C,T_2=400˚C	3.69
Total heat available for power generation	$Q_4 + Q_6$	Q_4=1.32 Q_6=8.60	9.92

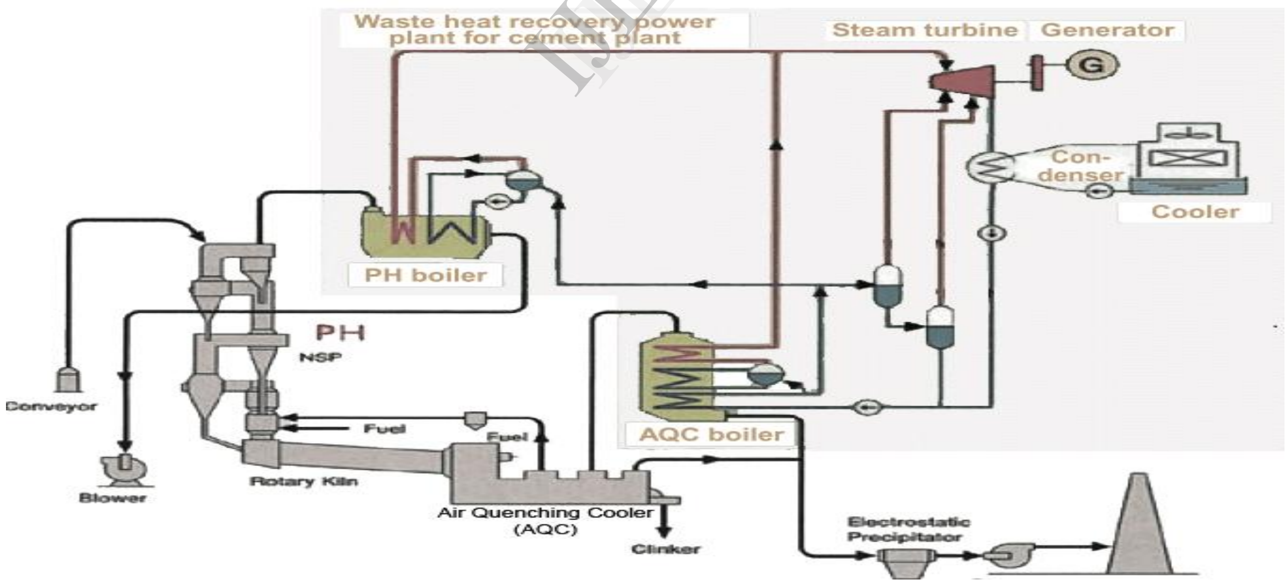

Fig 3.Waste heat recovery power plant

- Combustion system improvement
- Adding multistage preheater with Pre-Calciners
- Adopting new pyroprocessing technologies
- Utilizing alternative fuel such as harvesting energy from Biomass and waste fuel for kiln firing
- Replacing high carbon fuel with low carbon fuel (i.e. switching From coal to natural gas)
- Applying a low clinker to final cement mixture ratio (i.e. increasing the ratio of cement additives that do not require Pyroprocessing)

V.CONCLUSIONS

A detailed energy audit analysis, which can be directly applied to any dry kiln system, has been made for a specific key cement Plant. According to the result obtained the overall system efficiency is 51.53%.The major heat loss sources have been determined as kiln exhaust (19.15%), cooler exhaust (12.8%) Heat through Preheater gas (24.4%) and combined radiative and convective heat transfer from kiln surfaces (6.1%).The Preheater Exhaust gas temperature is (361℃) and Cooler Exhaust gas temperature (268˚C) which are used in waste heat boiler for power generation. A waste heat recovery steam generation system was selected showing the energy saving potential of 2.62 MW from the waste heat streams with simple pay back of 30 months.

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