ISSN: 2455-6203
International Journal of Science Management & Engineering Research (IJSMER)
Volume : 05 Issue : 02 | July - 2020 www.ejournal.rems.co.in

Recovery of Waste Heat By Cement Plant for Power Generation

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***Abstract*—The Waste heat is heat, which is produce in a process where fuel combustion or chemical reaction, are occurred and then "rejected" into the environment even though it will be reused for some useful and economic purpose. The standard quality of heat is not the amount but still its "value". The process of how to recover this heat depends in part on the temperature of the waste heat gases and the economics involved. Large amount of hot flue gases is produced from Boilers, Kilns, Ovens and Furnaces. If waste heat will be recovered, it will be reducing the cost of primary fuel could be used. The energy rejected in waste heat cannot be fully recovered. Cement production is one oldest energy sector the world. In many reasons, energy cost is 50% to 60% of the production cost of cement. kiln need for large quantities of useful thermal heat for drying operation of cement kiln and electrical energy for operation of motors in grinding mills, fans, conveyers and other motor operated process equipment. The objective of this thesis work study the performance of the waste heat recovery (WHR) technique in detail to be a useful tool for overcoming the present-day energy shortage under different operational conditions and then compare the results for efficiency with predictions by available theoretical models. The thesis starts with comprehensive discussion regarding importance of waste heat recovery WHR methodology; it's suitability for heavy industries, flow sheets, and design considerations and applies Rankine cycle to generate electricity by use of waste heat in clinker burning process.**

Keywords— clinker, WHR, Rankine cycle, electricity, Waste heat

Introduction

India is the second largest cement producer in the world and accounted for over 8 percent of the global installed capacity as of 2019. Cement production reached 334.48 million tons (MT) in FY20. The cement production capacity is estimated to touch 550 MT by 2020. Of the total capacity, 98 per cent lies with the private sector and the rest with public sector. The top 20 companies account for around 70 per cent of the total cement production in India. The demand of cement industry is expected to achieve 550-600 MT per annum (MTPA) constantly by 2025 because of the expanding requests of different divisions, i.e., housing, commercial construction and industrial construction.

What is Waste Heat Recovery

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 "value". The strategy of how to recover this heat depends in part on the 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 losses arise both from equipment inefficiencies and form thermodynamic limitations on equipment and processes.

Waste Heat Temperature/Quality

The waste heat temperature is a key factor determining waste heat recovery feasibility. Waste heat temperatures can vary significantly, with cooling water returns having low temperatures around 100 - 200°F [40 - 90°C] and glass melting furnaces halving flue temperatures above 2,400°F [1,320°C]. In order to enable heat transfer and recovery, it is necessary that the waste heat source temperature is higher than the heat sink temperature.

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Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat's utility or "quality".

Problem Formulation.

In this thesis work 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. In many world regions, energy cost is 50% to 60% of the direct production cost of cement. Energy cost is incurred due to the need for large quantities of thermal heat for the kiln, calcinations and drying processes and electrical energy for operation of motors for grinding mills, fans, conveyers and other motor driven process equipment. In terms of absolute consumption, the cement industry occupies a front position in the ranks of energy consumed industries. The total energy costs [thermal and electrical) make up about 30 to 40 percent of the total production costs of cement. This is why efficient energy utilization has always been a matter of priority in the cement industry. Cement manufactures requires very high temperatures to initiate the reaction and phase changes necessary to form the complex mineral compounds that give cement its unique properties. Pyro-processing in large rotary kiln is the operational step that provides the energy and environmental conditions necessary for the reaction and phase change. This operation dominates the energy consumption and environmental impacts associated with the manufacture of the cement. Process improvement may be attained by energy management, applying more energy efficient process equipment and by replacing old installations by new ones or shifting to complete new types of cement production processes, cement kiln optimization process, performing the research and development necessary to prepare and burning the alternative fuels in cement kiln and to develop new cement manufactures.

Heat recovery from heat treatment furnace

In a heat treatment furnace, the exhaust gases are leaving the furnace at 900 °C at the rate of l;2100 m3/hour. The total heat recoverable at 180oC final exhaust can be calculated as

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

Q is the heat content in kCal

V is the flow rate of the substance in m3/hr
ρ Is density of the flue gas in kg/m3
Cp is the specific heat of the substance in kCal/kg °C
ΔT is the temperature difference in °C
Cp [Specific heat of flue gas) = 0.24 kCal/kg/°C
Heat available

[Q) = 2100 × 1.19 × 0.24 × [[900-180) = 4, 31,827 kCal/hr

Line-1 [4000 tons per day of clinker Kiln)

Waste gases, rejected from preheater and clinker cooler for production 4000 tons per day of clinker., properties are as given below:
Preheater Heat Exchanger 1 [Line 1 Preheater)
Waste Gas characteristics are as given below:
Waste Gas to be recovered = 213,000 Nm^3 / hour
Inlet Gas Temperature = 330°C
Outlet Gas Temperature = 229°C
Steam characteristics to be generated by waste gas are as shown below:
Steam Generated = 15.4 t/h
Steam temperature = 312 °C
Steam Pressure = 1.63 MPa
Clinker Cooler Heat Exchanger 1
Waste Gas characteristics are as shown below:
Waste Gas to be recovered = 103,323 Nm^3 / hour
Inlet Gas Temperature = 380°C
Outlet Gas Temperature = 98°C
Steam characteristics to be generated by waste gas are as shown below:
Steam generated = 8.5 t/h
Steam temperature = 355 °C
Steam Pressure = 1.63 MPa.

4.5 Line-2 [6780 tons per day of clinker Kiln)

Its production is 6780 tons per day of clinker. Waste heat gases, rejected from preheater and clinker cooler, properties are as given below:
Preheater Heat Exchanger 2 [Two Boilers)

Line-2 is a state of art technology and its preheater is double string. So at each string one boiler is installed and both are identical.

Waste Gas characteristics are as shown below:

Waste Gas to be recovered =195,500x2 Nm^3 / hour

Inlet Gas Temperature =310°C

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Outlet Gas Temperature = 228°C

Steam characteristics to be generated by waste gas are as shown below:

Steam Generated=23 t/h

Steam temperature = 301 °C

Steam Pressure = 1.63 MPa

Clinker Cooler Heat Exchanger 2

Waste Gas characteristics are as shown below:

Waste Gas to be recovered =174,000 Nm^3 / hour

Inlet Gas Temperature =380°C

Outlet Gas Temperature = 99°C

Steam characteristics to be generated by waste gas are as shown below:

Steam Generated=15.6 t/h

Steam temperature = 366 °C

Steam Pressure = 1.63 Mpa

Line-1

I/p %age of Line-1= [Steam generated by Line 1)*100 / [Total Steam Generated)

I/p %age of Line-1 = 23.9*100/70.4

I/p %age of Line-1 = 34%

Electricity Proportion = 5MW

Line-2

I/p %age of Line-2= [Steam generated by Line-2)*100 / [Total Steam Generated)

I/p %age of Line-2 = 38.6*100/70.4

I/p %age of Line-2 = 55%

Electricity Proportion = 7.9MW

Percentile Electricity Generation

Line-1

I/p %age of Line-1= [Steam generated by Line 1)*100 / [Total Steam Generated)

I/p %age of Line-1 = 23.9*100/70.4

I/p %age of Line-1 = 34%

Electricity Proportion = 5MW

Line-2

I/p %age of Line-2= [Steam generated by Line-2)*100 / [Total Steam Generated)

I/p %age of Line-2 = 38.6*100/70.4

I/p %age of Line-2 = 55%

Electricity Proportion = 7.9MW

Table-4.2.1 Technical specifications of Heat Recovery units

Item	Location	Waste Gas Nm^3/ Hr	Steam Capcity Tph	Steam Pres Mpa	Steam Temp °C
HRSG 1	Preheater line 1	214000	15.4	1.63	312
HRSG 2	Clinker cooler Line1	103333	8.5	1.63	355
HRSG 3	Preheater line 2	195500	11.5	1.63	301
HRSG 4	Preheater line 2	195500	11.5	1.63	301
HRSG 5	Clinker cooler Line2	173000	15.6	1.63	366

Conclusions

Exponentially increasing Energy costs, its acute shortage in Pakistan and pressures to reduce CO2 emissions are compelling the big industries to spend on alternate ways of curtailing the issue. The reasonable pay back times for heat recovery systems and the possibility to increase productivity coupled with the promising environmental effects of this investment is now attracting the investors & plant owners. The paper deals with a WHR project in a cement manufacturing plant for generation of electricity from waste heat previously being emitted to atmosphere. Also, the project facilitates considerable reduction in Co2 Emission without any additional GHG discharge. The installation of WHR has not only improve the energy efficiency but also the reliance on exhaustible fossil fuel-based power sources, thus contributing a lot in the sustainable growth of cement sector in Pakistan. The analysis of under consideration plant has been performed on the methodology of ACM004 of CDM. Following results are achieved.

- CO2 Reduction Possibilities
- From this project CO2 reduction potential is 47807 Ton/Year.
- Economic Efficiency
- Quantity of power generated KW 12900
- In house power consumption KW 838(6.5%)

Waste Heat and the Potential for Power Generation The amount of recoverable waste heat from an NSP kiln depends on several factors including the following:

- Moisture content of the raw material feed (i.e., determines heat requirement for the kiln and the amount of preheater exhaust needed for drying)
- Amount of excess air in the kiln
- Amount of air infiltration
- Number and efficiency of preheater/precalciner stages
- Configuration of the clinker cooler system

Table 4.2.2 heat balance sheet

S.NO	DESCRIPTION	EQUATION	DATA	RESULT [KJ/KG-CLINKER
1	Heat input			
2	Combustion of coal	$Q_1=m_cH_c$	mc=0115Kg/Kg-clinker,Hc=30,600KJ/Kg	3519[95%)
3	Sensble heat by coal	Q_2=mchc,hc=CT	Mc=0.115Kg/Kg-clinker,C=1.15 Kg/Kg0C,T=500C	7[019%)
4	Heat by material	Q_3=mmhm,hm=ct		

HEAT INPUT

HEAT	DATA	AMOUNT
Combustion of coal $Q_1 = m_cC.V$	**mc = 0.15 kg/kg-clinker, Hc =23, 800 kJ/kg**	**3570 [95.01%)**
Sensible heat by coal $Q_2 = m_ch_c$, h_c = CT	**m_c = 0. 15 kg/kg-clinker, C [specific heat for coal) = 0.9 kJ/kg^{0}C T=50^{0}C**	**8.625 [0.22%)**
Heat by raw material Q3 = $m_{rm}h_{rm}$, hrm = CT	**m_{rm} = 1.56 kg/kg-clinker, C = 0.9 kJ/kg^{0}C, T = 50^{0}C**	**70.2[1.86%)**
Organics in the kiln feed Q4 = FKh_{os}	**F = 0.10, K = 0.9%, h_{os} = 21. 036 kJ/kg [to Cement manufacturer's handbook.)**	**19 [0.50%)**
Heat by cooling air Q5 = $m_{ca}h_{ca}$	**m_{ca} = 2.98 kg/kg-clinker, h_{ca} = 30 kJ/kg [T = 30^{0}C)**	**89.4 [2.36%)**
Total heat input		**3757.225 [100%)**

HEAT OUTPUTS

HEAT	DATA	AMOUNT
Formation of clinker Q_6 = 17.196[Al_2O_3) + 27.112[MgO) + 32[CaO) - 21.405[SiO_2) - 2.468[Fe_2O_3)	**[Clinker composition is given in Table 1)**	**1795 [48.70%)**
Kiln exhaust gas $Q_7 = m_{eg}C_{p-eg}T_{eg}$	**m_{eg} = 2.27 kg/kg-clinker, C_{p-eg} = 1.0 kJ/kg ^{0}C, T_{eg} = 280 ^{0}C**	**635.6 [19.15%)**
Moisture in raw material and coal $Q_8 = m_{H2O}m_{water}$[$h_{fg[50\ 0C)}$ + $h_{315\ 0C}$ - $h_{50\ 0C}$)	**m_{water} = 0.008835 kg/kg-clinker [in coal + raw material), $h_{fg[50\ 0C)}$ = 2384 J/kg, $h_{50\ 0C}$ = 2591 J/kg, $h_{315\ 0C}$ = 3104 J/kg**	**26 [0.71%)**
Hot air from cooler Q_9 = mair-cohair-co	**mair-co = 1.42 kg/kg-clinker, hair-co = 220 kJ/kg [T = 400 ^{0}C)**	**207[5.50 %]**
Heat loss by dust Q_{10} = [$m_{dust-preheater}$+ $m_{dust-air\ cooler}$)$h_{dust;ave}$	**$m_{dust-preheater}$ = 0.042kg/kg-clinker, $m_{dust-air\ co}$ = 0.006 kg/kg-clinker, $h_{dust;ave}$ = 275 kJ/kg [Ref. [7])**	**11 [0.29%]**
Clinker discharge $Q_{11} = m_{cli}h_{cli}$;T=110^{0}C	**m_{cli} = 1 kg/kg-clinker, h_{cli} = 86 kJ/kg [Ref. [7])**	**86 [2.28%]**
Radiation from kiln surface $Q_{12} = \sigma \mathcal{E} A_{kiln}[T^4_s - T^4_\infty)/[1000\ \dot{m}_{clinker})$	**σ = 5.67X 10^8 W/m^2 K^4, Ɛ=0.78[oxidized surface [8]), A_{kiln} = 565.48 m^2, Ts = 581 K, T = 288 K, $\dot{m}_{clinker}$ = 6.944 kg/s**	**386 [10.27%]**

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Result & Discussion

The overall system efficiency can be defined by
$g = Q_6 = Q_{total\ input} = 1795=3686 = 0:487$ or 48.7%, which can be regarded as relatively low. Some kiln production systems operating at full capacity would declare an efficiency of 56% based on the current dry process methodology. The overall efficiency of the kiln system can be increase by recovering some of the heat losses. The recovered heat energy can then be used for different purposes, such as electricity generation and preparation of hot water. There are many major portion heat loss sources that would be considered for heat recovery. These are west heat losses by: (1) kiln exhaust hot flue gas (19.15%), (2) hot air from cooler stack (5.61%) and (3) radiation from kiln surfaces (10.47%).

This is an opportunity 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 cost-effective waste heat losses available are the clinker cooler discharge and the kiln exhaust gas. The exhaust gas from the kilns is, on average, 400^0C, and the temperature of the air discharged from the cooler stack is 215 ^{0}C. Both streams would be directed through a waste heat recovery steam generator [WHRSG], and the available energy is transferred to water via the WHRSG. The steam would be used to power a steam turbine driven electrical generator.

To determine the size of the generator, the available energy from the gas streams must be found. Once it will be determined, an approximation of the steam generating rate for a specified pressure can be found. The steam generating rate and pressure will determine the size of the generator. The following calculations were used to find the size of the generator,the final enthalpies have been calculated to be h_{air} = 173 kJ/kg, and h_{eg} = 175 kJ/kg. Therefore, the available heat energy would be:

$$\mathbf{Q_{available} = [m_{eg}(h_{eg1} - h_{eg2}) + m_{air}(h_{air1} - h_{air2})] X\ m_{cl} i}$$

$$\mathbf{Q_{available} = [2.094\ X\ (337 - 175) + 0.94\ X\ (220 - 173)\ X\ 6.944 = 2662\ kW}$$

Therefore, the useful energy that would be transferred through the Waste heat recovery generating is QWHSRG = 0.85 X 2662 = 2263 kW

The other step is to find a steam turbine generator set that can utilize this energy. Since a steam turbine is a rotating some of machinery, if properly maintained and supplied with a clean supply of dry steam, the turbine should last for a significant period of time. Considering a turbine pressure of 8.1 bars and a condenser pressure of 10.3 kPa, it can be shown that the net power, which would be obtained from the turbine, is almost 1000 kW. If we assume that the useful power generated is 1000 kW, then the anticipated savings will be based on the load reduction of 1000 kW. Assuming 8000 h of usage, we find

Energy saved = (Power generated) X(hours of usage)
Energy saved = (1000 kW) X (8000 h/yrÞ = 8 X 10^6 kWh/yr

The average unit price of electricity can be taken as 4.46 Indian rupee/kWh, and therefore, the anticipated cost savings would be
Cost savings =4.46X 8 X10^6 = 560; 000 USD/yr

If we assume that labor and maintenance costs averaged out to 21,000 USD annually, the savings becomes 545,000 USD/year.
The cost associated with implementation of this additional system would be the purchase price of the necessary equipment and its installation. An additional cost will be the required maintenance of the power generation unit. For the whole system shown in Fig. 4, based on our calculations, we were able to determine budget estimation between 700,000 and 750,000 USD, including shipping and installation. Hence, we can make a rough estimate for a simple payback period:

Simple payback period = (Implementation cost)/ (Annual cost savings)

$$\textbf{Simple payback period} = \frac{750{,}000\ USD}{540;\ 000\ USD/yr} = \textbf{1:38 yr or 17 months}$$

The energy savings by using a WHSRG system would also result in an improvement in the overall system efficiency. It should be noted that these calculations reflect a rough estimation and may vary depending upon plant conditions and other economic factors.

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