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Thermal Design of Waste Heat Recovery Unit For Cement Industry

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ABSTRACT

This research article presents a review of various works focused on waste heat in industry for improving energy efficiency. In WHRu, evaporator, super heater, steam drum, and turbine. The different reviews based on the aspects of heat recovery and the methodologies and technologies being employed for its optimization in industries also study through literature. This work also concentrated on the different parameters governing the waste heat recovery in the industries.

Keywords: Waste heat recovery unit, waste heat recovery generation, organic rankine cycle, economizer, evaporator and superheated, .energy output.

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I. INTRODUCTION

This currently, electrical energy is still one of the basic needs that should be fulfilled for human. Huge amount of electricity is required in domestic as well as commercial use. Energy usage which rises continuously initiates energy crisis mainly in manufacturing industries. In cement production plant large amount of flue gases are emitted while manufacturing of cement. These Flue gases in industry can be utilized for power plant system that is called Waste Heat Recovery Generation (WHR).Where the heat energy in these flue gases are used in power generation. Because designing this plant is expensive, checking the performance of WHRu plant design is done via simulation. Simulating this plant needs the right control system to produce proper performance.

The cement industry is one of the major industrial emitters of calorific value and feed water which is used as a producer of steam. Flue gas is a waste greenhouse kinds of input variables used; they are flow of exhaust gas which has a high temperature that is used to heat water that will produce steam to rotate turbines. The rotation of turbines will change the thermodynamic energy into electrical energy. This can be further used in cement manufacturing. In last few years electrical energy consumption in industries are increased by considerable amount so there is need to recover the energy from sources. Specifically electrical energy consumption increases by tremendous amount maximum part of electrical energy used in industrial sector, mainly in production industry. In this project we are recovering waste heat in flue gases, which are emitted from cement manufacturing industry. Steam generation is actually depends on rotation of turbine and turbine efficiency is depend on quality of steam produced. Quality of steam is depends on temperature and pressure of the generated steam. Cement manufacturing is highly intensive process which requires 3-4GJ of energy to manufacturing one tons of cement. In cement manufacturing processes large amount of flue gases are exhausted that flue gases contains greenhouse gases like CO_2, N_2, NO_2, H_2 etc. that are harmful to nature. So in this project we are reused flue gas for heating purpose of lost steam in WHRu and focusing on good quality of steam generated with varying pressure and temperature for improvement of turbine efficiency. This method can also be say as cogeneration which means combination of heat and power generation.

From various components in cement industry that flue gas passes from outside of the tubes and water is flowing through inside of the tubes. Flue gas passes from upward to downward and water flows from downward to upward which means they pass by counter flow so at top of unit water become superheated steam as it passes from sub unit like economizer, evaporator, steam drum and various stages. From superheater this superheated steam is passes to turbine for the purpose of rotation of turbine. While steam is passing through superheater its velocity, pressure and temperature is also considered which affects the quality of steam. For the purpose of power generation and thermodynamic energy is get converted in electrical energy. This generated electrical energy is further used in manufacturing of cement.

1.2 Objective

1] To understand whole cement manufacturing process in cement manufacturing industry

2] To understand heat sources for waste heat recovery from cement process in cement plant

3] Due to industrial trends and government policies for the pollution control from cement manufacturing process we selected cement plant.

4] To understands thermal design calculation

5] Validating calculation with simulation software

1.3 Scope

The scope for this project is to avoid and minimizes the wastage of heat lost from various components and reuses the reheating of steam. And that is useful to next WHRu design. Verification of thermal design of heat recovery unit in KED software.

II. LITERATURE REVIEW

The literature reviews throws some guiding points on waste heat recovery in cement industry and about waste heat recovery processes and their ideas.

Totok R. Biyanto1, et, al 'Design Plant-wide Control to Waste Heat Recovery Generation on Cement Industry' Based on PWC method, there are three kinds of control structures; they are boiler follow (BFC), turbines follow (TFC), and coordinate controller (CC). The output response resulted by this simulation show that CC is the most precise control structure to handle the load changes on WHRG plant. Steam drum is a unit operation affecting steam quality produced. To overcome this problem, this unit operating will pair three types of controller; they are mass flow controller, pressure controller, and liquid percent level controller. Three control elements in steam drum will be tested by using set point and disturbance change. Set point tuning is used to know the system performance. It is used to increase production with revamp set point value. Meanwhile, the tuning based disturbance change is used to control response system if disturbance happens from outside environment. This research conducted two kinds of test by disturbance tuning; the first is test with disturbance input value +5% and the second is disturbance input value -5%. Temperature on flue gas will be set as disturbance in this research, because temperature of flue gas always changes over time. The control structure in steam drum has a weakness; it cannot be used to control electricity rate based on load demand.

This research includes waste heat recover in plant and plant wide control of flue gases and recovery of waste heat through various processes.

1) Waste Heat Recovery Generation Plant

Waste Heat Recovery Generation (WHRG) is a power generation system that utilizes exhaust gas still has high energy value . There are two kinds of input variables used; they are flow of exhaust gas which has a high calorific value and feed water which is used as a producer of steam. Flue gas is a waste gas that is used to heat water that will produce steam to rotate turbines. The rotation of turbines will change the thermodynamic energy into electrical energy. Designing WHRG plant needs huge investment Costs. Therefore, in designing WHRG plant must be done a simulation in first to determine the value of its performance. There are three steps to simulate the plant design of WHRG. First, determine the overall unit operation. Second, determine the type of unit operations used. Third, describe the process flow of the WHRG plant. WHRG plant simulation software can make use of HYSYS. There are four steps that must be utilized. First, determine the composition of the whole stream. Second, determine the thermodynamic equations. Third, determine the overall unit operation. Fourth, enter parameters such as stream name, composition, temperature, pressure, and mass flow rate.

2) Plant wide Control

Plant wide control is one of the types of control strategies that are used to consider the overall operation of existing units in a plant, such as the interaction between the unit operation to determine the optimal operating system and security of the whole plant . There are two kinds of part used in plant wide control method . Top-down part is a method used to optimize a particular process by determining the advantageous function, while bottom-up part is a method used to maintain the stability rate of the system. Since this study was aimed to control WHRG plant by considering the stability rate, bottom-up part was utilized. The stages used in designing the research based on bottom-up part are: ƒ determining the operational objectives and limitations analyzing the degree of freedom in the form of degree of freedom value used to calculate the total of manipulated variable (MV) ƒ determining variable process needs controlling, determining the manipulator of production rate ƒ determining the manipulator of production rate ƒ determining the structure of regulatory control layer ƒ determining the adjustment of controller based on Relative Gain Array (RGA) method ƒ administering open loop test derived from the resulted system's responses.

JoseRubensdeCamargo-2013 et, al 'Waste materials co-processing in cement industry: Ecological efficiency of waste reuse'

It is imperative that state environmental agencies have the technical capacity to ensure that companies practice co-processing without endangering the health of workers and populations living near the plants. Ecological efficiency methodology provides a way to show that waste materials are a viable source of alternative fuel to kilns. CH4 is reused as of gases heat in WHRu. In or detriment current production requirements such as environmental and energetic restrictions are increasingly used alternative fuels derived from industrial waste. The cement industry has the potential of reusing waste from another industry as a substitute fuel or raw material .This activity is known as co-processing. Co-processing is defined as an incineration carried out in rotary kilns for clinker production, properly licensed for this purpose, with the use of energetic inside and mineral fraction exploitation as raw material without generation of new waste com- binned with the highly oxidizing environment and the large residence time of material exposed to these conditions, represent an alternative recognized properly and are disseminated to thermal destruction of industrial wastes.

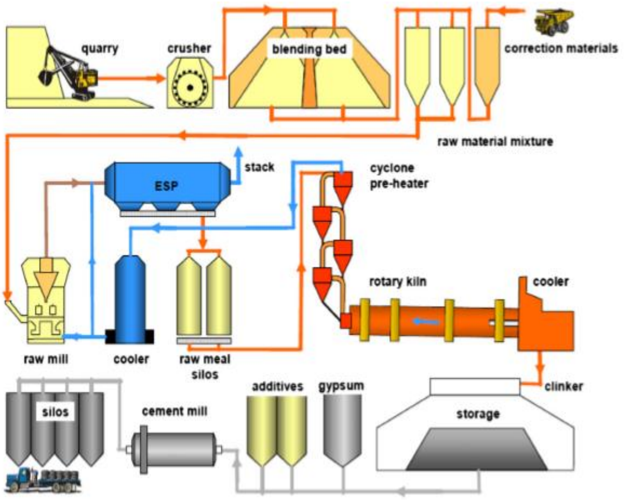

Fig No. 2.1:- Schematic representation of cement production

G. V. Pradeep Varmaa, ,et,al 'Parametric analysis of steam flashing in a power plant using waste heat of cement factory'

The current work, the optimum values for the high pressure flashing and the lower pressure flashing are searched and developed for the maximum heat recovery and also higher output from cogeneration plant. The identified key operational parameters are steam generating pressure, limit to high pressure flashing, limit to low pressure flashing and flash mass ratio. Waste heat recoveries cement plant whose capacity is 4000 TPD has been selected for case study which is located in Telangana, India. The schematic flow diagram of the plant. The working fluid passed through feed pump is sent into air quenched cooler (AQC) boiler and preheated (PH) boiler. The mass, m11 is saturated water, supplied to AQC, PH boiler and high pressure flusher (HPF). The saturated water to AQC is vaporized and superheated) in later stages. The saturated water is evaporated and superheated in PH boiler. The saturated water after flashing enters to HPF where the steam and water are separated. High pressure flashed steam is supplied to the flash steam turbine at appropriate place. The saturated water is passed through a flashing valve enters into the low pressure flusher (LPF) where water is flashed again. The flashed steam is supplied to flash steam turbine. The two streams of superheated vapour from AQC boiler and PH boiler are mixed and expanded through turbine to generate power. The rest of the preheated working fluid is separated into saturated vapour and saturated water. The saturated vapour from two flash chambers is supplied to turbine to generate more power. The turbine exhaust is condensed in the condenser, and passes through condensing pump to be mixed with saturated water from the low pressure flasher. A cement factory cogeneration plant, the conventional steam power plant has been replaced by a double flash steam power plant. The results are focused to search the best condition for HRSG pressure, HP flasher, LP flasher and flashing amount. There is a relation between flash mass and exhaust gas temperature. An optimum flash mass ratio can be selected at a minimum flue gas temperature. The current work suggests 0.5 temperature ratio for both HP flasher and LP flasher. The suggested flash mass ratio is 0.25 to result approximately 90oC of exhaust gas temperature at AQC. On overall basis double flashed system proves over conventional plant by increasing heat recovery and so power output.

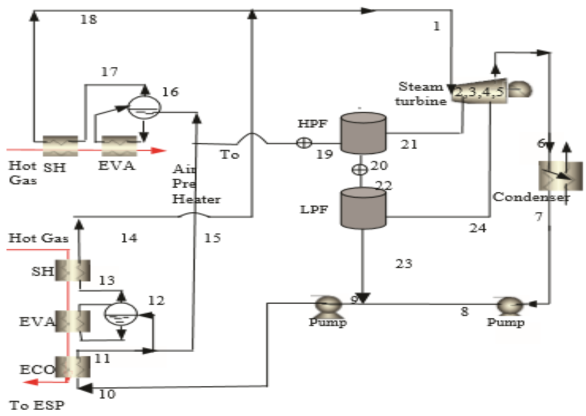

Fig No 2.2-Schematic flow diagram of cogeneration plant in a cement factory

Qi Zhang, Xiaoyu Zhao et.al. 'Waste energy recovery and energy efficiency improvement in China's iron and steel industry'.

Understand the basics 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. However, much of the heat could be recovered. The boiler efficiency increases with increasing inlet oxidizing air temperature when the relative humidity is the same. The main reason for this is that the humidity ratio is higher when the inlet temperature is higher, so the dew point temperature will be higher. Therefore, the recovered heat in the condensing heat exchanger is higher. When the inlet oxidizing air temperature is the same, the boiler efficiency increases with increases in relative humidity. When the inlet oxidizing air temperature is 5 _C, the humidity ratio and the humidification amount of oxidizing air after heat exchange between the flue gas and oxidizing air is shown in. It is shown that the dew point temperature increases with increasing relative humidity, although the humidification amount decreases as relative humidity increases. At the same time, the temperature of the emission flue gas changes slightly the boiler efficiency is higher when more latent heat is released in the condensing boiler.

S K Gupta / S K Kaul et.al. 'Waste heat recovery power plants in cement industry'

As mentioned above, normally, the first priority for utilization of the waste heat is, for the drying of raw materials and coal, since the efficiency of energy conversion system, from thermal to electricity, like in WHRPP, is as low as 18 to 20% (conversion losses are very high). Second priority is given to the power generation. Though, incorporation WHRPP, increases complexity of the system, to some extent, it is still worth considering, as power is generated at much lower cost, than that available from Grid.

As broad criteria, at places where un-interrupted power supply is available at cheaper rates, it may not be economical to install WHRPP. Places where electricity rates are high, or there are frequent power interruptions, use of WHRPP is very lucrative. Moisture in raw materials has an important influence on the sizing of the power generation plant. This fact is depicted in Fig -1. It shows that the waste heat recovery power plant is sized based on the different moisture conditions in raw material / coal i.e. the outlet gas temp from waste heat recovery system is decided, so as to cater to the moisture drying requirement. The moisture content in the raw material increases during rainy season. Quantum of moisture, and the duration, varies from place to place. The sizing of WHRPP plant can be done for any of the following conditions:

1) Fig - 1(a) shows WHRPP matched to minimum moisture content in raw material. It can, therefore, run on full load only, during the extremely dry season. Whenever moisture is more than min. value, power generation would need to be curtailed, so that waste heat is first utilized for drying

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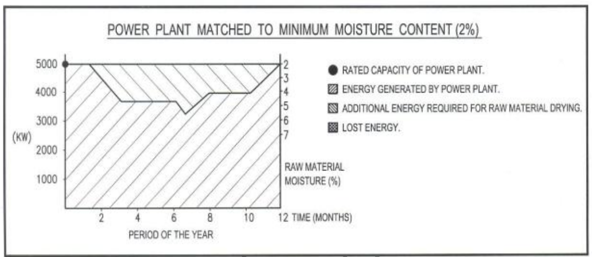

Fig – 2.3 (a): Power Plant Matched to Minimum Moisture Content (2%)

2) Fig - 1(b) shows the WHRPP matched to the average moisture conditions. The investment cost in this case, shall be relatively lower but the plant will not be able to recover the full amount of waste heat during dry season. Also, during extremely wet season, plant will have to be run at reduced capacity.

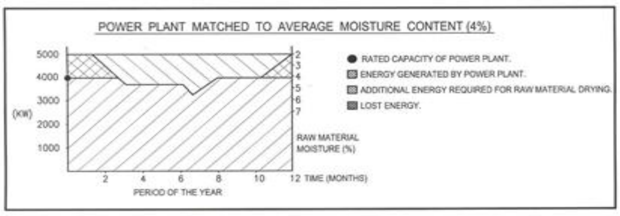

Fig -2.3(b): Power Plant Matched to Average Moisture Content (4%)

3) Fig - 1(c) shows WHRPP matched to maximum moisture content. Though investment will be lowest, a considerable heat shall be lost in dry and semi-dry seasons

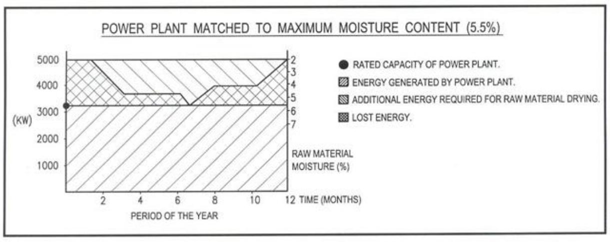

Fig -2.3(c): Power Plant Matched to Maximum Moisture Content (5.5%)

3.3 A techno-economic study of the above three alternatives for a particular plant, would decide the size of the WHRPP. The technology and system selection for WHRPP should be flexible, so that it is able to meet the fluctuating heat requirement for the raw material/ coal drying, depending upon the varying moisture content in the raw material/ coal. Besides the techno-economic study, weightage must be given to the fact that a size of WHRPP, which can be self-sufficient for running the main clinkerisation unit on its own, shall provide a steady and un-interrupted kiln operation.

3.4 As shown in Fig - 2, as a rule of thumb, around 30 kwh of electricity can be generated per tonne of clinker, from a 5-stage preheater kiln, by utilising the waste heat of exhaust gases from Preheater & Grate Cooler. It is based on the normal operating conditions, and partly, accounting waste heat for drying-up of moisture in the raw material and coal (av. moisture).

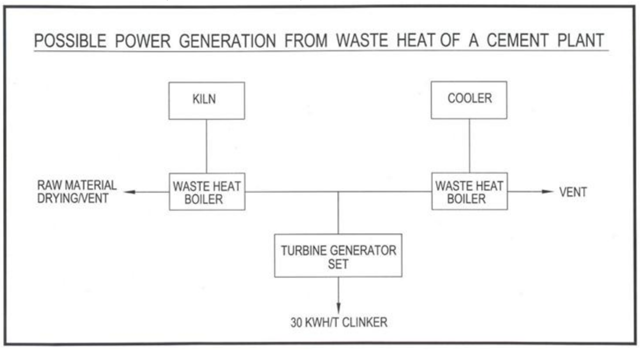

Fig – 2.4: Possible Power Generation from Waste Heat of a Cement Plant

Based on the above, amount of power which may be generated for the standard sizes of plants, is:

- 4500 tpd: 5.6 MW
- 6000 tpd: 7.5 MW
- 10,000 tpd: 12.5 MW

III. PROPOSED AND WORK

The study is carried out on the research based on the waste heat recovery. The based literature study is implemented for developing the proposed research work. The proposed research work aims for developing the waste recovery system for the cement plant. The fig.1.1 shows the proposed research study model. The waste gases are utilizing for warming of firing coal so that the efficiency can be improves up to certain. In this research work the blowing air also used in order provided the sufficient air flow for burning of fuel.

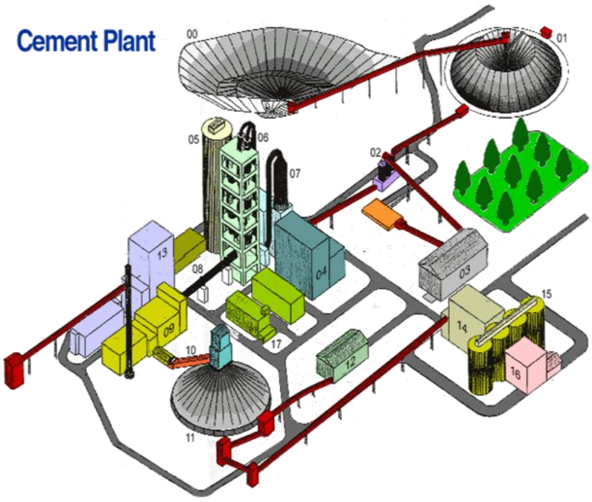

Fig 2.5 Cement Plant

THE FLUE GASES RELEASED FROM PREHEATER CONTAINS THE FOLLOWING GASES.

CO=0.2%, CO_2=29.8%, H_2O=9.8%, N_2=56.80%, SO_2=0%, O_2=3.4%

After deciding to design to WHR unit first to understand of WHR unit and the requirement of their parameter so in this thermal designs of WHR unit we designing following calculation:-

- •Specific heat calculation
- •Velocity calculation of water and steam side,
- •Study of mollier chart,
- •Liquid properties of thermal conductivity, connectivity, viscosity etc.,
- •Standard and normal pressure conversion ,
- •Dimensionless number and their significant and their formulas
- •Density calculations,
- •Heat duty,
- •Pressure drop calculations,
- •Blow down losses, all this calculation are calculated.

EQUATIONS

4. THERMAL DESIGN CALCULATIONS WORK

4.1 Flue gas side calculation:-

(Superheater):-

T_i = 290°C; T_o =283.6°C.

Tavg = (Ti+To)/2

= (290 +283.6)/2

= 286.8°C.

Area1 = (tube pitch-outer diameter) ×tube length× (number of tube-1)

= (0.098-0.0381) ×11.5× (70-1)

= 47.53065 m2

Total area (At) = Area1 + Surrounding Clearance

= 47.53065 + 4.6 = 52.13065 m2

Velocity

Temperature correction factor (Tc) = (t+273)/273

= (290+273)/273

= 2.0622

Pressure correction factor (Pc) = (P+10332)/10332

= (-575+10332)/10332

= 0.94434

F= (466000 ×Tc)/Pc

=1017.626279 (Am3/hr.)

F=A×V

V= 5.422414 m/sec.

Radiation heat loss

Q_r= ε×A×ΔT

Area of cube = 2(l×b+b×h+l×h); l=37m; b=6.9m; h=13.1m

ΔT= (Surface temperature – Atmospheric Temperature) = (60 – 30) =30°C

A= 1660.78m2; ε= 15; ΔT

Qr= 15×1660.78 × 30

= 747.351 kcal/hr.

Superheater:-

m=ρ × v

P =1.4229; V= 442545 m3/hr.

m = 1.4229 × 442545 = 629.69 × 103

Q = m× Cp× ΔT

=629.69×1.15×(290-283)×0.98 ….(2% blow down loss)

Qavail= 4.67 × 106 kj/hr.

= 1.116× 106 kcal/hr.

Quse = Qavail – Qr = 1.16 × 10 6 - 747

= 1.11 × 106 kcal/hr.

4.2 Water Side Calculation:-

Superheater:-

Area calculation

Area of 1 tube

A= π × ID × L

= π × 0.03485 × 11.5

= 1.259 m^2.

Mass flow rate:-

Q= 25301 kg/hr.

=7.028 kg/s

Density (at 236.25°C) =819.06 kg/m^3

Specific volume (236.25 °C) = 1.22× 10^{-3} m^3/ kg

Volume Flow Rate (at 236.25°C.) = mass flow rate × specific volume = 7.028 kg/s × 1.22× 10^{-3} m^3/kg

=0.00857 m^3/sec

Velocity:-

Q = A×V

V = Q/A= 7.028/1.259

= 5.58 m/s

Reynolds Number:-

Re= (ρ×v×l)/μ

Leq = 4A/P

A= 1.259; H=11.5

P=2(πDi + H) = 2(π×0.03485+11.5) =23.21

Leq= (4 × 1.259)/ 23.21=0.216

Re= (819.06 × 5.58 × 0.216)/ (17.38× 10^{-6})

= 57.1815 ×106 (Turbulent flow)

Prandtel No:-

Pr = (μ×Cp)/k

= (17.386 ×10-6 × 1.9)/37.35

=9.21 × 10^{-7}

Nusselt Number:-

$Nu= 0.023 \times (Re)^{0.8} \times (Pr)^{0.33}$

$=0.023 \times (57.1815 \times 106)^{0.8} \times (9.21 \times 10\text{-}7)^{0.33}$

$=142.31$

Superheater

$Q = m\times Cp\times \Delta T$; (value heat transfer coefficient of cp=1)

$1.16 \times 106= m \times 1 \times (271.8 – 200)$

m = 16155.98 kg/hr.

IV. CONCLUSION

Flue gases released from preheater boiler is at 164.7 °c which can further be used in coal mill to remove moisture. Because if these gases if we release to atmosphere that will be hazardous to environment and peoples health. There is generation of 25 tons of steam from our designed preheater boiler. Due to using of all wasted steam, in steam generator there are two modes and hence they are generating overall capacity of 12MW electricity for plant. The steam electricity generation rate is 5.8 TPH per MW. The things behind that are our WHRu is generating high pressure steam. Overall power generation of plant is 12 MW by Air quench chamber and preheater but from preheater power generation is 4 MW from preheater of steam. Number deeps can be selected according to the calculated heat transfer area. Theoretical calculations are gets closer to the expected results after 5 to 6 iterations. Overall cost gets reduces after selecting appropriate material.

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