POWER GENERATION FROM WASTE HEAT EXTRACTED THROUGH CLINKER PRODUCTION IN CEMENT INDUSTRY

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ABSTRACT

This paper revolves around the power generation from the waste heat extracted through clinker production in the cement industry. Paper includes the power generation calculation for a cement plant and the different methodologies(cycles) used to generate power. Waste heat power generation has a wide scope in future to reduce carbon emissions and to optimizes resources as well as energy savings.

Keywords :Power cycles ,Power calculation etc.

1) INTRODUCTION

New suspension process (NSP) kilns include multi-stage preheaters and pre-calciners to preprocess raw materials before they enter the kiln, and an air-quench system to cool the clinker product. Kiln exhaust streams, from the clinker cooler and the kiln preheater system, contain useful thermal energy that can be converted into power. Typically, the clinker coolers release large amounts of heated air at 250 to 340° C (480 to 645° F) directly into the atmosphere. At the kiln charging side, the 300 to 400° C (570 to 750° F) kiln gas coming off the preheaters is typically used to dry material in the raw mill and/or the coal mill and then sent to electrostaticprecipitators or bag filter houses to remove dust before finally being vented to the atmosphere. If the raw mill is down, the exhaust gas would be cooled with a water spray or cold air before it entered the dust collectors. Maximizing overall kiln process efficiency is paramount for efficient plant operation, but remaining waste heat from the preheater exhausts and clinker coolers can be recovered and used to provide low temperature heating needs in the plant, or used to generate power to offset a portion of power purchased from the grid, or captive power generated by fuel consumption at the site. Typically, cement plants do not have significant low-temperature heating requirements, so most waste heat recovery projects have been for power generation. The amount of waste heat available for recovery depends on kiln system design and production, the moisture content of the raw materials, and the amount of heat required for drying in the raw mill system, solid fuel system and cement mill. Waste heat recovery can provide up to 30 percent of a cement plant's overall electricity needs and offers the following advantages:

- Reduces purchased power consumption (or reduces reliance on captive power plants), which in turn reduces operating costs
- Mitigates the impact of future electric price increases
- Enhances plant power reliability
- Improves plant competitive position in the market
- Lowers plant specific energy consumption, reducing greenhouse gas emissions (based on credit for reduced central station power generation or reduced fossil-fired captive power generation at the cement plant)

2) BACKGROUND

As majority of the nations used non-renewable source of energy that lead to the emission of greenhouse gases, it became essential to regulate emissions and reduce CHGs that cause global warming.A voluntary treaty was signed by 141 countries at the Kyoto conference to reduce greenhouse emission. The concept of carbon credits was thus born at the conference.

Almost all cement plants are working today on improving fuel efficiency, power efficiency, renewable energy, Waste heat recovery etc.

3) METHODOLOGY OR POWER CYCLES FOR WASTE HEAT RECOVERY

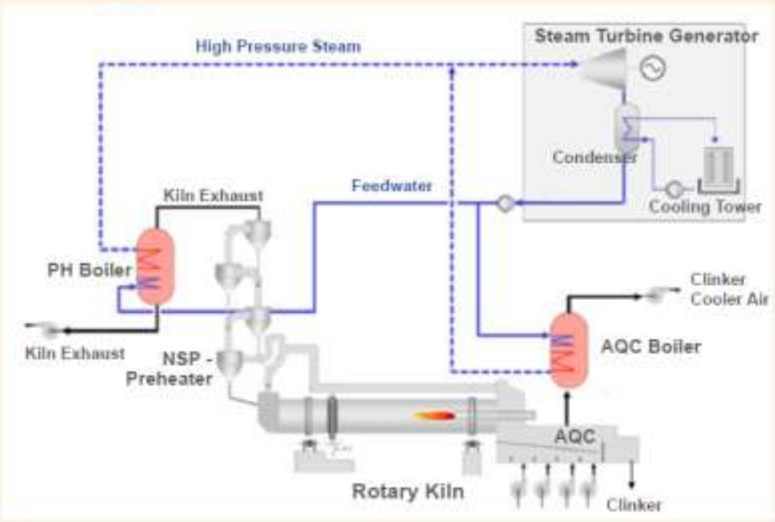
Waste heat recovery power systems used for cement kilns operate on the Rankine Cycle. This thermodynamic cycle is thebasis for conventional thermal power generating stations andconsists of a heat source (boiler) that converts a liquid workingfluid to high-pressure vapor (steam, in a power station) that isthen expanded through a turbo generator producing power.Low-pressure vapor exhausted from the turbo generator is condensedback to a liquid state, with condensate from the condenserreturned to the boiler feed water pump to continue thecycle. Waste heat recovery systems consist of heat exchangersor heat recovery steam generators (HRSGs) that transfer heatfrom the exhaust gases to the working fluid inside, turbines,electric generators, condensers, and a working fluid coolingsystem. Three primary waste heat recovery power generationsystems are available, differentiated by the type of workingfluid as follows.

3a). STEAM RANKINE CYCLE (SRC)–

The most commonly usedRankine cycle system for waste heat recovery power generationuses water as the working fluid and involves generatingsteam in a waste heat boiler, which then drives a steam turbine.Steam turbines are one of the oldest and most versatilepower generation technologies in use. As shown in Figure 4,in the steam waste heat recovery steam cycle, the workingFluid water is first pumped to elevated pressure beforeentering a waste heat recovery boiler. The water is vaporizedinto high-pressure steam by the hot exhaust from the processand then expanded to lower temperature and pressure in aturbine, generating mechanical power that drives an electricgenerator. The low-pressure steam is then exhausted to acondenser at vacuum conditions, where the expanded vaporis condensed to low-pressure liquid and returned to the feedwaterpump and boiler.

Steam cycles are by far the most common waste heat recoverysystems in operation in cement plants, and generallyreflect the following:

Figure 4: Waste Heat Recovery System on NSP Cement Kiln



Source: Adapted from Holcim 2012, 2013

- Most familiar to the cement industry and are generallyeconomically preferable where source heat temperatureexceeds 300° C (570° F).
- Based on proven technologies and generally simple to operate.
- Widely available from a variety of suppliers
- Generally have lower installation costs than other Rank in cycle systems on a specific cost basis (US$/kW)
- Need higher-temperature waste heat to operate optimally(minimum >260° C (500° F))—generation efficiencies fallsignificantly at lower temperatures, and lower pressure andtemperature steam conditions can result in partially condensed

steam exiting the turbine, causing blade erosion• Often recover heat from the middle of the air coolerexhaust flow to increase waste gas temperatures to anacceptable level for the system, but at the expense of notrecovering a portion of cooler waste heat• Often require a full-time operator, depending on localregulations

- Require feed water conditioning systems.
- Generally require a water-cooled condenser; air cooledcondensers can be used but create a performance penaltydue to higher condenser vacuum pressures.

• In general, match well with large kilns and systems withlow raw material water content (resulting in higher wastegas temperatures)

3b). ORGANIC RANKINE CYCLES (ORC)–

Other types of workingfluids with better generation efficiencies at lower heat source temperatures are used in organic Rankine cycle (ORC) systems.The ORCs typically use a high molecular mass organic workingfluid such as butane or pentane that has a lower boiling point,higher vapor pressure, higher molecular mass, and higher massflow compared to water. Together, these features enable higherturbine efficiencies than those offered by a steam system. The ORC systems can be utilized for waste heat sources aslow as 150° C (300° F), whereas steam systems are limited toheat sources greater than 260° C (500° F). The ORC systemsare typically designed with two heat transfer stages. The firststage transfers heat from the waste gases to an intermediateheat transfer fluid (e.g., thermal transfer oil). The second stagetransfers heat from the intermediate heat transfer fluid to the organic working fluid. The ORCs have commonly been usedto generate power in geothermal power plants, and morerecently, in pipeline compressor heat recovery applications inthe United States. The ORC systems have been widely usedto generate power from biomass systems in Europe. A fewORC systems have been installed on cement kilns. The ORC'sspecific features include the following :

• Can recover heat from gases at lower temperatures thanis possible with conventional steam systems, enablingORCs to utilize all recoverable heat from the air cooler.

• Operate with condensing systems above atmosphericpressure, reducing risk of air leakage into the system andeliminating the need for a de-aerator.

• Not susceptible to freezing.

• Because ORCs operate at relatively low pressure, theycan operate unattended and fully automated in manylocations depending on local regulations.

• The organic fluid properties result in the working fluidremaining dry (no partial condensation) throughout theturbine, avoiding blade erosion.

• Can utilize air-cooled condensers without negativelyimpacting performance

• Lower-speed (rpm) ORC turbine allows generator directdrive without the need for and inefficiency of a reductiongear.

• ORC equipment (turbines, piping, condensers, heatexchanger surface) is typically smaller than that requiredfor steam systems, and the turbine generally consists of
fewer stages.

• Although ORCs can provide generation efficienciescomparable to a steam Rankine system, ORCs are typicallyapplied to lower temperature exhaust streams, andlimited in sizing and scalability, and generally are smallerin capacity that steam systems.

• Depending on the application, ORC systems often have ahigher specific cost (US$/kW) than steam systems.

• The two-stage heat transfer process creates some systeminefficiencies

• The heat transfer fluids and organic fluids normally usedin ORCs are combustible, requiring fire protection measuresand periodic replacement over time. Also, there maybe environmental concerns over potential system leaks.

• In general, ORC systems are well-matched with small- tomedium-size, high-efficiency kilns or kilns with elevatedraw material moisture content

3c). THE KALINACYCLE is another Rankine cycle that uses abinary mixture of water and ammonia as the working fluid,which allows for a more efficient energy extraction fromthe heat source. The Kalina cycle takes advantage of theability of ammonia-water mixtures to utilize variable andlower temperature heat sources. The Kalina cycle has anoperating temperature range that can accept waste heat attemperatures of 95° C (200° F) to 535° C (1,000° F) and isclaimed to be 15 to 25 percent more efficient than ORCsat the same temperature level. The Kalina cycle is in marketintroduction, with a total of nine operating systems in diverseindustries such as steel and refining, and in geothermal powerplants where the hot fluid is very often a liquid below 150 °C(300 °F).11 Kalina cycle systems are now being piloted in thecement industry.12 Key features of the Kalina cycle include the following (Gibbon 2013, Mirolli 2012):

• Can be used in lower temperature applications thanconventional steam Rankine cycle systems

- Highly flexible; the system has a high turn-down ratio andfast response to changes in heat source temperature andflow.
- The ammonia-water mixture can be controlled to achieve improved heat transfer and higher efficiency by matchingwaste heat temperatures and flows
- The binary working fluid is non-flammable.
- The technology is in the early stage of market introductionwith limited suppliers and experience.

4) POWER CALCULATION FROM WASTE HEAT EXTRACTED THROUGH CLINKER

Let us consider following parameters for a cement plant single unit at different tapings which is generally observed for the tapings as

Exhaust heat from	**Inlet temp**	**Out let temp**	**Absolute Pressure (kg/cm2)**	**Gas flow at NTP Nm3/hr**	**Specific heat Kcal/Kg/Deg Cent. (approx)**	**Density of Flue gas (Kg/Nm3)**
Pre heater	285	200	0.965	485200	0.35	1.42
AQC Mid tap-1	410	105	0.995	212000	0.317	1.29
AQC Mid tap-2	565	125	0.995	1E-13	0.31	1.29

1) Δ T (Temp Diff.) = Inlet Temp – Outlet Temp.

a) For Preheater

Δ T = 285-200 =85 Degree centigrade.

b) For Air cooled condenser tap-1 (at Cooler)

Δ T = 410-105 =305 Degree centigrade.

c) For Air cooled condenser tap-2 (at Cooler)

Δ T = 565- 125 = 440 Degree Centigrade.

2) **Gas Flow volume at mentioned temp and pressure = (gas flow * (273+Inlet temp)/ ((273+Normal Temp.)*Absolute Pressure)**

a) **For Preheater**

= 485200*(273+285)/((273+20)*0.965))

=957546.9062

b) **For Air cooled condenser tap-1 (at Cooler)**

=212000*(273+410) / ((273+20)*0.995))

=496667.6385

c) **For Air cooled condenser tap-2 (at Cooler)**

= $1*10^{-13}$ *(273+565) / ((273+20)*0.995))

=$2.87444*10^{-13}$

3) **Density of Gas at Inlet Temp. = Density of flue Gas (Kg/M^3)* Gas Flow (NM^3/Hr) / Gas Flow Volume.**

a) **For Preheater**
=1.42*485200 / 957546.9062 (Gas volume from 2-a)
=0.719530287

b) **For air cooled condenser tap -1 (at Cooler)**
=1.29*212000/496667.6385 (Gas volume from 2-b)
=0.550629795

c) **For air cooled condenser tap-2 (at cooler)**
=$1.29*1*10^{-13}$ / $2.87444*10^{-13}$ (Gas volume from 2-c)
=0.448782995

4) **Heat Delivered for generation of power Kcal/Hr = Δ T*Gas flow volume at mentioned temp*Density of gas at inlet temp.*Specific heat(kcal/kg/Deg cent.).**

a) **For Preheater**

=85*957546.9062*0.719530287*0.35

=20497274 Kcal /Hr = 43.66 % of Total heat delivered

b) **Forair cooled Condenser tap -1 (at Cooler)**

=305*496667.6385*0.550629795*0.317

=26441413.8 Kcal /Hr = 56.33 % of Total heat delivered.

c) For air cooled Condenser tap -2 (at Cooler)

$=440*2.87444*10^{-13}*0.448782995*0.31$

$=1.75956*10^{-11}$Kcal /Hr

Total Heat Delivered for generation of Power Kcal /Hr = a+b+c

$=20497274+26441413.8+1.75956*10^{-11}$

=46938687.8

5) Total Available Energy in Kj/Hr = Total Heat * 4.18

=46938687.8*4.184 **(1 Cal =4.184)**

=196391469.8 **(Power = Energy (Joule) / Time(Sec))**

6) Equivalent Power to heat available (in MW /Hr) = Total available energy /(3600*1000).

=196391469.8 / (3600*1000)

=54.55318604

- **Considering power plant efficiency at 18% than Power generation in MW**

=54.55318604*.18

=9.819573488

7) Heat rate = Total heat consumed in 1 Hr (Kcal) / total power generated (KW).

= 46938687.8 / 9819.573488

=4780.114723K Cal/ K W Hr

If there are a no. of units in a cement plant as 2 or 3 than power generation is the multiple of those. As for 2 nos of unit :-

Total Power Generation =2* Power generation from single unit.

=2*9.819573488

=19.639 MW at considering 18% efficiency.

5) CONCLUSION

1). Waste heat recovery power plant is a best alternate of renewable energy to overcome energy problems as well as carbon emissions in cement plants to save environment. Also it reduces the green house effects. It is ecofriendly. We can see from power calculation that a 9MW power can be generated from the waste heat extracted through clinker production in cement industry which is being released to atmosphere directly through stacks.

2). Can be reduced purchased power consumption, thus operating cost.

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