RECOVERING THE ADVANTAGE

ANTHONY HINDE, EXERGY SPA, ITALY, EXPLAINS HOW WASTE HEAT RECOVERY SYSTEMS IN THE CEMENT SECTOR ARE GAINING A WIDER APPLICATION IN THE INDUSTRY.

Introduction

The cement industry is one of the most energy-intensive of all the manufacturing industries, where total energy consumption accounts for around 50% of all cement production costs. Moreover, the cement process is characterised by significant heat losses through the clinker cooler and the kiln preheater system of 30 – 50%. These two figures alone adequately explain why Waste Heat Recovery systems in the cement sector for producing clean electricity from exhaust gases are technologies that are gaining a wider application in the industry and whose benefits are well known.

In order to recover waste heat from the preheater exhaust and clinker cooler exhaust gases in the cement plant, the most suitable technologies are either Steam Rankine Cycle, or Organic Rankine Cycle (ORC). Steam Rankine cycles can be more efficient when exhaust gases exceed 300°C while Organic Rankine Cycles are the most efficient choice for temperatures as low as 150°C and bring added benefits in terms of operational simplicity and lower maintenance.

WHR ORC latest improvements

In recent years R&D activity in ORC waste heat recovery technology has brought new improvements: reducing initial economic investments for cement companies while increasing plants' efficiency and profitability. A major innovation in ORC technology has been the introduction of the Radial Outflow Turbine (ROT) technology. Designed and patented by Exergy, the ROT is the first turbine of its kind to be used in ORC systems. Different from the axial and radial inflow configurations, the Radial Outflow Turbine is capable of converting the energy contained in the fluid into mechanical power with high efficiency. Employing the ROT technology in an ORC system for WHR applications is a simple, efficient and economically viable solution:

- Higher efficiency than an axial turbine allowing up to 20% more power. This higher performance is related to:
  - Up to 6 stages on a single disk reducing the size and length of the turbine compared to axial turbine.
  - Less tip leakage and disk friction losses.
  - Minimum 3D effect thanks to the low blade height and low blade height variation.
- No gearbox needed thanks to the low rotational speed (3000 – 1500 rpm) that allows a direct coupling with a generator with two or four poles and more reliability for the overall system.
- Little limitation on cycle pressure and on blade manufacturing leading to a high flexibility that extends the range of application.
- Low vibrations that lead to a long life of the plant.
- Simple construction technology that is compact and easy to transport and install.
- Easy and low cost maintenance. The mechanical group of the turbine containing the bearings, oil lubrication system and seals can be easily removed without need of draining the organic fluid away from the cycle thus reducing the downtime of the plant to 6 hours during maintenance. This relates to the need for fluid drainage, and therefore approximately 1 week or more when compared with other technologies.

The main components of the ORC WHR system using the Radial Outflow Turbine are:

- The waste heat recovery unit, taking the heat energy from the exhaust gas and transferring it to an intermediate fluid, usually oil, or water, and bringing that heat to the ORC process.
- The turbine: it is the key component of the plant, producing mechanical energy that is converted into electricity by a generator directly coupled with the turbine shaft.
- The heat exchangers: they extract the heat from the intermediate thermal fluid. Shell and tube heat exchangers are usually applied but they can vary geometry and configuration depending on the energy source and the total thermal input.
- The feed pump brings the organic fluid from the condensation pressure to the maximum pressure of the cycle.
- The condenser: with the direct air to fluid heat exchanger, the organic fluid is cooled and liquefied before entering the pump. The use of air condenser brings several advantages:
  - Eliminates the requirement for water to treatment and make up.
  - Reduces the condensing pressure of the cycle, leading to higher power production.
  - Reduces the equipment to install thus minimising plant costs.

When required a water-cooled condenser can also be used.

The use of an intermediate loop to transfer the waste heat from the cement process to the ORC cycle has the following advantages.

Table 1. **Characteristics of the plant and of the WHR system applied**

Location	**Flow of clinker cooler air (1)**
Turkey	145 000 Nm³/h
Plant capacity	**Temperature of clinker cooler air (1)**
9000 tpd clinker and cement	345°C
Operating hours	**Flow of clinker cooler air (2)**
7500/year	205 000 Nm³/h
Fuel used	**Temperature of clinker cooler air (2)**
Coal, Petcoke	345°C
Application	**Cooling agent**
Heat Recovery (cement mill)	Air Cooled Condenser
Model used	**Electrical generation gross**
EPSd 510	5000 KWe
Flue gas outlet temperature (1,2)	**Gross Efficiency:**
170°C	22%

Table 2. **Profitability of the plant**

Electricity Value	US$70/MWh	US$100/MWh	US$150/MWh	US$200/MWh
CAPEX(€)	12 500 000	12 500 000	12 500 000	12 500 000
Net cash flow per year	2 100 000	2 850 000	4 070 000	5 290 000
Payback Time	Approx. 6 Years	Approx. 4 Years	Approx. 3 Years	Less than 3 years
IRR (internal rate of return)	9%	16.5%	28.2%	40%

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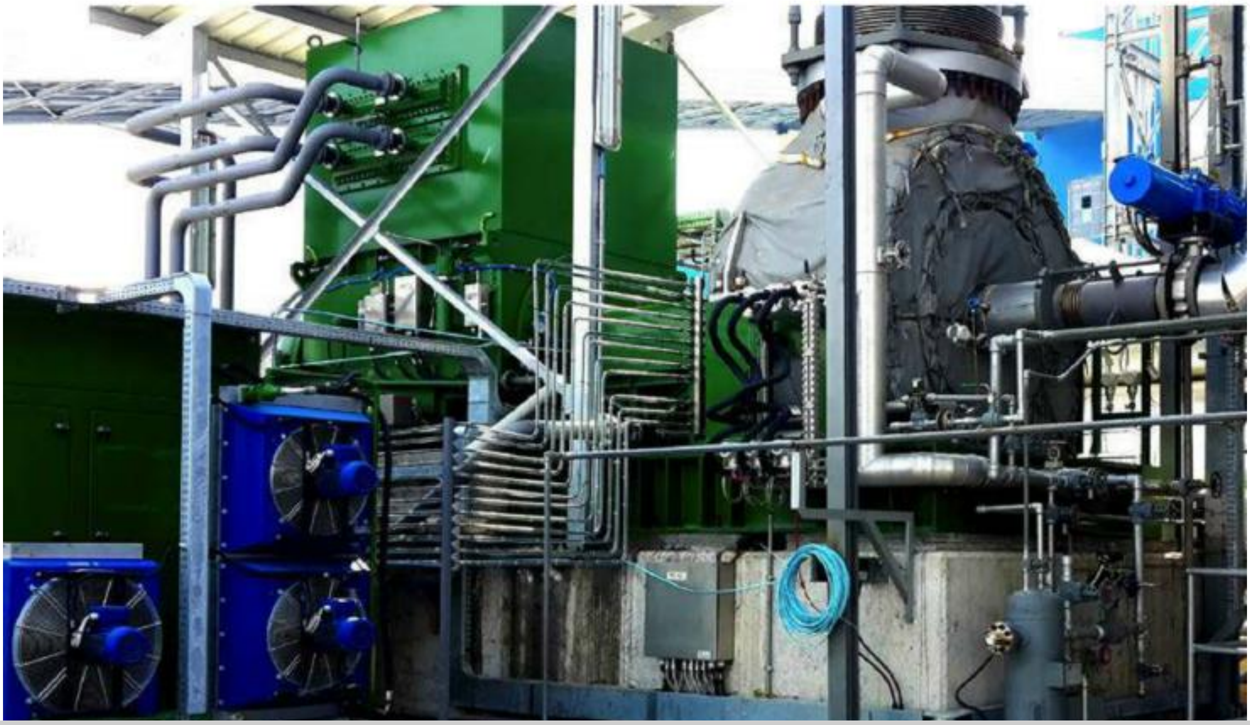

- Recovers exhaust gases with a high concentration of particulate or corrosive substances without decreasing the heat exchanger efficiency of the ORC system.
- Adjusts the heat input without affecting the industrial process or the engines only bypassing part of the thermal fluid flowing in the loop.
- Avoids shut down of the industrial process when the ORC system needs to run the periodical maintenance.

All the advantages offered by this ORC plant configuration using the ROT turbine translate into economic benefits and competitive initial capital investments. Installing this ORC WHR system has a typical payback time of 3 to 7 years depending on the electrical output of the ORC required, the cement plant configuration and other factors such as the price of electricity.

The application of EXERGY's ORC waste heat recovery systems utilising the ROT can be applied to cement plants of any size for a maximum of total power installed of 50 MWe.

WHR case study for a cement plant

An example of the application of the ORC waste heat recovery system that EXERGY has studied for a client is a 5 MWe ORC unit that recovers the exhaust gases of two Kiln coolers of a cement plant located in Turkey.

Characteristics of the plant and of the WHR system applied in the power plant is composed of:

- A Waste Heat Recovery system consisting of:
  - Waste heat recovery exchanger that transfers the heat from the flue gases to a thermal oil reaching an outlet temperature of 270°C and an inlet temperature of 130°C. This temperature has been calculated to guarantee the maximum heat recovery for power production.
  - Thermal oil tank.
  - A thermal oil loop interconnecting the Waste Heat recovery system to the ORC module.
- The ORC module with the main components that are shown in Figure 1 and include preheater, evaporator, and a superheater to heat up the vapour of working fluid coming out from the evaporator before this enters the turbine. This increases power generation from the turbine. An air-cooling system has been chosen as a condensing system thus eliminating any use of water and minimising the cost of the equipment in comparison to a water-cooled system.

Profitability of the plant and payback time

Table 2 shows a business plan on a duration of 10 years for different electricity price scenarios with profitability and return on investment for this ORC WHR system.

Conclusion

EXERGY's ORC WHR systems utilising the Radial Outflow Turbine can offer the cement industry a competitive solution to recover heat losses and produce clean electricity to supply the plant's production process or to sell electricity to the grid. This solution enables a cement company to increase its energy efficiency in the production process, to benefit from economical advantages that can help companies becoming more competitive in the market, as well as adding green credential thanks to the reduction of carbon emissions in the plant.