A 5MWe ORC unit was installed at CRH's plant at Rohožník, Slovakia, in 2014

Going organic

Recent years have seen cement producers focus on improving energy efficiency with waste heat recovery (WHR) becoming an increasingly popular alternative. Turboden explains the benefits of organic Rankine cycle (ORC) technology and takes a closer look at investment options.

■ *by **Turboden SpA,** Italy*

Several waste heat recovery (WHR) technologies are available to the cement industry. Organic Rankine cycle (ORC) technology has been a proven viable option for the sector since the end of the 1990s.

In the last 20 years, WHR plants have been developed extensively in China (addressing a government obligation). The uptake has been more modest in other Asian countries such as India, Thailand and Bangladesh, while elsewhere the introduction of WHR systems is taking smaller steps (with the exception of Turkey, where around 10 WHR plants were built in the last decade).

The potential of WHR remains considerable and widely unexploited. In some cases the implementation of WHR plants is held back, even in regions with medium-high power prices, by barriers related to restrictions in capital expenditure, the need for off-balance sheet investments and other financing or investment limitations.

However, the development of different financial and investment solutions that allow cement producers to benefit from lower power expenditure provided by WHR systems is supported by the cement company's need to remain financially focussed on its core production process.

WHR systems in cement process

In the cement production process there are two main hot gas streams where sensible heat can be recovered and transformed into electricity that is usually self-consumed by the plant.

The heat contained in the clinker cooler and preheater gas hot streams is typically transferred to the ORC unit through a thermal oil, saturated steam or pressurised water circuit or directly to the organic fluid in the case of direct exchange systems.

The advantages of installing a WHR system are well known to cement producers and include:

- lower costs charged by the plant's power supplier
- reduced water consumption
- lower production costs, thereby improving competitiveness
- no additional fuel consumption
- CO_2-free way to generate power
- a greener corporate image.

The Turboden ORC unit can efficiently use exhaust gases to produce useful electric power

As there are no fuel costs, the economic feasibility of a WHR system is mainly related to the following factors:

- cost of electricity – WHR systems start to be economically feasible when power costs are above €50/MWh (US$60/MWh)
- investment cost (capex) – this depends on specific site conditions (size of the plant, standards to be followed, type of cooling system, cost of the local workforce, etc.) and technology selected. Typical installed values range from €1500/MW to €2500-3000/MW.
- operating and maintenance costs (opex) – with the selected technology and specific site workforce cost as key factors

Typically, WHR plants can be considered a positive investment when the system's pay-back time is below 6-8 years and the internal investment rate (IRR) over 10 years is above 8-12 per cent.

Often a dedicated heat recovery exchanger is installed for each heat source. The two heat recovery exchangers have different technical features due to the different characteristics of the exhaust gas, particularly the high dust content (20-100g/Nm^3) and the type of dust (abrasive in the clinker cooler gas, soft and sticky in the preheater gas).

To prevent any impact of the WHR system on the main production process, the exchangers are installed in the bypass to the main gas duct.

ORC-based WHR in the cement plant

ORC as a technology has been commercially available since the 1970s, originally used for geothermal energy exploitation and more recently – since the '80s and '90s – for power production from biomass combustion, and solar and heat recovery from industrial processes.

ORC has become a competitive alternative to steam technology, especially in the size between 5-20MWe, thanks to several features and advantages, including:

No water consumption
One of the main advantages of the ORC technology compared to steam is the option to configure the system without any water use and consequently, reduce the expenditure related to water consumption. This makes ORC particularly advantageous on sites where water availability is an issue.

Totally automatic system
WHR plants based on ORC have a high level of automation and are designed to automatically self-adjust to the actual operating conditions. Variations in exhaust gas temperatures and flows will not affect the functionality of the system, just the power output. The result is a totally automatic plant with unmanned operations: no full-time dedicated personnel has to take care of the WHR system. About 10h/week are required for general checks and very simple routine activities.

High power production, especially for water-free configurations
ORC technology, using organic fluids with peculiar thermodynamic characteristics, allows producers to maximise power generation leveraging:

- optimal coupling between the heat source and the organic fluid thermal capacities – the organic fluid can be selected from time to time to optimise the heat exchange profile.
- very high turbine efficiency – due to the specific characteristics of the fluid to be expanded (such as flow, pressure, enthalpy drop) turbines used in ORC plants typically reach isentropic efficiency around 85 per cent or more.
- in a water-free configuration the condensation of the working fluid must take place in air-cooled condensing (ACC) systems – as a result of the relatively high condensing pressure (characteristic of some organic fluid), the ACC system can be designed to be very effective, with a condensing temperature very close to the ambient temperature.

No supervision personnel
An ORC system does not need supervision personnel in normal operating conditions nor in shutdown procedures. ORCs are remotely monitored and require minimal annual maintenance, thereby allowing the cement plant technicians to focus on the cement production process.

Minimum maintenance requirements and long life without major overhaul
Maintenance activities and costs of the ORC system are minimised compared to steam turbines due to several characteristics of the ORC technology, including:

- organic fluid dry expansion in the turbine (no erosion of blades)
- non-aggressive and non-corrosive organic fluid
- low rpm of the turbine.

Flexible operation in a wide range of thermal power loads with high efficiency even at partial load
In cases of multiple kilns or variable heat source loads, the ORC system can maximise the energy produced annually.

Comparison with traditional steam Rankine (SR) systems

In Asia, WHR systems often apply the very traditional water-based Rankine cycle. When compared with ORC systems, the main feature of this WHR technology is the use of water as a working fluid. Due to its nature, water is corrosive and erosive, leading to relatively high operating and maintenance costs. SR plants consume significant amounts of water, even with ACCs, but their efficiency is good if a high-temperature heat source is found (eg, mid-tapping on clinker cooler and not too many preheater cyclones on the kiln line). In the case of ACCs (dry cooling), because of the water-condensing pressure at ambient temperature, the SR efficiency is significantly lower than that of ORC systems. Taking into account these indications, an SR plant typically requires about 15-20 people for its operation, representing a higher labour cost than ORC systems. This is the main reason why the uptake of SR plants is high in countries such as China, India and other Asian markets as workforce costs are low while water availability is good. At the same time, due to the high personnel needs, SR plants for WHR in the cement installations can be found in Western countries, where the ORC technology is typically preferred.

Turboden experience

Italy-based Turboden has more than 35 years' experience in the ORC field. Today, there are about 360 Turboden ORC plants, 330 of them in operation with an average availability higher than 98 per cent. Cumulative operating hours exceeds 10,000,000, reflecting Turboden's after-sales experience.

In terms of WHR applications in the cement industry, Turboden supplied its first ORC plant in 2010 when it delivered to Cimar's plant in Ait Baha, Morocco.

This first unit was followed by five more:

- Cimar Morocco (HeidelbergCement) – a 2MWe Turboden ORC unit has been working since 2010 at the company's Ait Baha plant. In 2014 this unit was hybridised with an integration of the thermal input given by solar power through solar concentrating system.
- Holcim Romania (LafargeHolcim) – a 4MWe ORC was commissioned at the Aleşd works in 2012.
- CRH Slovakia – a 5MWe ORC unit has been working at the Rohožník plant since 2014.
- CarpatCement (HeidelbergCement group) – Turboden supplied a 4MWe ORC unit at the Fieni facility in Romania in 2015.
- In Switzerland a 2MWe ORC was commissioned for an undisclosed customer at the end of 2016.
- Turboden is currently building an innovative 2MW direct exchange ORC unit at Cementi Rossi's Piacenza plant in Italy.

In addition, since December 2014 Turboden has been participating in the European Commission-financed TASIO project to help develop new solutions to recover waste heat in energy-intensive processes in several industrial sectors, including the cement industry, and


A 2MWe Turboden ORC unit was installed at Cimar, Morocco, and later the facility was hybridised with a solar concentrating system

transform this heat into useful energy.

The project addresses the implementation of a full demonstration of a direct exchange heat recovery system for electrical energy generation at Cementi Rossi's cement plant in Italy. Installation of the ORC was due during 2017 with commissioning in the first part of 2018.

Financing and investing schemes

The uptake of ORC systems as a viable option for cement companies depends on sound financing and investment opportunities. A range of such sources is available and explained below.

Financing

Institutional investors

In some countries, because of geopolitical and macroeconomic reasons, finance is only available at interest rates over 10 per cent, putting important constraints on the investment in WHR plants. In such countries, the possibility to get international financing at a lower rate can support the customer's business plan. International institutions such as the International Financing Corporation (IFC) and the European Bank for Reconstruction and Development (EBRD) may be interested in financing industrial projects with WHR plants. A cluster of such projects can be financed in a tailored arrangement.

Export credit

A further option available to the cement company with the benefits of deferred payments and lower interest rates is to apply for financing with the supplier's export credit agencies (eg, Sace in Italy). Both buyer's and supplier's credit arrangements are available, depending on the size of the project. The cost of the operation as well as the length of the deferred payment term depends on the country, project size and customer type. For example, Turboden has achieved successful operations leveraging Sace for WHR projects in Turkey.

Investment

In some cases, cement producers require an external investor to finance the project. In addition to leasing or renting options, build-own-transfer (BOT), build-own-operate-transfer (BOOT), ESCO schemes or customised contract are possible. In BOT or BOOT schemes, a third company invests in the WHR plant sharing the benefits with the cement maker who provides the waste heat sources and the land where to install the WHR system. Many different solutions and schemes can be studied to address both investor and cement maker needs.

Turboden is in contact with several potential investors interested in proposing BOT and BOOT schemes for cement producers.

Conclusion

Technical solutions for a WHR plant using Turboden ORC are mature and proven, and have been demonstrated to present several advantages compared to other technologies.

Barriers to project realisation remain, even in countries where power prices are high. In these cases, the move to a successful project warrants a closer look at available financing schemes and the involvement of third parties as investors. However, WHR systems can provide a significant cost-saving opportunity for cement producers. ■