3.3 ORC waste heat recovery with Exergy's Radial Outflow Turbine

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Waste heat recovery (WHR) has proven to be a market-ready and widely employed technology that can help cement plants achieve energy efficiency targets effectively. These systems represent flexible and economically viable solutions to increase sustainability and profitability of a cement business, reducing energy demand and associated operating costs and CO_2 emissions. Exergy's organic Rankine cycle (ORC) WHR system, based on the Radial Outflow Turbine, can offer all the advantages of a traditional ORC system over a steam Rankine cycle system, combined with some enhanced features and performance that Exergy's proprietary technology can deliver.

In 2020 the Global Cement and Concrete Association (GCCA) – comprising 40 member companies representing almost 40 per cent of global cement production – announced its commitment to deliver carbon-neutral concrete production by 2050. Among the targets determined in its roadmap to Net Zero is a 20 per cent reduction in CO_2 emissions per tonne of cement by 2030. This goal will be a challenge for the sector considering that the direct CO_2 intensity of cement production soared by 1.8 per cent each year during the 2015-20 period, according to the International Energy Agency (IEA), whereas it should be decreasing at a rate of three per cent per year.

The key actions outlined by the GCCA to reach its CO_2 reduction milestones in the next decade are based on:

- increasing clinker substitution
- reducing fossil fuel usage and increasing the adoption of alternative fuels
- improving the efficiency of cement production
- investing in technology and innovation.

Cement companies have already started investing to reduce process carbon emissions through new technology, and lower energy-related emissions by shifting to renewable energy sources. However, more efforts are needed to meet the ambitious targets set for this sector. Among the technologies suitable to curb carbon emissions, waste heat recovery (WHR) has been gathering momentum and is proving to be an economically viable and market-ready solution.

In fact, cement is one of the manufacturing processes with a higher potential for heat recovery as up to 40-45 per cent of the heat produced is released as exhaust gases from the preheater and clinker cooler. This waste heat is a valuable resource that can help efficiently reduce both the carbon and energy intensity of the cement manufacturing process.

ORC WHR vs traditional steam Rankine cycle technology

The technologies for WHR in the cement sector are either the steam Rankine cycle or organic Rankine cycle (ORC). Steam Rankine cycles are usually more efficient when exhaust gases exceed 350˚C, while ORCs are the most advantageous choice for temperatures as low as 150˚C or for small power output applications at any temperature. In certain cases, ORC is the only practical solution, for example, when water is not available at site. Compared to a steam cycle, the ORC solution offers several superior features (see Table 3.3.1). Benefits include:

- flexibility of operation: the turbogenerator group can work with optimal efficiency in a wide range of conditions and when part of the heat source is not available, eg, when the upstream process is working on partial load.
- high efficiency: this is maintained under different operating conditions (unlike steam systems), and allows users to exploit the maximum energy available from the process.
- modular and compact configuration: the layout of the system can be varied to comply with strict size requirements of a single module without affecting efficiency of the system.
- no need for water: the system does not use water as working fluid and the condenser can be air cooled. This is a significant advantage for cement plants situated in remote locations or where water is not available.
- simple plant design: associated costs (ie, foundations, transportation, assembly, auxiliary systems) are much lower as the system is composed of smaller, preassembled items and the auxiliary systems are minor. Lower costs mean more competitive investment costs and faster payback.
- automated solution: the ability to run the system without an operator implies lower running costs. Moreover, this feature makes ORC the perfect choice for remote locations where remote control is a must.
- low maintenance: the maintenance programme is based on yearly controls and rare, predictive intervention on the rotating equipment.
- no need for continuous refilling: whilst the water treatment system of a steam cycle requires the continuous refilling of chemicals, the organic fluid and the heat transfer fluid are more economical and refilling can be estimated at 5-8tpa, meaning less than one tank per year.

In response to rising global demand for clean and cost-effective energy, improvements in ORC technology have been made to reduce initial investment costs and increase performance. In 2010, leading ORC provider Exergy launched an innovative technological breakthrough called the Radial Outflow Turbine (ROT) (see Figure 3.3.1). Thanks to the ROT's configuration, the system can convert the energy contained in the organic fluid into mechanical power with higher efficiency compared to traditional ORC turbines on the market.

Exergy's ROT is unique in the ORC market and offers several benefits, including:

- higher efficiency than an axial turbine: the higher performance is related to:
  - up to seven stages on a single rotor disk reducing the size and length of the turbine compared to an axial turbine

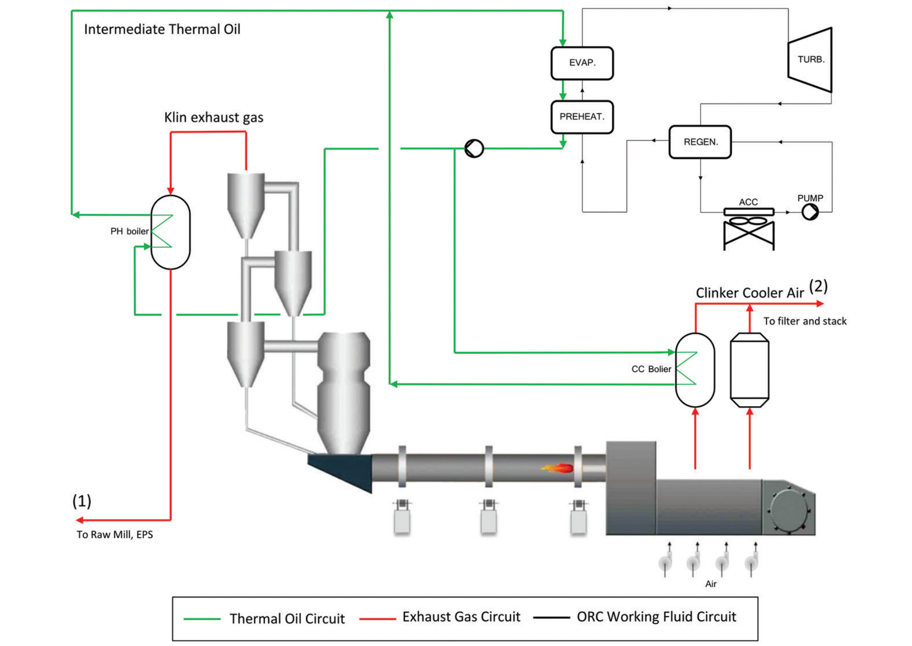
Table 3.3.1: comparison between the steam Rankine cycle and ORC

Feature	Steam	ORC
Modular configuration (easy to transport)	Poor	Good
Flexibility in operation	Poor	Good
Water consumption	Poor	Good
Chemicals/fluid refilling	Poor	Good
One supplier for all major performance critical equipment	Poor	Good
Associated costs (foundation, assembly)	Poor	Good
Stand-alone remote-control configuration	Poor	Good
Low maintenance	Poor	Good
System cost	Average	Good
Proven WHR technology	Good	Good
Additional power produced	Good	Average

Poor – Average – Good

Figure 3.3.1 Exergy's Radial Outflow Turbine

Figure 3.3.2: layout of an ORC WHR system for a cement application



Source: Exergy International Srl

  - less tip leakage and rotor disk friction losses
  - minimum 3D effect thanks to the low blade height and low blade height variation.
- less limitation on cycle pressure leading to superior flexibility, extending the range of application
- simpler construction technology, more compact and easier to transport and install
- no gearbox needed thanks to the low rotational speed of the turbine that allows a direct coupling with the generator
- lower vibrations, which leads to longer plant life
- easy and low-cost maintenance: the mechanical group of the turbine containing the bearings, oil lubrication system and seals can be easily removed without the need to drain the organic fluid from the cycle. This also reduces plant downtime significantly when compared with other technologies.

All these advantages make Exergy's ORC solutions highly competitive, flexible and efficient.

Exergy's WHR application for the cement sector

Exergy's ORC systems that utilise the ROT can be efficiently applied to WHR from the discharged gases of the preheater and clinker cooler. They can be used in cement plants of any size, with output in the range of 1-20MWe, in a modular configuration for a total maximum installed power of 50MWe.

The typical design of a WHR system for a cement plant application consists of an intermediate loop employing a heat transfer fluid – usually oil, pressurised water or saturated steam – to transfer the heat to the ORC cycle (see Figure 3.3.2). Thermal oil is usually preferred for flexible high-enthalpy heat recovery, while steam is used for smaller size high-enthalpy heat recovery, and pressurised water is the preferred option where the environment does not allow flammable fluids and efficiency of the system is not the key factor.

A typical ORC unit works as follows:

1. The organic fluid, vaporising, extracts heat from the primary fluid into a series of primary heat exchangers (preheater, evaporator, superheater).
2. The organic fluid vapour expands in a turbine.
3. A recuperator recovers the heat still available into the outlet flow of the turbine.
4. A condenser extracts the low-temperature heat contained in the fluid.
5. The pump gives the fluid the maximum pressure to get back to the heat exchangers.

The system allows the use of both water- or air-cooled condensers so it is more flexible and adaptable to all conditions, offering greater flexibility compared to a steam cycle and is more environmentally friendly.

Exergy's ORC power plants for WHR applications are flexible and can be tailored and applied either to newly built facilities or in existing plants. Today, Exergy has a portfolio of 10 WHR power plants with a capacity of approximately 30MWe either installed or under construction worldwide.

Investment

Installing an ORC WHR system in a cement plant has a typical payback period of 3-6 years depending on the electrical output of the ORC required, the cement plant design and other variables, such as the cost of electricity. These payback periods can be lowered by other factors related to local government incentives, such as carbon credits and any additional premium for saved CO_2 emissions.

Case study

The case study below presents an overview of an Exergy WHR ORC cement plant application for Italy-based producer Cementirossi (see Figure 3.3.3). Key features of the project include:

- cement plant location: Pederobba (TV)
- date of WHR implementation: 2020
- WHR plant capacity: 3.5MWe
- clinker production line capacity: 2500tpd
- heat source temperature (diathermic oil): 280-100˚C
- water or cooling agent: air-cooled condensing
- gross efficiency: 22.8 per cent
- installation: outdoor.

Project challenges

Project challenges included respecting the restrictions of the site due to the nearby area, which also imposed strict limits for noise emissions. Cementirossi also requested a non-flammable working fluid in the ORC cycle to ensure safety of plant operations.

Solution

To resolve the issue of on-site space contraints, Exergy opted for a compact solution, where the unit was preassembled on skids with the turbines, generator and lubrification and seal oil unit closed in a container of standard ISO40 measures. To maintain high efficiency of the cycle while employing a non-flammable working fluid, Exergy optimised the cycle design and introduced a reheating system in combination with the ORC. Adding a reheating system to the ORC cycle resulted in a 10 per cent additional

Figure 3.3.3: Exergy's Radial Outflow Turbine

cycle efficiency compared to an analogue cycle with the same temperature limit.

With this solution, Exergy has enhanced Cementirossi's WHR ORC system performance, delivering maximum cycle efficiency and safer operations for the plant thanks to the choice of a non-flammable working fluid.

Conclusion

WHR represents a valuable technology that can help the cement sector achieve its decarbonisation targets while also benefitting from additional advantages, including:

- optimising efficiency of the manufacturing process
- reducing energy costs
- reducing operating costs
- reducing primary energy and fossil fuel demand
- facilitating access to electricity for remote or isolated cement plant sites with difficult access to the grid.

"To help cement producers invest in this technology, specific and tailored supporting schemes and targeted public finance to lower the initial financial risk are needed."

However, barriers to the adoption of WHR systems still remain. To help cement producers invest in this technology, specific and tailored supporting schemes and targeted public finance to lower the initial financial risk are needed. This is essential to make low-carbon cement manufacturing economically viable and speed up the transition to net zero.

More information

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