ENHANCING EFFICIENCY

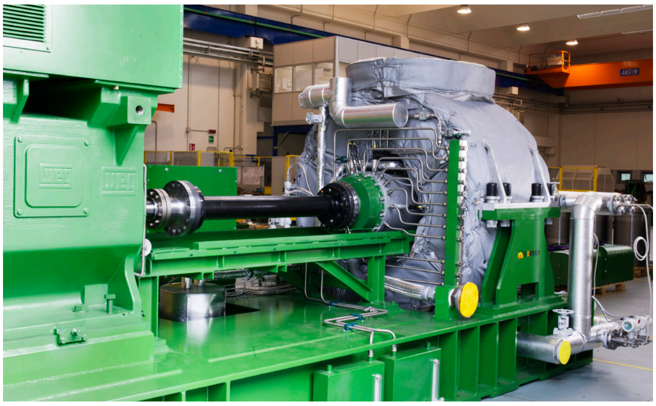
Sergio Morlacchi, EXERGY, explains how the integration of waste heat recovery systems into cement plants could help enhance the overall energy efficiency of the cement manufacturing process, while helping to lower emissions.

Despite the effect of the COVID-19 pandemic on economies all over the world and the consequent dramatic contraction of demand in the cement sector, cement production reached 4.2 billion t in 2020 globally, maintaining almost the same levels as the year before. Even with the pandemic continuing to affect global economies, cement demand is projected to increase by 2.45% in 2022, and reach a production increase of 5% in 2030, as reported in the IEA's World Energy Outlook.

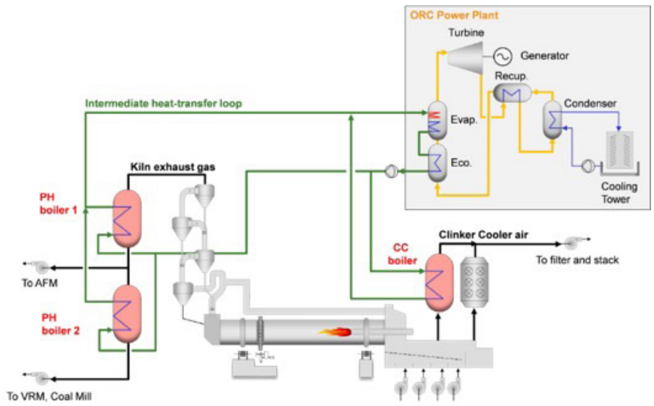
The cement sector is a significant contributor to global annual energy consumption and carbon emissions.

The direct CO_2 intensity of cement production grew at a rate of 1.8% per year during 2015 – 2020, despite needing to reach a decline of 3% annually to meet the target of Net Zero by 2050. Therefore, the sector is facing the difficult challenge of meeting growing demand while limiting CO_2 emissions.

One key lever for reaching the goal of carbon emissions reduction is improving energy efficiency in the cement manufacturing process. Progress in thermal and electrical energy consumption to produce clinker has been enormous in recent decades due to the continuous modernisation of kilns, with dry-process kilns replacing wet-process kilns, as well as the implementation of modern technologies in new installations. To accelerate on this road towards energy efficiency, an effective and market-ready solution for thermal energy utilisation should be introduced. This is the integration of Waste Heat Recovery (WHR) systems in cement plants. These can contribute to enhance the overall energy efficiency of cement manufacturing while also helping to lower emissions deriving from electrical energy consumption.



A Radial Outflow Turbine on its skid.



Layout of an ORC WHR system for a cement application.

Exergy's compact ORC air cooled unit at Cementi Rossi's cement factory in Italy.

Improving ORC

The cement manufacturing process uses a high amount of thermal energy in the kiln and raw material preheating and burning process. A huge part of this heat energy, as much as 40 – 45%, is lost mainly as waste gases. This waste heat can become the resource used to feed a WHR system and generate electricity. The commonly employed technologies for a WHR system in a cement plant are the Steam Rankine cycle or Organic Rankine Cycle (ORC). These methods differ in their choice of working fluid – the steam cycle uses water and ORC uses an organic fluid, typically a hydrocarbon. Steam Rankine cycle systems have been the traditional and more widely employed solution in previous decades, but in recent years ORC applications have experienced a rapid increase in adoption for small-to-medium size and temperature applications, due to some advantages over steam cycle systems:

- Modular and compact design, easily customisable, with low associated cost for foundation and assembly and reduced footprint.
- Automated solution with no need for operators, thus leading to lower running costs.
- High efficiency of the cycle at a variety of operating temperatures and loads.
- No water treatment plant or make up water required.
- Well suited for cycling environments and where fast starts/stops are required.
- Easy maintenance leading to lower maintenance costs.

Advancements in ORC technology in recent years have helped mitigate CAPEX expenditures for these installations while increasing plant efficiency and profitability.

Exergy is able to provide state-of-the-art ORC technology, utilising the Radial Outflow Turbine (ROT). Designed by EXERGY, the ROT is covered by current and pending patents and is the first turbine of its kind to be utilised in an ORC system. The ROT, unlike axial and radial inflow configurations, can convert the energy that is contained in the fluid into mechanical power with higher efficiency.

Employing the ROT technology in an ORC system for WHR applications brings additional benefits due to its configuration and characteristics:

- A broader range of applicable fluid conditions thanks to the radial outflow arrangement of turbine stages.
- A more flexible and efficient design due to straight blades and radial configuration.
- Lower noise and vibrations due to a direct drive low speed turbine.
- Improved maintenance and reduced downtimes with a built-in mechanical group easy to extract.
- High reliability thanks to the standard mechanical design for each turbine frame.
- A trade-off between performance and competitiveness is achievable with the unique multiple pressure admissions on a single disk turbine.
- State-of-the-art efficiency achieved with a high number of stages on a single disk turbine.

All these factors contribute to a more competitive, flexible, and efficient machine.

WHR ORC for cement plants

ORC WHR systems for the cement sector are typically designed with an indirect heat exchange by means of an intermediate loop utilising a heat transfer fluid (HTF), usually thermal oil, pressurised water or saturated steam.

The power plant consists of a WHR system and an ORC module. The WHR system extracts the thermal power from the exhaust gases in the pre-heater and clinker cooler and uses a thermal oil loop to interconnect the system to the ORC module. The intermediate fluid transfers heat to the organic fluid in the ORC evaporator, where the organic fluid vaporises. The vaporised fluid then passes to the turbine where it expands, causing the turbine to spin, creating electricity in the generator. The vaporised organic fluid then continues through the cycle to the condenser, where it once again becomes a liquid. It then passes through the pump before beginning the cycle again.

In the ORC cycle, the condenser can be either air or water cooled. The use of an air condenser brings several advantages:

- It eliminates the requirement for the consumption of water, thus increasing sustainability.
- It reduces the condensing pressure of the cycle, leading to higher power production.
- It reduces the equipment to install, thus minimising plant costs and footprint.

Exergy's ORC power plants for WHR applications are flexible and can be customised and implemented either in newly built facilities or retrofitted plants. The ORC unit can be installed in cement plants of any size in a range from 1 – 20 MWe, as well as in modular configuration for a maximum of 50 MWe total installed power. Exergy currently has a portfolio of 10 power plants for around 30 MWe installed power or under construction worldwide.

Case study

Installing an ORC WHR system in a cement plant has a typical payback time of 4 – 8 years depending on the electrical output of the ORC required, the cement plant configuration, and other factors such as the selling price of electricity. These payback times can be lowered by other factors related to local government incentives such as carbon credits, green certificates, and any additional premium for saved CO_2 emissions.

An example of Exergy's ORC WHR solution designed for a cement plant is presented in Tables 1 – 3. In this case, the WHR ORC module is designed to deliver 6.6 MWe of clean electricity for a cement plant with a production line capacity of 4000 t of clicker per day, equipped with a preheater and clinker cooler.

Table 1. Cement plant technical details.
Cement plant capacity – 4000 t (clinker)/day
Flue gas flow from kiln preheater (PH) – 280 000 Nm³/h
Flue gas temperature after kiln preheater (PH) – 400˚C
Flue gas temperature required (PH) – 250˚C
Flue gas flow from clinker cooler (CC) – 170 000 Nm³/h
Air flow temperature after clinker cooler (CC) – 300˚C
Ambient temperature – 20˚C
Operating hours – 8400 h/year

Table 2. Performance of the ORC WHR system applied.
Available thermal power – 27 200 kwth
Generated power – 6600 kwe
Generated electricity – 52 800 MWh/y
Carbon emissions avoided – ~25 000 t CO_2/y

Table 3. Economics.
Electricity value – €135/MWh
O&M Ccost – €8/MWh
WHR system EPC cost – €18 million
Useful life – 20 years
Payback time – 4 years

The solution presents many benefits in terms of carbon neutrality, energy efficiency and profitability. The electricity produced by the ORC module can be employed to supply the plant's production process, thus reducing the conventional energy demand and the associated costs for electricity that in a cement plant represents a high share of the total operating costs. Moreover, the system helps to decarbonise the cement production process, saving approximately 25 000 t of CO_2 per year.

With an initial capital investment that includes the whole WHR system with EPC costs, the power plant has a payback time of 4 – 5 years, considering a cost of electricity at €125 – 135/MWh.

The business model does not consider any local benefits such as carbon credits, which can substantially improve the business case.

Conclusion

The energy transition is a huge global challenge and in order to reach the Net Zero target by 2050, multiple efforts need to be made by everyone involved. Cement is one of the most energy-intensive industrial businesses and for this reason, some attempts have been made by the sector to optimise the manufacturing process thanks to new advanced technologies available on the market. Waste Heat Recovery is one of these technologies, but its potential remains largely untapped. For a cement company, the advantages and the benefits of installing a WHR power plant can be numerous:

- Increased efficiency of the process.
- Reduced operating costs.
- Reduced energy demand and costs.
- Reduced carbon footprint.
- Facilitated access to electricity with independent microgrids for remote or isolated sites.
- A market-ready, viable and widely proven solution in the market that can be implemented in a short time to accelerate the decarbonisation process.
- A low maintenance technology, with a long useful life, high availability (+99%) and minimum downtimes.

The cement sector is looking into this solution with growing interest, but further implementation of the technology is hampered by the lack of financial support for the initial investments. This should be encouraged by policy support from local governments with tax credit and incentives tailored for this application in order to reduce the initial investment and its payback period. ■

About the author

With a degree in Mechanical Engineering from Politecnico di Milano, Sergio Morlacchi has extensive experience in the energy sector with a special focus on renewables. Since 2013, Sergio has held several positions at EXERGY. Today, he is Business Development Manager and deals with new market opportunities both within Italy and abroad.