GENERATING GREEN POWER AND HEAT

Andrea Barbon, Turboden, explores a smart combination between electric power and heat for district heating.

Increasing energy efficiency is becoming a more and more important topic in the energy intensive industries. One of the latest opportunities investigated by Turboden is the co-existence of heat recovery, aiming to produce both electric and thermal power for District Heating (DH) Networks.

The motive is to identify future challenges in order to reach a future renewable non-fossil power, and to place heat supply as part of the implementation of overall sustainable energy systems. Cement plants close to cities where heat is supplied through DH networks should be interested in investigating this technical solution, in order to enhance the important role that DH has to play in future sustainable energy systems, together with a traditional heat recovery system for power generation. Heat recovery application in cement plants has been widely employed in the last 20 years, especially converting exhaust gas heat into electrical energy by means of Rankine cycle technologies – both with steam and organic fluid turbines.

Cement producers already know the advantages of having a heat recovery system installed in their plants. These include lower electricity costs; an increase in

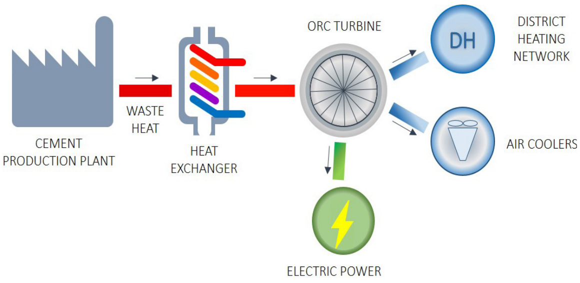

Figure 1. Basic process scheme of a DH network downstream CHP ORC.

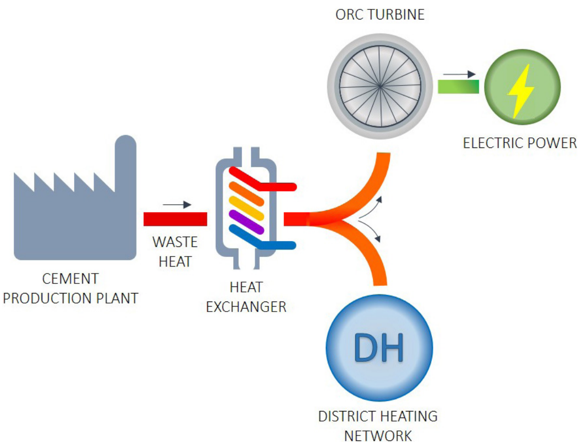

Figure 2. Basic process scheme of an HE ORC in parallel with a DH network.

competitiveness; no additional fuel consumption; a CO_2-free way to produce electricity; a greener image; etc.

DH network developments

First generation DH networks were introduced in the US in the 1880s, using high temperature steam as a heat carrier; several technological improvements have been carried out since then, with a future fourth generation due to start in 2020.

The trend throughout these three generations has been towards lower distribution temperatures and changing the heat carrier. A future fourth generation of DH technology should comprise even lower distribution temperatures. The state-of-the-art nature of DH technology is more efficient, allowing the following:

- Lower supplying temperatures, dropping from almost 200°C down to 50 – 60°C.
- Different heat carrier – easier to handle – such as hot water, instead of steam or pressurised water.

Organic Rankine cycle working principle

Organic Rankine cycle (ORC) technology is based on the Rankine cycle principle, meaning that the heat coming from the heat carrier is used to pre-heat and vaporise the ORC working fluid. The organic working fluid is then expanded through the turbine, which is connected to an electric generator. The exhaust organic vapour flows through the regenerator, where it heats the organic liquid and is then condensed. The condensed organic working fluid is then pumped into the regenerator and evaporator, thus completing the closed-cycle operation.

Combined heat and power (CHP) ORC units have a heat user that valorises the low temperature heat (up to 90°C) released through a hot water stream at the ORC condenser's outlet. Due to high efficiencies, Turboden CHP units have been particularly successful in biomass plants, since the low temperature heat is used as hot water mainly to feed the DH networks (164 reference plants) or for wood drying (124 references).

High efficiency (HE) ORC units release condensation heat by means of a cooling water circuit with dry coolers, cooling towers, or directly to ambient air with an air cooled condenser, thus avoiding any water consumption.

In HE ORC units, the condensing temperature is lower compared with CHP ORCs, therefore providing higher electrical conversion efficiencies.

ORC integration in DH networks

The easier – although not the most efficient overall – solution to feed the DH network through a heat recovery system, is to use the high temperature heat recovered from the cement production process and convert it into low temperature heat for the network.

A more efficient alternative is to install an ORC to take advantage of the difference between high and low temperature heat streams, thus providing enough heat to DH and producing electricity to reduce cement plant captive consumptions. ORC technology turns medium to high temperature streams into electrical energy and low temperature heat that is made available at the condenser's outlet. This low temperature heat may be dissipated into the atmosphere or otherwise used in case a heat user valorises the co-generated heat.

Both HE and CHP ORC units are suitable to be coupled with DH networks:

- CHP ORC units lead to higher global efficiencies, since the DH network is placed downstream of the ORC. This solution became convenient considering the trend of decreasing operating temperatures of latest DH networks.
- An HE ORC unit may be used in parallel with a medium to high temperature DH network. Thus, the heat recovered from the process is used to feed either the DH network or the HE ORC. In this solution, the heat recovered is converted into electrical energy by means of an ORC turbine when the DH network demand is null or lower compared to design conditions. One of the advantages of ORC technology is well exploited here, as high efficiency at partial loads matches with the highly variable demands of DH networks.

Downstream CHP ORC

Shown in Figure 1, the most efficient solution, from a thermodynamic point of view, is to use high temperature heat to feed the ORC and to use low temperature heat – in the form of hot water, available at the ORC condenser – to feed the DH network. This solution lines up with the lower (below 100°C) operation temperature required by new generation DH networks.

In addition to this, in case the demand for heat from the DH is zero (a realistic summer condition), the ORC can switch to power only mode. Power only mode operates with a lower cooling water temperature, meaning higher electrical efficiency. In this case, the cooling water at the outlet of the condenser is dissipated with the same cooling water circuit by means of air coolers or cooling towers.

For medium/high temperature thermal power recovered by a cement plant's exhaust gases (within 15 – 20 MWth at 300 – 350°C), the waste heat recovery electrical efficiency is 18 – 20% in a cogeneration setting when the DH is in operation, and 22 – 24% in electrical power only mode when the DH demand is zero. In cogeneration setting, the thermal efficiency (which is the ratio between the heat released to the DH network and the total heat recovered from the exhaust gases), is 79 – 77%, with an overall loss of 3% calculated on the total thermal input. The overall global efficiency of the heat recovery system reaches 97%.

Working in parallel

When the existing DH network is first or second generation (meaning operating temperatures higher than 80 – 100°C), the most suitable solution is to have the ORC unit and the DH network working in parallel (Figure 2).

When the DH demand is lower compared to the heat recovered from the cement plant, the ORC will produce electrical power by using the otherwise wasted heat. This also works during partial load operations of the DH network, highlighting one of the ORC's strengths, which is the high electrical conversion efficiency during partial loads. The ORC can work down to 10% of the design thermal load and the electric efficiency remains high down to 50% of the thermal load.

This scenario uses HE ORC units because the CHP ORCs are suitable only when the water temperature available at a condenser's outlet flange is not higher than 90°C. In HE ORC units, the low temperature (40 – 50°C) thermal power available at the ORC condenser is released to the air, since it is not suitable for existing DH network needs.

Case study

One of Turboden's latest references in cement application is based on this second possibility. DH distributor operator, CADCIME, already had an existing heat recovery system, recovering heat from the Holcim cement plant in Eclépens (Switzerland), to provide heat to the DH network. The company chose Turboden ORC technology to make the system more efficient.

The selected – currently under construction – ORC unit integrates in the existing hot water heat recovery system using the following:

- High temperature heat to produce electric power efficiently.
- Low temperature heat, which is released downstream of the ORC, to the DH network (100 – 150°C).

The ORC unit is capable of producing 1.2 MWe, with a thermal input of 6.5 MWth that is obtained from the cement plant flue gases. The aim of the project, developed by CADCIME with the help of Turboden, is to both reduce cement plant captive consumptions and meet thermal power needs for DH networks through the use of a heat and power combined waste heat recovery system, based on ORC technology.

ORC in cement heat recovery

ORC is a mature technology that has been commercially available since the 1970s, originally for geothermal energy exploitation and, more recently (since the 1980s and 1990s), is also used for power production from biomass combustion, solar, and heat recovery from industrial processes.

Turboden has almost 40 years of experience in the ORC field and several steps have been made to improve the technology. There are about 380 Turboden ORC plants where the average availability of the operating fleet exceeds 98% and more than 15 million operating hours have been reached.

Until now, the most common technology used in cement heat recovery was based on steam, while ORC technology has started to be used in the last 10 years and has the potential to be employed more and more in new heat recovery projects. This is because it is suitable for medium to high temperature streams.

Future cement processes will become more and more efficient, thus leaving low temperature exhaust gases available for the heat recovery plants, which can be easily exploited with ORC technology.

ORC typical size ranges from 1 to 15 – 18 MWe. Improvements on the size have been carried out over the last years, with the successful deployment of an 8 MWe ORC in a biomass plant, a 10 MWe ORC in the steel industry, and a 16 MWe ORC in a geothermal project.

As an indication, the power that can be generated by a heat recovery system in a typical cement making process can range from 0.5 to 1 MWe per tonne per day of clinker production capacity (assuming heat recovery from both the kiln and cooler waste flows). Using these figures, it can be estimated that the energy produced by a heat recovery system accounts for between 10% and 30% of the total electricity consumed by a cement plant.

Specific to the heat recovery from the cement production process, several reference projects have been deployed by Turboden. These include the following:

- Ciment du Maroc (Heidelberg group – former Italcementi Morocco) – Ait Baha plant. A 2 MWe Turboden ORC unit has been working since 2010. In 2014, this unit was hybridised with the integration of the thermal input given by solar power through a solar concentrating system.
- Holcim Romania (LafargeHolcim group) – Alesd plant. A 4 MWe ORC was started up in 2012.
- CRH Slovakia (Former Holcim) – Rohoznik plant. A 5 MWe ORC unit has been working since 2014.
- Carpat Cement (Heidelberg group) – Fieni Romania plant. A 4 MWe ORC unit was started up in 2015.
- Jura cement (CRH Group) – Switzerland. A 2 MWe ORC unit was started up at the end of 2016.
- Cementi Rossi – Piacenza (Italy) plant. A 2 MW direct exchange ORC unit was started up in July 2018.
- Cadcime, Holcim Eclepens – Eclepens plant. A 1.4 MWe ORC is under construction.
- Cimko Narli (Sanko Group) – Turkey. A 7 MWe ORC is under construction.
- Sonmez Cimento – Turkey. A 8 MWe ORC is under construction.

Conclusion

Thanks to its ability to recover heat at low temperatures, together with good electrical efficiency, high flexibility, and minimum operation and maintenance costs, ORC technology is a technological solution for the effective and profitable implementation of systems for heat recovery from cement processes.

The characteristics of ORC technology match with the decrease of available temperature, due to the increasing efficiency of cement plant production, and the lower temperature needs of latest generation DH networks. Turboden considers this coexistence as one of the major opportunities to increase the efficiency and the competitiveness of cement plants, thus reducing CO_2 emissions. ■

About the author

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