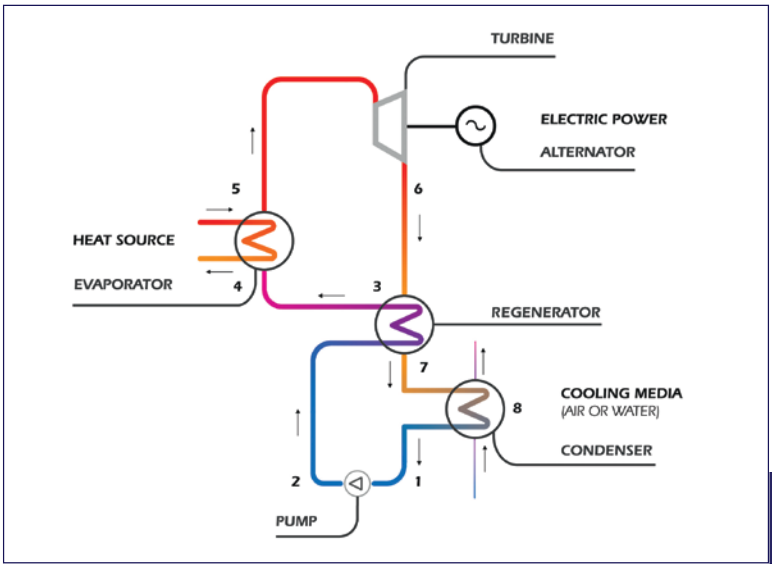
HEAT RECOVERY

Putting industrial waste heat to use

Organic Rankine Cycle turbines can be used to increase the energy efficiency of various industrial operations by turning waste heat into useful energy. *Sabrina Santarossa* explains.



Flow diagram of the ORC process
Diagram: Turboden

Sustainability and environmental protection have become important subjects in the discussion of industry, society and government. Driven by these topics, targets have been set to reduce the dependency on fossil fuels, to lower carbon dioxide emissions and to lower water consumption.

Energy-intensive industries have already started to look to increase energy efficiency, not only because of targets to reduce carbon dioxide, but also to reduce operating costs of industrial processes and to increase competitiveness.

Waste heat recovery principles

One key way to increase industrial energy efficiency and help to lower carbon dioxide emissions is to install a waste heat recovery (WHR) system, recovering thermal energy that would otherwise be wasted from production processes. The heat recovery potential of industry worldwide is still huge and widely not exploited.

The thermal energy recovered by the WHR system can be:

- utilised as thermal energy for different purposes (ie district heating, process uses);
- converted through a Rankine cycle (using steam or an organic fluid), both into electrical and thermal energy at lower temperatures with a combined heat and power (CHP) WHR system; or
- converted through a Rankine cycle (using steam or an organic fluid) into electrical power.

The last is the most common solution in energy-intensive industries like cement, glass, steel and non-ferrous factories since they typically do not need low-grade thermal energy.

WHR plants are usually placed as a bypass to the main exhaust gas stream so not to affect the main industrial process in terms of performance, functionality, operation and availability.

ORC technology

One solution to increase efficiency for energy-intensive industries is based on Organic Rankine Cycle (ORC) technology.

The main difference between ORC and the better-known steam Rankine cycle is the fluid used in the cycle. ORC uses organic fluids (refrigerants, hydrocarbons and siloxanes for example) instead of water. The use of a high molecular mass fluid brings several differences and advantages compared to steam Rankine cycle, especially in the range of medium and low power production (below 20 MW).

Steam-based WHR systems are more suitable for large (>15 MW), single heat recovery source and electrical power only systems – and in countries where there is high availability of water. On the other hand, ORC-based WHR systems work for small and medium-sized systems in the range of 1–15 MW, where there is heat recovery from multiple sources and where there is lack of water.

For ORC-based WHR recovering heat at temperature higher than 300°C the electrical conversion efficiency of the WHR can reach 25–28%, depending on the exhaust gas flow rate and the ambient temperature at the site of installation. As a general rule, the higher the temperature of exhaust

WHR in the steel industry

One important energy-intensive industry is steel. In the several processes of the steel making process, the Electric Arc Furnace (EAF) gives a large amount of waste heat. Various Turboden ORC plants are already installed in several steel industries in Europe and Japan, with a power range from 2 to 8 MW.

In 2015, WHR plants in the ORI Martin steel making plant in Brescia, Italy started up. The projects involved a major revamping of the electric steel melt shop, and the installation of the WHR system which produces saturated steam, exported to local utility A2A for the city's district heating network during winter, and to the 1.9 MW Turboden ORC (pictured) during summer.

This is a successful case where both electricity and heat are produced, and the industry is giving benefits to the local community.

WHR in the cement industry

Making cement is one of the highest energy-intensive processes, producing a high amount of carbon dioxide not only from fuel combustion, but also from the chemical reactions involved in the clinker production.

Two main heat sources are available for heat recovery: clinker cooler hot air and pre-heater tower hot gas. The Carpat Cement plant in Fieni, Romania (pictured), run by the Heidelberg group, has benefited from a 4 MW ORC unit which was installed in 2015.

Heat contained in pre-heater and clinker cooler exhaust gas is transferred to the ORC through a thermal oil circuit. The condensation of the organic fluid is done in an air condenser, thus no water is used nor consumed in the WHR plant.

Beside Heidelberg, other big cement producers have Turboden ORC units in their plants, including LafargeHolcim, CRH, Sanko and Cementi Rossi.

gases, the higher the conversion efficiency of thermal power into electrical power.

ORC is a mature technology that has been commercially available since the 1970s, originally for geothermal energy exploitation and then also for power production from biomass combustion, waste-to-energy and heat recovery from industrial processes and small combined cycle plants.

How ORCs work to recover heat

The waste heat present in the industrial hot gas stream(s) can be transferred to the ORC turbine by means of an intermediate circuit, or directly to the ORC fluid (ie a direct heat exchange solution).

By utilising an intermediate circuit with a hot temperature heat transfer fluid – thermal oil, pressurised water or saturated steam – it is possible to easily recover heat from several sources.

There are many operational advantages in using an intermediate heat transfer loop – in particular thermal oil is an organic medium that remains liquid and is very stable at high temperatures (there is no change of phase in the thermal oil loop), with intrinsic lubricant characteristics. It presents no issues of corrosion or erosion.

The hot heat transfer fluid intermediate stream is pumped to the ORC power plant, and the heat coming from the heat transfer fluid is used to pre-heat and vapourise the ORC working fluid. The working fluid is then expanded to drive the turbine, which is connected to an electric generator.

Following this process the exhaust vapour flows through the regenerator, where it heats the organic liquid and is then condensed in the cooled condenser (which can be air or water cooled), releasing the condensing heat to ambient air or the cooling water circuit. The organic working fluid is then pumped into the regenerator and evaporator, thus completing the closed-cycle operation.

When using a direct heat exchange solution there is no intermediate circuit, the liquid ORC working fluid is pre-heated and evaporated in a heat exchanger where the hot gas passes through. This solution is particularly convenient for heat recovery from single source and results in higher efficiency for low–medium temperature sources at a lower investment cost.

Both in the case of intermediate circuit or direct heat exchange, the operation of the ORC plant and the complete WHR system is fully automatic in normal operating conditions as well as in shut-down procedures, without any need of supervision personnel. In case of fault conditions, the ORC plant will be switched off automatically from the heat transfer fluid circuit and from the electrical grid.

ORC has become a competitive alternative to steam technology, especially below 20 MW. The modules can be designed with a high level of automation to adapt to variations on temperatures and flows, and as such do not need supervision personnel – just remote monitoring. They can operate flexibly, with high efficiency even at partial loads down to 50%. They can also operate down to 10% of thermal load.

Conclusions

Waste heat recovery potential is still huge and not yet fully exploited. ORC-based WHR plants can ensure high efficiency heat recovery combined with high availability, no water consumptions and no need of dedicated operators.

WHR systems give the opportunity to decrease the cost of electricity bills for industry as well as lowering the dependency on the electricity grid.

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Turboden has been operating ORCs for 35 years and has 350 ORC plants in operation and a further 30 under construction.

WHR in the glass industry

Glass production can be divided into two main families: float glass and container glass. The furnaces used to melt the raw materials to produce glass usually have a high temperature gas flow rate available for the heat recovery.

A 1.3 MW ORC unit was installed at the beginning of 2012 in the AGC float glass production factory in Cuneo, Italy. The WHR system recovers heat from the glass production line, lowering the temperature of a single stream exhaust gas and transferring the heat to the ORC through a thermal oil circuit. The furnace in Cuneo was revamped during summer 2017 and the WHR system was restarted during autumn 2017.