

# ABB's flexible ORC power plant

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The process heat is generated to a considerable extent from fossil fuels and, in some countries, partly from alternative fuels. The electricity used is, to a large degree, generated in power plants which also run on fossil fuels. Consequently, the energy consumption of a cement plant creates direct and indirect CO<sub>2</sub> emissions due to energy use. Finally, clinker burning produces additional CO<sub>2</sub> emissions.

Therefore the discussion on climate change and energy efficiency drives the effort to increase energy efficiency in the cement industry. Cement plants will have to strengthen their efforts to increase energy efficiency and thereby reduce energy consumption. One focus is to increase the reuse of thermal energy to a maximum. Many cement plants have installed additional preheater stages to dry the raw mix and/or used the waste heat for drying processes for alternative fuels to improve the use of thermal energy.

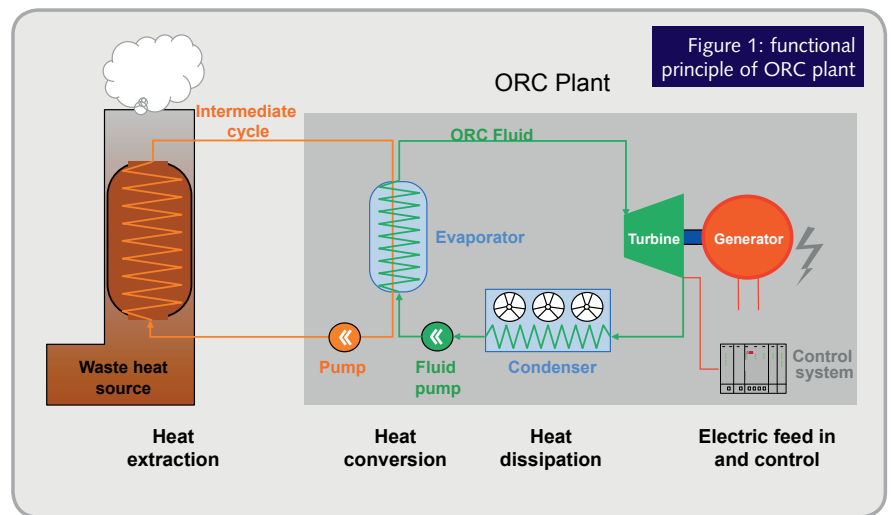
However, there are still considerable amounts of heat not used and cooled down before released to the chimney. In efficient plants there is thermal energy left that is ready to use for heat recovery.

## Why ORC technology to convert waste heat into electricity?

After the efficiency of a cement plant has been improved by using the waste heat within the process, the remaining waste heat can be converted into electricity. The remaining waste heat has a low temperature, specifically the waste gas after the preheater tower. Temperatures in efficient cement plants can be as low as 300°C or lower. At these temperatures a conventional steam turbine process cycle reaches the technical and economical limitations to convert waste heat into electricity.

Therefore, the ABB power plant is based on Organic Rankine Cycle (ORC)

*Increasing energy efficiency is one of the most important current entrepreneurial challenges. The cement manufacturing process is highly energy intensive. The use of fuel energy has a magnitude of approximately 3-3.5 GJ/t clinker and the electrical energy consumption at roughly 100kWh/t.*



technology (further referred to as 'ABB ORC power plant') to match the requirements. The ABB ORC power plant is designed to make use of exactly this waste heat, converting low-temperature waste heat from cement plants into electricity.

## The ABB ORC power plant

The core of the power plant is a one-stage turbine. Due to the waste heat's low-temperature, water vapour can not be used efficiently, both in terms of energy and of costs. Therefore, organic fluids are utilised.

Organic media evaporate at relatively low temperatures and condense against ambient air at a pressure over 1bar, thus no vacuum has to be produced in the condenser. Between the evaporation and condensation pressure/temperature levels, the organic fluid delivers a considerable amount of energy when it is expanded in the turbine.

The ORC power plant consists of the following main systems:

- heat extraction
- heat conversion
- heat dissipation
- electric feed in and control.

## Ecological and economical heat extraction

### Ecological and economical intermediate cycle with water

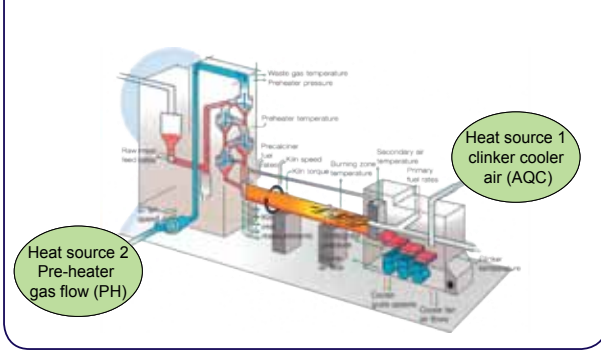
The waste heat is transferred with a hot water intermediate cycle to the ABB ORC power plant.

The ABB design using hot water in the intermediate cycle allows the transfer of the heat to the power plant and several heat sources can easily be integrated. The use of hot water makes the plant operationally safe and ecological compared to thermal oil often used in ORC cycles, no fire load in case of a malfunction (eg leakage) and has low operational costs.

Compared to water, the expensive medium thermal oil needs specific measures for fire protection, needs to be changed after a certain operation time and has a considerable impact on the environment in case of leaks.

Moreover, water has clearly defined physical properties and does not spoil the heat exchanger if an exceptional heat load is applied. Finally, water has a higher specific heat capacity and a lower viscosity which also makes it energetically more attractive.

Figure 2: typical waste heat sources in a cement plant



**Waste heat sources in a cement plant**

In cement plants the waste heat can be extracted from one or two sources:

- from the clinker cooler air (AQC)
- from the waste gas after the preheater tower.

Heat source 1, the cooler air (AQC), can be cooled down as much as possible to extract a maximum of heat. Therefore, a conversion system with low operating temperatures is advantageous.

The waste gas after the preheater (heat source 2) is used in the subsequent process step: heat is used in the raw mill to dry and preheat the raw mix. Therefore, the temperature must not be reduced below, typically, 200°C. This limits the extractable amount of heat.

The highly-variable conditions of the cement plant (temperatures, flow rates, drying requirements etc) make it necessary to accurately examine the operating conditions, ideally over one year. This is particularly easy when a computer system is installed which records the respective production data of the plant. The precise examination of the cement plant data enables ABB to an optimised design of the ABB ORC power plant.

The waste heat extraction in cement plants make a critical part of engineering for the power plant. Specifically the high dust load of the waste gas after the preheater tower places high requirements on the design of the heat exchangers.

The heat exchanger in the clinker cooler air stream has similar dust loads. Contrary to the preheater waste gas stream, the air after the clinker cooler is totally dry, but the dust is hard and abrasive. Therefore, at the entry of the heat exchanger, the necessary reinforcement has to be considered.

The dust load of the preheater gas is

approximately 50-100g/Nm<sup>3</sup>. Additionally, the respective humidity must be considered. As the temperature of the waste gas cannot be reduced to a very low level (temperature requirements of the raw mill) the danger of condensation is, in normal cases, negligible.

The dust issue is taken into consideration by the heat exchanger design. The exchanger is a bare tube type with geometry designed accordingly.

**Heat conversion**

In the conversion cycle, waste heat is used to preheat, evaporate and superheat the organic fluid under high pressure. The superheated fluid is then expanded in the turbine and the mechanical work is converted into electrical energy in the generator.

After the turbine vapour enters the condenser, where it is liquefied and slightly undercooled. Finally, the liquid is again put under high pressure in the fluid pump and conveyed via the heat recovery heat exchanger (heat recovery from the vapour) to the evaporator and the cycle is closed.



Figure 3: layout of the ABB ORC power plant

**Heat dissipation**

As within every thermal power plant, the vapour has to be liquefied. Therefore, the condensing heat has to be discharged to the environment. For this last process step a condenser is necessary. Condensers can be conventional wet cooling towers or dry air condensers.

Water usage and water saving are big issues in many countries. Therefore,

when considering this topic with regard to sustainability, the ABB ORC power plant specifically uses high-end dry condensers designed to avoid water consumption. Due to the appropriate design, the condensers can be operated with low specific electricity consumption at small temperature differences between the condensing organic vapour and the ambient air.

**Electric feed-in and control**

The electrical power is fed into the plant's grid from the generator at an appropriate voltage level, usually medium voltage. The electrical container centralises breakers, safety equipment and the necessary control devices. Where necessary (specifically with the fluid pump) variable speed drives are installed to ideally match the operation of the ORC power plant to the operating conditions of the cement plant.

**Flexible use and integration of the ABB ORC power plant**

Compact plant design allows flexible integration in existing plants. The main modules are designed as standard modules, which form the ABB ORC power plant. This means the power plant can easily be adapted to every waste heat source by only altering the intermediate

cycle to the respective industrial plant. The conversion module is designed for unchanged operating process conditions. Moreover, due to its very compact construction, the power plant is designed to only use a small surface area.

Figure 3 shows the compact ABB ORC power plant: at the bottom level

all components that need observation or maintenance (electro-mechanical components such as turbine, pumps, generator, valves, etc) are installed. The middle floor level contains all static components: process heat exchangers and piping. The top of the steel frame carries the condensers.

Due to its modular design, the ABB system can be integrated into nearly all



Figure 4: illustration of ABB's ORC power plant layout with clinker cooler HEX

industrial processes. The intermediate cycle allows for flexible integration into existing plants as illustrated in Figure 4.

The adaptability in its application allows for the economic use of waste heat, with temperatures starting from 150°C, to generate power starting at 500kW until double-digit MW.

**ABB ORC power plant allows flexibility for further thermal optimisation**

Cement plants are using greater amounts of alternate fuels, which often have to be dried. Specifically wet sludge from municipal sewage plants is often used as a fuel. To dry wet sewage sludge ABB offers a drying system which can be combined with the ABB ORC power plant. The drying system works at low temperatures. It uses the water from the intermediate cycle after leaving the ABB ORC power plant. Therefore, electricity generation from waste heat can be combined with an innovative low-temperature sludge-drying process.

**Benefits of a waste heat recovery system**

High and rising energy costs and the requirement to reduce CO<sub>2</sub> emissions are the main drivers for investing in heat recovery systems. The reasonable payback time for an ABB ORC power plant and the possibility of increasing productivity combined with positive environmental effects is attracting investors and plant owners.

The installation of an ABB ORC power plant in a highly-efficient cement plant contributes to further enhancement of energy efficiency and to a reduction in the CO<sub>2</sub> emissions caused by electricity

consumption. The reduced power consumption equals a reduction in CO<sub>2</sub> emissions of several thousand tonnes per year, depending on the size of the plant and on the country of the installation.

In addition to that, the water consumption of the cooling processes in the cement plant can be reduced. This contributes to environmentally-friendly cement-making process by conserving the increasingly important resource of (potential) drinking water.

Figure 5 shows the efficiency increase from a typical installation of an ABB ORC power plant in a midsize cement plant.

Investment costs and efficiency improvements depend on the number of waste heat sources, waste air/exhaust gas conditions, temperatures, dust load, availability, plant process, electricity price and business model.

The ABB ORC power plant technology offers the following benefits:

- low capital expenditures due to standard components and compact design
- fast installation through professional planning and execution
- simply-designed heat exchangers
  - pure counter flow, air to liquid HEX
  - automatic cleaning, eg by knocking
- low temperatures in the organic cycle, leading to small heat transfer surfaces
- high turbine efficiency with excellent part load behaviour
- no water cooling: dry air cooled condensers
- fast start-up times, also from cold
- automatic operation without personnel
- low operation and maintenance costs
- plant operation with proven technology at low risk.






**Summary**

Recovering waste heat to the maximum extent in cement plants and its conversion into electricity leads to a remarkable increase in plant energy efficiency. ABB ORC power plants are a proven technology to use low-temperature waste heat sources to produce electricity.

ABB's plant design allows a flexible integration into existing plants and enables cement plants to use waste heat for current or future thermal optimisation, including drying alternative fuels.

The ecological and economic improvements make investments in this area attractive. ABB ORC power plants boost electrical energy efficiency in cement plants by up to 20 per cent, reduce indirect CO<sub>2</sub> emissions considerably and save water. █

Figure 5: energy efficiency improvement by waste heat conversion

<p>Electricity consumption for 1t cement</p>  <p>~ 105kWh/t cement</p>	<p>Cement production medium plant</p>  <p>2200tpd ~ 690,000tpa</p>	<p>Electricity consumption yearly</p>  <p>72,000 MWh/yr</p>	<p>Electricity earnings yearly</p>  <p>80 €/MWh = 5.8 mio. €/yr</p>
<p>Heat Recovery &amp; ORC power generation module</p> 	<p>Electricity production</p> <p>3 MWeI</p>	<p>Electricity production yearly</p> <p>15,000 MWh (net)/yr</p>	<p>Electricity earnings yearly</p> <p>80 €/MWh = 1.2 mio. €/year</p>

**Potential improvement in energy efficiency = ~ 20%  
Reduction of CO<sub>2</sub> emission ~ 10,000tpa**