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Thomas Börrnert is the head of the new established department heat recovery, in the Business Unit Minerals at ABB Switzerland. The department provides turn key waste heat recovery systems to produce electrical power from waste heat and offers analysis for industry plant cost saving potential using waste heat recovery. Thomas Börrnert has over 15 years experience with ABB in various positions starting in power generation business, business consulting and business development.

# SAVE 20 % ELECTRICITY BY CONVERTING LOW TEMPERATURE WASTE HEAT INTO ELECTRICITY

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## ABSTRACT

Cement plants are huge energy consumers and produce large amounts of waste heat in the waste gas after the pre heater tower and in the excess air after the clinker cooler. These two waste heat streams are in most cement plants not used to date, although they are very valuable energy sources.

ABB's new type of small power plant is designed to use low and mid temperature waste heat sources as from 150°C and to convert them into electric energy – efficiently, economically and CO<sub>2</sub> free. Therefore waste heat even from modern and efficient cement plants can be used to generate electricity, i.e. sources in the temperature range far below 350°C and especially below 300°C. To use low temperature waste heat sources the ABB power plant operates on the ORC technology, which will be outlined.

In the near future electricity prices will rise; moreover CO<sub>2</sub> emissions will have to be reduced. Thus also CO<sub>2</sub> emissions will be more and more a position in the accountancy of cement plants, which stimulates the companies to reduce their CO<sub>2</sub> emissions. To make use of the waste heat to be more efficient, thus to reduce energy consumption and CO<sub>2</sub> emissions is a promising way into this direction.

We will present results of assessments in various cement plants, how low temperature ORC plants are integrated and how energy efficiency can be boosted by up to 20% and more. The technical solution and the modular plant concept are demonstrated.

We will discuss possible waste heat sources in various types of cement plants, their specifications and how they could be used. We will show examples of ORC plant integration in cement plants and finally we will give an overview on economic figures and benefits from installing waste heat recovery plants.

## 1 Introduction

Increasing energy efficiency is one of the most important current entrepreneurial imperatives – for ecological and economic reasons.

Cement plants are huge energy consumers: their heat consumption lies in the order of magnitude of 3 – 3,5 GJ/t clinker and electricity consumption at roughly 100 kWh/t. The heat is generated to a considerable extent from fossil fuels and, in some countries, partly from alternative. The electricity used is to a large degree generated in power plants, many of which also run on fossil fuels. Therefore the energy consumption of a cement plant causes direct and indirect CO<sub>2</sub> emissions. Finally, clinker burning produces additional geogenic CO<sub>2</sub> emissions.

Therefore cement plants will have to increase their efforts to improve energy efficiency and thereby reduce energy consumption.

One basic idea is to move plants as close as possible to "adiabatic operating conditions", in other words: waste heat shall be recovered to a the maximum extent.

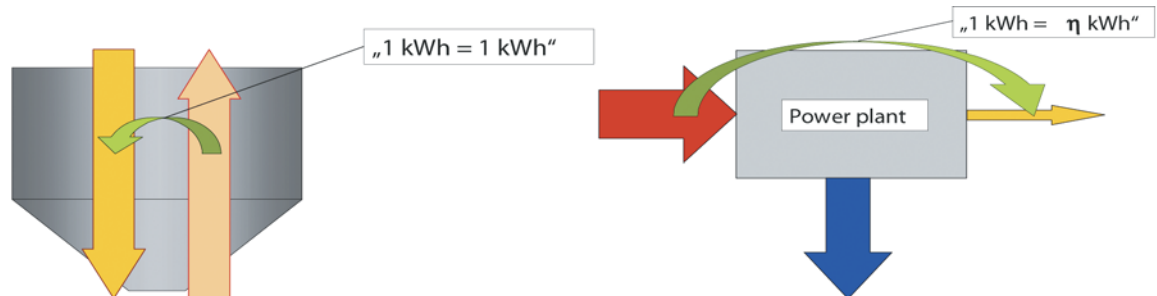
## 2 Waste Heat Recovery and Waste Heat Conversion

Modern cement plants can be thought of as huge heat exchangers. After firing the kiln (and eventually the pre calciner), the heat in the stack gas and from the hot clinker is used to a more or less large extent in the plant:

- Secondary air pre heating
- Tertiary air preheating
- Preheater tower with 3 – 6 stages to preheat the raw mix
- Waste heat recovery to dry alternative fuels
- Use of clinker cooler waste heat to feed district heating systems
- Etc.

Waste heat recovery as the most important measure towards low heat losses therefore has the highest priority. It is the most efficient way to increase energy efficiency: the efficiency of heat recovery is high: one kWh of waste heat reused in the plant ends in one kWh of useful heat.

After the efficiency of a cement plant has been driven to the economic optimum, the remaining waste heat can be converted into electricity. It must be kept in mind, that with any conversion technology the thermal efficiency of the conversion ( $\eta$ ) comes into the game. Therefore one kWh of used waste heat only produces  $\eta$  kWh of useful energy - but now it is electrical energy.



Picture 1 : Comparison of waste heat recovery and waste heat conversion left hand picture: waste heat recovery in a cyclone right hand picture: waste heat conversion in a power plant

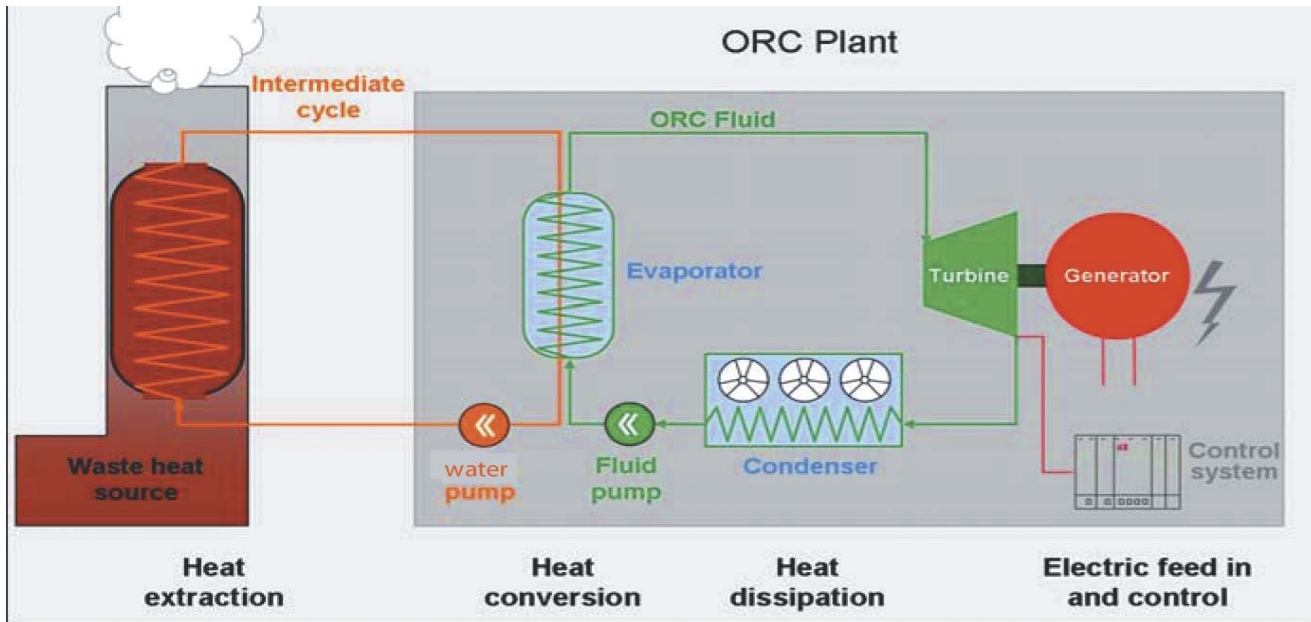
One thing is obvious: the more efficient the cement plant, the lower the waste heat temperatures, specifically the temperature of the waste gas after the preheater tower. Temperatures after the preheater tower in efficient cement plants can be considerably below 300°C. Therefore waste heat conversion technology has to be configured to match this situation.

Our power plant based on Organic Rankine Cycle (ORC) technology is designed to make use of exactly this low and medium temperature waste heat. Therefore it excellently converts low temperature waste heat from cement plants into electricity.

## 3 Working Principle of the ABB ORC Power Plant

The Organic Rankine Cycle (ORC) power plant consists of the following main systems:

- Heat extraction
- Heat conversion
- Heat dissipation
- Electric feed in and control



Picture 2: Functional principle of an ORC Plant

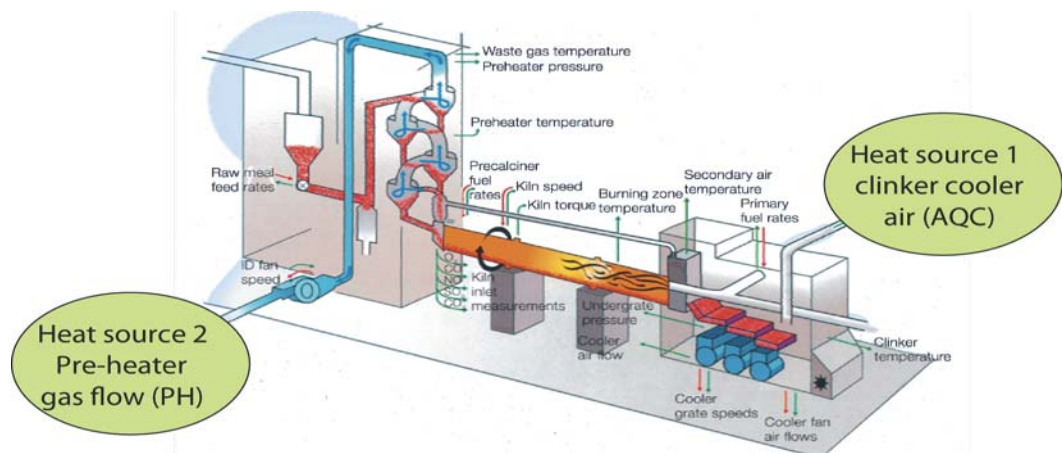
The core piece of the power plant is a steam turbine. Due to the low waste heat temperature the temperature of the steam is low as well. Therefore water vapor can not be used efficiently, both in terms of energy and of costs.

Here organic fluids are to be used. Organic media evaporate at relatively low temperatures and condense against ambient air at a pressure over 1 bar, 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.

### 3.1 Heat Extraction

In cement plants the waste heat is normally extracted from two sources: from the clinker cooler air (AQC) and from the waste gas after the preheater tower.



Picture 3: Typical waste heat sources in a cement plant

Heat source 1, the cooler air (AQC) can be cooled down as much as possible to extract the 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 an expert system is installed which records the respective production data of the plant. The precise examination of the cement plant leads to an optimized design of the (ORC) power plant and thus avoids too big an installation (unnecessarily economically expensive) or a too small power plant (loss of precious electricity from waste heat).

The waste heat sources in cement plants make great demands on the engineering of the heat extraction part of 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.

### Clinker Cooler (AQC)

The heat exchanger in the clinker cooler air stream is loaded with a comparable dust load. 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.

### Preheater

The dust load of the preheater gas lies in the order of magnitude of 50 – 100 g/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.

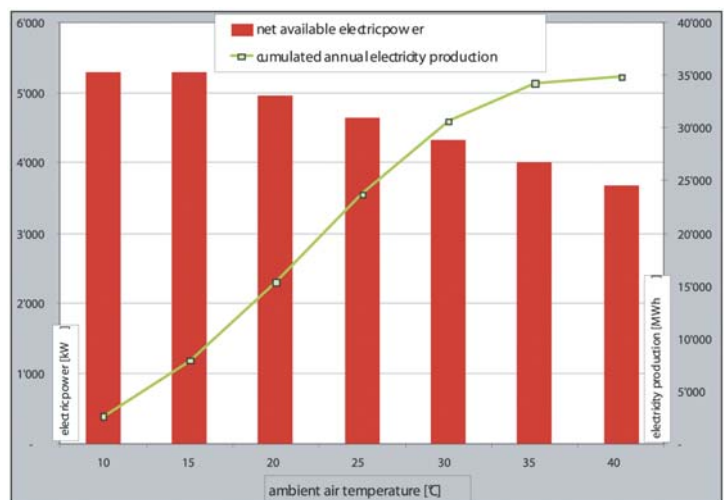
The dust issue is taken into consideration by the heat exchanger design. The exchanger is a bare tube type with geometry designed accordingly. The past has shown (the longest used heat exchanger of that type has been in operation since 1991 on the heavy dust side in a cement plant), that this heat exchanger type withstands the high dust load in the waste gas after the preheater tower. If specific circumstances should make it necessary, the heat exchangers are designed to carry dust blowers at the relevant points.

## 3.2 Heat Conversion

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

The back pressure after the turbine depends on the outside air temperature (OAT): the warmer the weather, the higher the back pressure and thus the lower the produced electrical power.

After the turbine the organic vapor flows through a heat recovery heat exchanger and is cooled. Then the vapor enters the condenser,



Picture 4: The net available electric power over one year

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 vapor) to the evaporator and the cycle is closed.

### 3.3 Heat Dissipation

As with every thermal power plant, the vapor 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.

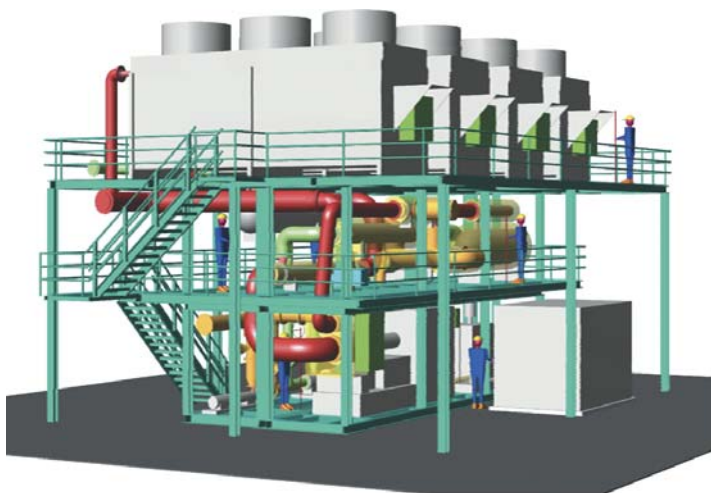
Water usage and water saving are big issues in many countries. Therefore, when considering this topic with regard to sustainability, our ORC power plant uses specifically designed high end dry condensers to avoid water consumption. Due to the appropriate design, the condensers can be operated with low specific electricity consumption at the small temperature differences between the condensing organic vapor and the ambient air.

#### 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 centralizes breakers, safety equipment and the necessary control devices. Where necessary (specifically with the fluid pump) variable speed drives are installed to match the operation of the ORC power plant ideally to the operating conditions of the cement plant.

## 4 ABB ORC POWER Plant Design

The main modules are designed as standard modules, which form our 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 industry plant. The conversion module is designed for unchanged operating process conditions. Moreover the power plant is designed to only use a small surface area, due to a very compact construction.



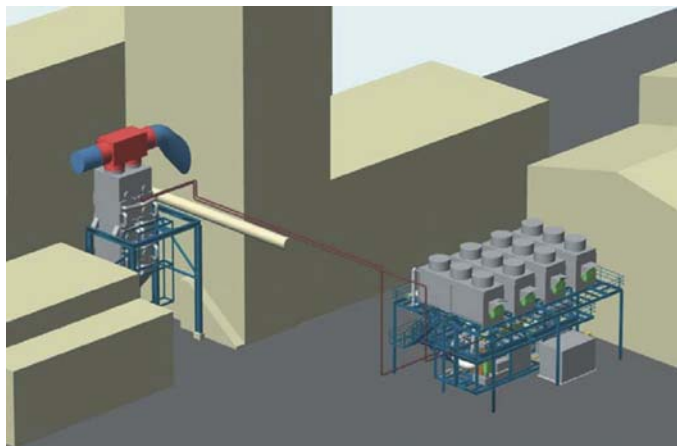
Picture 5 : Illustration of our ORC power plant

Picture 5 shows the compact and modular design of the power plant: at the bottom level all components, that need observation or maintenance (electro-mechanical components as turbine, pumps, generator, valves etc.) are installed. The middle floor level contains all static procedural components: process heat exchangers, piping. The top of the steel frame carries the condensers.

Due to its modular design, our system can be integrated in nearly all industrial processes. The two cycle system allows a flexible integration in existing plants as illustrated in picture 6.

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

The ORC power plant is - from the cement maker's point of view - an installation of secondary importance, therefore it must not interfere with or even disturb the core process of cement making. This need is accommodated by installing the heat exchangers in a bypass mode. Under normal operating conditions, the



Picture 6: Illustration of our ORC power plant layout with clinker cooler HEX

waste gas and the clinker cooler air, flow through the heat exchangers. If for any reason the ORC power plant should be out of operation while the kiln is under full operation, the waste gas bypasses the heat exchanger and takes the conventional route through the cooling tower. In bypass mode the clinker cooler air is cooled in the existing cooler before it enters the dust precipitator.

### 5 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 to

invest in heat recovery systems. The reasonable pay back times for an ORC power plant and the possibility to increase productivity coupled with the positive environmental effects of this investment is now attracting investors and plant owners.

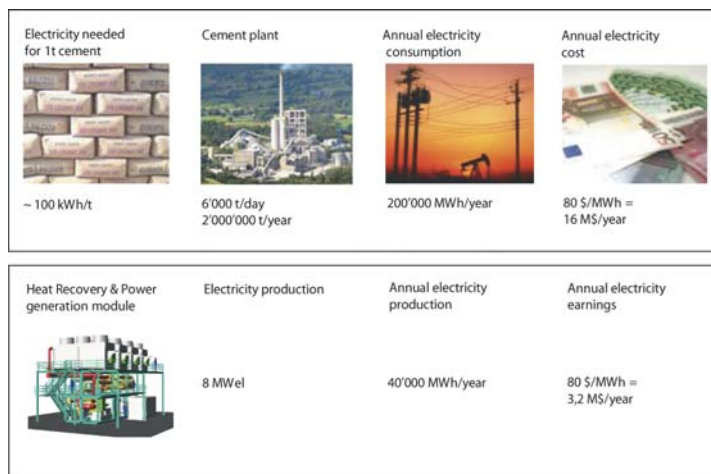
The installation of an ORC power plant in a highly efficient cement plant (waste gas temperature after preheater typically between 250 and 300°C) contributes to further enhancement of the energy efficiency and to a reduction of the CO<sub>2</sub> emissions caused by electricity consumption. Even in such cases, the reduction of electricity consumption runs up to nearly 20%.

The reduced electricity consumption equals a reduction of CO<sub>2</sub> emissions of app. 10'000 t per year, depending 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 the sustainability of cement production by conserving the more and more important resource of (potential) drinking water.

Picture 7 shows the efficiency improvement of a typical installation of an 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



**Potential annual electricity cost saving = ~ 20 %**  
**Reduction CO<sub>2</sub> emissions = ~ 24'000 t/year (depending on grid factor)**  
 Picture 7: Energy efficiency improvement by waste heat conversion

### 6 Summary

Recovering waste heat to the maximum extent and improving waste heat conversion in cement plants leads to a step change in energy efficiency improvements. ORC power plants are a proven technology to use low temperature waste heat sources to produce electricity.

The ecological and economic improvements now make investments in this area attractive. ORC power plants boost electrical energy efficiency in cement plants by up to 20%, reduce indirect CO<sub>2</sub> emissions considerably and save water at the same time.