H·REII Heat Recovery in Energy Intensive Industries

PROJECT CO-FINANCED BY THE LIFE+ PROGRAMME OF THE EUROPEAN COMMISSION

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1.2.5.8 "Cogeneration",

1.4.2.4 "Energy recovery from kilns",

4.2.3.2 "Conegeration with Organic Rankine Cycle (ORC) process – cement plant in Morocco & Romania

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List of content

1. Analysis of the current BREF document

"Reference Document on Best Available Techniques in the BREF CEMENT, LIME and MAGNESIUM OXIDE Manufacturing Industries" issued on May,2011

After a carefully analysis of the BREF document: "Reference Document on Best Available Techniques in the BREF CEMENT, LIME and MAGNESIUM OXIDE Manufacturing Industries" issued on 2010, it is necessary to fix the following preliminary points:

1. the HEAT RECOVERY is mentioned in all the three industries as BAT for the reduction of the energy consumption for thermal needs:
   - for CEMENT industries,
     see BAT n. 6, point b) and BAT n. 8 (ref.: § 1.5.3.2, page 174);
   - for LIME industries,
     see BAT n. 33, point a) (ref.: § 2.5.3, page 315);
   - for MAGNESIUM OXIDE industries,
     see BAT n. 57, point a) (ref.: § 3.5.3, page 374);

2. the HEAT RECOVERY techniques to be adopted are then widely described ONLY in the CEMENT industries, while for LIME and MAGNESIUM OXIDE industries the description is quite limited (probably, due to a not significant profitability in the costs-benefits analysis).
   - for CEMENT industries, see § 1.4.2.4, page 104;
   - for LIME industries, see § 2.4.2 – Table 2.35, page 272;
   - for MAGNESIUM OXIDE industries, see § 3.4.3, page 356;

3. COGENERATION techniques are indicated in BAT n. 6, point b) and BAT n. 8 as measures for reaching the overall reduction of the energy consumption thanks to the use of energy (thermal and electric) recovery systems.

4. Furthermore, the reported information and the data about the use of ORC cogenerating processes for energy recovery in cement manufacturing need for AN IMPORTANT REVISION: nowadays, the operational performances and the economical profitability related to the ORC plants result generally increased and more advantageous. As a consequence, also their application in the cement industries needs for new and more detailed reference elements to be added in the related BREF document.

2. Relieved discrepancies to be revised about the "COGENERATION" in the CEMENT industries

In the following lines, the information and data in the current BREF document are implemented or compared with the investigated new and more detailed elements that should be mentioned in a BREF document review.

§ 1.2.5.8 – Cogeneration (See page 39)

Current version	**Reviewed version**
" For the first time in a German cement kiln, the Organic Rankine Cycle (ORC) process for the cogeneration from low temperature waste heat has been applied."	*"Since its first application in the cement kiln of Lengfurt (Germany), the Organic Rankine Cycle (ORC) process for the cogeneration from low temperature waste heat is now evaluated and applied in various new cement plants. Nowadays, the Organic Rankine Cycle (ORC) turbogenerator is an effective power plant for decentralized small- to medium-scale energy applications, for an electric power output ranging, from approximately 500 kWe up to about 10 MWe."*
"The results available from the German cement plant indicate that 1,1 MW electrical power can be generated with the given mode of operation."	*"The results available from the ORC turbogenerator recently installed (2010) in the cement plant of Ait Baha (Morocco) indicate that up to 1,5 MWe can be generated with the given mode of operation.* *Furthermore, the new cement plant (starting-up in 2012) of Alesd (Romania) has been duly designed in order to co-generate up to 4 MWe by means of an ORC turbogenerator. In addition, another 5 MWe ORC heat*

	recovery power plant is going to start up in 2013 in the cement plant of Rohožník (Slovakia)".

§ 1.4.2.4 - Energy recovery from kilns and coolers/cogeneration (see page 104)

Description

The amendment proposal is:

"In general, the principle behind all the processes of combined heat and power (or "cogeneration") is the recovery of the waste heat from a fuel combustion into an electricity generation system.

On the other hand, many industrial applications eject heat at negative characteristics for the traditional schemes, so that traditional steam cycles wouldn't allow a profitable recovering heat in middle-temperatures range, because of significant economic reasons.

In the cement industry, the more frequent choice of using an ORC turbogenerator is reflecting the increased performances in terms of recovered electrical power from low temperature exhaust gases, which has led to even more profitable results. Furthermore, this more powerful energy recovery has also implied an indirect reduction of the CO_2 emissions"

Achieved environmental benefits

The amendment proposal is:

"the benefits from the ORC processes - in terms of CO_2 emissions and reduction in the consumption of primary energy - for the ITALIAN cement industry have been already quantified thanks to the H-REII project (H-REII project, co-financed by the Life+ programme of EU – ref.: LIFE08 ENV/IT/000422) *activities, as follows:*

Potential production of Electric power by ORC processes

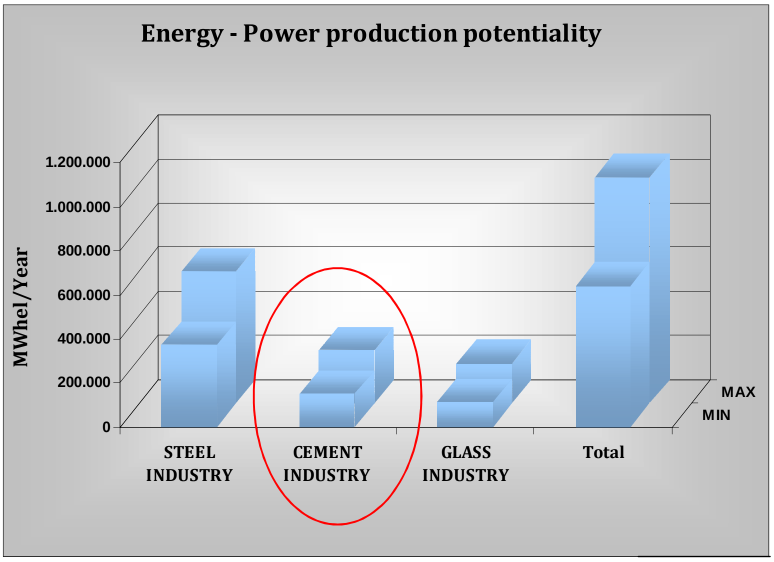

Figure 1 Potential production of Electric power by ORC processes

Related achieved CO2 emissions in Italy

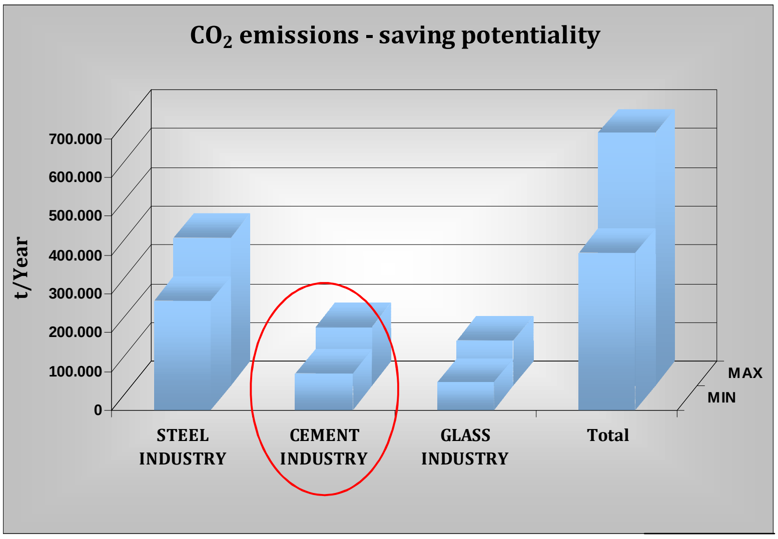

Figure 2 Related achieved CO_2 emissions

Cross media effects

No changes.

Operational data

The amendment proposal is:

"Nowadays, the available technologies allow increased performances of using an ORC turbogenerator in cement manufacturing:

Ait Baha (Morocco) Plant, 2010:

heat recovery from the KILN EXHAUST GAS.

Intermediate thermal oil loop to transfer HEAT to the ORC cycle;

Condensating HEAT dissipated through intermediate water cooling loop and dry-air cooling system.

Heat source: exhaust gas at 330°C

Gas cooled down to 220°C (extra heat used for raw material pre heating)

ORC electric power: ca. 2 MWe"

Alesd (Romania) Plant, 2012:

heat recovery from the KILN EXHAUST GAS with intermediate thermal oil loop and from the CLINKER COOLER AIR with a second loop of pressurised water to transfer HEAT to the ORC cycle;

Condensating HEAT dissipated through intermediate water cooling loop and wet cooling towers.

Clinker production capacity: ≈ 4.000 ton/day

Heat source: exhaust gas @ 360°C (PRS) and 250 °C (C C)

Thermal oil (PRS) and pressurised water (CC) heat recovery loops

ORC electric power: ca. 4 MWe"

Rohožník (Slovakia) Plant, 2013:

Heat recovery from the KILN EXHAUST GAS with intermediate thermal oil loop and from the CLINKER COOLER AIR with a second loop of pressurised water to transfer HEAT to the ORC cycle;

Condensating HEAT dissipated through intermediate water cooling loop and wet cooling towers.

Clinker production capacity: ≈ 3.600 ton/day

Heat source: exhaust gas @ 360°C (PRS) and 310 °C (C C)

Two thermal oil heat recovery loops

ORC electric power: ca. 4 MWe"

Applicability

No changes.

Economics

The amendment proposal is:

"Nowadays, according to the increased sizes with higher performances of the current ORC turbogenerators and to the increasing primary energy costs it is possible to allow a more attractive and profitable Businnes Plan in cement manufacturing. The Heat recovery with its related electric power self-production leads to an increased competitiveness due to the lower costs of electric power used in the processes for producing the same quantities of cement. Furthermore, the presence of heat recovery plants that produce power with no emission and fuel consumption implies economic benefits also for the grid: reduction of distribution losses, stabilization of grid load and reduction of blackouts frequency."

Driving force for implementation

No changes.

Example plants and reference literature

In the current version of the BREF, the other mentioned examples are not distinguishing between the plants with conventional steam cycle and the ones with ORC process.

Furthermore, it results that the Lengfurt cement plant is the one and only applying an ORC solution and that its choice seems mainly due to the funding by German government.

The amendment proposal is:

"there are other cement plants applying energy recovery by means of an ORC turbogenerator:

- *Ait Baha in Morocco: Cement plant with installed an ORC turbogenerator, size 1.5MWe* for heat recovery (started up in 2010);
- *Bihor in Romania: Cement plant with installed an ORC turbogenerator, size 4MWe* for heat recovery (start up in 2012);
- *Rohožník in Slovakia: Cement plant with installed an ORC turbogenerator, size 5MWe* for heat recovery (foreseen start up in 2013).

Reference literature

It should be added the following list:

- Chinese, D., Meneghetti, A., Nardin, G. Diffused Introduction of Organic Rankine Cycle for Biomass-based Power Generation in an Industrial District: a Systems Analysis, Int. J. Energy Res., 28, 1003-1021, 2004.
- Angelino, G., Gaia, M., Macchi, E. A Review of Italian Activity in the Field of Organic Rankine Cycles, Proceedings of the Intl.VDI Seminar (Verein Deutsche Ingenieure), Bulletin 539, VDI-Düsseldorf, 465-482, 1984.
- Quoilin, S., Lemort , V., Technological and Economic Survey of Organic Rankine Cycle Systems , Proceedings of European Conference on Economics and Management of Energy in Industry. Vilamoura, Portugal, 2009.
- http://circa.europa.eu/Public/irc/env/ippc_brefs/library
- Riccardo Vescovo Turboden srl: "Waste heat into power" Waste heat generation August 2011

§ 4.2.3.2 - Cogeneration with Organic Rankine Cycle (ORC) process (see page 425)

It should be added a sub-paragraph on:

Working principle

The heat contained in the exhaust gas is transferred indirectly -via a thermal oil circuit- or directly to the ORC plant.

The ORC plant produces electricity and low-temperature heat through a closed thermodynamic cycle which follows the principle of the Organic Rankine Cycle (ORC).

In the ORC process, designed as a closed cycle, the organic working medium is pre-heated in a regenerator and in a pre-heater, then vaporized through heat exchange with the hot source. The generated vapour is expanded in a turbine that drives an asynchronous generator. Leaving the turbine, the organic working medium (still in the vapour phase) passes through the regenerator that is used to pre-heat the organic liquid before vaporizing, therefore, increasing the electric efficiency through internal heat recovery. The organic vapour then condenses and delivers heat to the cooling water circuit. After the condenser, the working medium is brought back to the pressure level required (for turbine operation) by the working fluid pump and then preheated by internal heat exchange in the regenerator.

The low-temperature heat is normally discharged to a thermal user or to the atmosphere through air cooled radiators inserted in a closed cooling water circuit (evaporative cooling towers can also be employed).

The operation of the ORC plant is fully automatic in normal operating conditions as well as in shut down procedures without any need of supervision personnel. In case of faulty conditions, the ORC plant will be switched off automatically and separated from the thermal oil circuit and from the electrical grid.

The ORC module is designed to automatically adjust itself to the actual operating conditions: variations on exhaust gas temperatures and flows (in reasonable span times) will not affect the functionality of the system (but just the power output).

Description of a cement plant with ORC Based Heat recovery System

The use of an-organic fluid enables efficient use of a lower temperature thermal source stream as exists in cement production processes, to produce electricity from a power plant that operates automatically requires minimal supervision and maintenance, and can be configured for no water consumption.

Thermal energy contained in the two main waste heat stream – Kiln gas after pre-heating cyclones and Clinker cooler air – is captured by waste heat oil heaters (WHOH), and transferred to the ORC turbogenerator using a closed loop thermal oil sub-system (Ref. Figure 3). The location of the WHOHs depends on specific plants related factors and is defined in concert with plant operators and referenced suppliers with the aim of:

- *Not affecting the optimum cement production operation,*
- *Minimizing effects on existing equipment (mills, fans, filters, etc.).*
- *Guaranteeing reliable and durable operations,*
- *Minimizing investment cost.*

The ORC turbogenerator accepts the hot thermal oil generated in the WHOHs and converts approximately 20% of the input thermal power into electric power.
The balance of this thermal power is removed from the cycle by a closed loop cooling sub-system that typically dissipates it to the Environment.
The electrical power can be delivered to the grid or used to feed the cement plant internal electric grid.
As alternatives to thermal oil heat recovery systems, either pressurized water or saturated steam solutions can be adopted to extract heat from the hot gas and transfer heat to the ORC plants.
As an indication, the power that can be produced by an ORC system in a typical cement making process can range from 0.5 to 1.5 MW/ Thousand metric tons per day of Clinker production capacity (assuming heat recovery from Both kiln and cooler waste flows).

Using this Figure, it can be estimated that the energy produced by an ORC can account for around 10 – 20% of the total electricity consumed by a cement plant.

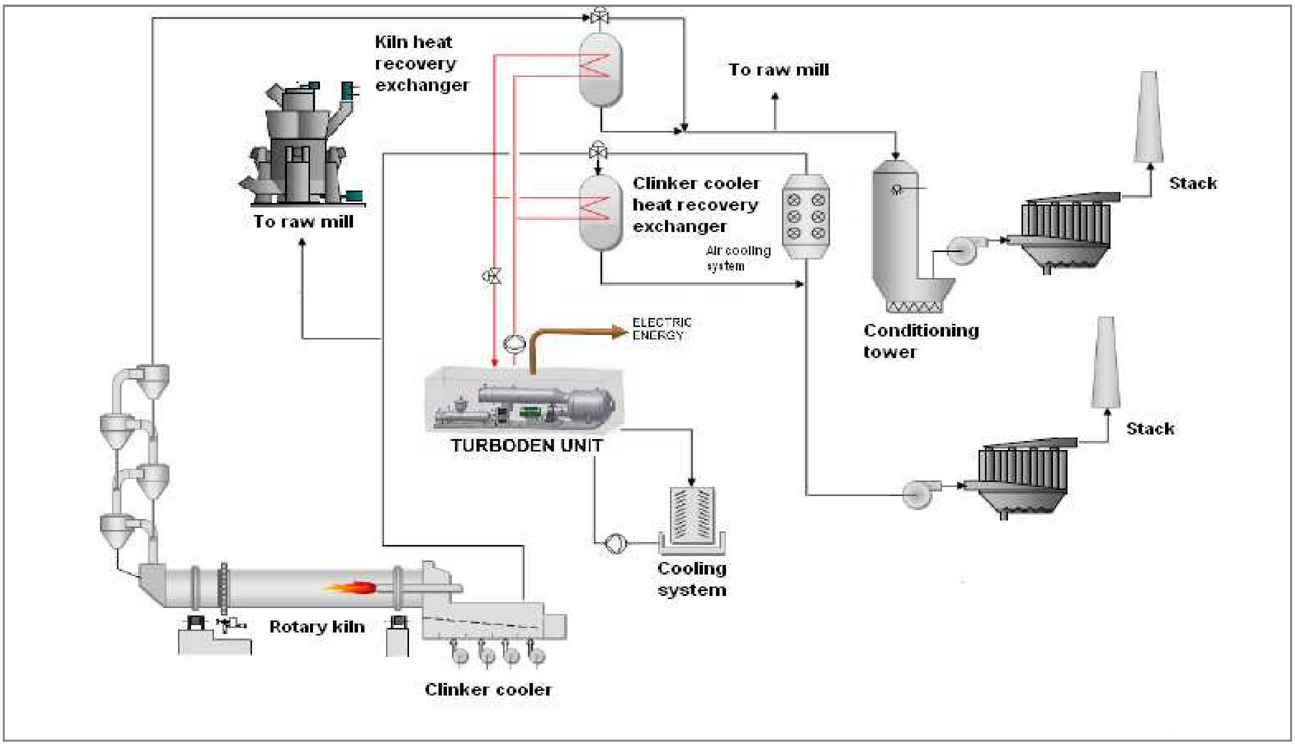

Figure 3 Example of ORC based Heat Recovery System in a cement plant.

The application of ORC turbogenerators in cement plant in Ait Baha, Morocco (2010) has the following characteristics:

Heat recovery from the KILN EXHAUST GAS.

Intermediate thermal oil loop to transfer HEAT to the ORC cycle;

Condensating HEAT dissipated through intermediate water cooling loop and dry-air cooling system.

Heat source: exhaust gas at 330°C

Gas cooled down to 220°C (extra heat used for raw material pre heating)

ORC electric power: ca. 2 MWe"

The application of ORC turbogenerators in cement plant in Alesd, Romania (2012) has the following characteristics:

Heat recovery from the KILN EXHAUST GAS with intermediate thermal oil loop and from the CLINKER COOLER AIR with a second loop of pressurised water to transfer HEAT to the ORC cycle;

Condensating HEAT dissipated through intermediate water cooling loop and wet cooling towers.

Clinker production capacity: ≈ 4.000 ton/day

Heat source: exhaust gas @ 360°C (PRS) and 250 °C (C C)

Thermal oil (PRS) and pressurised water (CC) heat recovery loops

ORC electric power: ca. 4 MWe"

The application of ORC turbogenerators in cement plant in Rohožník, Slovakia (2012) has the following characteristics:

Heat recovery from the KILN EXHAUST GAS with intermediate thermal oil loop and from the CLINKER COOLER AIR with a second loop of pressurised water to transfer HEAT to the ORC cycle;

Condensating HEAT dissipated through intermediate water cooling loop and wet cooling towers.

Clinker production capacity: ≈ 3.600 ton/day

Heat source: exhaust gas @ 360°C (PRS) and 310 °C (C C)

Two thermal oil heat recovery loops

ORC electric power: ca. 4 MWe"