LIFE Project Number

LIFE10 ENV/IT/000397

BAT and BREF

Internal document code:				
Version:	03			
Date:	30/06/2014			
Status:	PU			
Dissemination level:	PU	PP	RE	CO
	Public	Limited to other program participants (including the Services Commission)	Reserved for a group specified by the Consortium (including the Services Commission)	Confidential, only for the members of the Consortium (including the Services Commission)
Author:	D. Forni			
Project:	Integrated fumes depuration and heat recovery system in energy intensive industries (EII)			
Acronym:	H-REII DEMO			
Code:	LIFE10 ENV/IT/000397			

The European Union established common provisions to prevent and reduce the emissions from industrial activities, with the Directive 96/61/EC "concerning integrated pollution prevention and control". The Directive requires a mandatory integrated permission for the industrial activities listed in annex 1 in order to achieve a high level of protection of the environment.
This Directive and the following recasts 2008/1/EC and the 2010/75/EU Industrial Emission Directive, set up the Integrated Environmental Authorisation, Integrated Environmental Evaluation, etc. taking in consideration all the environmental aspects (air, water, soil, waste) not to encourage the shifting of pollution from one to another.
The emission limits are set considering the best available techniques (BAT) of each sector, these are a dynamic reference and are regularly reviewed to reflect the enhancements and innovations. The BAT represent the most effective and advanced solutions, under economically and technically viable conditions, to prevent and, where that is not practicable, to reduce the impact on the environment as a whole.

The BAT reference documents are developed for each sector under the Directive in a forum coordinated by the European IPPC Bureau, involving the stakeholders (Member States, the associations of the industries concerned, non-governmental organisations promoting environmental protection and the Commission), with mirror working groups at national level. Bat reference documents contain the techniques considered for the definition of BAT, the BAT conclusions (stating for the most relevant ones the applicability, emission and consumption levels, etc.) and the emerging techniques (novel techniques that, once developed, could provide lower emissions or same emissions with lower costs).

The annex III of the 2010/75/EU directive lists the criteria for determining best available techniques, among those is worth to remember "the furthering of recovery", "energy efficiency", "the length of time needed to introduce the best available technique".

The BAT reference documents should be updated not later than 8 years after the publication of the previous version, but the time lag is affected by a number of factors and can also be considerably shorter. For instance with the entrance into force of the 2010/75/EU a number of reference documents has been updated, mostly to work on the section of the BAT conclusions, thus leaving no room to add new techniques.

Considering the schedule for the revision of the BAT reference documents and the demonstration activity of the HREII demo project, a sectorial document for the metal sector was prepared and submitted to the Italian working group involved in the update of the non ferrous metals reference document. To make it more understandable and manageable was provided also a second document of less than two pages, the "Addendum proposal", with a concise introduction and the text of the proposed addendum as emerging techniques to the copper and ferro-alloys sections.
The documents has been sent to all the stakeholders participating to the Italian working group: the Ministry of Environment, the Regional bodies in charge of coordinating the integrated permitting and the sectorial enterprise association. Even if some feasibility studies were carried out by different Italian manufacturers of ORC systems, the contribution was not transmitted to the European forum, since there are no existing plants in the non ferrous metals sector.

Moreover also the document on the cement sector, prepared during the HREII project has been revised and updated also to take into consideration the new installations.

Hereafter are collected the three above mentioned documents.

LIFE Project Number

LIFE10 ENV/IT/000397

Addendum proposal for the emerging techniques section of Copper and ferro-alloys

Internal document code:				
Version:	final			
Date:	30/10/2013			
Status:	approved by the HREII DEMO Observatory			
Dissemination level:	PU	PP	RE	CO
	Public	Limited to other program participants (including the Services Commission)	Reserved for a group specified by the Consortium (including the Services Commission)	Confidential, only for the members of the Consortium (including the Services Commission)
	X			
Author:	HREII DEMO Observatory			
Project:	Integrated fumes depuration and heat recovery system in energy intensive industries (EII)			
Acronym:	H-REII DEMO			
Code:	LIFE10 ENV/IT/000397			

INTRODUCTION

Heat recovery is present in the BREF rev 3 of Non-Ferrous Metal Industries in the BAT conclusions (general, copper, alumina, lead and tin, zinc, ferro-alloys and nickel)[1], and in some cases it is also specified that the recovered heat can be used to produce electricity (copper, zinc and ferro-alloys).

In the entire document there is only one explicit reference to the Organic Rankine Cycle (the table without number and title at pag. 984, in 9.3.8.1 "Recovery of heat from semi-closed furnaces"), within the techniques that have to be considered in the determination of BAT for ferro-alloys.

In this context of high international competition, growing energy prices and rising climate change awareness, the energy efficiency and the recovery of wasted energy are a central topic, not anymore limited to the industries under IPPC and emission trading.
If there are no internal or external uses of the recovered waste heat, its conversion in electricity is an option that must be evaluated.
The Organic Rankine Cycles (ORC) generators accept low grade heat, operates fully automatically in all working conditions with good performances also at partial loads. Those cycles are spreading for the electricity generation from waste heat recovery in various sectors, with new plants built in the last 5 years in cement (2 plants in Europe and 1 in Mediterranean area[2]) and in the flat glass manufacturing (2 plants in Italy[3]).
At the moment there are no installations in the field of non-ferrous metal industries, but there are a number of feasibility studies in ferro-alloys (silicon metal, ferro-manganese, ferro-chrome) and copper (primary copper smelter and rolling mill), some at an advanced stage.

Economic benefits need to be evaluated case by case, since they are related to the price of electricity and the availability of supporting schemes for waste heat recovery or innovative systems.
Environmental benefits due to the lower electricity consumption have to be evaluated on country basis considering the average emission factor for electricity generation.

1. ADDENDUM PROPOSAL

The following addendum are proposed in the sections of emerging techniques:

3.4 Emerging techniques
The following techniques are emerging techniques, which means that these techniques are not fully implemented in the copper industry:
Heat recovery in primary copper smelter and rolling mill for electricity generation via ORC modules with sizes ranging from hundreds of kW to various MW.

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[1] General BAT conclusions 14.1.2 "Energy management", Copper 14.2.3 "Energy", Alumina 14.3.2.1 "Energy", Lead and tin 14.4.2 "Energy", Hydrometallurgical zinc production 14.5.2.1.1 "Energy", Ferro-alloys 14.7.2 "Energy", Nickel 14.8.2 "Energy"

[2] Turboden references, www.turboden.eu

[3] Waste heat recovery expertise, D. Forni, Glass WorldWide August 2013.

9.4 Emerging techniques

The following techniques are emerging techniques, which means that these techniques are not fully implemented in the ferro-alloy industry:
Heat recovery from submerged arc furnace for electricity generation via ORC modules with sizes ranging from hundreds of kW to various MW.

LIFE Project Number

LIFE10 ENV/IT/000397

Waste heat recovery to power in non-ferrous metal industries

Internal document code:				
Version:	final			
Date:	30/10/2013			
Status:	approved by the HREII DEMO Observatory			
Dissemination level:	PU	PP	RE	CO
	Public	Limited to other program participants (including the Services Commission)	Reserved for a group specified by the Consortium (including the Services Commission)	Confidential, only for the members of the Consortium (including the Services Commission)
	x			
Author:	HREII DEMO Observatory			
Project:	Integrated fumes depuration and heat recovery system in energy intensive industries (EII)			
Acronym:	H-REII DEMO			
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1. Waste heat recovery

A considerable amount of heat is wasted in many industrial plants because exhausted gases with relevant heat content are often discharged directly to the atmosphere or have to be cooled before the gas treatment. The cooling process, such as mixing exhausted gases with fresh air, spraying water in a quenching tower, etc., implies additional costs for systems, operations and maintenance.
It can be both economically and environmentally convenient to exploit this otherwise dispersed heat to meet heat demands inside or outside the industry premises. If the recoverable heat does not match any internal heat demand, the transportation of heat to external users or its transformation in electricity must be evaluated (Figure 1).

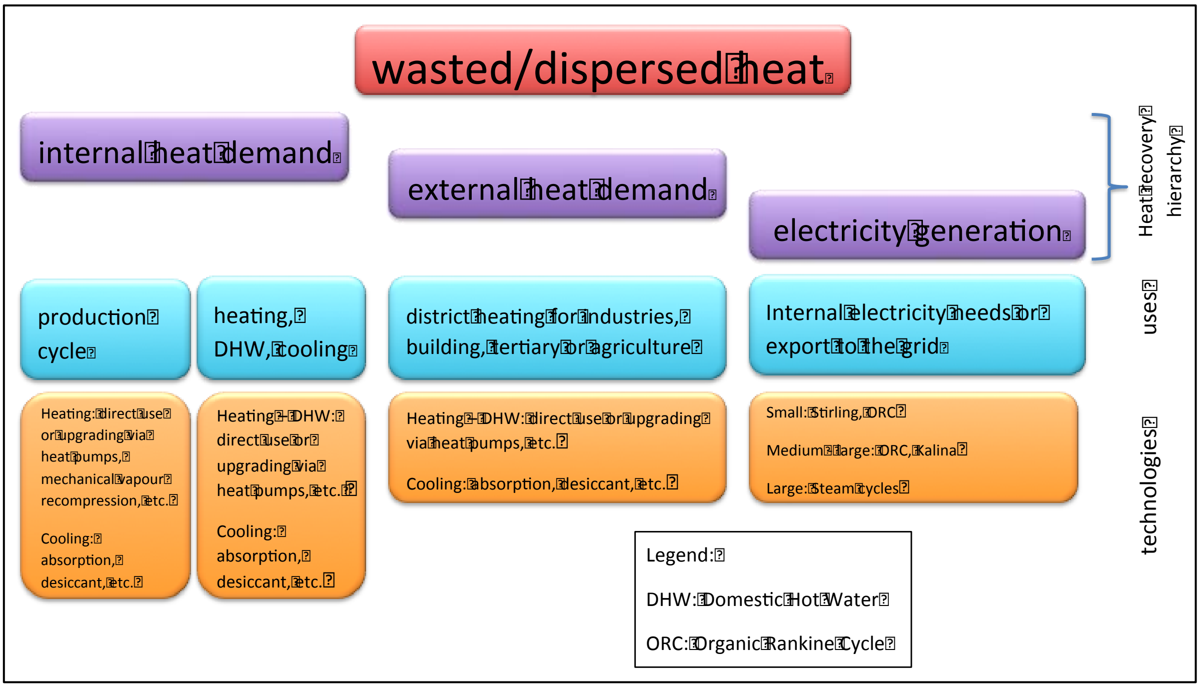

Figure 1 Waste/dispersed heat recovery opportunities and hierarchy.

2. Electricity generation from waste heat

If certain quantity and quality requirements of waste heat are met and there are no interesting internal or external uses, the heat can be exploited to generate electricity. For recovering heat quantities in the order of megawatts, a system based on a Rankine cycle is the standard solution for the electricity generation. The choice between an Organic Rankine Cycle (ORC) or a steam cycle depends on the temperature and the quantity of recoverable heat. The ORC turbogenerators are more convenient, considering investment, operational and maintenance costs, for mid and low temperature heat sources - about 250°C or, in some cases, even lower - and electrical power up to 10 MW.

The ORC turbogenerators showed their reliability in the last three decades, with hundreds of applications in the geothermal and biomass sectors and are now used to exploit dispersed heat in the glass, cement and iron and steel industries.

3. Organic Rankine Cycle

An ORC turbogenerator works through sealed organic fluids, like siloxanes, hydrocarbons or refrigerant chosen in accordance of the application (see [1], [2] and [3]). The thermal input for the ORC unit is typically the heat contained in the exhausted gases, which can be transferred directly to the working fluid or indirectly, through different heat carriers (thermal oil, steam, pressurized water, etc.) in an intermediate heat transfer loop.
The ORC outputs are electricity and low-temperature heat, usually discharged through air-coolers.
The ORC turbogenerator is based on a closed thermodynamic cycle where (Figure 2) the organic working medium is pre-heated in a regenerator (2→8), then vaporized through heat exchange with the hot source (8→3→4). The generated vapour is expanded in a turbine (4→5) that typically drives an asynchronous generator. Leaving the turbine, the organic working medium, still in the vapour phase, passes through the regenerator (5→9) to pre-heat the organic liquid before vaporizing, therefore, increasing the electric efficiency through internal heat recovery. The organic vapour then condenses (9→1), delivering 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 (1→2) and starts again the cycle.

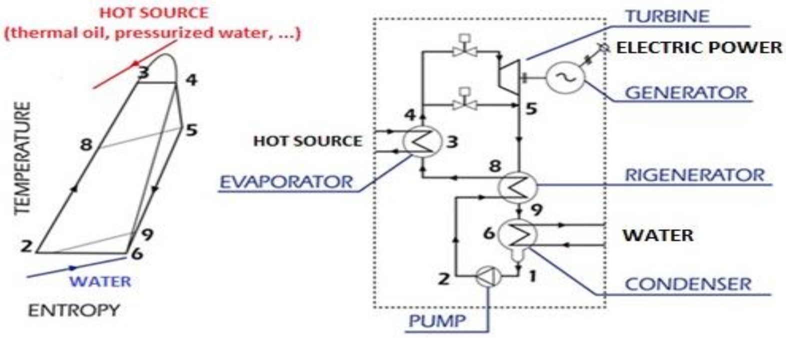

Figure 2 Process diagram of an ORC turbogenerator (right) and its representation on the T-S diagram (left)

The ORC shows a high efficiency (up to 24%) for waste heat streams over 300°C. It has lower sensitivity to temperature and flow rate changes and can work at partial load down to 10% of the nominal thermal input, still with a high efficiency, thanks to the characteristics of the working fluid, guaranteeing absence of liquid at the inlet of the turbine in any load condition.
The ORC has low operating costs, does not need water treatment or consume water. Its operation 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 both from the intermediate heat transfer circuit and the electrical grid.

Description of an ORC-based heat recovery system

The use of an organic fluid enables efficient use of high and low grade thermal streams, e.g. Electric Arc Furnace exhaust, copper flash smelting furnace exhaust, re-heating furnace heat streams in rolling mills etc.

The heat is typically captured by intermediate heat exchangers, like waste heat oil heaters, and transferred to the ORC turbogenerator using a closed loop heat transfer sub-system. Thermal oil heat recovery systems, pressurized water or saturated steam solutions can be adopted to extract heat from the hot gas and transfer heat to the ORC plants.
The location of the heat exchangers depends on specific plants related factors and is defined concertely with plant operators and referenced suppliers with the aim of:

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

The ORC turbogenerator accepts the hot heat carrier generated in the primary heat exchangers 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 self-consumed inside the plant or delivered to the grid.

4. ORC-based energy recover systems

4.1. Heat recovery from ferro-alloys submerged arc furnaces

Ferro-alloys are used in a variety of industrial sectors, like the steel and iron industries, the aluminum industry, in the chemical industry and in cement industry.
Ferro-alloys are broadly divided into two big categories: bulk ferro-alloys and special ferro-alloys. In the first group are included ferro-silicon, ferro-manganese and silicomanganese, ferro-nickel and ferro-chrome.
All these metals are usually produced in submerged electric arc furnaces (SAFs), which can be open, semi-closed or closed. The operation of the furnace is typically continuous. The liquid metal tapped from the furnace is then further refined and worked.
The furnace off-gas are collected and then cleaned by a suitable system. At the furnace outlet, it still has high thermal energy content at mid and low temperature that can be recovered for thermal purposes or to produce electricity.
For more technical and economic details about the ferro-alloy sector, we refer to [4].

ORC-based waste heat recovery systems can be well suited to recover this waste heat and to increase the overall efficiency of the process, producing electric energy with high conversion efficiency. The environmental benefits achieved through waste heat recovery are clear. Indeed it can be roughly estimated that if the ferro-alloy producers within EU27 would have installed an ORC-based heat recovery system, then the avoided CO_2 emissions could roughly amount to approximately 350.000 t/y.

Operational data

It is worthwhile to recall that a steam power plant of around 40 MW has been installed in the ferro-silicon plant rated around 110 MW owned by Finnfjord AS in Norway.
An ORC-based waste heat recovery system that recovers the waste heat in the exhausted gas of an Electric Arc Furnace in a steelmaking shop at Riesa (Germany) will be started up at the end of 2013. The main characteristics of the ORC unit employed here are summarized below

- Production process: Steel production process (Electric Arc Furnace) rated around 70 MW;
- Primary heat source: Electric Arc Furnace exhausted gas, used to produce steam at 27 bar and 245°C;
- ORC heat source flow rate: ~ 20 t/h;
- Electric power: ~3 MW.

Feasibility studies

Below the results of some feasibility studies for the application of ORC turbogenerators in the ferro-alloy sector are summarized.

- ***heat recovery in a silicon metal plant:***

  Production process technology: Submerged Arc Furnace rated around 35 MW;
  Intermediate thermal oil loop to transfer waste heat to the ORC cycle;
  Heat source: exhausted gas at approximately 350°C;
  Cooling water temperature in/out of the ORC condenser 23/31°C;
  ORC electric power: ~ 3,3 MW.

- ***heat recovery in a ferro-manganese plant***

  Production process technology: Submerged Arc Furnace rated around 30 MW;
  Intermediate thermal oil loop to transfer waste heat to the ORC cycle;
  Heat source: exhausted gas at approximately 400°C;
  Cooling water temperature in/out of the ORC condenser 30/40°C;
  ORC electric power: ~ 6 MW.

4.2. Heat recovery in the Copper Industry

Copper and Copper alloys production is a very important sector within the non-ferrous metal industry. It is highly energy intensive and employs a great variety of technologies. Two production routes are possible: the primary and secondary production processes.
The ***primary copper production process*** relies on various stages of refining, starting with copper-sulphidic ores to copper cathodes, which have a high purity grade (99.95 % of Cu). Roughly speaking, the process consists of: melting, converting, fire refining and electro refining. From the heat recovery point of view, the first two stages show a very high recovery potential.
There is a great number of furnaces, converters and fire-refining furnaces for realization of the process. In the EU27, the most common melting furnace is the Outokumpu flash furnace. This furnace employs a "top-down" approach and entails blowing oxygen, air, dried copper concentrate and silica flux in a hearth furnace (see [5]). The process is continuous and is nearly auto thermal, so that small quantities of fuel are needed in order to adjust the furnace temperature. In any case a high quantity of hot SO_2 rich off-gas at high temperature (over 1,000°C) is produced. The heating value of this off-gas can be recovered and used for thermal purposes (see [5]). It could be exploited to produce electricity as well.
Further oxygen blown converters must be used to further refine the molten "matte". There are two main converting processes, namely batchwise and continuous. The most popular

batchwise converters in use are the Pierce-Smith converters. The process is nearly auto-thermal, so that a restrained amount of fuel is needed. Furthermore, in the process SO_2-bearing off-gas is produced at high temperature, which is collected and, normally, diluted to air ([5]). The thermal energy content in this exhausted gas might be recovered to produce electricity.

Secondary copper production process results from pyrometallurgic routes that are in principle similar to those of the primary copper production. However, secondary smelting stages depend strongly on the secondary material used, in particular, on its copper content, on the other constituents and the organic impurities that the scrap can contain. Hence, the number of production stages and the type of the employed furnace may vary in accordance to the secondary raw materials.
The furnaces normally used in the secondary copper production plants within EU27, according to the available data, are submerged electric arc furnaces, ISASMELT furnaces and blast furnaces. The converters in use are Pierce-Smith converters and TBRC (Top Blown Rotary Converter) furnaces. Finally for fire-refining, heart-type and rotary anode furnaces are employed.
The processes are analogous to those described above. The main difference consists, however, in using fuel for secondary copper production, to make up heat deficits in the furnace, while in primary copper production the process is nearly auto thermal.
For further details see [4].

With regard to the ***wire-rod production*** the following processes are interesting for heat recovery purposes.

- Southwire process;
- Contirod process;
- Properzi & Secor process.

All these processes are similar to each other with variations in the casting geometry (see [4]).

The waste heat in the exhausted gases of the furnaces used within these processes can be recovered and used to produce electric energy.

Operational data

The copper producer Aurubis AG in its plant in Hamburg has installed a steam power plant that recovers waste heat, producing thereby electric energy.

Feasibility studies

Below are summarized the results of feasibility studies for the application of ORC turbogenerators in the copper sector.

- **heat recovery in a primary copper smelter (melting furnace and converters):**

  Plant production capacity around 200,000 t/y of anode copper;
  Intermediate thermal oil loop to transfer waste heat to the ORC cycle;
  Heat source: exhausted gas at approximately 1200°C;
  Cooling water temperature in/out of the ORC condenser 25/40°C;
  ORC electric power: ~ 8 MW.

- **heat recovery in a copper rolling mill**

  Plant production capacity about 250,000 t/y of copper wire-rods;
  Intermediate thermal oil loop to transfer waste heat to the ORC cycle;

Heat source: exhausted gas between approximately 300/350°C;

Cooling water temperature in/out of the ORC condenser 25/35°C
ORC electric power: ~ 0,7 MW

In case of rolling mills it might be possible to adopt also direct exchange configurations, where the heat is transferred directly from the exhausted gas to the ORC working fluid.
In the Iron&Steel industry NatSteel-Tata group, started in 2013 the operation of a 0,7MW ORC plant with direct exchange on the pre heating furnaces of rolling mills in Singapore.
It would be interested to investigate its feasibility in the non-ferrous sector as well.

Economics

Waste heat recovery with related electric power self-production leads to economic benefits and a greater competitiveness due to the lower costs of electric power used in the processes. Moreover, the presence of heat recovery plants producing electric power with no emission and no fuel consumption implies economic benefits also for the grid: reduction of distribution losses, stabilization of grid load and reduction of blackouts frequency.
It is impossible to give average payback time of these systems, since the capital expenditure is site specific and on the economic savings depend on the price of the electricity.

Reference literature

It should be added the following list:

[1] 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.

[2] 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.

[3] 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.

[4] Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metal Industries, Draft 3 (February 2013).

[5] Davenport W.G., King M., Schlesinger M., Biswas A.K., Extractive metallurgy of copper, 2002 Elsevier.

Document title: BAT & BREF

Language: English

Content description: BREF CEMENT LIME and MAGNESIUM OXIDE

Revision of cogeneration Chapters:

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

Code: **B&B-CM-FI-100401_05**

Internal document code:	B&B-CM-FI-100401-05		
Version:	05		
Date:	27/09/2011, updated on 21-12-2011, 30-03-2012, 30-10-2012, 20-6-2014		
Status:	Approved by local observatory		
Dissemination level:	PU	PP	CO
	Public	Partners Project only (including Services commission)	Confidential Observatory Members Only (including Services commission)
Authors:	CSMT Revisor Turboden and FIRE		
Project:	"Policy and governance actions to reduce CO2 emissions by Energy valorisation of process effluents in Energy Intensive Industries"		
Acronym:	H-REII DEMO		
Code:	LIFE08 ENV/IT/000422		

List of content

5. Analysis of the current BREF document

"Best Available Techniques (BAT) Reference Document for the Production of CEMENT, LIME and MAGNESIUM OXIDE" Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control) Draft CLM BREF (June 2012)"

After a carefully analysis of the BREF document: "Best Available Techniques (BAT) Reference Document for the Production of CEMENT, LIME and MAGNESIUM OXIDE" issued on June 2012, it is necessary to fix the following preliminary points:

5.1. 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:
  § 1.2.5.7.1.2 Planetary (or satellite) coolers
  § 1.2.5.8 Cogeneration
  § 1.4.2.4 Energy recovery from kilns and coolers/cogeneration
  § 6.2.3 Cement manufacturing – cogeneration/recovery of excess heat
  see BAT n. 7, point b) and BAT n. 9 (ref.: § 4.2.3.2, page 349);
- for LIME industries, see:
  § 2.2.7.6 Rotary kilns with preheaters (PRK)
  see BAT n. 33, point a) (ref.: § 4.3.3, page 363);
- for MAGNESIUM OXIDE industries,
  § 3.4.3 Reduction of energy consumption (energy efficiency)
  see BAT n. 56, point a) (ref.: § 4.4.2, page 376);

5.2. 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 107;
- for LIME industries, see § 2.4.2 – Table 2.34, page 255;
- for MAGNESIUM OXIDE industries, see § 3.4.3, page 324;

5.3. COGENERATION techniques are indicated in BAT n. 7, point b) and BAT n. 9 as measures for reaching the overall reduction of the energy consumption thanks to the use of energy (thermal and electric) recovery systems.

5.4. 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.

6. 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 38)

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 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 also in European Member States other ORC turbogenreators were installed in cement plants: 4 MWe at Alesd (Romania) in 2013 and 5 MWe at Rohožník (Slovakia) in 2014".*

§ 1.4.2.4 - Energy recovery from kilns and coolers/cogeneration (see page 107)

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 EU27 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

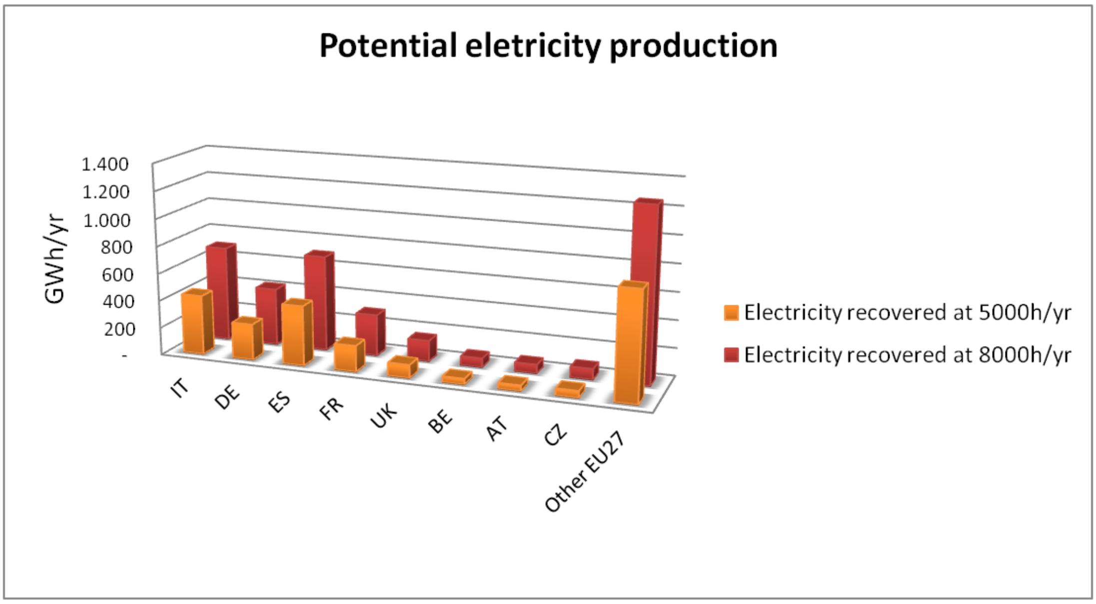

Figure 1 Potential production of Electric power by ORC processes

Related achieved CO2 emissions in EU27

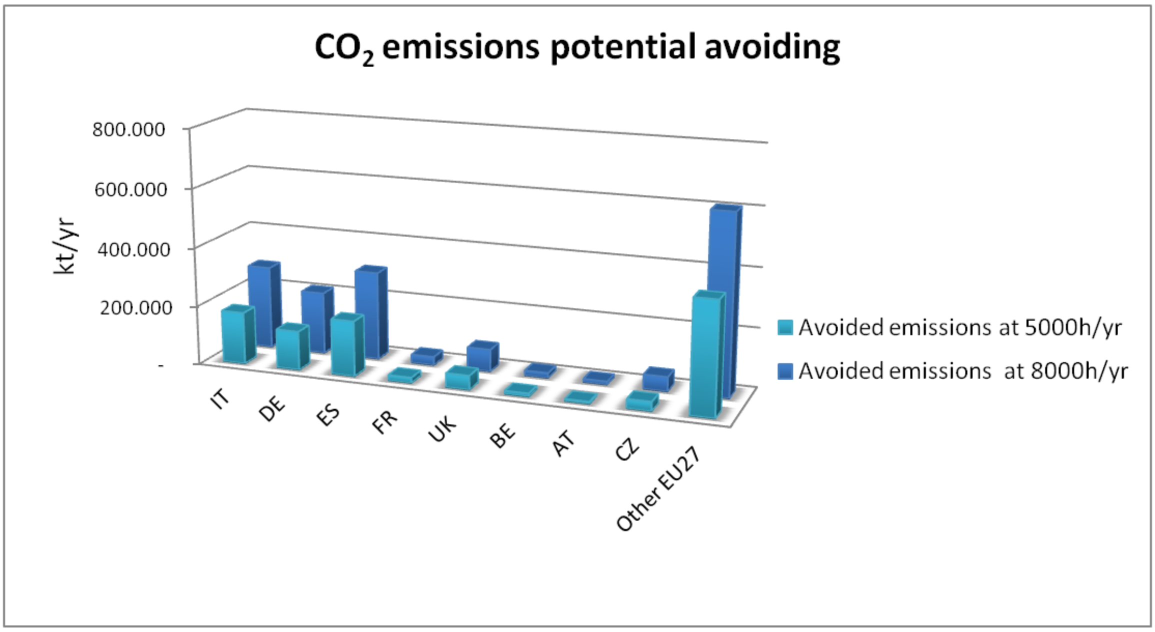

Figure 2 Related achieved CO_2 emissions

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, 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: ≈ 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, 2014:
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 Business 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 (started up in 2013);
- *Rohožník in Slovakia: Cement plant with installed an ORC turbogenerator, size 5MWe* for heat recovery (started up in 2014).

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 349)

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.

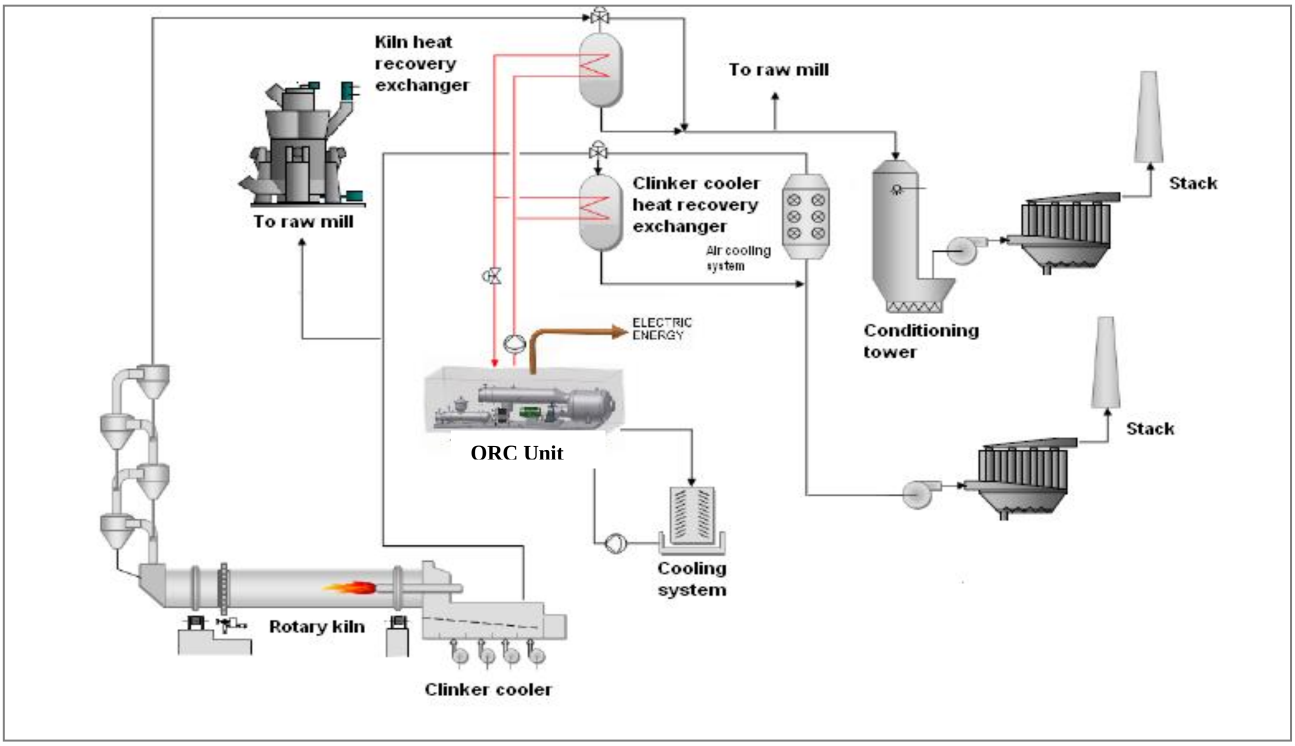

Figure 3 Example of ORC based Heat Recovery System in a cement plant.

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 (2014) 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".