H·REII
Heat Recovery in
Energy Intensive Industries
DEMO

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			
Code:	LIFE10 ENV/IT/000397			

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).

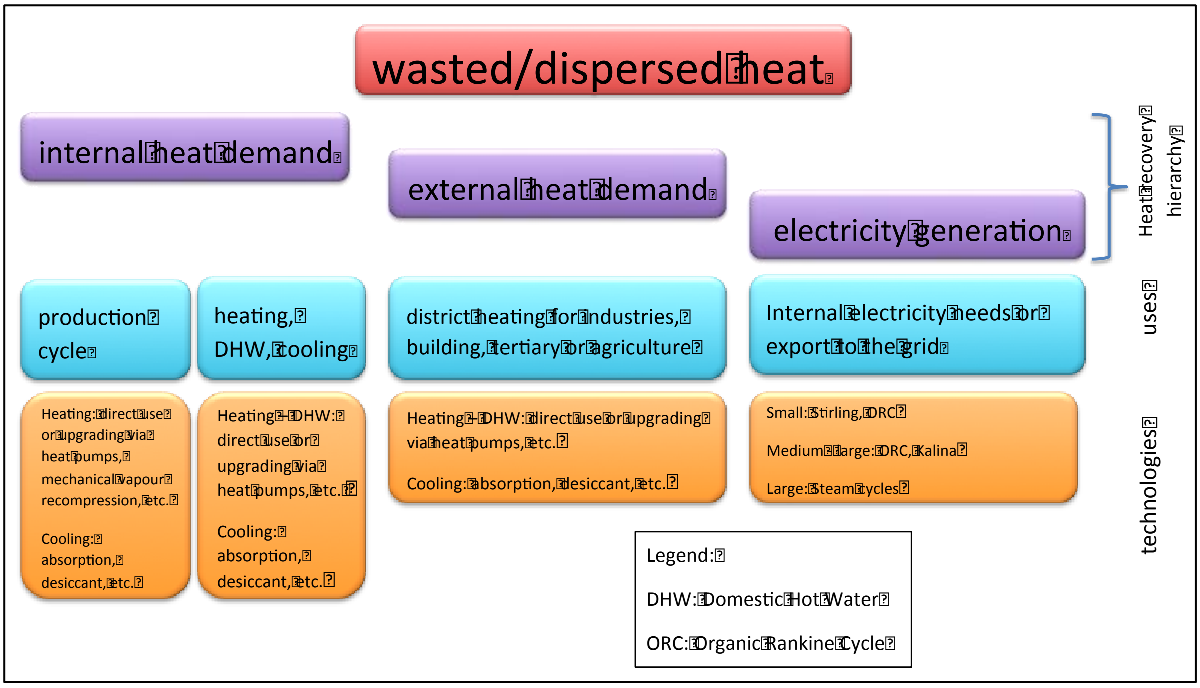

Figure 1 Waste/dispersed heat recovery opportunities and hierarchy.

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.

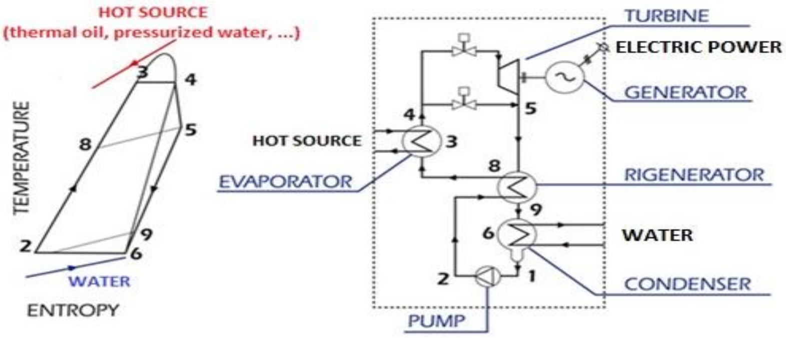

Figure 2 Process diagram of an ORC turbogenerator (right) and its representation on the T-S diagram (left)

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