PEER-REVIEWED PAPER

Innovative system for electricity generation from waste heat recovery

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Abstract

Energy intensive industries face strong international competition, growing energy prices and environmental limitations. In sectors like glass, cement and metals a number of industrial plants are at present dissipating in the environment huge amounts of heat. These flue gases have to be cooled before the gas treatment unit, via heat exchanger or adding fresh air. Both solutions introduce additional energy consumption.

Only in few cases this heat is recovered for internal needs, to satisfy heat demand or through an absorption chiller to cover cooling needs. Even less frequently it is exploited for external uses as feeding heat/cold to other industrial plants nearby or to a district heating/cooling system. Another possibility to be evaluated is to convert the waste heat into electricity, usually self-consumed. This electricity, generated without additional emission and fuel consumption, substitutes electricity withdrawn from the grid.

One of the solutions to generate electricity recovering heat, otherwise dispersed into the environment, is the Organic Rankine Cycle (ORC), with plants available in sizes from tents of kW to various MW. The ORC plants are characterized by fully automatic operation, generation efficiency modestly reduced at partial load and low maintenance costs. Those characteristics are relevant differences in comparison to traditional steam cycles.

There are already a number of successful installations of ORC in cement and glass sectors worldwide, while in the metal sector the first known experiences started very recently.

An innovative installation of heat recovery for electricity generation through an ORC in the steel sector is described. The paper illustrates the characteristics of the steel shop, the system layout and the solutions for the heat exchange.

Introduction

Many industrial processes waste a considerable amount of heat in the environment. Energy intensive industries face strong international competition, growing energy prices and environmental limitations, thus developing solutions in order to recover heat is an interesting opportunity to increase competitiveness. Bendig et al. [1] define waste heat in industrial processes comparing waste heat reserve and waste heat resource.

> *Waste heat as a reserve* is the net exergy that unavoidably leaves or is lost within an existing process after its integration, minus the exergy that cannot be recovered for technical or economic reasons. *Waste heat as a resource* is exergy that unavoidably leaves a process or is lost within it independent of the technological choices made within the process.

It is also worth notice that the recovery of other ways dispersed heat falls in a number of European directives, as the industrial emissions [2] and energy efficiency [3] ones. In this article, we only refer to waste heat as a reserve. Heat recovered can be converted into useful forms like electricity or district heating, but the priority should be put on direct use of the exergy, for instance within the process, in order to avoid other losses. This paper explains a flowchart for prioritize the valorisation of heat recovered in the section "Options for waste heat recovery". The direct use of heat recovered is not always technical or economic feasible, converting it into electricity could be the only way to valorise it. Main technical limits for waste heat to power (WHTP) are related to heat source temperatures, flow rate and for temperatures. Below 400 °C one of the most efficient technology is Organic Rankine Cycle (ORC) [5]. In the section "Waste heat to power with ORC technology – technical description" a typical schema for waste heat to power with ORC technology will be described. In most of application a heat carrier loop is necessary, but last technology development allow direct exchange between the heat source and the working fluid. A comparison with steam technology will be also provided. References in different industrial processes are presented in the section "Waste heat to power references", focusing on last development in the steel industry. Benefits and barriers of waste heat to power are presented in the section "Waste heat to power benefits" and the section "Waste heat to power barriers" respectively. Finally, conclusions are given.

Options for waste heat recovery

Heat recovered from an industrial process can be used in different ways, but in order to achieve the most efficient use, Weng et al. [6] propose an energy flow diagram for evaluating waste heat recovery potential (Figure 1).

Primary energy is consumed by the industrial process, but only a percentage of it can be considered effective energy. Of waste heat recovery potential, the priority should be given to avoidable waste heat, optimizing the production process and the control system. A heat recovery implemented before the optimization of the process, may result after the optimization less relevant/convenient. When the optimization is no longer technical and economic effective, the use of waste heat on site, through heat exchangers, heat pumps, heat storage and/or absorption cooler systems has to be evaluated. In order to avoid energy losses, the last stage is reuse waste heat off site. This can be managed trough heating and cooling grids or by converting it into electricity (WHTP). For temperatures of the heat sources below 400 °C, one of the most efficient technology is Organic Rankine Cycle (ORC)[5].

The evaluation of the best opportunity has to be made case by case, taking into account also the different prices and fiscal charges of the substitute heat/cool source for different users (industrial, residential, etc.), the demand and the uncertainties of the evolution of such demand in the future. Due to the aforementioned uncertainties and to reduce the investment the internal use is usually privileged.

To summarize the usual priorities for heat recovery, we propose the following flowchart (Figure 2).

The experience of over one hundred energy audits targeted to waste heat to energy in different industrial sectors in Italy [4] and feasibility studies for tents of plants in different sectors around the world – thus with different burden conditions – show that in a number of industrial processes the heat recovery for electricity generation should be carefully evaluated and in many cases it is the only possibility – under the techno-economic point of view – to recover the thermal energy otherwise dispersed into the environment. Many studies have been carried out in last years in order to evaluate the most performing technology for waste heat to power. When heat source temperatures range between 200 °C and 400 °C, one of the best performing technology is the Organic Rankine Cycle [5].

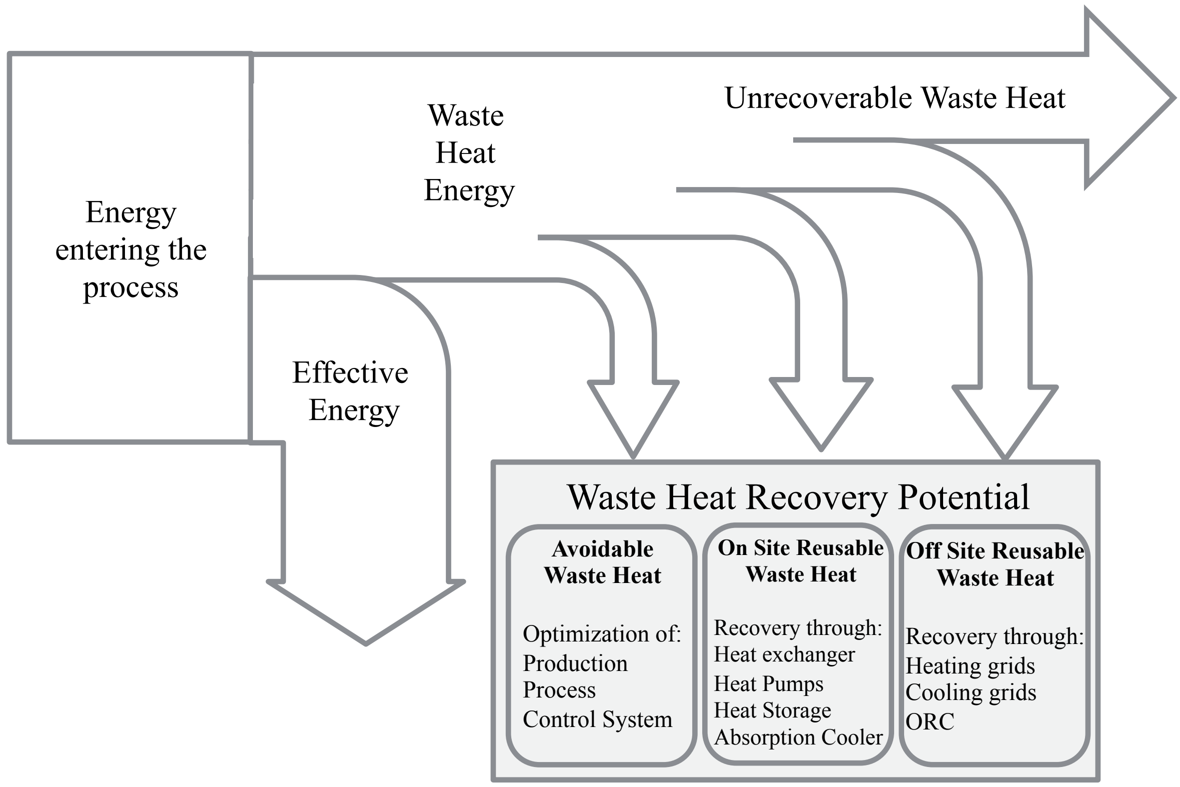

Figure 1. Energy flow diagram for evaluating waste heat recovery potential (inspired by [6]).

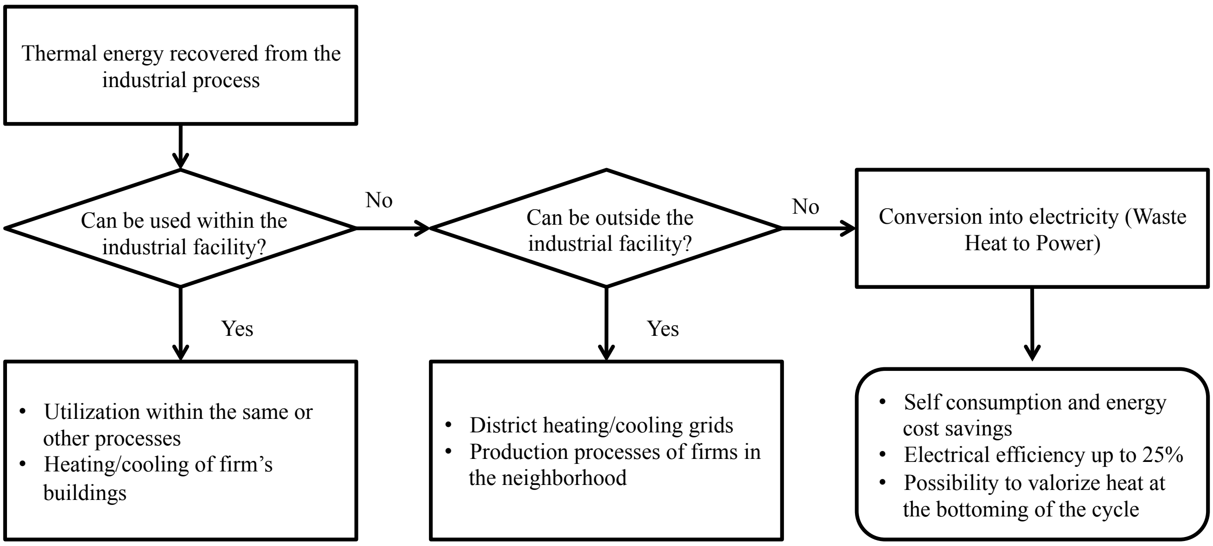

Figure 2. Flowchart of waste heat recovery priorities.

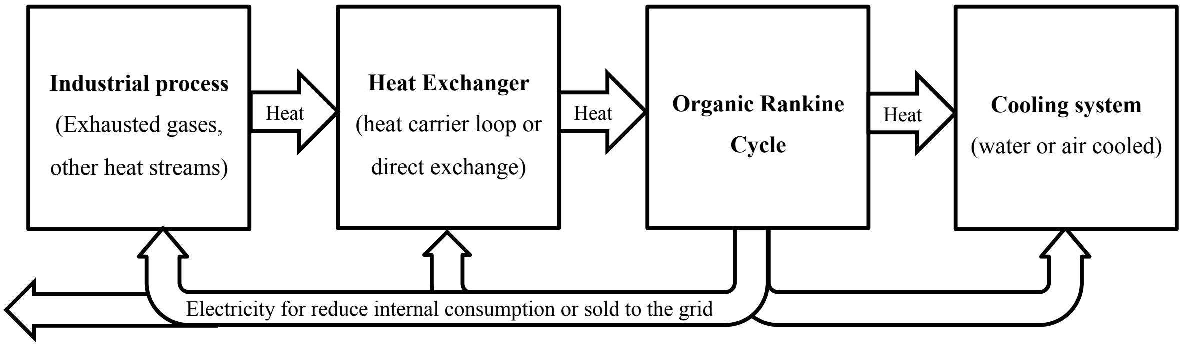

Figure 3. Waste heat to power system typical schema.

Waste heat to power with ORC technology – technical description

WASTE HEAT TO POWER TYPICAL SCHEME

In Figure 3, a typical scheme of a waste heat to power system is shown.

Several industrial processes waste heat in the atmosphere through exhausted gases of fuel combustion or through other hot streams. Heat exchangers can be installed when some requirements of heat source temperature, flow rate and chemical composition are met. In most of the cases heat source exchanges its energy to a heat carrier loop – usually thermal oil, saturated steam or pressurized steam – in order to avoid working fluid deterioration caused by temperature peaks. When heat source is not corrosive and the process has no temperature peaks exceeding working fluid limits, it is possible to build a heat exchanger between the heat source and the working fluid. This solution is usually called direct exchange. The ORC is shown in Figure 4.

The ORC package uses the hot temperature thermal input to pre-heat and vaporize the organic working fluid in the evaporator (8→3→4). The organic fluid vapour powers the turbine (4→5), which is directly coupled to the electric generator. The exhaust vapour flows through the regenerator (5→9) where it heats the organic liquid (2→8). The vapour is then condensed in the condenser (cooled by the water flow) (9→6→1). The organic fluid liquid is finally pumped (1→2) to the regenerator and then to the evaporator, thus completing the sequence of operations in the closed-loop circuit.

HEAT TRANSFER: HEAT CARRIER LOOP AND DIRECT EXCHANGE SOLUTIONS

Most of real applications involving ORC technology use a heat carrier circuit filled with thermal oil, saturated steam or other. This is necessary in applications in which temperature peaks can deteriorate the organic working fluid properties. Moreover, some industrial processes have a cooling system working with these fluids, thus is easier to feed the ORC system. But a heat carrier circuit requires higher investment due to pipes' complexity. During last years ORC manufacturers developed heat recovery solutions also with direct exchange between the heat source and the organic working fluid. This is possible only if the heat source is not corrosive and its temperature peaks do not exceed working fluid limits. First direct exchange application was started up in 2009 recovering exhaust gas from an internal combustion engine fuelled with biodiesel, and other two ORC units were started up in similar projects. The second application for direct exchange

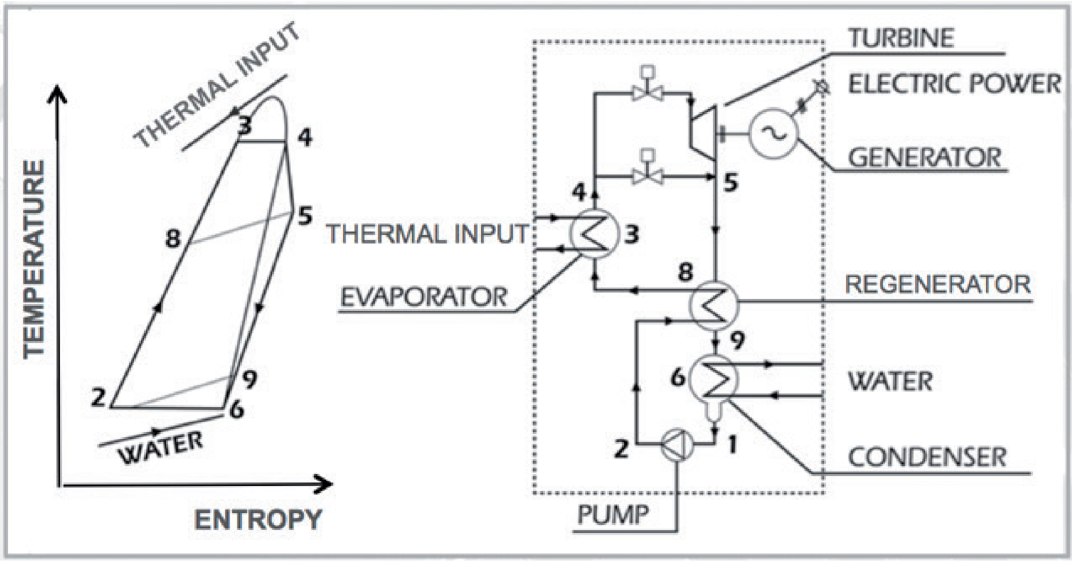

Figure 4. Organic Rankine Cycle typical configuration (source: Turboden).

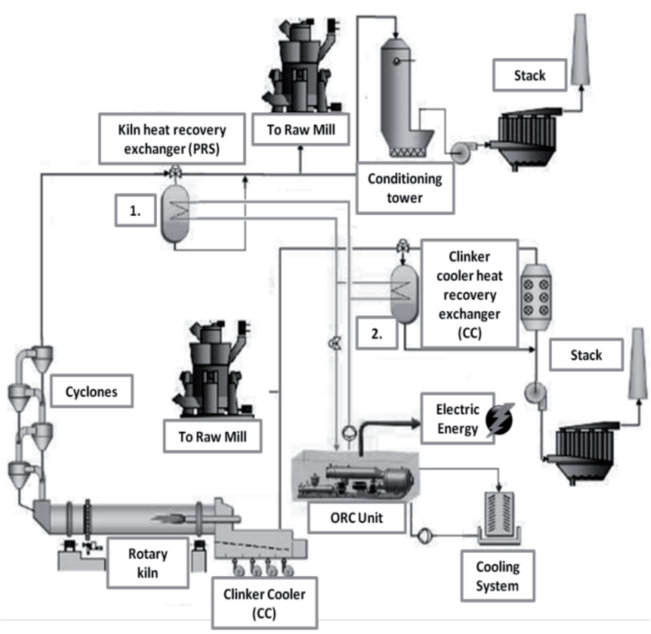

Figure 5. Heat recovery system with ORC technology in the cement industry typical layout (source: Turboden).

solution started up in February 2013 is heat recovery from rolling mills reheating furnace in the steel industry. This case is detailed in next paragraph. Other project, currently under development, involves gas turbines and glass factories.

Waste heat to power references

CEMENT INDUSTRY

The first examples of waste heat recovery to power with ORC in the cement industry are reported on the Best Available Technique References (BREF) for cement industry [7] both by means of ORC and steam-cycle technology. Steam technology has many references in China, where cement plants have higher production capacity and are full integrated with steam turbine power plant. In last five years many ORC heat recovery plants have been starting up. A simplified scheme of an ORC unit installed in a cement factory is reported in Figure 5. Raw materials are preheated in multiple cyclones, which use exhausted gases coming from the rotary kiln. Thermal energy of these gases (300–450 °C) can be recovered by means of a heat exchanger (1 in Figure 5). After being cooked in rotary kiln at 1,200 °C, clinker has to be cooled. The second heat source is represented by gasses coming from this clinker cooler (300 °C) that are recovered by another heat exchanger (2). Usually heat exchangers work with diathermic oil, which maintains temperature at a stable value. Then heat is exchanged from diathermic oil to organic fluid and electricity is generated by ORC unit.

According to the available information, the ORC heat recovery plants already in operation worldwide in the cement industry are reported in Table 1.

ORC heat recovery systems in the cement industry may generate up to 20 % of the cement plant electricity consumption [8]. This value is the result of a feasibility study, with real data, for the application to an existing cement plant in Italy.

In Europe there are more than 250 cement plants and according to the methodology presented in [8], based on the results of 21 energy audits in the cement sector, the theoretical ORC potential has been estimated in more than 500 MW_{el}.

GLASS INDUSTRY

Glass products can be divided in flat glass, container glass and other [10]. ORC heat recovery plants have been installed at the bottoming of two flat glass production sites [11], because it is a continuous process with annual operating hours usually exceeding 8,000 hours and a plant lifecycle of almost 15 years. Heat recovery with ORC from container glass plants is theoretical feasible, but there are no references yet. Usually ORC power that could be installed in one site is lower compared with flat glass, but container glass plants in EU27 are more than 170, while float glass furnaces are 58 [10]. In Figure 6 a typical process schema is reported.

Float glass furnaces are usually fuelled with natural gas. The combustion gases may be cooled into a quenching tower (tra-

Table 1. ORC heat recovery plant in the cement industry worldwide.

Year	Cement Plant	ORC Manufacturer	ORC gross power [MW]
1999	Heidelberg Zement, Germany	Ormat	1.5
2010	Italcementi – Ciment du Maroc, Marocco	Turboden	1.8
2012	Holcim Romania	Turboden	4
2013	Jura Cement, Switzerland	ABB	2
2014	Holcim Slovakia	Turboden	5

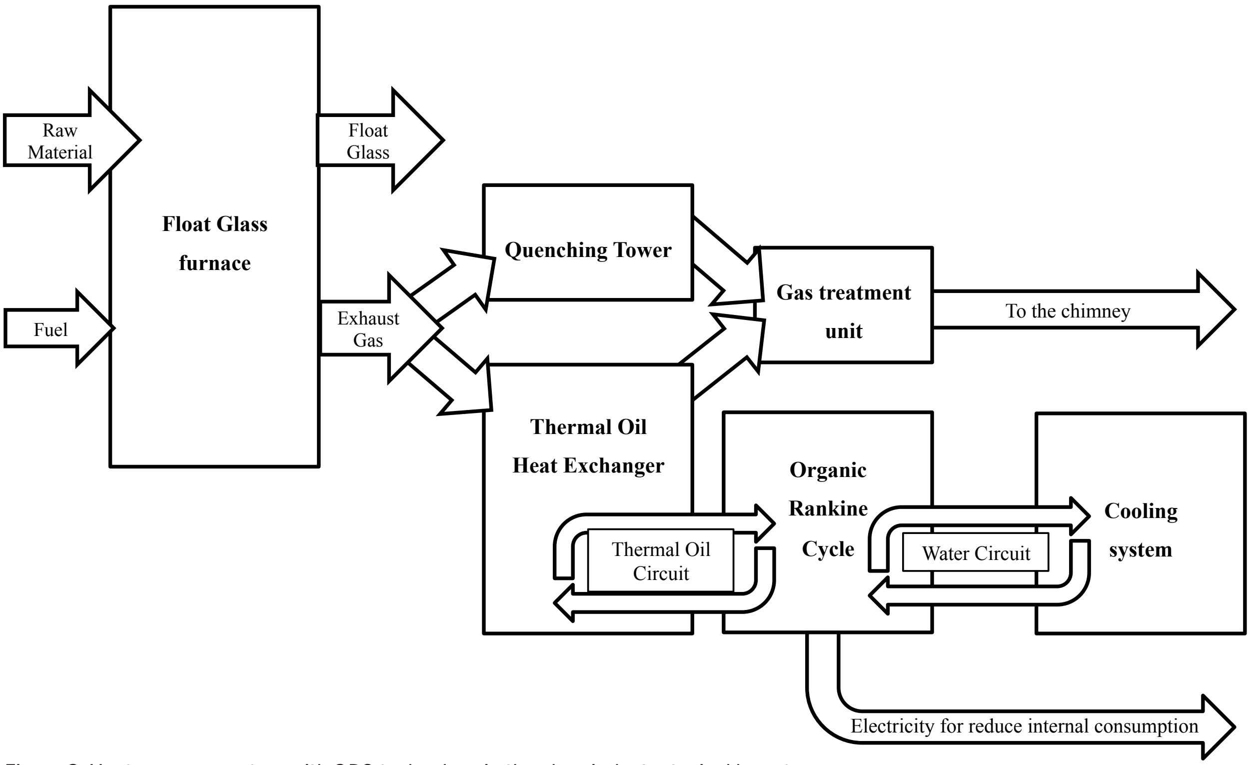

Figure 6. Heat recovery system with ORC technology in the glass industry typical layout.

ditional schema) or exchange their thermal energy to a thermal oil heat exchanger. The thermal oil feed the ORC unit that converts thermal energy into electricity. The design data for a 1.2 MW_{el} ORC installed in a heat recovery system from a float glass furnace are reported in Table 2.

The main technical issue is related to the composition of the exhaust gases: if they are corrosive, heat exchanger may be built with more expensive material or have to been cleaned regularly. The heat exchangers in the glass sector usually show special design and/or automatic cleaning systems to lengthen the cleaning intervals. In this layout, the heat exchanger of the heat recovery system bypasses the quenching tower in order to minimize the impact on the process: in case of any problems related to the heat recovery system the exhausted gases are directed to the already existing quenching tower. At the bottoming of the heat recovery system, an additional fan could be required, in order to respect the flow rate requested by the fumes treatment system.

According to the available information, the ORC heat recovery plants already in operation worldwide in the glass sector are reported in Table 3.

In Europe there are around 60 flat glass plants and according to the methodology presented in [8], based on the results of 15 energy audits in the flat glass sector, the theoretical ORC potential has been estimated in around 80 MW_{el}.

STEEL AND METALLURGY INDUSTRY

In the steel industry, heat recovery systems with ORC technology have been developed from two heat sources: exhaust gas of reheating furnaces of hot rolling mills plants and Electric Arc Furnace production cycle.

Heat recovery from rolling mill reheating furnace with direct exchange

On February 2013, Turboden srl started up the first ORC that recovers heat from exhausted gases of a reheating furnace in hot rolling mills. A simplified scheme of the heat recovery system is shown in Figure 7.

Steel temperature needs to be increase up to 1,500 °C before being processed by the rolling mills through a reheating furnace, usually fuelled with natural gas. The exhausted gases are clean enough to allow the direct exchange with the organic working fluid: avoiding the installation of a thermal oil circuit decreases investment costs significantly. The ORC unit generates electricity that is self-consumed by the industrial plant. Cooling system is performed by air cooler filled by industrial water.

Table 2. ORC design data for a float glass furnace heat recovery plant in Cuneo, Italy.

Hot source	Thermal oil in a closed circuit
Inlet thermal power to the ORC	5,078 kW
Thermal oil temperatures (In/out ORC)	307/205 °C
Thermal power to the cooling water	3,831 kW
Cooling water/glycol temperatures (in/out ORC)	25/35 °C
Gross electric power output	1,253 kW
Net electric power output	1,200 kW

Table 3. ORC heat recovery plant in the glass industry worldwide.

Year	Glass Plant	ORC Manufacturer	ORC gross power [MW]
2011	Vetrerie Sangalli Manfredonia, Italy	Ormat	2.0
2012	AGC Cuneo, Italy	Turboden	1.3

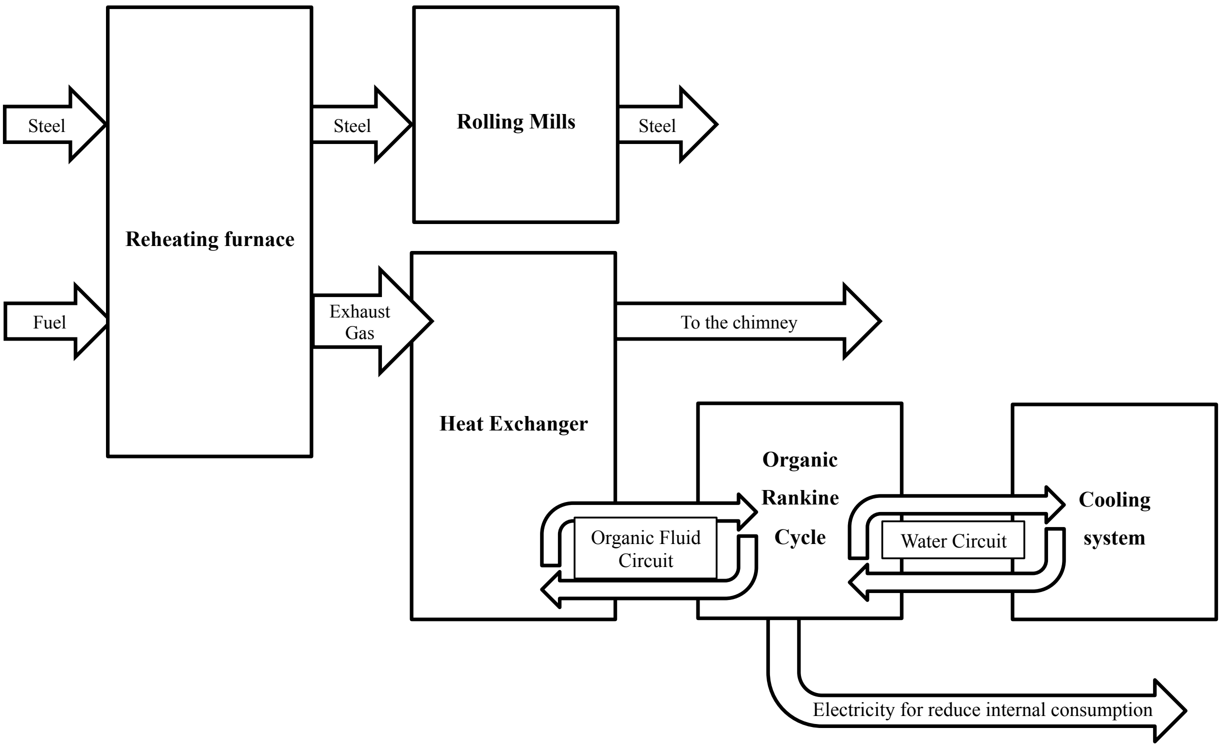

Figure 7. Heat recovery system with ORC technology from exhaust gas of reheating furnaces in hot rolling mills.

Table 4. ORC design data for a hot rolling mill reheating furnace heat recovery plant in Singapore.

Hot source	Reheating Furnace Exhaust Gas
Inlet thermal power to the ORC	2,820 kW
Thermal oil temperatures (In/out ORC)	400/220 °C
Thermal power to the cooling water	2,272 kW
Cooling water/glycol temperatures (in/out ORC)	32/47 °C
Gross electric power output	555 kW
Net electric power output	523 kW

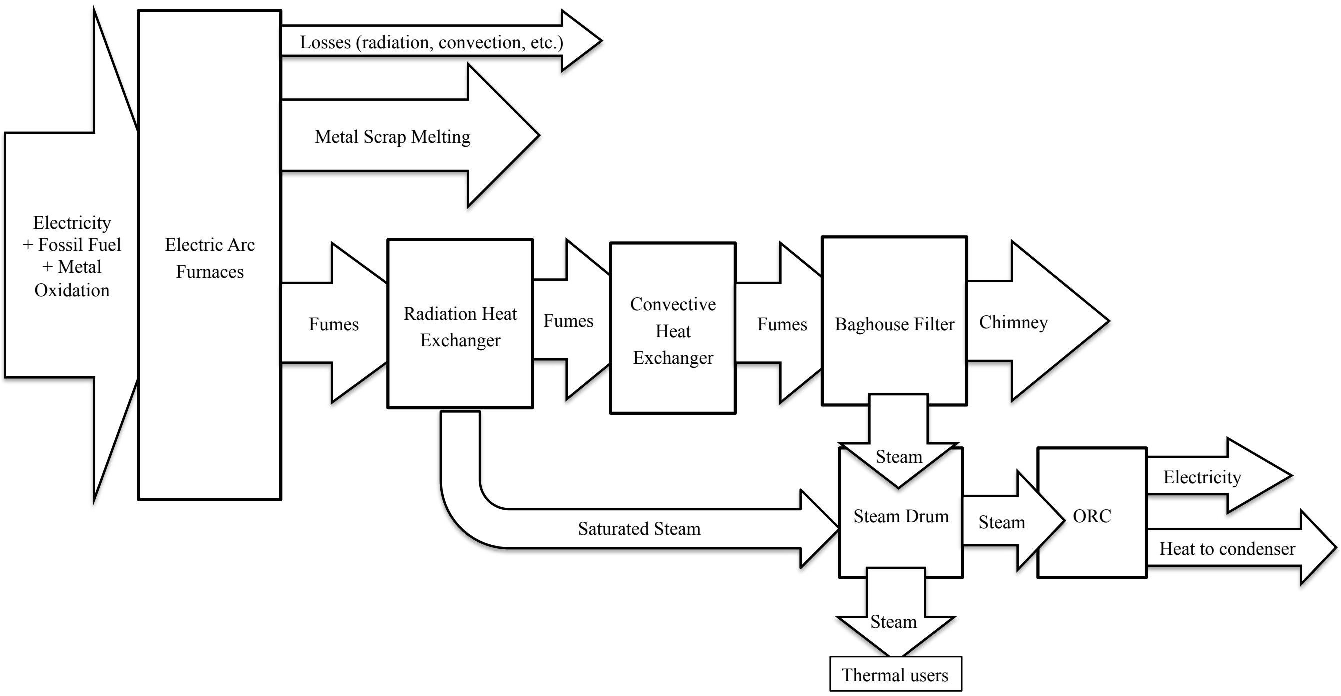

Figure 8. Heat recovery system with ORC technology from exhaust gas of an Electric Arc Furnace.

The first installation is located in Singapore, but it is very similar to most of the rolling mills spread all over the world. The design data of the plant are reported in Table 4.

The operational data of this plant, which will be analysed in a future paper, show that the ORC is able to follow the thermal load, adapting quickly to thermal power availability. It is important to highlight that this flexibility could not be performed with steam turbines of this size.

This first plant can be replicated for all hot rolling mills, both those located at the end of integrated steel plants (blast furnace and converter shop) and those at the exit of electric arc furnaces.

In Europe there are over 260 rolling mills [12], and according to the methodology presented in [8], based on the results of 6 energy audits in rolling mills, the theoretical ORC potential has been estimated in over 300 MW_{el}.

Heat recovery from Electric Arc Furnace with pressurized steam heat carrier loop

On December 2013, Turboden srl started up the first ORC that recovers heat from exhausted gases of an Electric Arc Furnaces in the Feralpi Group plant of Riesa, Germany. The heat recovery system and the ORC were specifically developed for this application in the framework of the EU funded HREII-demo (Heat Recovery in Energy Intensive Industry) project [13]. A simplified scheme of the solution adopted is shown in Figure 8.

The steel smelting process in an Electric Arc Furnace is a batch flow: thermal flow varies during the melting cycle and while the scrap material is loaded into the basket there is no thermal power available. Thus a steam drum has been developed in order to storage thermal energy. Exhaust gases temperatures may rise up to 1,500 °C: their energy is recovered through a first radiation heat exchanger that produce saturated steam at the temperature of 245 °C and at the pressure of 27 bar. This steam passes through a drum that stores its energy. At the bottoming of the radiation heat exchanger, exhausted gases have a temperature of almost 600 °C and are processed in the baghouse filter, decreasing their temperature of almost 100 °C. Residual energy is recovered by a convective heat exchanger that fill the steam drum. Thus the thermal power made available is quite stable during the processes.

The heat exchanger is based on an evaporative cooling system: the heat is subtracted by a partial evaporation of the pressurized water circulating in the piping. The advantages of this approach are that the higher surface temperature of the piping avoid the possibility of acid condensation, the temperature remains constant with less mechanical stress for the piping, avoiding moreover the possibility of peak loads. Furthermore the circulation flow is lower and consequently the consumption of the circulation pumps.

Thermal energy stored in the steam drum may serve thermal users (i.e. district heating) or being converted into electricity by an ORC cycle. Steam features – low pressure and low temperature – make it no suitable for being expanded in traditional steam turbines. In the Riesa project, almost 10 tons per hour of the steam stored in the steam drum is sold to an industrial process through the district heating grid. The remaining 20 tons per hour feeds the ORC system, which generate up to 2.7 MW of electricity.

In Europe there are almost 200 EAF [12], and according to the methodology presented in [8], based on the results of 3 energy audits in EAF, the theoretical ORC potential has been estimated in over 400 MW_{el}.[1]

1.Schemes, pictures and information on the plant and working data will be provided in the slides of the presentation at eceee 2014 Industrial Summer Study.

Table 5. ORC design data for the Electric Arc Furnace heat recovery plant in Riesa.

Hot source	Saturated Steam with 27 bar
Inlet thermal power to the ORC	13,517 kW
Thermal oil temperatures (In/out ORC)	245/100 °C
Thermal power to the cooling water	10,640 kW
Cooling water/glycol temperatures (in/out ORC)	26/44 °C
Gross electric power output	2,680 kW
Net electric power output	2,560 kW

Waste heat to power benefits

The dispersed heat, from waste can become a valuable source of energy that could enhance the competitiveness of the industry. The recovered heat substitutes heat generated by other sources, usually not renewable, thus its costs and emissions, moreover the heat recovery reduces the temperature of the exhaust gasses, thus the need to cool the gases before the gas treatment unit, by vaporizing water or blowing fresh air or etc. If the recovered heat is used to generate electricity, this emission free energy lowers the needs of the electricity withdrawn from the grid, eliminating the emissions and the costs associated to the not anymore purchased electricity.

In the reference documents developed in the framework of the industrial emissions directive [2] for different industrial sectors, heat recovery is one of the typical crosscutting measures, moreover the Directive numbers the heat not only among the emissions, but also among pollution, even if the Directive contains no limits for the heat emissions. The Energy Efficiency Directive [3], to be transposed within June 2014 will hopefully be able to further focus the attention on waste heat recovery for heating and cooling purposes, requiring a cost benefit analysis for plants over 20 MW.

The WHTP system can be synergic with gas treatment: generating electricity from recovered thermal energy can cover the electricity needs of the gas treatment unit. There can be also possible synergies with external use of recovered heat: typically district heating/cooling has a fluctuating demand and an ORC generator can work at full rate in off-peak periods and at partial load in peak periods, maximizing the heat recovery all the year around. Thus heat recovery for electricity generation is not necessary alternative, but can also be complementary to the heat recovery for heating and cooling promoted by the Energy Efficiency Directive.

ECONOMIC FEASIBILITY

In a WHTP system there is no fuel cost and the cash flow is almost the value of the generated electricity, valorised as not bought from the grid, as it is normally self consumed. The operation and maintenance costs are low and usually around 10 % of the cash flow of self consumed electricity. Thus the economic feasibility is heavily linked to the price of electricity, in case we are looking at WHTP system alone. In [29] there are four examples, for cement, glass, steel and gas compressor station with electricity avoided buying cost in the range of €0,07–0,08/kWh, investment costs in the range of €2,6–3,3 M per MW of gross electric power, leading to payback time of 7–9 years and internal rate of return of 9–13 %, with a discount rate of 8 %.

Payback time can be substantially reduced, making it more interesting from industrial point of view, by higher electricity costs or by incentives.

Often a WHTP system is one of the parts of a bigger system, like a gas treatment unit or a district heating project. Adding the WHTP system is a limited additional investment but it can reduce the payback, enhance the efficiency and reduce the greenhouse gas emissions of the entire system. In order to make a comparison, we will consider four different scenarios:

1. the heat recovery system from the industrial process sells the heat recovered to a district heating grid: no investment for ORC nor electricity revenues;
2. the heat recovery system from the industrial process sells the heat recovered to a district heating grid during wintertime and feeds the ORC during summertime;
3. the heat recovery system from the industrial process always feeds the cogenerative ORC that generates electricity – with lower efficiency compared to the other two ORC solutions, where the heat discharged by the ORC, at lower temperature, is dispersed in the environment – and feed the grid with the discharge heat;
4. the heat recovery system from the industrial process only feeds the ORC that only generates electricity with higher efficiency compared to the cogenerative mode.

For all the four scenarios we consider 15 MW of thermal power and 6,800 annual operating hours. We assume that the thermal energy requested by the district heating grid is the 50 % of the total energy recovered, 51 GWh per year. Energy available as input for the ORC varies case by case. The value of the thermal energy feed to the district heating network is assumed as €20/MWh. The value for the self consumed, thus no more purchased electricity is considered €70/MWh. Inputs are reported in Table 6.

According with the authors experience in real projects under development, investment costs (CAPEX) are assumed as:

- Heat recovery system (steam/hot water boiler): €7 M;
- Additional investment for DH connection: €1 M;
- Additional investment for ORC: €2.4 M;
- Balance of plant component: 5 % of the total investment.

Total CAPEX, annual OPEX and payback time, calculated with a discount rate of 6 %, are reported in Table 7.

If the number of operating hours per year is lower – for example due to lower plant activity or, excluding case 4, for

Table 6. Input data for economic feasibility.

	CASE 1 – DH Only	CASE 2 – DH on winter ORC summer	CASE 3 – ORC CHP	CASE 4 – Only ORC	Unit of measure
Thermal power recovered	15	15	15	15	MW
Operating hours	6,800	6,800	6,800	6,800	h/yr
Potential Energy	102,000	102,000	102,000	102,000	MWh/yr
District Heating Annual Request	50 %	50 %	50 %	0 %	
Energy Available for the ORC	0	51,000	102,000	102,000	MWh/yr
ORC net efficiency	0 %	19 %	16 %	19 %	
ORC net electric power	0	2.85	2.4	2.85	MW
Net electricity produced	**0**	**9,690**	**16,320**	**19,380**	**MWh/yr**
Electricity revenues	0.00	0.68	1.14	1.36	M€/yr
Thermal energy sold to the DH	**51,000**	**51,000**	**42,840**	**0**	**MWh/yr**
Thermal energy revenue	1.02	1.02	0.86	0.00	M€/yr
Total Annual Revenues	**1.02**	**1.70**	**2.00**	**1.36**	**M€/yr**

Table 7. Economic feasibility results: CAPEX, OPEX, cash flow and payback time.

	CASE 1 – DH Only	CASE 2 – DH on winter ORC summer	CASE 3 – ORC CHP	CASE 4 – Only ORC	Unit of measure
Total CAPEX	8.4	10.9	10.9	9.9	M€
Annual OPEX	0.10	0.15	0.15	0.12	M€/yr
Annual Cash Flow	0.92	1.55	1.85	1.24	M€/yr
Discounted Pay Back Time	**13.6**	**9.4**	**7.5**	**11.2**	**years**
Net Present Value 18 years	1.6	5.8	9.1	3.5	M€
Internal Rate of Return 18 years	8.4 %	12.5 %	15.7 %	10.4 %	%
Avoided greenhouse gas emissions	11,477	15,604	16,616	8,314	tCO_2/year

lower heat demand from the grid – the net present value reaches zero just under 6,000 hours in case 1, around 5,000 hours in case 4, around 4,500 hours in case 2 and under 4,000 hours in case 3.

Case 1 and 4 are the most sensitive to the variation of operating hours, at 7,500 hours per year the net present value becomes €2.7, €7.7, €11.3 and €5.0 M for cases 1, 2, 3 and 4 respectively.

The results of the comparison, based on real data from a feasibility study for an existing plant, show that, in this specific case, adding a WHTP system with the ORC system decrease the project payback time, improving the economic feasibility of district heating grid projects.

The avoided greenhouse gas emissions are conservatively calculated considering the average EU-27 emission factor for consumed electricity (429 $kgCO_2/MWh_{el}$) [33] and for heat the emission factor of natural gas (202 $kgCO_2/MWh$) [34] and 90 % boiler efficiency.

Waste heat to power barriers

Firstly, the lack of certain and long-term regulatory framework and targets for energy efficiency could hinder investments in waste heat valorisation. For instance the energy efficiency directive 2012/27/EU is a step towards the good direction but it is necessary that European Member States during the transposition and implementation phase consider the potential of heat recovery applications, especially referring to article 8 and article 14: compulsory energy audits for large enterprises and support for recovery of waste heat, whenever is technically and economically feasible. As in the case of the electric arc furnace presented in the paper, the WHTP is not excluding the heat recovery to feed district heating or cooling systems. These measures could catalyze investment in the energy efficiency market, helping to reach the objective of 20 % increase in energy efficiency. During the energy audit, special attention should be placed in the gas cooling – often compulsory before the waste gas treatment – as it is possible to put heat exchanger(s) and a

Rankine cycle instead of adding air to cool down. This way, the electricity consumption of the waste treatment can be covered.

With a WHTP the whole system can be considered cogenerative at first sight, since there is a "simultaneous generation in one process of thermal energy and electrical or mechanical energy" according to the definition in [3] and [35]. This does not mean that those systems fall in the high efficiency cogeneration, supported by the framework set up by the Directive 2004/8/EC and transposed in each member state. This is because the guidelines for the implementation and application of the Directive [36] consider only the heat output of the electricity generation cycle as useful heat (i.e. it satisfy an economically justifiable demand, which otherwise would be satisfied by other energy generation processes). In cogeneration systems supported by the Directive the useful heat is provided after the electricity generation cycle, while in WHTP it is usually provided only before, since the heat temperature after the generation cycle can be very low, with very limited practical uses. This means that in European Member States WHTP systems are not supported by the high efficiency cogeneration framework. Considering the different characteristics of WHTP a supporting system designed for the cogeneration would not best fit the WHTP, nevertheless some kind of support is needed to make this investment appealing for the industry.

The economic obstacle is a key issue: investment payback times for the implementation of technologies related to WHTP are longer than the 3–4 years, usually considered acceptable by the for industrial players. For this reason, creating ad hoc incentives mechanism or including in existing supporting schemes could help in overtaking this barrier.

Conclusions

WHTP systems based on ORC start to be present in a number of sectors of the energy intensive industry and in the gas compressors stations. The reasons for this diffusion can not be explained only with favourable burden conditions (e.g. high electricity prices and/or high incentives), otherwise there would be a concentration in well defined areas and/or sectors. The ORC are installed in complex industrial plants and have to be evaluated case by case in comparison with the other alternatives.

These plants are mature, the reliability of ORC is demonstrated by consistent track record in last three decades in renewables sector and the other main component of the system, the heat exchanger, is already diffused in many applications. The demonstration plant, developed in the HREII – demo project, which started the operation at the end of 2013, is showing the feasibility of waste heat recovery for power generation and contemporary feeding a district heating, for an Electric Arc Furnace, which furthermore has the additional complexity to be a batch process.

The application of WHTP systems is favourable under the economic and environmental point of view in many sectors. The payback time longer than the usually accepted by industry is a limiting factor for the diffusion of these systems, even if other economic indicators are positive.

The WHTP is not necessarily in competition or alternative to other uses of waste heat, it can also be synergic. To enhance the diffusion of these systems in the more common retrofit situations, a supporting mechanism (e.g. incentive, soft loan, guarantee fund), ad hoc or anyway tailored, is required.

Glossary

BREF	Best Available Technique References
CAPEX	CApital EXpenditure
EAF	Electric Arc Furnace
OPEX	OPerational EXpenditure
ORC	Organic Rankine Cycle
WHTP	Waste Heat To Power

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