Performance evaluation of an ORC integrated to a waste heat recovery unit in a Steel mill

Presented by Miguel Ramirez
OUTLINE

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INTRODUCTION

WASTE HEAT RECOVERY (WHR)

• European industry generates annually approx. 3700 TWh of heat and only 54% arrives to its final destination. (Eurostat, 2012)

• Assuming that 50% of total available waste heat can be recovered would imply a potential of 1000 TWh of useful heat per year.

• The use of this amount of waste heat for heating, cooling and power generation would entail saving of fossil fuels, and a reduction in GHG emissions of about 2200 million ton CO2/year.
## INTRODUCTION

### WHRU and ORC units

### Industries with highest potential

<table>
<thead>
<tr>
<th></th>
<th>Cement</th>
<th>Steel &amp; Metallurgy</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat source temp</td>
<td>300° - 350°C</td>
<td>700° - 1200°C</td>
<td>350° - 450°C</td>
</tr>
<tr>
<td>Operating hours</td>
<td>up to 7900</td>
<td>&lt; 7500</td>
<td>&lt; 8500</td>
</tr>
<tr>
<td>ORC usual power</td>
<td>3-5 MW_e</td>
<td>2-10 MW_e</td>
<td>0.5-3 MW_e</td>
</tr>
</tbody>
</table>

### ORC units integrated in industrial WHR plants

<table>
<thead>
<tr>
<th>Installed capacity, MW_e</th>
<th>No of plants</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>25</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>30</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

Source: FIRE, Federazione Italiana per l’uso Razionale dell’Energia & Turboden s.r.l.

Source: Turboden s.r.l.

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PITAGORAS DEMO PLANT - BRESCIA

**Process:** Steel mill, Brescia, Italy
**Electricity generation:** April to October (approx. 1800 kW\textsubscript{el})
**District Heating:** October-April (approx. 10MW\textsubscript{th})
PITAGORAS CONCEPT

- Stops every 50min for tapping phase
- Temperature and volume rate fluctuations

EAF

200 - 900°C

Quench tower

150 - 350°C

Exhaust gas filtration system

WHRU

300 - 1600°C
MAIN TECHNICAL CHALLENGES

- **Particles** in exhaust gases properties – deposition

- **Discontinuity of the available waste heat**
  The EAF works as a **batch process** due to the melting phase and the tapping phase

- **Heat source highly fluctuating**
  During the tapping phase the available waste heat is drastically reduced. High peaks of heat source during start-ups of the furnace.

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**iRecovery® by TENOVA**

**STEAM ACCUMULATOR**
Stabilizes steam supply, peak control and reduction
**DEMO PLANT (I)**

**Electric Arc Furnace (EAF)**
- Mixed EAF: scrap melting with electrodes + natural gas burners.
- Flue gas flow partially directed to the WHRU or to the Quenching Tower, depending on operation mode.

**Waste Heat Recovery**
- Saturated steam generation via thermal exchange with EAF exhaust gases
- 4 Evaporators and 1 Economizer and Steam Drum
- Natural draft (no circulation pumps)
- Nominal Volume flow: 100,000 – 150,000 Nm$^3$/h
- Inlet waste gas temperature: 500 - 750 °C
- Boiler working pressure: 16 - 26 bar (g)
- Steam temperature: 204 - 228 °C
- Steam generation max: 30 t/h
- Pneumatic system to remove dust cake to maintain tubes clean.
**DEMO PLANT (II)**

**Steam accumulator**
- Buffering capacity 6,0 MWth
- Volume 150 m³
- Admissible maximum pressure 30,0 bar(g)

**Feed water tank**
- Capacity 20,0 m³/h
- Volume 30 m³
- Admissible maximum pressure 6,0 bar(g)

**District heating station, A2A**
- Nominal thermal power 10,0 MWth
- Steam flow rate 18,0 t/h
- Working pressure 10,0 bar(g)
ORC Turbine

- Working fluid: “MM” Silicone oil (hexamethyldisiloxane)
- Inlet pressure – working fluid: 7.8 bar(a)
- Outlet pressure – working fluid: 0.18 bar(a)
- Nominal thermal power input: 10.4 MWth
- Nominal gross power output: 1.88 MWe
- Nominal net electric power output: 1.82 MWe
- Net electric efficiency: 17.5%
MONITORING & DATA ANALYSIS

- Monitoring start: September 2016
- Data collection every 60 sec
- Temperature, pressure, volume rate, energy meter, gases and fluids...

Equations:

\[ Q_{fg} = V_{fg} \cdot \rho_{fg} \cdot (H_{in} - H_{out}) \]

\[ Q = \dot{m} \cdot (H_{in} - H_{out}) \]

\[ W_{ORC,net} = W_{OUT} - W_{ORC,consumption} \]

\[ \eta_{ORC}\% = \frac{W_{ORC,net}}{Q_{evap}} \]
DATA ANALYSIS

Flue gas flow WHRU/Q Tower

Steam Parameters - WHRU

ORC Power

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RESULTS

STEAM ACCUMULATOR

a) Extended steam supply during the WHRU long stops

b) ORC output during discontinuous discharges of the WHRU
## RESULTS

### ORC PERFORMANCE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue gases inlet temperature</td>
<td>°C</td>
<td>529,6</td>
</tr>
<tr>
<td>Flue gases outlet temperature</td>
<td>°C</td>
<td>200,2</td>
</tr>
<tr>
<td>Flue gases flow rate</td>
<td>Nm³/h</td>
<td>50409,8</td>
</tr>
<tr>
<td>Steam evaporator inlet temperature</td>
<td>°C</td>
<td>180,9</td>
</tr>
<tr>
<td>Steam evaporator inlet pressure</td>
<td>bar</td>
<td>8,0</td>
</tr>
<tr>
<td>ORC expansor inlet temperature</td>
<td>°C</td>
<td>162,2</td>
</tr>
<tr>
<td>ORC expansor outlet temperature</td>
<td>°C</td>
<td>44,3</td>
</tr>
<tr>
<td>ORC expansor inlet pressure</td>
<td>Bar(a)</td>
<td>4,1</td>
</tr>
<tr>
<td>ORC expansor outlet pressure</td>
<td>Bar(a)</td>
<td>0,2</td>
</tr>
<tr>
<td>Heat load steam accumulator</td>
<td>kW</td>
<td>8953,9</td>
</tr>
<tr>
<td>Heat load ORC evaporator</td>
<td>kW</td>
<td>5722,8</td>
</tr>
<tr>
<td>Power self-consumption</td>
<td>kW</td>
<td>25,5</td>
</tr>
<tr>
<td>Net Power ORC Output</td>
<td>kW</td>
<td>1103,5</td>
</tr>
<tr>
<td>Net ORC efficiency</td>
<td>%</td>
<td>19,3</td>
</tr>
</tbody>
</table>

**RESULTS**

**ORC PERFORMANCE**

![Graph showing ORC performance parameters](image-url)

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### ECONOMIC FIGURES

#### INVESTMENT

<table>
<thead>
<tr>
<th>Project</th>
<th>Cost (Mio. €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste heat recovery system</td>
<td>6,4</td>
</tr>
<tr>
<td>ORC module</td>
<td>1,5</td>
</tr>
<tr>
<td>DH net connection</td>
<td>0,4</td>
</tr>
<tr>
<td>Miscellaneous (civil works and engineering)</td>
<td>0,8</td>
</tr>
<tr>
<td><strong>Total Installation Cost</strong></td>
<td><strong>9,1</strong></td>
</tr>
<tr>
<td>Plant adaptation costs</td>
<td>1,1</td>
</tr>
<tr>
<td>Innovation costs</td>
<td>1,8</td>
</tr>
<tr>
<td><strong>Total Project Cost</strong></td>
<td><strong>12,0</strong></td>
</tr>
<tr>
<td>Investment subsidies: EC – Pitagoras project *</td>
<td>2,5</td>
</tr>
</tbody>
</table>

#### COSTS

<table>
<thead>
<tr>
<th>Cost</th>
<th>Cost (Mio. €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation and maintenance costs</td>
<td>0,18</td>
</tr>
</tbody>
</table>

#### REVENUES **

<table>
<thead>
<tr>
<th>Revenue</th>
<th>Revenue (Mio. €/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues from heat sold</td>
<td>0,5</td>
</tr>
<tr>
<td>Savings electricity costs</td>
<td>0,4</td>
</tr>
</tbody>
</table>

Preliminary economic evaluation shows **payback period of 12 yrs.** The specific incentive mechanisms based on White Certificates that are in force currently in Italy reduces the payback time of the plant to **4-6 years.**
CONCLUSIONS

- A Waste Heat Recovery unit was installed in high peak fluctuation and discontinuous process of an EAF of a steel plant

- Waste heat is recovered using the iRecovery® of Tenova with an implemented dust removal system

- Fluctuation from the heat source was solved using a steam accumulator capable to extend the ORC operation for periods of approx. 50min

- Positive returns in terms of environmental benefits and energy efficiency, industrial competitiveness, social acceptance

- ORI Martin is the first steel industry to supply waste thermal energy to the urban district heating grid

- Process optimization still ongoing
CONSORTIUM

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THANK YOU