Principio de funcionamiento del Ciclo Rankine Orgánico y principales campos de aplicaciones: casos de éxito

The Green Expo 2015
September 23\textsuperscript{th} 2015 - World Trade Center, Mexico City
Summary

1. Organic Rankine Cycle: Working principle and technological key features

2. Field of applications and cases of success

3. Turboden srl, a MHI group company
Turboden designs and develops turbogenerators based on the **Organic Rankine Cycle (ORC)**, a technology for the combined generation of heat and electrical power from various renewable sources, particularly suitable for distributed generation.

**ORC solution from 1 MW to 20 MW**
Key features of the technology

- **Organic working fluid:** suitable organic fluid to optimize performances exploiting low temperature hot sources (e.g. geothermal water)
- **High efficiency** and **ease of operation** for community size plants (from 1 MW up to 20 MW)
- **Compact pre-assembled solution:** shop pre-assembled and delivered to the installation site
- **No water consumption nor water treatment system**
ORC provides significant advantages as compared to steam

Organic working fluid

- Large and robust slow turbine, low peripheral speed (~3,000 rpm) → low wear
- Small enthalpy drop (typically 3 stages turbines)
- No needs of superheated vapour. Condensation in the turbine is physically not possible
- Working fluid is not corrosive and is a natural lubricant for turbine, heat exchangers and piping

→ Turbine efficiency > 80 %, good part load efficiencies
→ Long life of the system and low maintenance required

Operational advantages / results:

- Ease of control and operation, even when big fluctuations in primary heat sources
- Simple start-stop procedures
- Automatic and continuous operation
- Excellent partial load behavior
- Minimum operator attendance needed
- No skilled personnel required (i.e. certified steam engineer)
- No water consumption nor water treatment

→ Automated and unmanned systems
→ High availability > 96% (8,000+ hours per year at nominal load)
→ Low OPEX

✔ Simple & automatic management
✔ High efficiency even at partial load
✔ High availability and long life components system
✔ Low OPEX
Summary

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Waste heat recovery

Turboden ORC units allow to recover waste heat from processes and/or in combined cycles, in order to generate electrical power.

Waste heat recovery technology is **fuel free and zero CO₂ emission**

8,000+ hours per year at nominal load

- Combined cycle with internal **combustion engines and gas turbines**
- Heat recovery from industrial process waste heat:
  - Cement
  - Glass
  - Steel
- Waste to energy: **incinerator and gassificator** of urban solid waste

Proven experience worldwide: 23 reference projects with leader customers
Binary geothermal plants

Turboden ORC units allow to generate electrical power from low enthalpy geothermal source

- Direct exploitation of low enthalpy geothermal reservoir (hot water at 100÷180 °C)
- Separation water of high enthalpy flash geothermal plants

**Case of success: geothermal plants in Bavaria (Germany)**

- Exploitation of a low enthalpy reservoir (hot water at 120÷140 °C)
- 4 geothermal power plants commissioned in the last few years
- ~ 20 MWe installed in operation
- No water consumption
- No CO2 emissions

5.6 MWe geothermal ORC Turboden plant for Hochtief Energy Management Kirchstockach – Munich, Germany
European biomass model

260 plants in Biomass

In 26 countries

<table>
<thead>
<tr>
<th>Biomass ORC units in Europe</th>
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</table>

By applications:

- **110 CHP District heating**
  From 300 kW to 3 MW

- **101 CHP in wood industry**
  (Sawmills, pellet industry, MDF, OSB, etc.)
  and agroindustry (rice husks, etc.)
  From 600 kW to 3 MW

- **6 CCHP (trigeneration) in public buildings**
  (Combined Cooling Heating & Power)
  From 600 kW to 1.8 MW

- **20 Power only**
  From 600 kW to 13 MW

**Keys of success of biomass European model**

- **Cogeneration** (hot water for district heating, wood industry process needs, cooling, etc.)
- **Integration with wood industry**
- **Biomass available on site as waste** (sawmill waste wood, forest thinning, etc.)
- **Easy operation and low OPEX**
- **High price of electricity and feed-in tariff for renewables**
Summary

1. Organic Rankine Cycle: Working principle and technological key features
2. Field of applications and cases of success
3. Turboden srl, a MHI group company
Over 30 years of experience in ORC turbogenerators

1980 - Founded by Mario Gaia, professor at Politecnico di Milano

1990’s – First ORC projects in solar, geothermal and heat recovery applications

1998 – First ORC biomass plant in Switzerland (300 kW)

2000’s - ORC biomass plants in Europe

2009 - United Technologies Corp. (UTC) acquires the majority of Turboden’s quotas. PW Power Systems supports Turboden in new markets beyond Europe. 100 plants sold

2013 - MHI acquires the majority of Turboden. Italian shareholders stay in charge of management

Today - Over 300 plants in the world, 240 in operation, 200 employees, ~100 M€ turnover (2012)

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## Turboden ORC Plants in the World

### Plants by Country

<table>
<thead>
<tr>
<th>Country</th>
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<th>Geothermal</th>
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### Plant Operations and Construction

- **Biomass**: In operation 218, Under construction 43, Total 261
- **Geothermal**: In operation 5, Under construction 4, Total 9
- **Heat Recovery**: In operation 18, Under construction 8, Total 24
- **Waste to Energy**: In operation 7, Under construction 2, Total 9
- **Solar**: In operation 4

*Hybrid Heat Recovery and Solar Thermal Power plant*
Turboden at a glance

Thanks for your attention!
Questions?

Visit us at:
Turboden website: www.turboden.eu
Official YouTube Channel: https://www.youtube.com/user/TurbodenItaly

Simone Passera
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Back up slides
5.6 MWe geothermal ORC Turboden plant for Hochtief Energy Management, Kirchstockach – Durnhaar, Germany - 2012
HR in cement industry

<table>
<thead>
<tr>
<th>Year of start up</th>
<th>References in cement plants</th>
<th>Heat source</th>
<th>ORC gross power [MW]</th>
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<td>Heidelberg Cement – Cartpatcement Romania</td>
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(PH): preheating system, (CSP): concentrated solar power, (CC): clinker cooler
Reference case study: PRS and CC gas waste heat recovery
Customer: Carpatcement Holding – Heidelberg Group
Site: Fieni, Dâmbovița County, Romania
Status: in operation since QII 2015
ORC electric power: ~ 3.8 MW

- Clinker production capacity: ~ 3,500 ton/day
- Heat source: exhaust gas @ 370°C (PRS) and hot air @ 290°C (CC)
- Thermal oil heat recovery loops
- Cooling with ACC
Combined Cycle with GE LM 2500 (preliminary layout, top view)
Combined Cycle with GE LM 2500 (preliminary layout, lateral view)
Combined Cycle with GE LM 2500 (preliminary layout, lateral view)

Combined cycle: ORC is working

Single cycle: ORC is off
Thermodynamic principle

The turbogenerator uses the hot temperature thermal oil to pre-heat and vaporize a suitable organic working fluid in the evaporator (8 3 4). The organic fluid vapor powers the turbine (4 5), which is directly coupled to the electric generator through an elastic coupling. The exhaust vapor flows through the regenerator (5 9) where it heats the organic liquid (2 8). The vapor 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.
Flexible and automatic operation

"One of the key points in the success of ORC technology is the capability to adapt to load variation easily and quickly."

- Part load operation down to 10% of nominal load.
- Maintains 90% of cycle efficiency down to 50% of loading.

**ORC Partial Load Efficiency**

**Cooling water temperature effect on cycle efficiency**

Turboden ORC units automatically adapt the cycle at the ambient temperature variations.
Heat recovery – main components

- Gas turbine
- Internal combustion engine
- Industrial processes waste heat
- Etc..

Heat source

Heat exchangers

Electric power

Heat dissipation system

- Cooling tower
- Water cooled condenser
- Air cooled condenser

ORC Turbogenerator

Heat carrier loop
- Pressurized water
- Saturated steam
- Thermal oil
- Direct exchange
**Reference Plant:**
Heat recovery from Solar TITAN 130 gas turbine in a Gas Turbine Power Plant (GTPP) in Russia (Moscow region)

- Gas Turbine prime power: 25 MWe
- Gas Turbine efficiency: 30%

**Direct exchange configuration:** 18 MWth waste heat recovery unit
**ORC electric power:** 3 MW - Direct exchange cogenerative solution
**ORC thermal power:** 15 MWth of hot water at 90°C

Customer/Project Developer: Polyimpex/Energo development LCC
Status: Under construction
Turboden Scope of Supply

What we can do (EP of main components)

✓ **ORC unit**: equipment, technical advisory to erection, commissioning, start-up
✓ **Waste heat recovery unit**: EP (if needed)
✓ **Exhaust gas line BoP**: EP (if needed)
✓ **Heat dissipation system**: EP (if needed)

What we do not do (EPC turnkey solution)

✓ **Site preparation**
✓ **Mechanical and electrical erection**
✓ **Civil works**
✓ **Connection to the grid**
✓ **BoP**
✓ **Permits, legal, etc..**
How to recognized an opportunity

Few simple guide lines to follow

• **Specific CAPEX [$/kW installed]**

✓ **Size of the project:** the bigger, the better (at least 1 MW as ORC power output is preferable)

✓ **Hot source temperature:** the higher, the better (exhaust gas at least 250-300 °C, liquid at least 100 °C)

✓ **Hot source cleanness:** dirty and aggressive exhaust means complex and expensive systems

✓ **Complexity:** the easier, the better (electric connection, layout, etc.)

• **Electricity value on site:** the greater, the better (incentivation, green certificate, tax credit programs, etc.)

• **Operating hours:** the greater, the better (typical values are 7,500 hours/year)

IRR and PBT
First glance at economics

CAPEX for the whole heat recovery system varies depending on:
- Source cleanness
- Process stability
- Layout constraints
- Heat carrier
- Cooling system
- Other

![Graph showing Total HR plant CAPEX (€/kW) vs ORC size (kW)]
Biomass

Turboden product line

- **CHP units 1-3 MWel** at ~19% efficiency* for **cogeneration plant** (60-80 °C outlet water)

- **HRS units 1-10 MWel** at 24%+ efficiency* for **pure power generation** (25-35 °C outlet water)

- Largest Turboden unit under construction: **HRS 6.5 MWel**

**Typical scheme of a biomass CHP plant (ORC split)**

* **Fuels**
  - Wood biomass: sawdust, woodchips, bark, treated wood
  - Other biomass: dried sewage sludge, green cuttings, rice husk, vinasse and vine cuttings, wood industry waste material etc.
  - Waste material
  - ...

* **Heat consumers**
  - District Heating networks
  - Timber drying in sawmills
  - Saw dust drying in wood pellet factories
  - Wine industry
  - MDF/PB Producers
  - Refrigeration (and Tri-generation)
  - Greenhouses and pools
  - ...

*Gross of captive consumption, calculated on thermal power input to the ORC
Biomass world’s largest ORC based power plant –
British Colombia, Canada

Reference project: biomass-fired power plant
Customer: West Fraser Timber Company
2 Site: Chetwynd and Fraser Lake, BC, Canada
Fuel: wood residues from sawmill operations and logging residues
Start-up: January 2015
ORC electric power: 2 x 13 MW gross (4 ORC units 6.5 MW each)

Project features:
- World's largest biomass ORC based power plant (20yr PPA to provide 180 GWh/year to utility company BC Hydro)
- Heat source for the ORC: thermal oil close loop
- ORC working fluid: cyclopentane

Source: http://www.environmentalleader.com/2012/05/03/west-fraser-timber-company-to-install-13-mw-biomass-plant-sell-power-to-utility/
Geothermal

✓ ORC technology is particularly suitable for the exploitation of medium to low enthalpy sources.
✓ Cost-effective solution with power output up to $15 \text{ MW}_{el}$ and water temperature above $100^\circ C$.
✓ No standard heat/cooling sources $\rightarrow$ highly customized solutions
Reference Plant - Sauerlach

**Plant type:** Two level cycle geothermal unit
**Customer:** SWM - StadtWerke München (public utilities company)
**Site:** Bavaria, Germany
**Start-up:** February 2013
**Heat source:** geothermal fluid at 140°C
**Cooling device:** air condensers
**Total power:** 5+ MW\textsubscript{el} plus 4 MW\textsubscript{th} decoupling for district heating
**Working fluid:** refrigerant 245fa (non flammable)
Reference Plant - Dürrnhaar

**Customer:** Hochtief Energy Management GmbH  
**Site:** Dürrnhaar (München)  
**Start-up:** December 2012  
**Heat source:** geothermal fluid at 138°C  
**Total electric power:** 5.6 MW  
**Scope of supply:** EPC contract for the complete ORC unit, including the Air Cooled Condenser and the geothermal balance of plant
Reference Plant - Kirchstockach

**Customer:** Hochtief Energy Management GmbH  
**Site:** Kirchstockach (München)  
**Start-up:** March 2013  
**Heat source:** geothermal fluid at 138°C  
**Total electric power:** 5.6 MW  
**Scope of supply:** EPC contract for the complete ORC unit, including the Air Cooled Condenser and the geothermal balance of plant
Reference Plant - Traunreut

Customer: Geothermische Kraftwerksgeellschaft Traunreut mbH
Site: Traunreut (Bavaria)
Status: Under construction
Heat source: geothermal fluid at 118°C
Total electric power: 4.1 MW
Total thermal power: 12 MW (to the district heating)
Scope of supply: Supply of the complete ORC unit, including the Air Cooled Condenser and control system of geothermal site
References – Low temperature water

**Waste-to-energy – Mirom, Belgium**

Heat recovery from **pressurized water** boiler in **waste incinerator**

*Customer:* MIROM (Roeselare), Belgium  
*Source:* hot water at 180° C (back at 140° C)  
*Cooling source:* air coolers  
*ORC electric power:* 3 MWe  
*Electrical efficiency:* 16.5%  
*Availability:* >98%  
*Start up:* Q2 2008

**Waste-to-energy – Séché, Francia**

Heat recovery from **pressurized water** boiler in **waste incinerator**

*Customer:* Séché Environnement  
*Location:* UIOM ALCEA de Nantes, France  
*Source:* hot water at 200° C (back at 130° C)  
*Cooling source:* air coolers  
*ORC electric power:* 2.4 MWe  
*Electrical efficiency:* 16.5%  
*Start up:* Q3 2014
Plant type: Heat recovery from low pressure steam in waste incinerator

Incinerator:
A grate furnace of 5 t/hr (PCI = 2200 kcal/kg)
A recovery boiler: 14 t/h steam at 350 °C, 29.5 bar,
A back pressure turbine of 1MW
A district heating fed by steam at 4 bar with a steam exchanger
hot water boiler of 7 MW.

End user: UVE du SYDOM (operated by VEOLIA propriétéRhin Rhone) – Lons le Saunier - France

Under construction - expected startup: Q2 2015

Heat source: low pressure steam at 4,5 bars 180°C (back 78°C)

Cooling source: air

Total electric power: 750 kW
Net electric efficiency: 13.6%
Intermediate thermal oil loop solution:
Conceptual scheme

ORC based heat recovery solution:
Thermal Oil / Pressurised Water / Steam heat recovery exchangers with exhaust gas. Silicon Based fluids, hydrocarbon used as working fluids.
Gross cycle efficiency: up to 10%

Reciprocating Engine

TURBODEN ORC UNIT

ELECTRIC ENERGY

Heat Exchangers

Typically not included in Turboden scope of supply
First Turboden direct exchange application: Visano

**Project:** FinPower  
**ORC module:** TURBODEN 6 HR DIR. EXCH. (ORC gross power output 500÷600 kWe)  
**Status:** In operation since II quarter 2009  
**Location:** Italy, Visano (BS)  
**Primary heat source:** Exhaust gas from diesel engine, 1 x 7 MWe Wartsila using vegetable oil fuel  
**Client:** agriculture and farming