ORC Binary solutions for high enthalpy resources

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What Turboden does: Organic Rankine Cycle systems

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.

200 kW – 20 MW per single shaft
## Range of Application

<table>
<thead>
<tr>
<th>Temperature</th>
<th>LOW (&gt; 100 °C)</th>
<th>MEDIUM (&lt; 200 °C)</th>
<th>HIGH (&gt; 200 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geothermal</strong></td>
<td>1 - 20 MW</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Waste-heat</strong></td>
<td>0.2 - 20 MW</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biomass (*)</strong></td>
<td></td>
<td></td>
<td>0.2 - 15 MW</td>
</tr>
<tr>
<td><strong>CSP Solar</strong></td>
<td></td>
<td></td>
<td>0.2 - 15 MW</td>
</tr>
</tbody>
</table>

(*) and Waste to Energy
Turboden: 35 years of ORC, since 2013 part of Mitsubishi Heavy Industries

- Over $40 billion (in fiscal 2014)

- The largest segment of MHI over $16 billion (in fiscal 2014)

- > 330 ORC plants globally, 0.5 GW ORC power

- >100 units globally, >3 GW power

- ~20% market share
Turboden is a leading company in the ORC field with 260 plants in operation and more than 8 million hours of operation cumulated.

TURBODEN GLOBAL AND PROVEN EXPERIENCE

- Plants: 334
- Countries: 35
- Total capacity: 509 MWe
- Cumulative operation time: 8 million hours
- Average availability: 99%

Update September 2016
### MHPS Experience in Africa

#### Kenya / Olkaria

<table>
<thead>
<tr>
<th>COD</th>
<th>Olkaria I</th>
<th>Olkaria II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#1 1981</td>
<td>#1 2003</td>
</tr>
<tr>
<td></td>
<td>#2 1982</td>
<td>#2 2003</td>
</tr>
<tr>
<td></td>
<td>#3 1985</td>
<td>#3 2010</td>
</tr>
<tr>
<td>Type</td>
<td>Single Flash, Single Flow, Down Exhaust</td>
<td>Single Flash, Single Flow, Down Exhaust</td>
</tr>
<tr>
<td>Output</td>
<td>15,000 kW / unit</td>
<td>34,830 kW / unit</td>
</tr>
<tr>
<td>Speed</td>
<td>3,000 rpm</td>
<td>3,000 rpm</td>
</tr>
<tr>
<td>Steam Pressure</td>
<td>5.0 bara</td>
<td>4.8 MPa</td>
</tr>
<tr>
<td>Steam Temp.</td>
<td>151.9 °C</td>
<td>150.3 °C</td>
</tr>
<tr>
<td>Exhaust Pressure</td>
<td>0.13 bara</td>
<td>0.07 bara</td>
</tr>
</tbody>
</table>
Turboden experience in Africa

**Site:** Kapishwa, Zambia  
**Year:** 1988  
**Heat source:** Geothermal fluid at 88°C  
**Total electric power:** 2 x 100 kW

**Reference case study:** PRS gas waste heat recovery  
**Customer:** Ciments du Maroc – Italcementi Group  
**Site:** Ait Baha, Morocco  
**Start-up:** in operation since November 2010  
**ORC electric power:** ca. 2 MW  
**Availability:** > 98%  
No Water consumption
Advantages of geothermal binary plants for high enthalpy

- Capable to exploit the separated hot brine & steam to maximize the power output
- Comparable efficiency with flash plants (for small units < 15 MW)
- Comparable cost (USD/MW) with flash plants (for small units < 15 MW)
- Possibility to install wellhead units: early generation, relocation option, no complicate steam gathering system
- Low/negligible emission of CO$_2$ and local air pollutants
- Low requirement for land
- Stable base-load energy (no intermittency)
- Relatively low cost per kWh
- Proven/mature technology
- Scalable to utility size without taking up much land/space
Binary Geothermal Well Head Units: examples
Detail of a Well Head Unit
Short video: how a Binary Well-head unit looks like
Project Overview of the largest binary turbine ever built by Turboden

**Plant type:** ORC geothermal unit  
**Customer:** GEOEN - MB Holding  
**Site:** Croatia  
**Start up:** 2018  
**Heat source:** geothermal brine and steam @170°C  
**Cooling device:** Air Cooled Condenser  
**Generator nameplate capacity:** 19.5 MVA (single ORC turbine)  
**Design power** 15 MW  
**Working fluid:** Isobutane  
**Scope of supply:** Engineering, procurement and Construction of the full ORC power plant, including civil and steam-field
The Velika Ciglena project area is located in the SW part of Pannonian basin, in the Bjelovar subdepression (NE part of Croatia). The reservoir was discovered in 1990 by the VC-1 well within the scope of exploration for oil, conducted by INA-Naftaplin. Oil was not found, but a promising geothermal potential was established. A casing was lowered into the well at the depth of 2574 m. An unusually high temperature (172 °C) was registered.
3D Layout

Layout optimized to:
- reduce CAPEX
- reduce the footprint
- simplify access & maintenance operations

- ACC optimized to reduce noise emissions according to regulations
- Clever use of the area available: regenerator and pumps under the ACC, rational heat exchangers’ arrangement
- Overall footprint: 50 x 100 m
Binary cycles can be combined with traditional flash steam plants

- 20 - 40% additional power according to reinjection limits (scaling issues)
- No additional drilling required
- Binary plant can use existing cooling system
- Easy access to financing because there is no resource risk
- Environmentally friendly (larger CO₂ displacement)
Binary cycles can be an efficient solution for wellhead plants

- Competitive efficiency with resource enthalpy up to 1500 kJ/kg
- Binary plant can use dry cooling system
- Environmentally friendly (full reinjection)
- Lower O&M and higher reliability compared to flash plants
THANK YOU FOR YOUR ATTENTION

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