Short Review of the Long History of ORC Power Systems

Lucien Y. Bronicki
Carnot Teachings

The economy of the combustible is only one of the conditions to be fulfilled in heat engines. In many cases it is only secondary. It should often give precedence to safety, to strength, to the durability of the engine, to the small space which it must occupy, to small cost of installation, etc. To know how to appreciate in each case, at their true value, the consideration of convenience and economy which may present themselves; to know how to discern the more important of those which are only accessories to balance them properly against each other, in order to attain the best results by the simplest means: such should be the leading characteristics of the man called to direct, to co-operate towards one useful end, of whatsoever sort it may be.

“On ne doit pas se flatter de mettre à profit, dans la pratique, toute la puissance motrice des combustibles. Les tentatives que l'on ferait pour approcher de ce résultat seraient même plus nuisibles qu'utiles, si elles faisaient négliger d'autres considérations importantes. L'économie du combustible n'est qu'une des conditions à remplir par les machines à feu, dans beaucoup de circonstances, elle n'est que secondaire, elle doit souvent céder le pas à la sûreté, à la durée de la machine, au peu de place qu'il faut lui faire occuper, au peu de frais de son établissement, etc.

Savoir apprécier, dans chaque cas, à leur juste valeur, les considérations de convenance et d'économie qui peuvent se présenter; savoir discerner les plus importantes de celles qui sont seulement accessoires, les balancer toutes convenablement entre elles, afin de parvenir par les moyens les plus faciles au meilleur résultat, tel doit être le principal talent de l'homme appelé à diriger, à coordonner entre eux les travaux de ses semblables, à les faire concourir vers un but utile de quelque genre qu'il soit.”

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“…in order to attain the best results by the simplest means:”
The Long History

1823  Sir Humphrey Davy suggest the ORC as an alternative to steam

1824  Carnot Teachings

1853  Du Trembley applies the ORC to ship propulsion (ether as motive fluid)

1883  Gantt, Maury, Wood studies of working fluids

1888  Yarrow develops the “Zephyr” for small boats, commercially not successful

Rapid improvements in the steam engine design and construction curtail the development of non-aqueous Rankine cycle systems.
The Long History

1930’s
Luigi D’Amelio experiments with ethyl chloride at the University of Naples

1935
Small solar pump based on D’Amelio’s work

1940’s
- 1 MW geothermal plant in Citara, Ischia Island using Ethylene
- Gasperini and Grassi develop SOMOR solar pump using a refrigerant

1958 to 1961
Tabor and Bronicki establish criteria for the selection of suitable fluids to optimize efficiency at the National Physical Laboratory in Jerusalem, Israel

1961
A new ORC cycle was developed with a 3kW prototype and presented at the UN conference in Rome. This work led to the establishment of Ormat in 1965.
D’Amelio’s first ORC turbine
SOMOR Commercial Solar Pump
1940’s
Test were conducted with 16 different potential motive fluids to determine their reactivity to common metals and mineral oils.
### The Long History

**1965**
Ormat commercializes its fuel powered ORCs from 0.5 to 4kW, for remote unattended operation.

**1970’s**
Gianfranco Agelino, Ennico Macchi and Mario Gaia pursue to develop a 3KW ORC, leading to the establishment of Turboden in 1980.

**1980’s**
Turboden manufactures units from 300kW up mainly for CHP using biomass.

**1990’s**
Ormat has substantial growth in the use of ORC in geothermal worldwide, Turboden provides numerous CHP systems in Europe.

**2000**
A number of ORC packagers and component suppliers are available along with new technologies and research.
First Ormat hermetically sealed solar unit powering an electric water pump in Mali, Africa

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TURBOGENERATOR</strong></td>
<td></td>
</tr>
<tr>
<td>Nominal Output</td>
<td>600 W</td>
</tr>
<tr>
<td>Boiler Temperature</td>
<td>90 – 125 ºC</td>
</tr>
<tr>
<td>Max Power Output</td>
<td>700 W</td>
</tr>
<tr>
<td><strong>COLLECTORS</strong></td>
<td></td>
</tr>
<tr>
<td>Total Net Collector Area</td>
<td>43 m²</td>
</tr>
<tr>
<td>Auxiliary Mirror Area</td>
<td>16 m²</td>
</tr>
<tr>
<td>Max Heat Output</td>
<td>12 kW</td>
</tr>
<tr>
<td>Average Useful Heat Output</td>
<td>35 kWh/day</td>
</tr>
<tr>
<td><strong>PUMP</strong></td>
<td></td>
</tr>
<tr>
<td>Max Flow at 40m head</td>
<td>3 000 l/hr</td>
</tr>
<tr>
<td>Average Quantity Pumped</td>
<td>11 000 l/day</td>
</tr>
</tbody>
</table>
Fuel operated Hermetically Sealed ORC Units
3000+ build for Remote Unattended Sites

120 Remote ORC Units
Providing Power and Heat to
62 Remote Gate Valve Stations
along the TransAlaska Pipeline
-most still in operation since 1976

Boiler temp 130 °C ; ambient temperature +35 to -60 °C
Propane consumption at 600 W : 1.2 kg/hr ; operating hours: 26 Million
## Dual Fluid Radioisotopically Heated ORC

<table>
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<tr>
<th>Characteristic</th>
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<tbody>
<tr>
<td><strong>ORC</strong></td>
<td></td>
</tr>
<tr>
<td>- First Stage:</td>
<td></td>
</tr>
<tr>
<td>Boiler Temperature</td>
<td>195°C</td>
</tr>
<tr>
<td>Condensing Temperature</td>
<td>112°C</td>
</tr>
<tr>
<td>- Second Stage:</td>
<td></td>
</tr>
<tr>
<td>Boiler Temperature</td>
<td>100°C</td>
</tr>
<tr>
<td>- Condensing Temperature</td>
<td>45°C</td>
</tr>
<tr>
<td>- Electrical Output</td>
<td>680 W</td>
</tr>
<tr>
<td><strong>Heat source Cobalt 60 Isotope</strong></td>
<td></td>
</tr>
<tr>
<td>Life span: 2 years</td>
<td></td>
</tr>
<tr>
<td>Thermal Output</td>
<td>4.8kW</td>
</tr>
</tbody>
</table>
5 MW Solar Pond Power Plant
1982 at Dead Sea, Israel

<table>
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<tr>
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<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Ormat Energy Converter</td>
<td></td>
</tr>
<tr>
<td>Brine Inlet Temp.</td>
<td>85 °C</td>
</tr>
<tr>
<td>Brine Flow Rate</td>
<td>10M l/hr.</td>
</tr>
<tr>
<td>Cooling Water Inlet Temp.</td>
<td>27°C</td>
</tr>
<tr>
<td>Cooling Water Flow Rate</td>
<td>10M l/hr.</td>
</tr>
<tr>
<td>Turbine Stage Efficiency</td>
<td>83%</td>
</tr>
<tr>
<td>Generator Output</td>
<td>5070 kW</td>
</tr>
<tr>
<td>Net Output</td>
<td>4000 kW</td>
</tr>
</tbody>
</table>
A number of prototypes (most are decommissioned)

- Mutnovsky geothermal plant in Kamtchatka
- I.K. Smith, City University of London, triangular cycle, screw expander
- MTI
- Sundstrand
- EDF Ammonia bottoming ORC
- Thermoelectron
- BiPhase turbine
- Bertin
- Rocketdyne
- Lappeenranta University of Technology
- IHI
- Kalina
- Barber Nichols – 2 plants (still in operation)
- Ben Holt – 2 plants (still in operation, refurbished with Ormat turbines)
Ormat’s First Commercial Geothermal ORC
1984

1984 Wabuska Geothermal Power Plant, Nevada
– still in commercial operation

Simple ORC
Source at 104 °C
Sink at 25 °C
Output gross 800kW
net 720kW
The Long History

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Agelino, Macchi and Gaia pursue to develop a 3KW ORC, leading to the establishment of Turboden in 1980.

1980’s
Turboden manufactures units from 300kW up mainly for CHP using biomass
Ormat commissions its first geothermal ORC

1990’s
Ormat has substantial growth in the use of ORC in geothermal worldwide,
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2000
A number of ORC packagers and component suppliers are available
Comparing ITLU and Supercritical Cycles

Source at 137/98 °C
Cooling water: 39 °C
Output gross/net 35.4/32.9 MW
Two-Phase Geothermal Power Plant
1994 Azores Islands, Portugal

Fluid: N-pentane
Source: 158.5 °C; 2 phase flow (total): 390 ton/hr
Cooling air: 30 °C
Output gross/net: 7490/6385 kW
Ormat’s 30 MW Geothermal Combined Cycle
Puna, Hawaii, operating since 1992
Ormat’s First Application of ORC to a Gas Compressor Station, operating since 1999

Heat source: Exhaust of RR RB211 Gas Turbine
Capacity (mechanical drive): 25 MW
ORC capacity: Gross/Net  6.46/5.72 MW
ORC net efficiency: 17.3%
Ambient temperature: +35 °C to -35 °C
Present ORC Manufacturers, Integrators, Suppliers

- Ormat
- Turboden
- TAS
- Atlas Copco
- United Technologies Pure Cycle – discontinued
- General Electric
  - Clean Cycle – small, some installations
  - ORegen – first pilot under construction
- Exergy
- SME:
  - Electratherm
  - GMK
  - Tri-O-Gen
  - Energent
GeoTek Energy LLC

• Integration of Pumping and Power Production in ORC
EXERGY RADIAL OUTFLOW TURBINE

In the radial outflow turbine, the flow enters axially into the center and flows radially outwards through the various stages.

Main features:

- Cross section increases across the expansion stages, together with the increment of volumetric flow, allowing for a high volumetric ratio
- Multiple stages and pressures on a single disk
- Low vibrations, due to distance ‘B’ being fixed no matter how many stages
- Straight blades
- Overhung configuration
- Available on a wide range of power output
Hurdles and Challenges for Geothermal

Geothermal Plants: Integration of Upstream and Downstream

• Similarities with oil and gas
  • “Fuel” supply similar to oil and gas – exploring, drilling
  • Power conversion similar to thermal power plants

• Differences
  • Link of upstream and downstream
  • Value of one barrel produced
    • Oil: $30 ?
    • Water at 150°C: 30 Cents

• The challenge
  • Explore, drill, produce for the same cost per barrel as oil BUT for 1/100 of the revenue, at availabilities of Base Load Power Plants
Hurdles and Challenges for ORC Heat Recovery

Waste Heat Recovery: Always Secondary

- Will not be “off the shelf” for industrial processes
  - Each application requires substantial engineering
  - Space and process constraints are unique to the site
  - Little tolerance for being offline
- Industrial processes became more efficient, reducing quality and quantity of waste heat

- Utilization of exhaust heat from combustion engines is better, but engines are becoming more efficient
Ormat: 35 Years of ORC Pioneering and Commercialization

From 2kW power units at a hot spring of 120°F (48.9°C) in Alaska (1979) to a 95 MW power plant at a high enthalpy resource of 382°F (194.4°C) in New Zealand (2013)

World’s Largest Binary Power Plant!
• Over four decades of experience
• Established renewable pure-play
• Technology leader with over 82 U.S. patents
• Over 1600 MW of constructed capacity
• Owns and operates 595 MW of installed capacity in 17 complexes and power plants

THANK YOU!

84 MW Ormat plants in Reno, NV: supplies electricity to all households in Reno