OTEC power, research and implementation by the Korean Government: Case study of a 1MW power plant for the Republic of Kiribati

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Ministry of Oceans and Fisheries(MOF) of Republic of Korea
1. OTEC history and current status

- 2015: 100kW OTEC plant (NELHA/MOE)
- 1993: 250kW Open Cycle (PICTHA)
- 1983: CWP At Sea Test (TRW for DOE)
- 1981: 100KW OTEC Nauru Plant (Toshiba)
- 1981: OTEC-1 Test (DOE)
- 1979: 50 kW Mini-OTEC Studies (Lockheed & Makai)
- 1975: NSF OTEC Studies (Lockheed, TRW)
- 1974: Hawaii Natural Energy Laboratory (NELHA)
- 1930: Georges Claude
- 1881: d’Arsonval

OTEC in 1927

http://www.makai.com/ocean-thermal-energy-
Ongoing project for OTEC demonstration

Oceans of power

To create an ocean thermal energy conversion (OTEC) power plant, the temperature difference between the ocean’s surface and deep waters must be at least 20°C. This means the world’s existing and planned stand-alone OTEC plants all sit within the planet’s warm “equatorial wallband.”

Goseong, South Korea
20 kilowatt plant, Korea (MOF)
(only operated in the summer)

Tarawa, Kiribati (by KRISO team)
1 megawatt plant, Korea (MOF)

Martinique, Fr (by Akuo E.)
10 megawatt plant, EU

20M OTEC pilot plant public demonstration in South Korea

Published on January 3, 2014

The OTEC team of Korea Research Institute of Ships & Ocean Engineering (KRISO) affiliated with Korea Institute of Ocean Science and Technology (KOST) has successfully finished its 20M OTEC pilot plant public demonstration.

The 20M OTEC pilot plant is a 5-meter-long, 20-inch-diameter heat exchanger known as the absorber. It is designed to be used in the ocean to absorb heat from the surface water and transfer it to the deep water, creating a temperature difference that can be used to generate electricity.

In addition, the prototype of the absorber was also deployed in the Gulf of Guinea in June 2014 for further experiments.

Also OTEC experts from other organizations gathered together to evaluate and improve the performance of the 20M OTEC plant on December 14, 2014. The OTEC team of KRISO has been working on a project called Development of Ocean Thermal Energy Conversion Technology to Demonstrate in a Marine Environment since 2014. Based on the success of the 20M OTEC pilot operation in 2013, the team is planning to further assess the feasibility and operation of a 20M OTEC plant in 2016.

The final goal of the project is to obtain technologies to design a 20M OTEC plant by 2018.
2. 1MW OTEC plant design

- Electric power can be generated by rotating a turbine using gaseous flow of evaporated working fluid. Warm surface and cold deep seawaters are used for heat source and sink, respectively.

![Diagram of OTEC plant design](image)

- Working fluid: R32 refrigerant
Analysis of 20kW OTEC for 1MW design

80.0%/1MW
93.1%/1MW
87.5%/1MW
90.0%/1MW

Power Plant Performance Summary

<table>
<thead>
<tr>
<th>Plant Performances</th>
<th>Symbols</th>
<th>Units</th>
<th>Cycle</th>
<th>Plant</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mass Flow Rate</td>
<td>( \dot{m}_w )</td>
<td>(kg/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Condensation Temperature</td>
<td>( T_C )</td>
<td>(°C)</td>
<td>11.3008475</td>
<td>11.3008475</td>
<td></td>
</tr>
<tr>
<td>- Evaporation Temperature</td>
<td>( T_E )</td>
<td>(°C)</td>
<td>24.14239</td>
<td>24.14239</td>
<td></td>
</tr>
<tr>
<td>- Pump Pressure Ratio</td>
<td>( \pi_{12} )</td>
<td></td>
<td>1.42494676</td>
<td>1.42494676</td>
<td></td>
</tr>
<tr>
<td>- Turbine Expansion Ratio</td>
<td>( \pi_{12} )</td>
<td></td>
<td>1.33934392</td>
<td>1.33934392</td>
<td></td>
</tr>
<tr>
<td>- Parasitic Pressure Loss</td>
<td>( \pi_{12} )</td>
<td></td>
<td>0.94092056</td>
<td>0.94092056</td>
<td></td>
</tr>
<tr>
<td>- Heat Absorption</td>
<td>( Q_{A2} )</td>
<td>(kW)</td>
<td>297.559077</td>
<td>354.85373</td>
<td></td>
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<tr>
<td>- Heat Rejection</td>
<td>( Q_{B4} )</td>
<td>(kW)</td>
<td>-288.983838</td>
<td>-343.853844</td>
<td></td>
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<tr>
<td>- Parasitic Heat Loss</td>
<td>( \Sigma A )</td>
<td>(kW)</td>
<td>3.3315506</td>
<td>0.00098412</td>
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</tr>
<tr>
<td>- Pump Power Consumption</td>
<td>( W_{12} )</td>
<td>(kW)</td>
<td>-0.5997599</td>
<td>-71.38429656</td>
<td></td>
</tr>
<tr>
<td>- Turbine Power Generation</td>
<td>( W_{T4} )</td>
<td>(kW)</td>
<td>9.17197247</td>
<td>1091.553285</td>
<td></td>
</tr>
<tr>
<td>- Net Cycle Power Output</td>
<td>( \Sigma W )</td>
<td>(kW)</td>
<td>8.57219257</td>
<td>1019.93898</td>
<td></td>
</tr>
<tr>
<td>- Pump Motor Efficiency</td>
<td>( \eta_M )</td>
<td></td>
<td>0.9</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>- Pumping Power Consumption</td>
<td>( W_{12} )</td>
<td>(kW)</td>
<td>-0.6665399</td>
<td>-79.29366224</td>
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<tr>
<td>- Generator Efficiency</td>
<td>( \eta_G )</td>
<td></td>
<td>0.931</td>
<td>0.931</td>
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<tr>
<td>- Gross Power Generation</td>
<td>( W_{G2} )</td>
<td>(kW)</td>
<td>8.55938775</td>
<td>1016.049908</td>
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<tr>
<td>- Parasitic Power Consumption</td>
<td>( \Sigma A W )</td>
<td>(kW)</td>
<td>-361.229363</td>
<td>-35.6%</td>
<td></td>
</tr>
<tr>
<td>- Net Electric Power Output</td>
<td>( \Sigma W' )</td>
<td>(kW)</td>
<td>654.820444</td>
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</tbody>
</table>
Design of 20kW OTEC plant as 1MW pilot plant

Condenser
Evaporator
Accumulator
Turbine-generator
Receiver
WF pump
Fabrication of pilot OTEC plant for 1MW

- 20kW OTEC pilot plant
Experiment of 20kW OTEC pilot plant

- Operation of 20kW OTEC

Demonstration of 20kW OTEC pilot plant based on R-32 Rankine cycle developed by Korea Research Institute of Ships and Ocean Engineering

2013. 12. 24

https://www.facebook.com/pg/OTECUT/videos/?ref=page_internal
Detail design of 1MW OTEC plant on offshore platform and land
3. 1MW OTEC structure design

<table>
<thead>
<tr>
<th></th>
<th>TLP (conventional)</th>
<th>Spar (Truss)</th>
<th>Semi-sub (4 Column)</th>
<th>FPSO (Ship Shape)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>![Diagram]</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
<td>![Diagram]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>TLP</th>
<th>Spar</th>
<th>Semi-sub</th>
<th>FPSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water depth (m)</td>
<td>Up to 1500</td>
<td>No practical limit</td>
<td>No practical limit</td>
<td>No practical limit</td>
</tr>
<tr>
<td>Trees (Stability Heave)</td>
<td>Wet or dry (Best)</td>
<td>Wet (Best)</td>
<td>Wet (Good)</td>
<td>Wet (Good)</td>
</tr>
<tr>
<td>Station-keeping</td>
<td>Steel tendons</td>
<td>Taut-spread wire or poly</td>
<td>Semi-taut spread wire or poly</td>
<td>Semi-taut spread wire or poly</td>
</tr>
<tr>
<td>Free hanging Riser</td>
<td>No (interaction with tendons)</td>
<td>No constraint</td>
<td>No constraint</td>
<td>No constraint</td>
</tr>
<tr>
<td>Hull weight sensitivity to topside</td>
<td>Most</td>
<td>Somewhat</td>
<td>Somewhat</td>
<td>Least</td>
</tr>
<tr>
<td>Economics</td>
<td>Expensive</td>
<td>Expensive</td>
<td>Not expensive</td>
<td>Relatively cheap</td>
</tr>
<tr>
<td>Payloads</td>
<td>Sensitive (≥25000 tons)</td>
<td>Somewhat</td>
<td>Large</td>
<td>Large</td>
</tr>
</tbody>
</table>

1MW – ID 1.2m HDPE / 10MW – ID 4m FRP / 100MW – ID 10m FRP

* Wire ; Reinforcement by tensile strength
* Lumped mass ; For Specific density
Design condition of 1MW OTEC plant

Environmental conditions (Tarawa, Kiribati)

Water depth: 1100m

<table>
<thead>
<tr>
<th></th>
<th>100yr Storm case</th>
<th>Max. Current case</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_s$ (m)</td>
<td>3.89 (~10.2)</td>
<td>1.49</td>
</tr>
<tr>
<td>$T_p$ (sec)</td>
<td>14.0 (~12.8)</td>
<td>14.0</td>
</tr>
<tr>
<td>Gamma of JONSWAP Spectrum</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Mean wind speed for 10 min. (m/s)</td>
<td>28.4 (~33.80)</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Current speed (m/sec)
- Surface: 1.40, 0.91
- 50m: 0.49, 0.79
- 100m: 0.30, 0.79
- 150m: 0.30, 0.79
- 350m: 0.21, 0.30
- 800m: 0.21, 0.30
- 1000m: 0.21, 0.30

* (   ) : external force environment around Fiji

Example of current profile at Tarawa waters

Bottom topography (SPC)
Design of offshore platform for 1 MW OTEC plant
Stability enhancement of floater

Type A
Type B

Pitch
Heave

Model test in regular waves

Heave
Pitch
Model test in irregular waves

OTEC A

OTEC B

Hs=10.2m
Tp=12.8s
Dynamic response test w & w/o riser

Case I
Case II
Case III

Heave [m]

Pitch [deg]

OTEC B TYPE
OTEC B TYPE W/Riser

IRW01 IRW02 IRW03 IRW03+Current

IRW01 IRW02 IRW03 IRW03+Current

Type B
Type A
Fatigue analysis of OTEC riser

- Multi-scale fatigue life prediction of composites: macro-level ↔ micro-level
Structural analysis of OST OTEC platform
Analysis and design of mooring systems and subsea power cable
Design of 1 MW OTEC plant

2nd deck

3rd deck

Top deck
Korea develops ocean thermal energy converter for Pacific island

Written by Kevin Tester

Classification society Bureau Veritas has issued an approval in principle for an Ocean Thermal Energy Converter (OTEC). The approval applies to a 1MW plant developed by the Korea Research Institute of Ships and Ocean Engineering (KRISO) which will be built for installation off the coast of South Tarawa, Republic of Kiribati, in the South Pacific Ocean.

Matthieu de Tugny, senior vice-president and head of offshore, Bureau Veritas, said: “This technology offers the potential for round-the-clock clean renewable energy from the ocean. We are excited to deploy our expertise in offshore energy, met-ocean studies and structures to help bring this project to fruition.”

OTEC takes advantage of the difference in temperature between deep cold and warm surface seawater. A working fluid is successively vaporised and condensed in a thermodynamic cycle, with the gas phase driving a turbo-alternator producing electricity.

KRISO’s 1MW OTEC plant is the first practical level of plant on a pathway to building a 100MW commercial system. It consists of an octagonal 5,700 tonne four-deck floating platform 35m across moored 6km offshore in a water depth of 1,300m. A 1,000m pipe 1.2m in diameter will be used to pump cool water up from the depths to be fed to process plant on the platform.
1MW OTEC demonstration plant
Performance test and transport to install

Design approval of 1/10MW OTEC plant on offshore platform will be tried in 2020

For multi-purpose use of discharged seawater for FEW application
Sustainable Seawater Utilization Academy
ODA projects often fail at the point of ownership transference

We need detailed program for full technology transference

A competent capacity-program designed and installed with local stakeholders
Who & What

1MW OTEC Demonstration Plant

KOICA
Korea International Cooperation Agency

Capacity-building for operation and maintenance by Kiribati people
Kiribati

Goseong, South Korea
20 kilowatt plant, Korea(MOF)
(only operated in the summer)

Tarawa, Kiribati (by KRISO team)
1 megawatt plant, Korea(MOF)
Electricity and GDP

Electricity use per capita (kWh per capita) vs. GDP - per capita (USD)

- Kiribati
- Netherlands
- South Korea
- USA
Obesity and Water

- Kiribati: Obese adult prevalence rate (%)
- Netherlands: Water (Population with improved drinking water sources - urban and rural)
- South Korea: Water (Population with improved drinking water sources - urban and rural)
- USA: Water (Population with improved drinking water sources - urban and rural)
Arable land and Climate change

- **Kiribati**: Arable land (Hectares) - 9,000, CO2 emissions (Kt) - 25,000
- **Netherlands**: Arable land (Hectares) - 10,000,000, CO2 emissions (Kt) - 1,000,000
- **South Korea**: Arable land (Hectares) - 2,000,000, CO2 emissions (Kt) - 500,000
- **USA**: Arable land (Hectares) - 5,000,000, CO2 emissions (Kt) - 1,000,000

Legend:
- Blue bar: Arable land (Hectares)
- Orange bar: CO2 emissions (Kt)
Our goal

Self-Reliant for Food, Energy, and Water
How and when?

1MW OTEC Demonstration Plant

2016
Design and fabrication of essential parts

2017
Design and fabrication of secondary parts

2018
Installation and test operation in the East Sea of South Korea

2019~2021
Transportation, installation and test operation in Tarawa, Kiribati

Preparation for technology transference

SSUA

Invitation of 2 SSUA participants to South Korea

Advanced courses

Education center for seawater plant
Most importantly, Our SSUA participants..
1MW OTEC demonstration plant
Installation for long term operation (2019~2020)
Power supply and cascade utilization based on 1MW OTEC plant operation
Thank you for your attention!