NEW TURBINES TO ENABLE EFFICIENT GEOTHERMAL POWER PLANTS

Phil Welch and Patrick Boyle
Energent
Kalina Cycle

1. **HOT GEOTHERMAL BRINE**
2. **SEPARATOR**
3. **VAPORIZATION**
4. **RECUPERATOR**
5. **GENERATOR**
6. **OIL COOLER**
7. **COOLING WATER OR AIR**
8. **BLOWER**
9. **AMMONIA RECOVERY**
10. **NITROGEN SOURCE**
11. **CONDENSER**
12. **SUBCOOLED LIQUID**
13. **LUBE OIL TANK**

Graph showing temperature and enthalpy (relative) with points labeled 1, 2, 3, and 4.
Euler Turbine – Radial Outflow
• A steam turbine for PRV replacement has to tolerate moisture formation during the expansion
• District steam systems often deliver “dirty” steam
Euler Turbine – 600 kW Kalina Cycle

- 27,800 rpm → single stage gearbox
- Moisture resistant → saturated vapor inlet
- 2-D titanium blades → rugged and corrosion resistant
- Efficient → 82%
We are currently building a 90 kW Kalina turbine using a scaled down version of the Bruchsal project. The unit will be installed near Nagano, Japan.
Variable Phase Cycle

HOT GEOTHERMAL BRINE

LIQUID-LIQUID HEAT EXCHANGER

COOLED GEOTHERMAL BRINE

HEATED LIQUID

TWO-PHASE EXPANDER

COOLING WATER OR AIR

CONDENSER

PUMP

SUBCOOLED LIQUID

Temperature (°C)

Enthalpy (relative)
Enthalpy $\rightarrow$ Two-Phase Kinetic Energy

- Pressure reduction $\rightarrow$ liquid flash
- Vapor shear stress breaks up the liquid phase into small droplets
- Vapor transfers momentum to the droplets

Small droplets $\rightarrow$ close-coupling of the gas and liquid phases $\rightarrow$ efficient acceleration
Early Two-Phase Separating Turbine
Demonstration of 890 kW, Wellhead Pressure Controlled to +0/-10 psia
Well Flow – 290,000 lb/h @ 612 psia, 488F, 32% Inlet Vapor Quality
Axial Impulse Turbine

Two-Phase Kinetic Energy → Shaft Power

Impulse Turbine – No reaction or pressure drop
  • Low operating speed
  • Low runaway speed
  • Low axial thrust

TWO-PHASE JET FROM NOZZLE

GAS

LIQUID
Measured Power vs. Predicted for Two-Phase Turbines

- geo east mesa
- geo roosevelt
- geo raft river
- geo desert peak
- geo coso
- geo cerro prieto
- liquid nitrogen
- refrigerant 134A
- Refrigerant 245fa
Carrier 19 XRT Chiller – Variable Phase Turbine

Two-Phase Turbine

75 Units in Operation for 10+ Years, with Absolutely No Turbine Problems
Variable Phase Turbine – LNG J-T replacement

- Generator
- LNG inlet plenum
- VPT nozzle (1 of 10)
- LNG flow
- VPT turbine rotor
Variable Phase Cycle – with VPT
Practical Example of Low Temperature Resource

• 1060 gpm geothermal resource @ 164°F, 40°F cooling water
• A specific ORC produces 400 kW net
• A VPC could produce 715 kW net → 80% more power
  – VPT rotor is 28” OD, 1800 rpm

Practical Example of Moderate Temperature Resource

• 450 gpm geothermal resource @ 300°F
• A specific ORC produces 675 kW net (170°F return)
• VPC: 1292 kW net (105°F return)
  or 923 kW net (170°F return)
  – VPT rotor is 2’ OD, 3600 rpm
R134a Performance vs Geothermal Return Temperature

97% Gen, 98% Gear, 77% Pump, 95% Motor, 80 °F Tcond, 100 MMBTU/hr @ 250 °F inlet, 160 °F return

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Exchanger Pinch Point</td>
<td>10 °F</td>
</tr>
<tr>
<td>ORC expander shaft efficiency</td>
<td>82%</td>
</tr>
<tr>
<td>VPT nozzle efficiency</td>
<td>92-97%</td>
</tr>
<tr>
<td>VPT rotor efficiency</td>
<td>78-85%</td>
</tr>
</tbody>
</table>

Calculated

Net Power (kWe) - no Cooling Parasitic

Return Temperature (°F)
ORC vs. VPC Comparison (90 °F Condensing Temperature)

VPC Performance Advantage
A 10 kW VPC test skid was built for validation of performance predictions.
Test results have been exceeding expectations
1 MW VPC Geothermal Plant

- Designed for DOE/Coso Geothermal
- Target: $2,000/kW installed
Variable Phase Cycle Advantage

Thermodynamics
- More power from geothermal resource → better project economics
  - Eliminates separator/preheater → simplified control/start-up

Synchronous speed (3600 rpm or 1800 rpm)
- Eliminates gearbox → eliminates lube oil system
  - Can eliminate shaft seal → hermetic turbine/generator with zero leakage
  - Overhung rotor eliminates coupling/field alignment
- Modularity → Family of designs

Discrete Nozzles
- Unlimited Pressure Ratio
- Increased turn-down
- Adjustability to changing resource conditions

Relatively Low Jet Velocity → well below erosion threshold

Impulse Turbine
- Low runaway speed
- Low thrust load
- Shaft seal against low pressure
- No close clearances with rotor
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