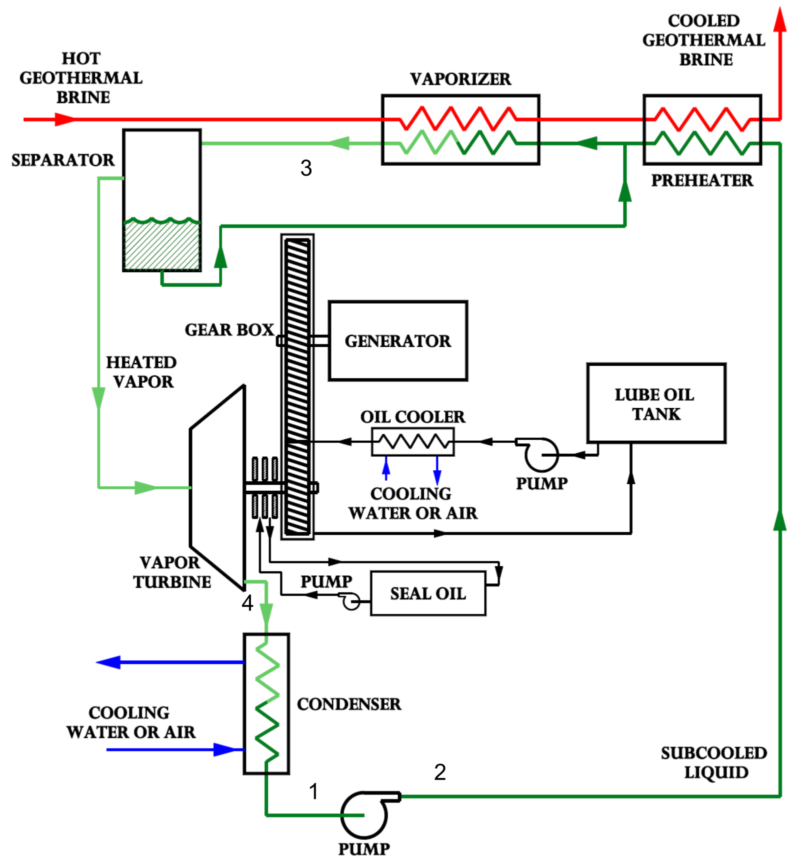
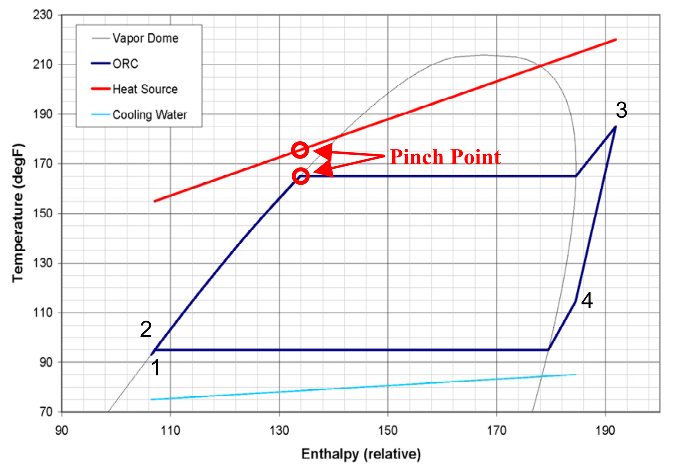
New Turbines to Enable Efficient Geothermal Power Plants

Organic Rankine Cycle





The organic Rankine cycle tries to match a sensible heat source with the latent heat of refrigerant vaporization. A pinch point is created, limiting the return temperature. The result is decreased geothermal utilization.

Radial inflow turbines are most commonly used.
Some negative features are: high optimum speed, 3-D blade geometries, and erosion susceptibility.

NEW TURBINES TO ENABLE EFFICIENT GEOTHERMAL POWER PLANTS
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KEYWORDS
geothermal utilization, low temperature geothermal, efficiency, exergy, thermodynamic cycle, binary cycle, Kalina cycle, Variable Phase cycle, organic Rankine cycle, radial outflow turbine, axial impulse turbine

ABSTRACT

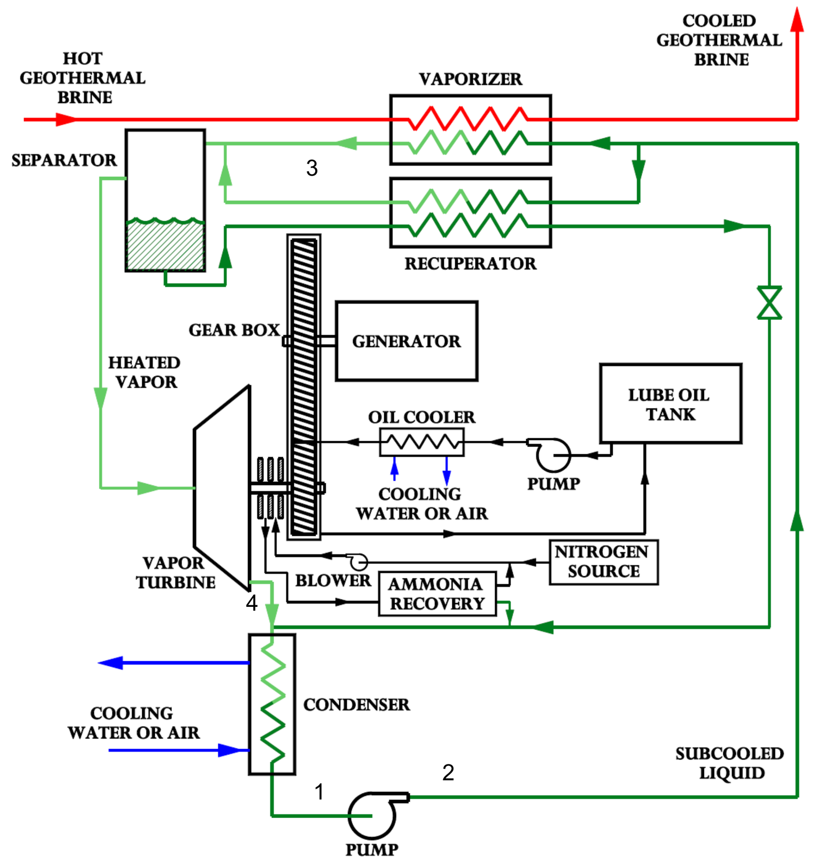
Efficient resource utilization is critical in the viability of geothermal projects. Novel thermodynamic energy conversion cycles exist that are superior to the traditional organic Rankine cycle. Two new turbines have been developed that enable the economic and efficient implementation of these cycles that maximize the geothermal resource utilization. The turbines, the Euler Turbine and the Variable Phase Turbine, can increase power production by as much as 30-50% from low temperature resources and enhanced geothermal resources when compared to commercially available organic Rankine cycles.

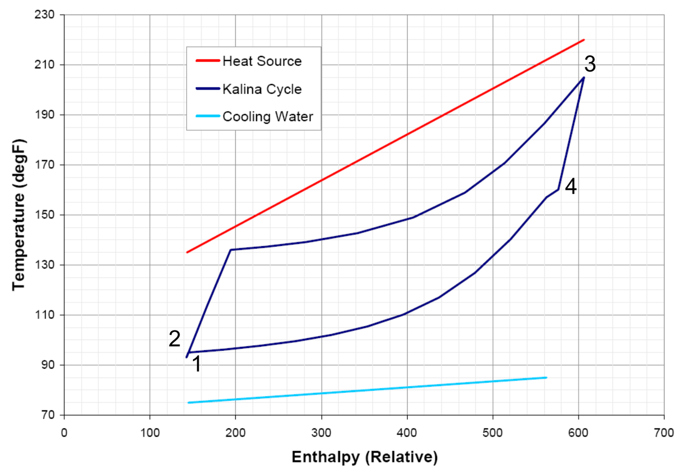
The Euler Turbine is a radial outflow turbine originally developed for energy recovery in steam systems. Commercial units of 275 kWe capacity are operating on steam, some with isentropic efficiencies above 80%. The Euler Turbine is also currently being implemented in a 600 kW Kalina cycle in Bruchsal, Germany.

The Variable Phase Turbine uses axial impulse turbine technology that is well adapted to the expansion of transcritical or flashing liquid flow. The high isentropic efficiency, typically greater than 80%, enables a liquid heat exchanger cycle to be used, avoiding the pinch point limitations of the evaporator in an organic Rankine cycle. Because this cycle can use a significantly lower exit temperature, significantly more energy can be extracted from a given resource. The resulting power advantage of 30-50%, leverages the total development cost of the geothermal project. A 40% increase in power production from a given geothermal resource lowers the total capital cost—including exploration, drilling, and surface plan— by 29%.

Results of analytical models for cycles utilizing the Euler Turbine and Variable Phase Turbine will be presented along with geothermal power plant designs for both. Additionally, experimental results of operating the first two-phase closed cycle power system with a Variable Phase Turbine will be presented.

Kalina Cycle

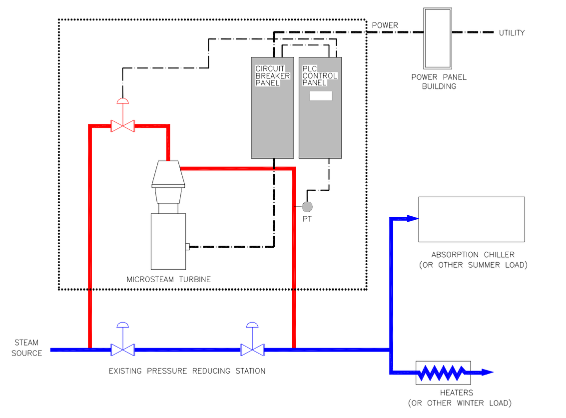




The Kalina cycle was invented by Dr. Alexander Kalina. Replacing the organic working fluid of the ORC is a non-azeotropic mixture of ammonia and water. The variable temperature boiling reduces the effect of the pinch point, allowing for a lower return temperature. The result is increased geothermal utilization.

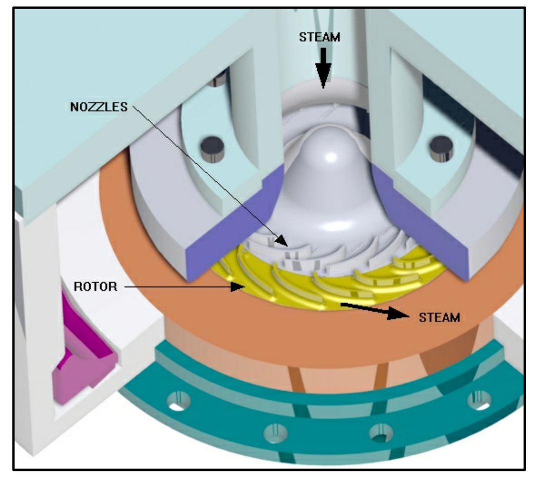
Euler Turbine

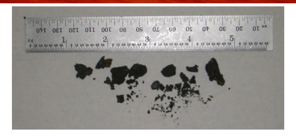
A radial outflow turbine, called the Euler Turbine, was developed for the target market of steam pressure reducing valve, or PRV, replacement. The Microsteam Power System uses an Euler Turbine to convert this previously wasted energy into power.
The highest measured shaft efficiency is over 80%.
More than a dozen units are located in hospitals, commercial buildings, and universities.



The radial outflow design of the Euler Turbine gives it high efficiency and ruggedness.
The optimum speed of a radial outflow turbine is about half that of a radial inflow turbine.
The pressure gradient and centrifugal forces at the nozzle-rotor interface of the radial outflow turbine are in the same direction, ejecting moisture and particulate outward.

Constructed from titanium alloy, the Euler Turbine is incredibly erosion resistant.
The nozzle and blade rows are 2-D, making them rugged and easily machined.

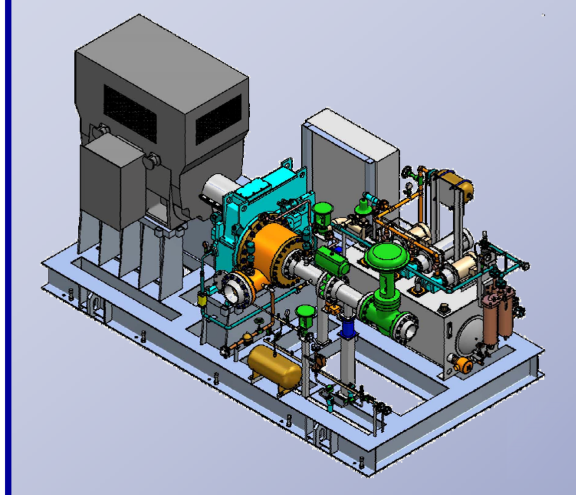


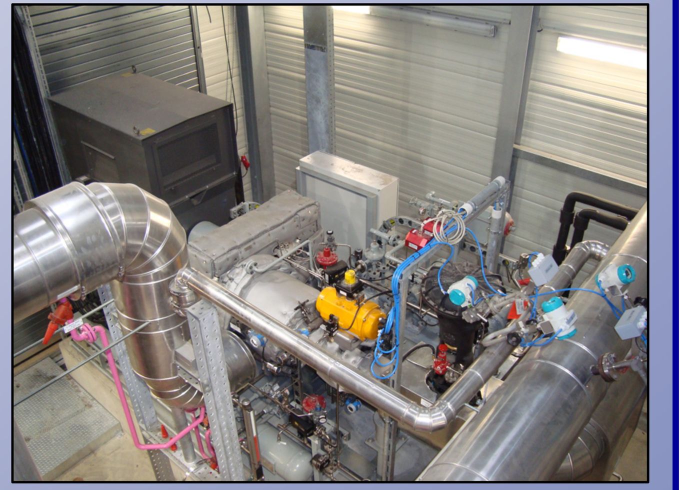


The ammonia-water mixture in the Kalina cycle doesn't vaporize entirely. A separator supplies saturated vapor to the turbine inlet, thus moisture resistance is important.

Euler Turbine technology was applied to a 600 kW Kalina cycle in Germany.
The turbine-generator system was factory tested at part load using a pressurized nitrogen system, 50 Hz diesel generator, and load bank for reduced installation time.

The unit is installed onsite, but unfortunately they have had problems with their hot water system, delaying startup.



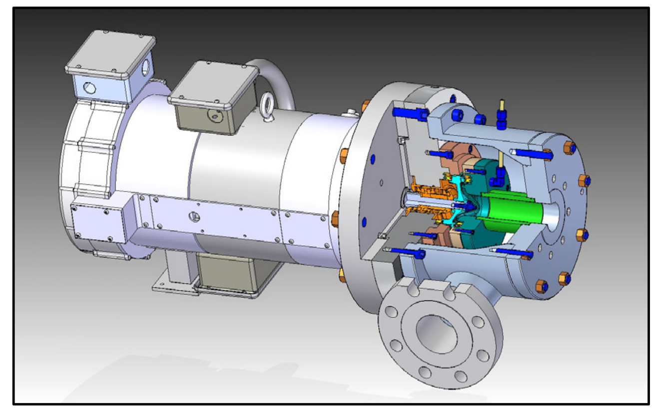


Ammonia Content	Mass %	92.7
Mass flow	kg/s	4.83
Inlet temperature	°C	115.3
Inlet pressure	bar a	20
Outlet pressure	bar a	7.81

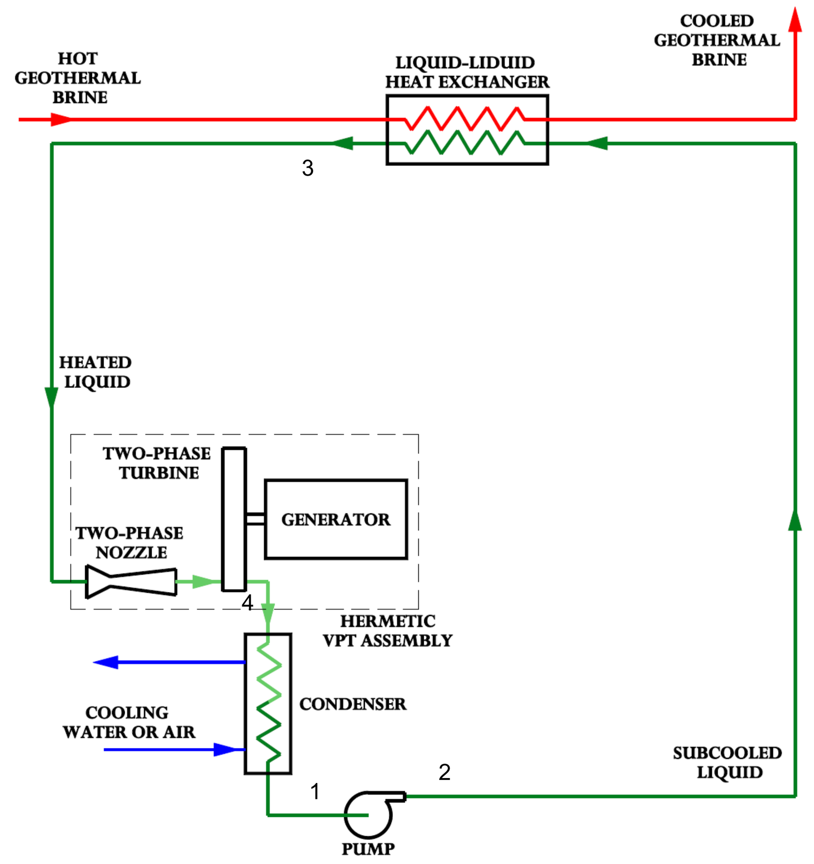
27,800 rpm → **single stage gearbox**
Moisture resistant → **saturated vapor inlet**
2-D titanium blades → **rugged and corrosion resistant**
Efficient → **82%**

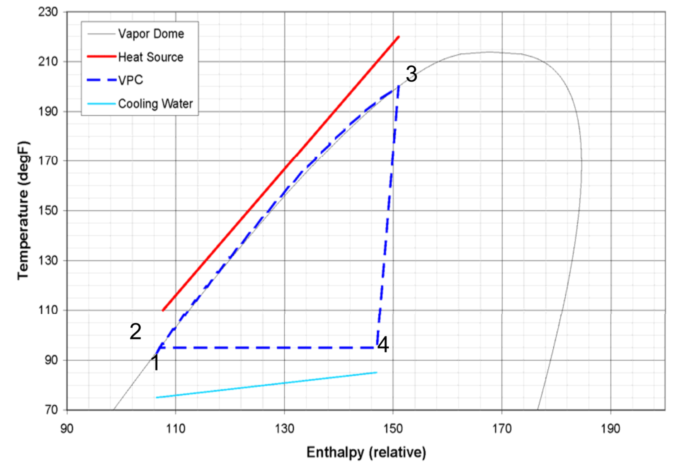
90 kW Euler Turbine with High Speed Generator

For a Kalina cycle plant in Japan we are supplying a 90 kW unit using Euler Turbine technology with a high speed generator.
The overall length is 2.5 feet.
The rotor is 4.6" in diameter and weighs 1.3 lb.



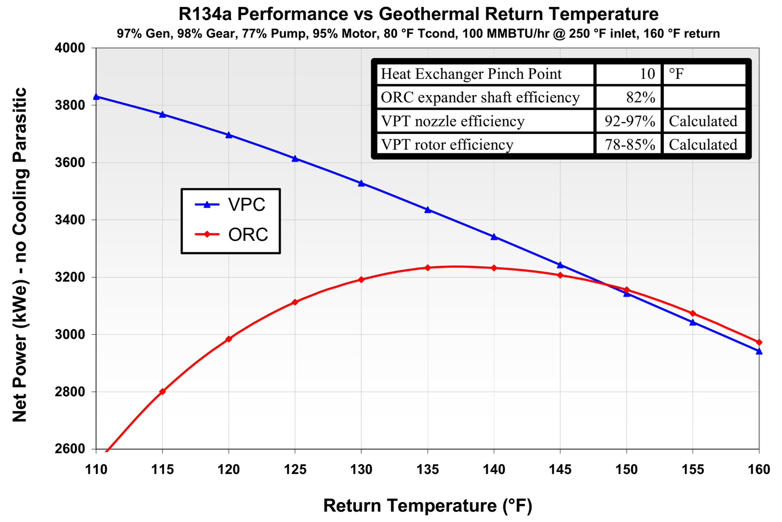
Variable Phase Cycle

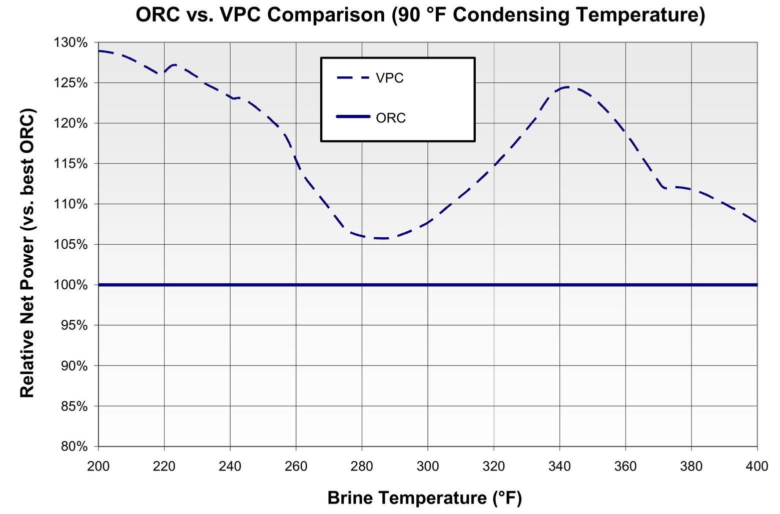




The Variable Phase cycle (VPC) eliminates the pinch point. Liquid refrigerant is pumped (1→2), heated to boiling in a liquid-liquid heat exchanger (2→3), put through a two-phase expander (3→4), and condensed (4→1).

The separator vessel as well as the preheater are eliminated. The necessary component to allow use of the VPC is an expander that can handle two-phase flow.

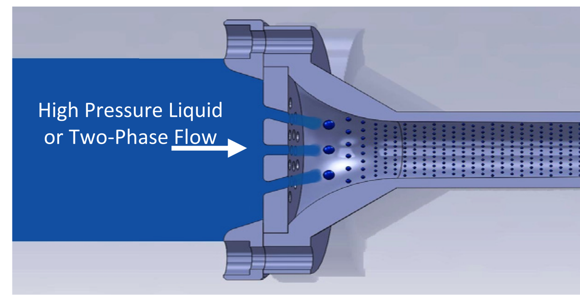




Variable Phase Turbine

Two-Phase Nozzle: Enthalpy → Two-Phase Kinetic Energy

- Pressure reduction → liquid flashes
- Vapor shear stress breaks up the liquid phase into small droplets
- Vapor transfers momentum to the droplets
  - Small droplets → close-coupling of phases → efficient acceleration
- Unlimited Pressure Ratio
- Equations derived at JPL. Experimentally verified.

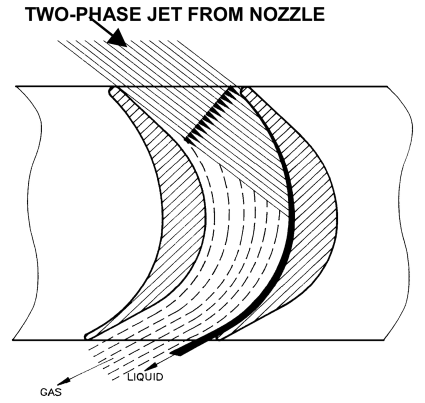


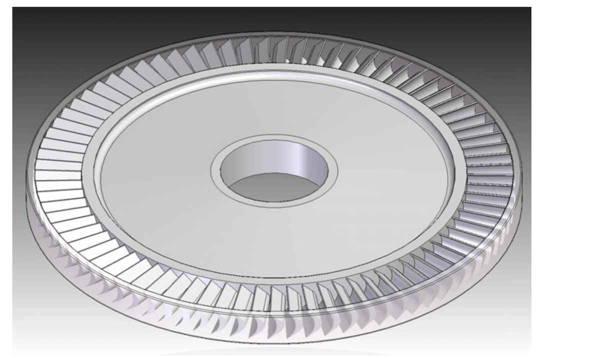
Axial Impulse Rotor: Two-Phase Kinetic Energy → Shaft Power

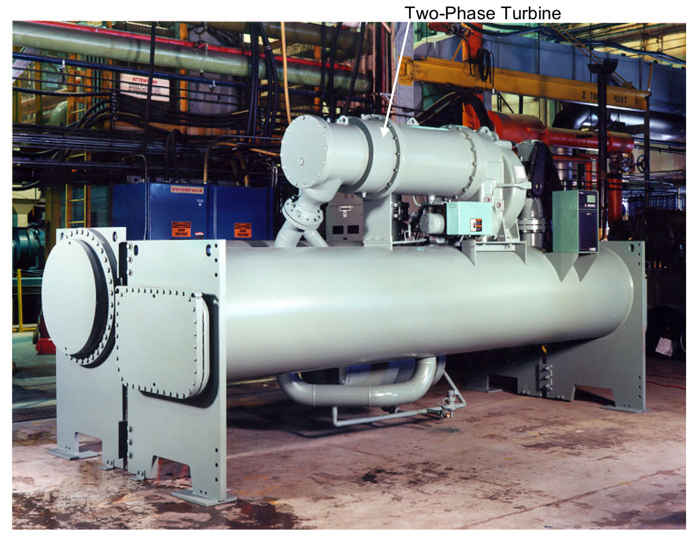
Relatively low jet velocities – high momentum of liquid working fluid
- Low operating speed – 3600 or 1800 rpm (synchronous speeds)
- Below erosion threshold

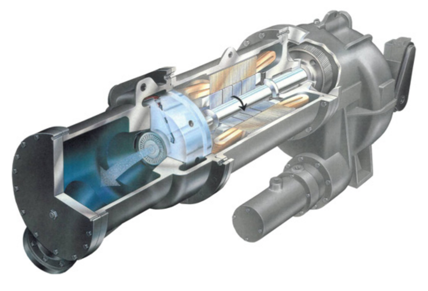
Impulse Turbine – No reaction or pressure drop
- Low runaway speed
- Low axial thrust

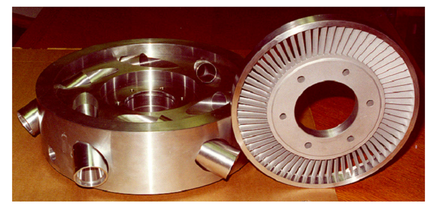
Special blade contour minimizes liquid momentum and friction losses











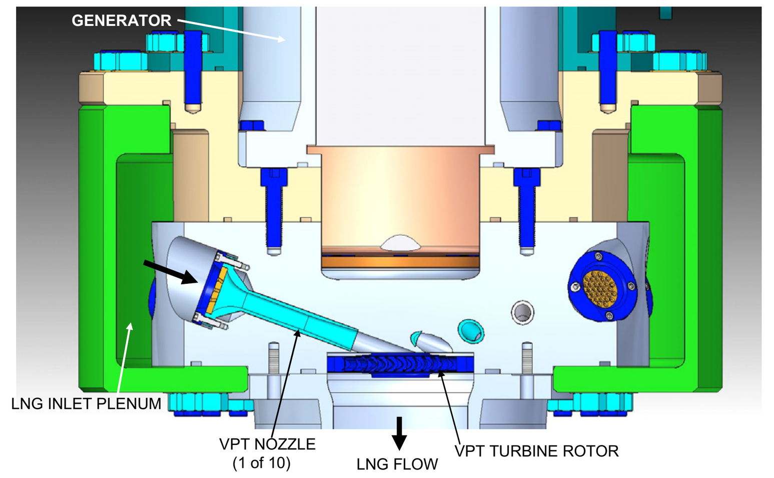
The Variable Phase Turbine, or VPT, combines the two-phase nozzle and axial impulse turbine technologies.

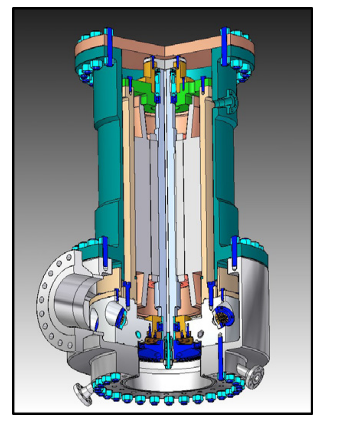
Its first commercial application was in a 500 ton electric chiller. In a vapor compression cycle, the expansion valve can be replaced with a two-phase turbine. The rotor is placed on the motor shaft to reduce the compressor load.
The system efficiency gain is 7-8%.

75 units have been in successful operation for over 10 years with absolutely no turbine problems.

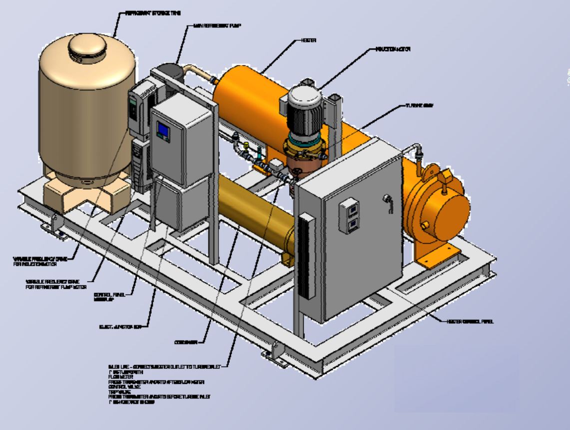
This cross-section shows the configuration of the VPT nozzles and rotor. Up to 12 discrete nozzle inserts are spaced around the rotor. This allows for modularity and the ability to adjust to changing resource conditions.

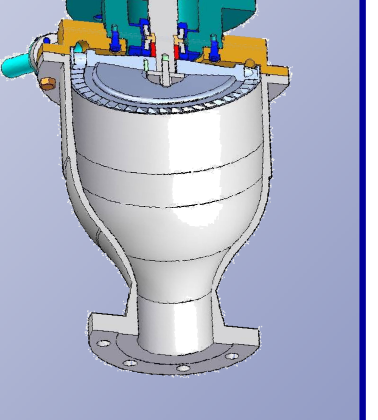
The application of this VPT is liquid J-T valve replacement in an LNG plant. The generator is submerged in the process LNG, eliminating the shaft seal.
We have an agreement with an Oil and Gas major to develop the turbine as it will improve their plants' outputs by up to 3%.



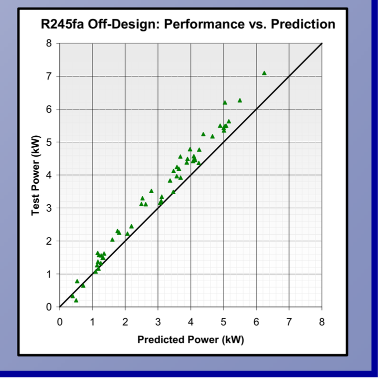


10 kW Pilot Plant

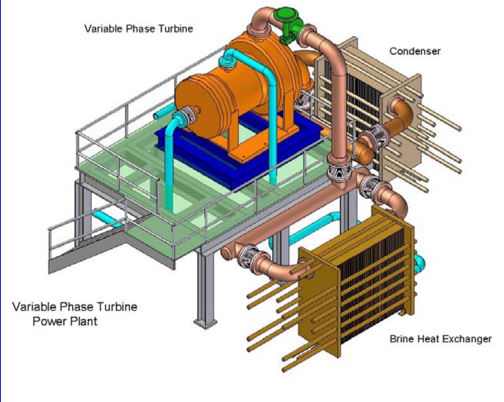




Energent built a 10 kW pilot plant to validate the performance predictions.
It is a self-contained, closed-loop VPC using an electric heater to simulate a heat source.
The system has performed better than predicted, validating the analytical model.



1 MW VPC Demonstration Plant



A DOE program has been awarded for a 1 MW VPC to be installed at Coso Geothermal. The heat source is 225 °F brine separated from the flash. Due to the high TDS, the heat exchanger will be a shell-and-tube type.

Summary of VPC advantages over ORC

Thermodynamics
- More power from resource → project economics
- Eliminates separator/preheater

Synchronous speeds (3600 rpm or 1800 rpm)
- Eliminates gearbox → eliminates lube oil system
  - Can eliminate shaft seal → hermetic turbine/generator
  - 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 clearances with rotor

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