BINARY PLANTS

GENERAL PRESENTATION

Context

Geothermal resources vary in temperature from app. 50°C to 350°C. With dry steam or flash steam plants an economical exploitation of the geothermal resource for electricity generation is efficiently and economically possible at temperatures of above 180 °C. Moderate-temperature geothermal water between 75 ° and 180 °C is by far the most common geothermal resource. Common dry steam or flash steam plants cannot efficiently exploit this low and medium temperature resource. **Binary cycle power plants** are able to exploit energy from geothermal water with temperature less than 175 °C. This system is currently state of the art for electricity production from low and medium temperature geothermal resources.

State of the art

A **binary cycle power plant** is a type of geothermal power plant that allows cooler geothermal reservoirs to be used than with dry steam and flash steam plants. They are used when the temperature of the water is less than 175 °C.

For binary plants two different systems currently are state of the art, the Organic Rankine Cycle (ORC) and the Kalina Cycle:

- In 1961 the first prototype of an **Organic Rankine Cycle** (ORC) was developed. An ORC uses an organic, high molecular one component mass fluid with a liquid-vapor boiling point, occurring at a lower temperature than the water-steam phase change. The working fluid in a Rankine Cycle is in a closed loop and is circulated and re-used constantly. Lowest possible temperature for ORC heat recovery is about 95 °C. With the pilot developed within the Low-Bin project, this temperature was lowered in 78°C
- The Kalina Cycle, invented by the Russian engineer Alexander Kalina and firstly demonstrated in 1967 in Paratunka, Kamchatka, Russia, is a thermodynamic cycle for converting thermal energy to mechanical power, optimized for use with low to medium temperature geothermal sources. The cycle uses a two component working fluid and a ratio between those components is varied in different parts of the system to increase thermodynamic reversibility and therefore increase overall thermodynamic efficiency. Multiple variants of Kalina cycle systems are specifically applicable for different types of heat sources.

The two systems differ especially in the used working fluid. As ORC uses a one component mass fluid, mostly butane or pentane hydrocarbon, the Kalina cycle uses a working fluid with at least two components (typically water and ammonia) that makes it possible to adjust the ratio between the two components in order to increase the thermodynamic efficiency of the Kalina system. The Kalina system shows higher efficiency in the use of the geothermal resource.

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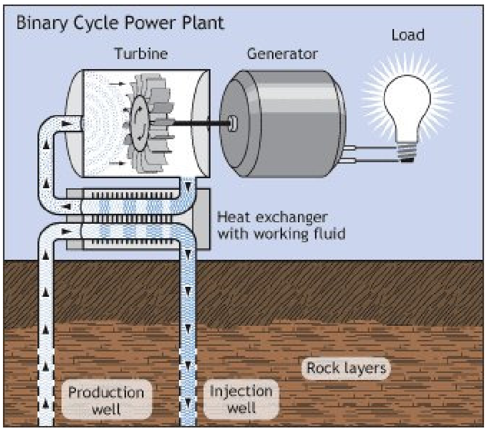
Geothermal solution

Moderate-temperature geothermal water between 75 ° and 180 ℃ is by far the most common geothermal resource. Common dry steam or flash steam plants were not been able to exploit this low and medium temperature resource. Research on a solution started already more than 50 years ago. The first binary cycle on ORC technology was already prototyped in 1961, the first binary cycle on Kalina technology in 1967. These demonstration projects were a breakthrough as they allowed the use of much lower temperature geothermal fields that were previously unrecoverable. In August 2006 a power plant in Alaska (Cheena Hot Springs) started that required temperatures of just 77 ℃. This is currently the geothermal plant with the lowest working temperature.

A binary plant is able to exploit the low to medium temperature geothermal resources for electricity production. Conducted as a cogeneration plant with cascade use of the geothermal resource the binary plant is also able to use the geothermal resource for direct uses like heat production, greenhouses, spa, drinking water, spirulina growing, etc. This cascade use of energy leads to an efficient exploitation of the geothermal source.

A binary cycle geothermal power plant pumps hot water from a production well through a heat exchanger. In the heat exchanger, heat is transferred from the geothermal water to a second "working" or "binary" fluid with a low boiling point. This binary fluid is pumped at fairly high pressure (500 PSI) through the heat exchanger, where it is vaporized and then directed through a turbine. The vapour drives the turbine and is then condensed by cold air radiators or cold water to its liquid state and cycled back through the heat exchanger. The cooled geothermal water is returned to the underground reservoir by the re-injection well.



The efficiency of a binary plant is comparably low and economics questionable at low temperatures. That is why binary plants are often constructed together with a district heating system as cogeneration plant. In Europe binary plants often are rather small plants, often in sizes less than one megawatt.

Higher temperature (>150℃) geothermal heat sources enable combined heat and power generation. The condensing temperature is set to a higher temperature, allowing the cooling water to be used for space heating. The global energy recovery efficiency is therefore increased, at the expense of the electrical efficiency. The ORC is perfectly adapted for this kind of application. However, it is important to keep in mind that for low-temperature geothermal sources (typically less than 100℃), the efficiency is very low and depends strongly on heat sink temperature.

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The Kalina Cycle shows better performance for lower temperature of the heat source (< 150 °C), while the ORC yields higher gross capacity for a heat source temperature above 150 °C. The maximum power points of the Kalina plants are found at higher return temperatures of the brine than those of the ORC. This quality is beneficial if the brine is used for electricity production and heating purposes at the same time. A shift of the maximum power point to lower return temperatures of the brine could be achieved by changing the set-up such as additional heat exchangers. In summary, the Kalina plants generally extract less heat from the geothermal brine than the ORC, but convert this heat with a higher thermal efficiency. On the other hand, the ORC suffer from a comparatively low thermal efficiency, especially in the lower temperature range.

As a result, binary power plants can generate electricity using geothermal reservoirs of lower temperature, increasing the number of geothermal reservoirs in the world that can potentially be used for generating electricity. Binary power plants are generally more expensive to build and operate than flashed steam plants. However, binary power plants use geothermal heat and water from low and medium temperature more efficiently and have no emissions.

Current research development to improve the efficiency of binary plants

Refrigerant based working fluid for low temperature use

UTC has developed an Organic Rankine Cycle (ORC) utilizing an organic based refrigerant as working fluid instead of water/steam. Through this refrigerant based working fluid commercial off-the-shelf air-conditioning and refrigeration equipment can be simply used for the bulk of the system. The ORC turbine is mostly identical to a standard centrifugal vapour compressor used in water-cooled chillers. The shell and tube heat exchangers used for the vaporizer-evaporator and condenser, are nearly the same to the chiller barrels found in the standard water chiller. This combination of equipment and supply chain synergy has created an extremely cost effective geothermal power plant. The system can operate on a wide range of geothermal resource temperatures starting as low as 74°C – the lowest temperature demonstrated anywhere in the world.

New geothermal heat extraction process on basis of biphasic fluids

Currently the Pacific Northwest National Laboratories (PNNL) works on an advanced heat recovery method to improve the efficient use of low-temperature 'hot rock' resources. The aim of the research work is to enable power generation by enhanced geothermal systems from low-temperature geothermal resources at an economical cost. PNNL will therefore develop a new biphasic fluid with rapid expansion and contraction capabilities. When exposed heat brought to the surface from water circulating in moderately hot, underground rock, the thermal-cycling of the biphasic fluid will drive a turbine to generate electricity. To improve efficiency, nano-structured metal-organic heat carriers are added to the system, which highly increase the power generation capacity to near that of a conventional steam cycle. This new technology is expected to be a leap in electricity production from low to medium geothermal resources.

FOCUSING ON THE GEOTHERMAL SOLUTION

Current status of the solution

		Comments
Scientific Project (only on paper or under preparation)	☐	
Demonstration project	☐	
Scientific Pilot	☐	
Industrial Pilot	☐	
Industrial stage	☒	Binary plant is a proven technology that is already in the industrial stage. Several companies are presently working to improve this technology.
Other?	☐	

Advantages

	(1, 2, 3, 4 or 5) *	Comments
Environmental	5	No emissions during the production process as it is a closed loop
Economical	4	State-of-the-art in low temperature geothermal exploitation, little problems in efficiency
Social	4	No pollution, clean energy, independence from fossil fuels
Scientifically	3	ORC and Kalina are proven technologies but the end of the research in binary plant technologies is not reached yet. Especially the increase of efficiency is one main field of research.

Advantages against other applications

- Utilizing low temperature geothermal resources for electricity production. There is no alternative for a binary cycle.
- Geothermal binary power generation is a completely pollution free technology as it is a closed loop system. This leads to an effectively reduction of greenhouse gases emissions to the atmosphere compared to power generation by fossil fuels.
- Geothermal resources are exploited with the highest possible efficiency, when electricity generation is combined with district heating. This improves the overall energy efficiency.
- Binary plants increase the use of renewable energy by a cost reduction to geothermal cogeneration (short term) and hot dry rock (long term) exploitation schemes.

Focusing on Economic Feasibility

- Estimated costs

  A standard binary plant of 5 MW is expected to have a total investment of 35 to 45 Mio €. The specific investment costs vary strongly by the heat source temperature, the heat sink temperature, the chosen conversion cycle and the depth of drilling.

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- Impact on profitability

  Without a binary plant low temperature geothermal resources cannot be exploited. This makes the technology favourable. The profitability of a binary plant depends on the temperature of the geothermal resource and the flow rate. The heat source temperature is the main factor, followed by the temperature of the heat sink.

EXAMPLES/CASE STUDIES

You can find here a list of examples for existing power plants

- Altheim, Austria (250 kW_e)
- Bad Blumau, Austria (0.25 MW_e)
- Bruchsal, Germany (0.55 MW_e)
- Cheena Hot Springs, USA (400 kW_e)
- Hilo, USA (30 MW_e)
- Husavik, Iceland (2 MW_e)
- Kizildere, Turkey (24 MW_e)
- Landau, Germany (3.2 MW_e)
- Maguarichic, Mexiko (300 kW_e)
- Neustadt-Glewe (max. 230 kW_e)
- Pico Vermelho, Azores, Portugal (10 Mw_e)
- Ribeira Grande, Azores, Portugal (13 MW_e)
- Simbach-Braunau, Austria ?? (0.2 MW_e)
- Soultz-sous-Forêts, France (EGS) (1.5 MW_e)
- Susanville, USA (600 kW_e)
- Svartstengi, Iceland (8 MW_e)
- Terceira, Azores, Portugal (12 MW_e)

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Geothermal binary plants of Europe

Country	Site	Installed Power MWe	Manufacturer
France	Soultz (EGS)	1.5	Turboden
Portugal	Azores, Ribeira Grande	13	Ormat
	Azores, Pico Vermelho	10	Ormat
	Azores, Terceira	12	Ormat
Germany	Neusdadt Glewe	0.2	GMK
	Landau	3.2	Ormat
	Unterhaching	3.7	Siemens (Kalina)
	Bruchsal	0.55	Siemens (Kalina)
	Simbach	0.2	Turboden
Austria	Bad Blumau	0.25	Ormat
	Altheim	1	Turboden
Iceland	Husavik	2	Exorka
	Svarstengi	8	Ormat
Turkey	Kizildere	24	Ormat

(from Low-Bin final workshop, held in Simbach-Braunau Friday 28 August,2009)

Case studies: the geothermal power plant Unterhaching

Location

Germany, Bavaria, Unterhaching

Technical characteristics of the operation

- ***Type of exploitation***

  The geothermal power plant Unterhaching exploits hot water with a Kalina Cycle system.

- ***Production***

  Electricity: Electricity production started in June 2009. A total of 21.500 MWh/a of electricity is produced with a capacity of 3.36 MWe.

  Heat: The geothermal power plant Unterhaching currently has a capacity of app. 38 MWth. In the final expansion a planned capacity of 70 MWth will be expected.

- ***Pilot project?***

  The geothermal plant in Unterhaching is no direct pilot project buthas set standards in two fields:

  - First use of a private insurance on non-discovery of the geothermal resource.
  - Pilot project for the use of the Kalina technology for electricity and heat production from geothermal energy resources in Germany.

- ***Specifications***

  Two successful drillings have been executed.

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– ***1st drilling (development well):*** In 3.350 m depth geothermal water with a maximum temperature of 122 °C and a flow rate of 150 m/s is existent.
– ***2nd drilling (reinjection well):*** In 3.580 m depth geothermal water with a maximum temperature of 133 °C and a flow rate of 150 m/s is existent.

- ***Impact on market***

  The power plant Unterhaching supplies 3,500 households with district heating

  Since the commissioning of the district heating network around 22,500 tonnes, on the long rund an expected number of 40,000 tonnes of CO^2, can be saved.

- ***Financial aspects***

  The total investment costs for the geothermal plant amount to app. 80 Mio €. The Kalina system including maintenance for 10 years is total up to 16 Mio €. The financing of the project consisted of the municipality's own resources (7.8 Mio €), debt and funding. The funding covered national and regional resources.

  National:

  - The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) corresponded largely to the project application, and granted funds in the amount of 4.8 Mio € including
    - Grant from the "Future Investment Programme" for seismic research
    - Investment subsidy of 1.2 Mio € for the promotion of demonstration projects
    - R&D contribution for accompanying research during the pump test of the 2nd drilling
    - Renewable Energy Programme (1.475 Mio €) for the district heating (Kreditanstalt für Wiederaufbau - KfW)
    - Subsidy of 4.8 Mio. € for the use of a Kalina system (BMU/KfW)
  - Loan of 22.4 Mio € for the promotion of demonstration projects (BMU)

  Regional:

  - Subsidy of 400.000 € for the non-discovery insurance (Bavarian State Ministry for Economic Affairs, Infrastructure, Transport and Technology)

SOURCES AND CONTACTS

EU-funded project Low-Bin
http://www.lowbin.eu/

Where is it possible to find more information, pictures, etc, (short extract)

Binary plant
http://en.wikipedia.org/wiki/Binary_cycle_power_plant

Organic Rankine Cycle
http://en.wikipedia.org/wiki/Organic_Rankine_Cycle

Kalina Cycle
http://en.wikipedia.org/wiki/Kalina_cycle

Husavik Geothermal Plant
http://www.oh.is/skrar/File/Skyrslur_og_greinar/Enskar/HUSAVIK_GEOTHERMAL_POWER_PLANT.pdf

Neustadt-Glewe Geothermal Plant
http://www.erdwaerme-kraft.de/

Maguarichic Geothermal Plant
http://www.ormat.com/FileServer/f1d7901fd797bec4b82469f71b4b7292.pdf

Susanville Geothermal Plant
http://www.energy.ca.gov/geothermal/direct_use_projects/SUSANVILLE_CITY.PDF
http://www.osti.gov/geothermal/servlets/purl/7336356-xGVlJm/native/7336356.pdf

Cheena Hot Springs Geothermal Plant
http://www.yourownpower.com/Power/
http://www.yourownpower.com/Downloads/PowerPlantReport.pdf

Hilo Geothermal Plant
http://www.punageothermalventure.com/PGV/16/equipment-technology

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