THE VELIKA CIGLENA GEOTHERMAL BINARY POWER PLANT

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ABSTRACT

The speech describes the binary power plant that will be installed at the Velika Ciglena geothermal field, in Croatia. Turboden awarded the Engineering Procurement and Construction of the binary power plant, including the engineering of the geothermal gathering and reinjection system. The design conditions allow for a 15 MWe design capacity. The Velika Ciglena field is a liquid dominated geothermal field known since the eighties. It is foreseen that after the first power plant, further potential expansion of the geothermal capacity installed will be possible in the area.

1. TURBODEN COMPANY AND EXPERIENCE

Turboden Srl is an Italian company founded in 1980 by Prof. Mario Gaia of Politecnico di Milano. Today it is the world leader in ORC systems, with more than 320 references worldwide. Since 2014, Turboden is part of the Japanese industrial giant Mitsubishi Heavy Industries, the world leader for installed power from geothermal sources. The long experience of Turboden in the construction of ORC turbo-generators made it possible to realize and commercialize modules with high performance as well as high reliability and availability, together with low maintenance and operational costs. Turboden ORC modules have demonstrated an average availability exceeding 98% and more than 7.200.000 operating hours have been reached.

The company strengths are the flexibility in the working fluid choice, with experience with nine different fluids already used and others under testing phase, and the related turbine optimization. Beyond the power plant supply, there is the after-sales service activity, with 24/7 remote assistance by Turboden from its offices in Brescia, Italy, where a team of engineers constantly check the performances of the Turboden ORCs. Turboden is promoting its versatile ORC technology and know-how in the geothermal energy field.

After the construction of prototype plants in Italy and Africa in the early Nineties, Turboden completed a 1,000 kWel plant in Austria: this plant is working since 2001. In Q4 2012 Turboden started up the first supercritical ORC plant in Europe, a 500 kW prototype with hybrid direct cooling, and tested its flexibility with highly variable heat input. Turboden has made plant performance optimization a key point to surpass its competitors and has thus won a tight competition achieving the award of tenders for the design, construction and start-up of 3 geothermal ORC plants in Bavaria (5+ MW each). These plants have been successfully commissioned and started-up in Q1 2013. Geothermal water at 140 °C is pumped from a depth of approximately 5,000 meters. These plants are air-cooled and carefully integrated into the rural context and prepared to supply heat to the existing district heating network. In 2015, another 4MW plant with similar technical features has been commissioned in the Bavarian region.

A further 5 MW geothermal plant (with 15% steam quantity) in the Oita prefecture in Japan, Kyushu Island, has been commissioned in June 2015 and since then, has been outperforming the guaranteed performance values. Beside the performances, also the availability has reached outstanding values: in the first year of operation from the very first start-up, therefore including also the fine tuning period, the availability and the capacity factor (energy produced / nominal energy) reached values around 98%. This project presents special electric features. The electric output can never exceed the 5 MW, therefore an automatic regulation system has been implemented. Moreover, it is possible to operate the plant in “island mode”, i.e. not connected to the electric grid.

Turboden has also recently built as EPC a 1,700 kWel plant in Soultz-sous-Forets (France), the first EGS (Enhanced Geothermal System) developed field in Europe. The water, injected under pressure, reaches deep impermeable rocks fractured by the drilling where it is heated at 170°C.

Finally, a 3 MW ORC plant has been awarded to Turboden and is presently under construction for the community of Afyonkarahisar (Turkey). It will exploit a 110 °C geothermal liquid source by means of water cooled ORC. This plant demonstrates that also small-scale / low-temperature ORC plants are feasible, even in less subsidized markets.

2. THE VELIKA CIGLENA PROJECT

The Velika Ciglena project is located in the Northeastern Croatia, where in the early 90’s, during an oil exploration, an unexpected high temperature water was found (about 170°C) [1]. The license was bought by Menderes Geothermal Elektrik Uretim A.S., a company part of the MB Holding group. MB Holding, active in construction and textile industries besides the energy sector, founded Menderes Geothermal Elektrik Üretim A.Ş. (MEGE A.Ş.) in 1999. In May 2006, MEGE started Dora-1 (7.95 MWe), the first private Geothermal Energy Plant in Turkey. Today, MEGE in Turkey has 3 plants in operation (+50 MW) and a fourth one under construction.

The full Engineering Procurement and Construction scope well-to-well, including the engineering of the geothermal gathering and reinjection system (turn-key EPC for all the surface facilities) has been awarded to Turboden for the Velika Ciglena project. The design conditions allow for a 15 MWe design capacity. Turboden will install a single turbine that will be the largest ORC turbine ever. The working fluid selected is isobutane and the cooling system will be an Air Cooled Condenser. An additional 1,5 MWe will be produced considering the expansion of the Non Condensable Gases (NCGs), that differently would be simply discharged in the atmosphere as a common practice for almost all the geothermal binary plants in operation (figure 1).

As geothermal consultant for the steam-field engineering, Turboden is cooperating with Mannvit, an international consultancy firm that provides services in the fields of engineering, geoscience, environmental studies, and construction material research and that has followed the project since the very early phase.

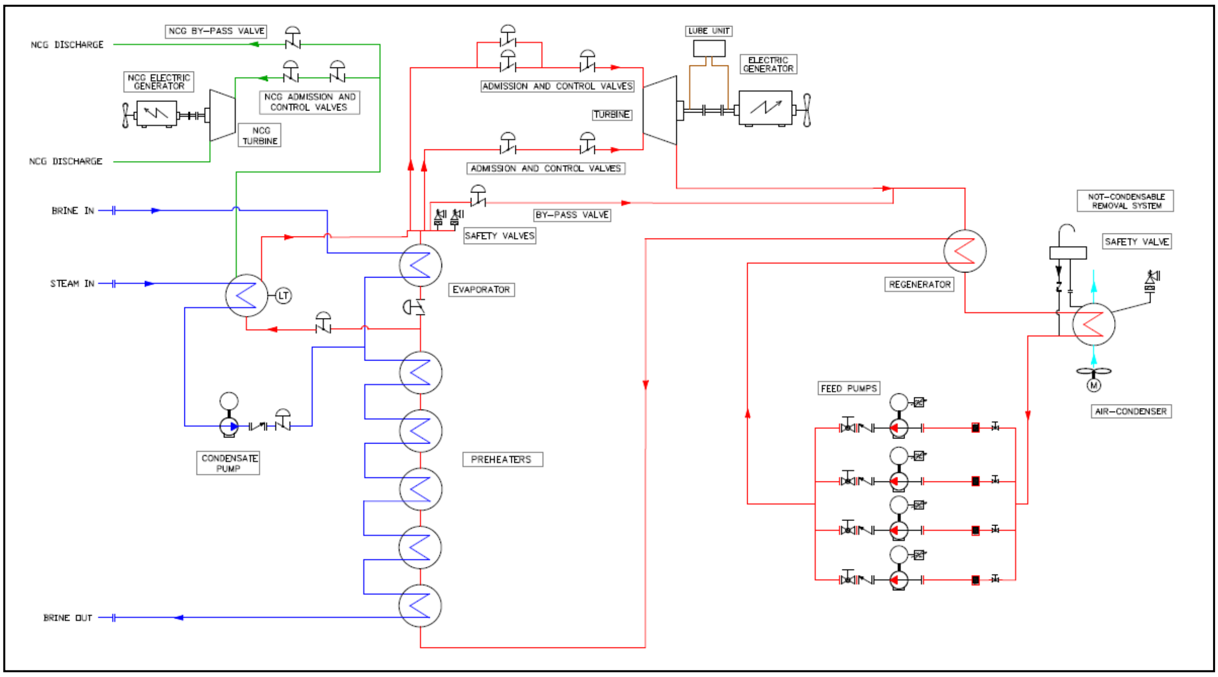


Figure 1 - Piping & Instruments diagram

3. THE GEOTHERMAL AREA

The Velika Ciglena project area is located in the Southwestern Pannonian basin, in the Bjelovar sub-depression, Northeastern Croatia (figure 2).

Figure 2 - Croatian part of the Pannonian Basin System

The reservoir was discovered in 1990 by the VC-1 well within the scope of exploration for oil, conducted by INA-Naftaplin. Oil was not found, but a promising geothermal potential was established. A casing was lowered into the well at the depth of 2574 m. An unusually high temperature (172 °C) was registered for the region. Currently, four deep wells are located on the project area (see the figure 3).

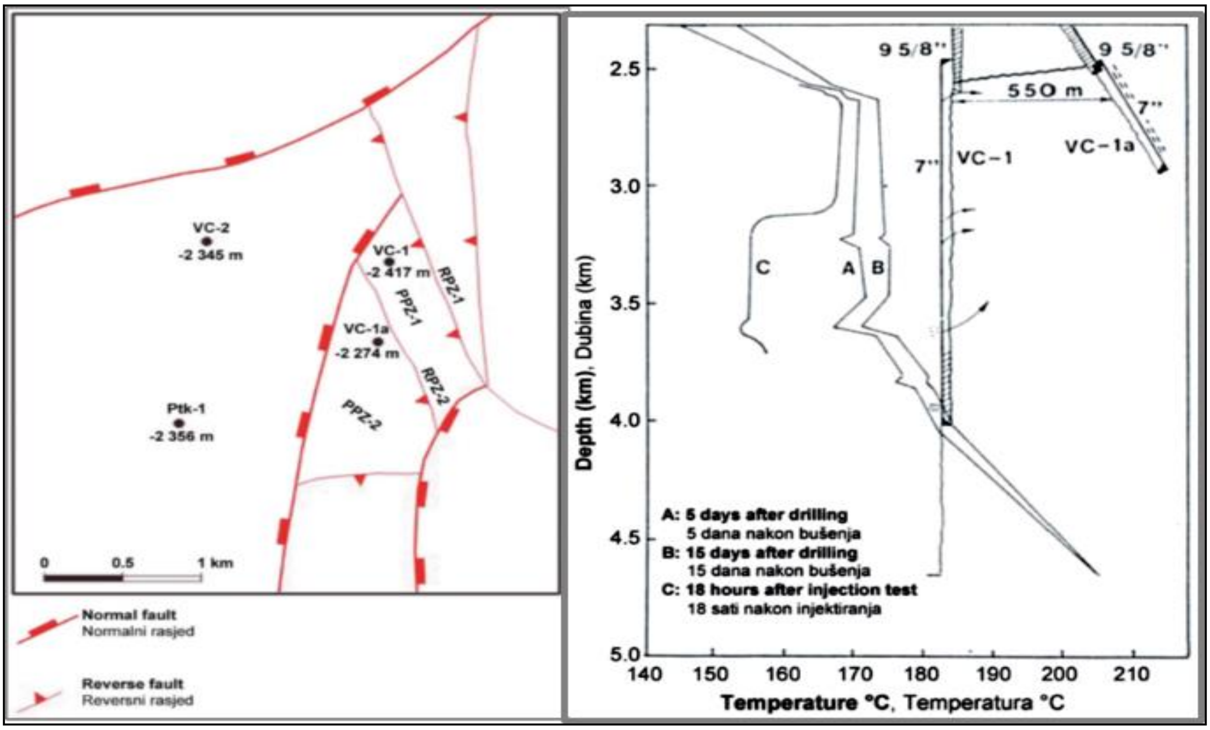
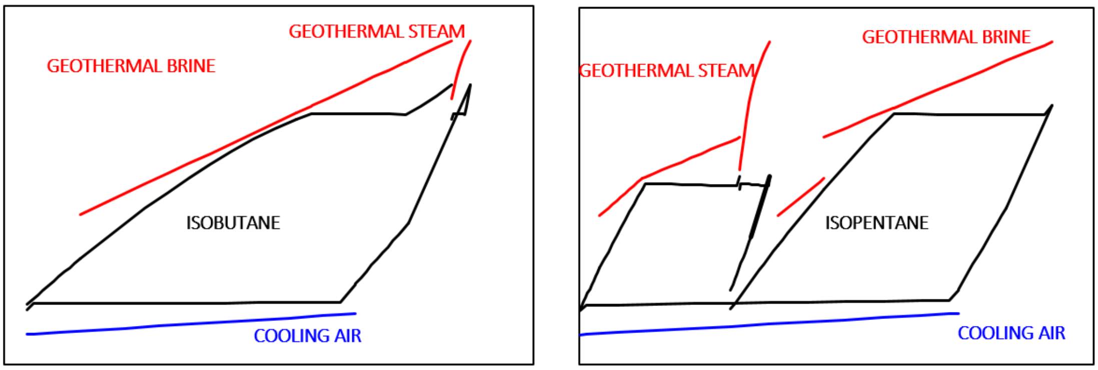


Figure 3 - Tectonic map of the Velika Ciglena geothermal reservoir and Temperature measurements in the VC-1 well

The selected configuration is to use wells VC-1 and VC-1A as production wells while VC-2 and PTK-1 are injection wells. The temperature measurement of VC-1 as a function of depth is illustrated in the figure 4 below. The diagram shows the measurements made after circulation and one well log measurement made after an injection test is also presented. The latter measurement indicates significant and quite uniform cooling at 3200-3600 m depth interval. This observation could be explained by the higher injectivity index of deeper zone compared to the top zone of the reservoir [3]. The design flow is 400 t/h per each well, at 25 bar WHP.

Figure 4 - (T, Q) diagrams for one pressure level and two pressure level cycle



4. THE PROCESS OPTIMIZATION

The inlet and boundary conditions of the Velika Ciglena project are summarized in Table 1:

Brine Temperature	°C	170
Brine Mass flow	kg/s	211
Separation Pressure	bar(a)	25
Steam Temperature	°C	170
Steam Mass flow	kg/s	11
Design ambient temperature (dry bulb)	°C	15

Table 1 - Resource data of Velika Ciglena project

As a standard approach, Turboden carried out an optimization process evaluating different plant configurations (one pressure level vs double pressure level) and different fluids. The selection of the fluid is made already considering which configuration of the plant is the best one. In other words, the two evaluations (fluid selection and cycle configuration) must be done at the same time.

The comparison has been carried out taking into account many parameters in order to make it meaningful: first of all the pinch point analysis, but also turbine efficiency, type of heat exchanger's geometry, design pressure, type of control of the cycle, cost of the equipment.
The best solution with one pressure level was reached with isobutane while a suitable fluid for a comparison with a two pressure level cycle was isopentane. As shown below, the best choice based on best match of heat exchange profiles is the sub-critical one pressure level cycle with isobutane.

Besides the performances, with an increase in net power output of +3,7%, the single level solution with only one turbine is an easier configuration that allows also lower investment costs. It has been calculated a difference of -7,9% in the capex (Table 2).

Table 2 - Power output and investment cost comparison

Single level compared with double level [Δ%]	
Net power output and energy production	**+ 3,7 %**
Investment cost	**- 7,9 %**

Once the best fluid and cycle configuration has been selected, the third step has been to adjust the cycle parameters (e.g. working fluid flowrate and evaporation pressure) - by means of a sensitivity analysis – in order to finally select the design point and geometry of equipment. The main parameter in the optimization of an ORC power plant is the heat exchanger's surface. Neither the cheapest plant nor the most expensive one in terms of cost / kW, is the most remunerative solution for a business plan: the optimum has to be discovered according to the specific case.

Turboden performed a sensitivity analysis to evaluate which was the optimum cost of surface / net power ratio, according to the economic boundary conditions, to calculate the payback time and merit in the overall Internal Rate of Return (IRR) of a more performing but expensive solution. The final offered solution has been recognized to produce 10% higher energy compared to the other competitors offering different plant configurations.

5. THE LARGEST ORC TURBINE EVER

Turboden during its more than 35 years of ORC manufacturing has always increased the size of its axial turbines step by step, enlarging the diameter of the shaft but keeping the same successful technical features that have always characterized its products for the efficiency and reliability. As shown in the figure 5, in the first years Turboden used one shaft for all its turbines. Then, growing up the size of the standard ORC units, a bigger shaft was installed for the units between the 2 and the 3 MW. From 2009 till 2014, the ORC sizes kept growing up to 8MW per single unit and so did the turbine: a larger shaft was implemented. During the last year, in 2015, the new challenges of the market brought the opportunity to Turboden to improve its innovation leadership by increasing the power limit of a single shaft ORC turbine to 20 MW.

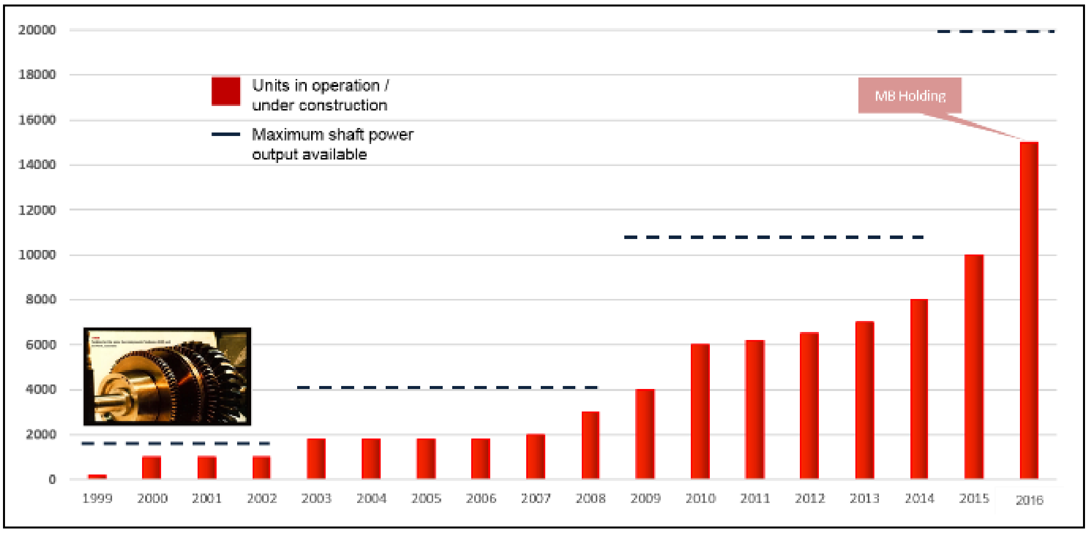


Figure 5 - Turboden single shaft turbines power output over time

Even if the size of the turbines keeps increasing, the concept of Turboden axial turbines has remained the same since the origin, with proven technical features that have made Turboden products famous for the efficiency and the reliability. In the last years, together with the size, Turboden increased also the number of stages of each turbine. Being able to select the right number of stages allows Turboden to reach always the top of the efficiency. In the axial configuration it is possible to make every stage work at the optimum distance from the rotation axis, so that the linear velocity is always suited to reach the highest efficiency.

The axial configuration is the most common in the Power Industry sector as it has a very high and proven efficiency and durability. Moreover, the axial configuration allows to get higher power output in a very compact design. In the last years the geothermal industry has been asking for larger capacity binary power plants, and therefore also the ORC turbines are growing. In 2015 the average size was 6,3 MW [4] but recently the trend shows a lot of requests in the 10 – 25 MW range.

For the Velika Ciglena project, Turboden will use the new turbine frame that can fit, with its larger capacity shaft, applications in the range of 20MW (for single shaft). In particular, this turbine is designed to produce 15MW electric gross. It has 5 stages that allow to reach an isentropic efficiency up to 91% (figure 6). The rotating speed is 1.500 rpm (no use of reduction gear is needed).

This turbine has been designed to maximize the performance not only in the design point, but in the whole working range: efficiency is very high in all the off-design conditions. This turbine is designed to run 99% of the time with an isentropic efficiency between 87% and 91% (according to the ambient temperature that spans from -2°C to +35°C).

These extraordinary results in turbine efficiency are the results of the long commitment of Turboden in R&D. Moreover, after the acquisition of Turboden by Mitsubishi Heavy Industries (MHI), many engineering activities are carried out in strong co-operation with Mitsubishi Turbine Team.

Figure 6 – The turbine for Velika Ciglena (15MW) is the first one with the new frame for application up to 20MW

The standard engineering activities that Turboden carried out in order to design a turbine are, among the others, Computational Fluid Dynamic Analysis, which includes Stator Rotor Fluid Dynamic Interaction and Turbulence Analysis: optimal performance is researched by improving the first guess geometry through an iterative approach.

Mechanical and thermal stresses on the casing and on the shaft are carefully checked in order to minimize the profile losses. Also a Rotor Dynamic Analysis and a Rotor Stress Analysis are carried out. All these analysis bring to a solution that not only maximizes the performance, but also allows to minimize the vibrations.

6. CONCLUSIONS

The Velika Ciglena project demonstrates the Turboden competence both in fluid and in process selection. With an ad-hoc turbine design with cutting edge solutions, it was possible to maximize the power output and the exploitation of the resource. With the largest ORC turbine ever manufactured, Turboden is focusing more and more its efforts to improve the efficiency and costs of geothermal binary ORC plants, thus allowing a wider diffusion of its technology. The Pannonian basin, like many other areas in the world, are perfectly suitable to be a breeding ground for binary technology.

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