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Developing Geothermal Energy in Croatia by Using Old Oil Wells for Power Generation

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ABSTRACT

In this study, first geothermal potential of Croatia is introduced. Then, information on regional geology and the area's geological setting, including structural geology, tectonics and heat flows are given. Afterwards, planning and execution stages of rehabilitation of oil and gas wells thorough workover operations converting them finally geothermal wells are presented. Testing results of newly created geothermal wells for the project target are examined. Finally, the basis of power generation capacity and future vision are reported.

Power generation project has been developed in Velica-Ciglena license area in which four abandoned oil wells are used, two for production and two for reinjection. It was planned a 16.5 MWe power generation capacity with 800 t/h flow rate obtained from production wells.

1. INTRODUCTION

In the Republic of Croatia, there is a several-centuries old tradition of exploiting geothermal energy for medical and bathing purposes. The temperatures of water from most of these activities are relatively low or about 40°C. Springs of about 60°C are, however, found in two locations, i.e. Topusca and Toplice. These aquifers are found in thick naturally fractured carbonaceous formations at shallow depths (Virkir-Ina, 1995). In addition to the use of geothermal energy in spas, technics and technologies for obtaining geothermal energy from deep geothermal reservoirs have been developed as a result of research into oil and gas reservoirs. In the search for hydrocarbon deposits, several promising geothermal reservoirs were discovered. Most of these are assumed to be closed or semi-closed hydrogeological units with little or no natural recharge. Their exploitation therefore requires reinjection (Virkir-Ina, 1995).

Jelic et al., 2005 declared 28 geothermal resources that were identified in Croatia. They also pointed out only 18 of them are utilized for direct use purposes.

Energy Institute of Croatia prepared a report in 1998 showing that there are several medium temperature geothermal resources with relatively lower temperature of geothermal water in the range of 90-140°C (Guzovic, et al., 2012).

Oil and gas wells in high heat flow areas have lately been popular and planned for using as geothermal resources. Serpen and Babalik, (2007) and Serpen, (2008) proposed using such geothermal potential for direct utilization of geothermal energy. Greenhouse heating with the heat provided by the oil wells of Karakush field has recently developed in the Adiyaman area of Turkey. The Velica-Ciglena project in Croatia would be one of the pioneers for power generation from existing abandoned oil wells.

2. REGIONAL GEOLOGY

Geological and geophysical exploration for hydrocarbon is the historical basis for geothermal exploration in this region. Regional gravimetry surveys which were started in 1941 showed up the local Tertiary basin and deep structures. Knowledge of local geological settings has since been improved mostly by use of two-dimensional seismic and drilling in the 1950s and 1960s (Virkir-Ina, 1995).

In general, there are two different regions in the Republic of Croatia both in geological and geothermal point of view. The Dinaric area lies in southeastern part of country with predominantly Mesozoic carbonate rocks characterized by 20 to 60 mW/m^2 terrestrial heat flow density. The northeastern part of country is found within the southern part of Pannonian basin which is dominated by clastic sedimentary units of Quaternary and Tertiary age that overly the crystalline bedrock and occasionally Mesozoic sedimentary units. Terrestrial heat-flow density is relatively high, ranging from 60 to 100 mW/m^2 (Jelic et al., 2005).

Pannonian is a sedimentary basin developed in Central Europe extending to northern Croatia in its southern part. Oil and gas exploration and exploitation activities had been conducted for the last 80 years, and 3500 wells have been drilled. Temperature measurements conducted in those wells have revealed anomalous heat fluxes up to 110 mW/m^2 in those parts of the country. It is believed that thinning earth crust in that region created high heat flow and also helped the formation of hydrocarbon resources within the sedimentary series.

Geothermal fluids circulate in the bottom of sedimentary series in highly fractured carbonate rocks which overly metamorphic basement. Sedimentary series have deposited in grabens which, in turn, have created favorable structures for circulation of deeply laying geothermal fluids. These are similar structures to Aegean region of Turkey and Basin and Range of USA. They are deeply seated occurrences with almost no outflowing regions to the surface. Had no hydrocarbon exploration been conducted they would not have been unearthed.

3. GEOLOGICAL SETTING

The Velica-Ciglena area is within the Pannonian basin system, which is an integral part of the Alpine Mountain belt. Stratigraphycally, the rocks observed in the area are of Tertiary, Mesozoic, and Paleozoic age. The Permian carbonates form the base of the geothermal systems, on the other hand, Mesozoic carbonates form the geothermal reservoirs, and Tertiary clastic rocks serve as cap rock for the geothermal systems.

The area was extensively deformed by Mesozoic thrusting and subsequently disrupted and strongly overprinted by a complex system of Cainozoic normal and wrench faults. In the area these features are locally hidden by a thick sequence of sedimentary rocks of Neogene-Quaternary age. Paleogene sedimentary rocks are not widely registered on the consolidated Paleozoic and Mesozoic rock basement. Neogene sedimentation dominated, however, the final stage of uplifting in the outlying portions of the Carpatians and Alps as general. Rapid subsidence, associated with large normal faults system formed a deep water basin, rapidly filled by a large progressing delta. These events mainly took place in the early to middle Miocene period ending in the upper Miocene-Quaternary time (Virkir and Ina, 1995).

Such opening up basins was in this location evidently complicated with a complex system of Late Miocene extensions and resulting strike-slip faults bounded with locally compressed deformations, which is important for the geothermal systems. In geothermal terms there is still a strong heat flux from the mantle and good sealing of young sediments. Fractured Mesozoic carbonaceous rock forms highly permeable geothermal reservoirs (Virkir and Ina, 1995).

4. VELICA-CIGLENA FIELD DEVELOPMENT

The Velica-Ciglena prospect is located 8 km from the Bjelovar town. The land relief is nearly a plain with the altitude of 130 m. There is a road nearby. Fig 1 shows license area on the topographic map with four located abandoned oil wells, which were drilled in 1990s by Ina-Naftalin for oil exploration purpose.

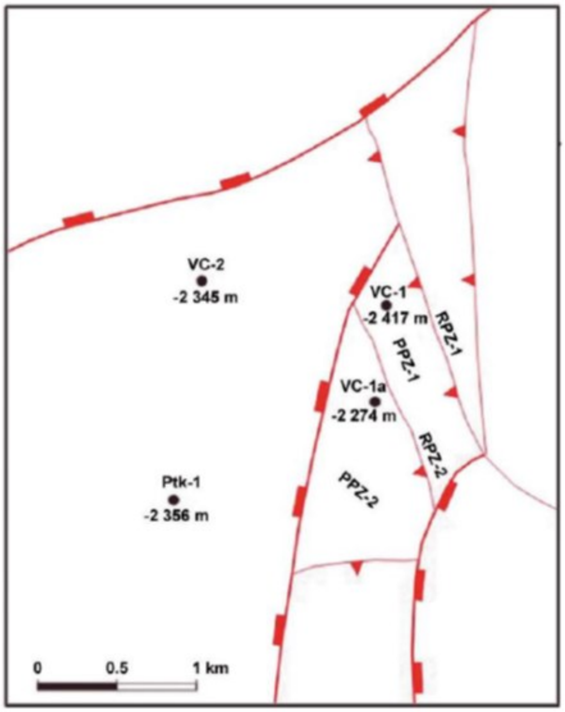

Figure 1:Map of Velica-Ciglena license area.

The first exploration well VC-1 was drilled to 4790 m with intermediate $9^{5/8}$" casing set to 2574 m at the top of Triassic carbonate breccias where high temperatures (170°C) were observed.

Further drilling through Mesozoic limestone and dolomite formations was conducted with sometimes total loss of circulations or some intervals were drilled underbalanced with nitrogen-water mixture circulation. Logging identified two highly fractured zones between 3000 m to 3600 m, but no oil. Carbonate formations were cased with 7" liner set at 4043 m and partly cemented. Drilling proceeded to 4790 m through Permian basement. Based on this discovery of geothermal potential a directional well (VC-1A) was drilled at the same location in 1991. This well drilled through Triassic carbonate complex and this section was cased by 7" slotted liner.

Fig 2 illustrates 3 temperature surveys taken in VC-1 well after drilling completed. The survey taken after an injection testing identified several high permeable zones.

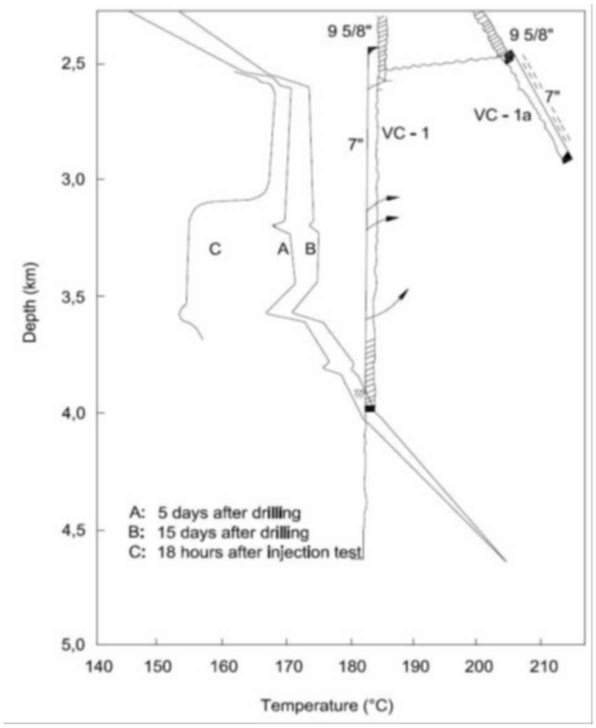

Figure 2: Temperature profiles of VC-1 well (Cubric and Kolbah, (2011)

Analysis of geophysical logs indicated a porosity of 30% in the upper zones, while lower zones porosity is around 16%. On the other hand, well logging and temperature surveying identified 5 permeable zones in well VC-1A (Cubric, and Kolbah, (2011).

Nearly constant temperature (zero gradient) from the top of reservoir to 3600 m implied that indicated permeable zones in both wells were connected to each other, and this reflects convection cell which formed a geothermal reservoir (Virkir, and Ina, 1995).

Several testing operations have been carried out in these two wells. But wells were tested with tubing string set within the wellbores, with oil wellheads and also disposal restrictions. Therefore, the wells were not properly prepared for geothermal testing during discharges. Testing could only be conducted with small flow rates (1200 m^3/day) and the production rates for higher flow rates were projected by simulations.

Interference test was conducted with VC-1 observation and VC-1A active wells. A pressure response in the test appeared in short time. It indicated possible short circuit in the future injection-production process. Using the pressure difference between initial pressure and build-up pressure it has been estimated that the reservoir contains water volume of 200 to 250 x10^6 m^3. This volume likely comprises the reservoir volume having only extremely high permeable zones, which could be a possible short circuit for injected water (Virkir-Ina, 1995). On the other hand, the indicated volume could also be attributed to drainage area volume.

(Virkir-Ina, 1995) proposed a 4.7 MWe exploitation geothermal power generation project with these two wells, using VC-1A production and VC-1 reinjection well.

A new exploitation project was devised in 2013, taking into account Virkir-Ina, (1995)'s warning about the short circuit potential, and it was decided to use two other abandoned oil wells, which are 1.5 and 2 km away, for reinjection purposes. In this case, the first two wells VC-1 and VC-1A would be used for production. This scheme would substantially increase power generation capacity and mitigate short time breakthrough potential of reinjected relatively cold waste water.

4.1 Workover Operations in VC-1 and VC-1A Wells

In the context of the new project, workover operations were planned and executed in all four wells with the purpose of converting these old oil wells into geothermal wells. First operations were conducted in VC-1 and VC-1A wells that are selected for production. The most important objective of those operations was to investigate the integrity of those well's casing strings. First, $9^{5/8}$” and 7” casings were separately tested under high pressure. Then, CCL, CBL, GR, and multi-caliper logs were run in $9^{5/8}$” and 7” casings checking properties such as wall thickness, ovality, ID and OD; and finally integrity of casings were confirmed. Logs have also identified and confirmed old perforated intervals registered in old reports. Afterwards, CBL logs were examined and compared with the old ones. Cementing of casing columns was found satisfactory in terms of isolation and prevention of deep and upper horizons communication. Furthermore, a high expansion spool was designed and installed (Fig. 3), in order to allow for the casing's thermal expansion.

The next step was to stimulate the potential production zones. The previously perforated permeable zones were re-perforated with more dense shots in order to develop and increase inflow area. Then, new perforations were shot at other potential permeable intervals omitted in the past. Afterwards, using a RTTS packer selective stimulation operations with 50 m^3 of 15% HCl acid were conducted to the perforated intervals.

Figure 3: Christmas tree (left) and geothermal wellhead (right) of VC-1A well

Finally, the existing Christmas trees of VC-1 and VC-1A wells were replaced by geothermal wellheads seen in Fig. 3 to complete conversion process.

4.2 Testing of VC-1 and VC-1A Wells

Static, dynamic temperatures and water loss measurements were conducted in VC-1 and VC-1A wells. Static temperature profiles confirmed temperature figures previously measured. Dynamic profiles were new and they revealed that water columns temperature reached close to the surface with very small losses. Water loss profiles also confirmed the perforated feeding intervals identified mostly by previous well logging. Static and dynamic pressure profiles helped to define bottomhole pressures, which were found slightly less than hydrostatic ones. Dynamic profiles indicated NCG flashing points in the wellbores that will help to identify setting depths for inhibitor coil tubes. The amount of dissolved in VC-1A and VC-1 was found 4 to 4.5% by weight of reservoir brine, respectively.

A drawdown test was also conducted in VC-1A well as seen in Fig. 4. The results of interpretation of this test are as follows:

kh: 144.5 D-m,

s: -6.75.

As seen from the above figures the permeability of the fractured carbonates are very high, and skin factor also indicates highly fractured media.

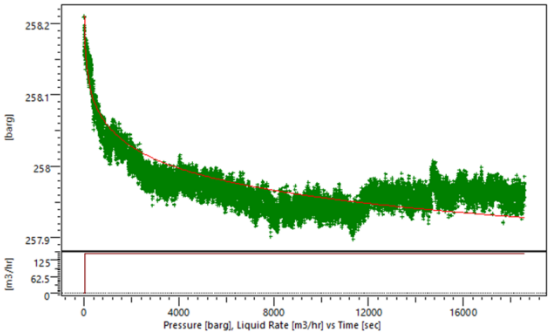

Figure 4: Drawdown test results conducted in VC-1A well

Production tests also were performed by discharging the wells up to 36 hours and their characteristic delivery curves were obtained. During the VC-1A tests the maximum production was reached to 350 t/h level since the flow pipe pipe diameter was 8”. From the trend of curve a 400 t/h of production could be estimated. On the other hand, VC-1 well with 10” discharge pipe reached to 380 t/h of flow rate. Production curves indicate approximately 400 t/h flow rate at 25 bar of wellhead pressure. Productivity index of VC-1A well was found as 587 m3/h-bar, which is unusually high.

4.3 Design Points for Power Plant

Fig. 5 illustrates a very simplified BOP conceptual design for VC-1 and VC-1A wells. Geothermal fluid from VC-1 and VC-1A wellheads flow to a common separator where water and gas (NCG+steam) are separated under 25 bar pressure. After separating conditions of operating wells under scheme are presented in Fig. 5.

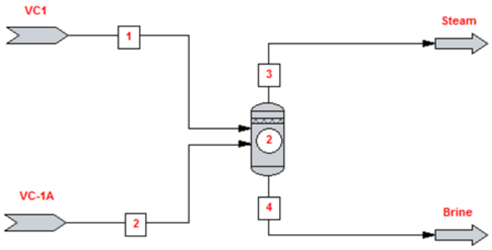

Figure 5: Simple conceptual scheme of BOP

A binary plant with 16.5 MWe gross and 14 MWe net capacities was envisaged and an order for manufacturing was placed. Since Velica-Ciglena resource's geothermal fluid has substantial amount of high pressure CO_2 to take advantage of its potential a CO_2 expander with a capacity of 1.5 MWe was added to the geothermal ORC power plant. This power figure is included in overall plant capacity given above.

4.4 Reinjection of Waste Water

Waste water discharged from the power plant is planned to be reinjected in two other abandoned oil wells, namely ptk-1 and VC-2. As seen the locations of these wells from the Fig. 1 they are roughly 1.5 and 2 km away from the production wells.

Workover operation was recently carried out in the well Ptk-1, and cement plug and a packer that had been set for abandonment purpose were cleared. When drilled initially that well had a total circulation loss at the bottomhole within the carbonate zone from which geofluid is produced through VC-1 and VC-1A wells. An acidizing operation was conducted with 50 m^3 of 15% HCl acid, to stimulate and increase injection capacity. Injectivity index, II of 15.4 t/h-bar prior to acidizing increased twofold to 33.33 t/h-bar after acidizing operation. Starting from this II figure, and taking into account of 20 bar pressure coming from the plant more than 400 t/h waste water could easily be reinjected in this well.

Workover operation for VC-2 well in under way in these days and similar operations (clearing cement plugs and packer) would be carried out. It is believed that similar results would be obtained when the operations are completed.

5. CONCLUSIONS

In the light of above mentioned the following conclusions are obtained:

- Velica-Ciglena is the first geothermal power generation project in Croatia.
- High permeability encountered in Mesozoic carbonates enabled the development of geothermal project
- Four abandoned oil wells are used for production and reinjection.
- Though oil wells were converted somehow to geothermal ones restricted diameters of existing ones prevented developing a larger capacity power generation project.
- High WHP's would enable reinjection operation without pumping help.
- A NCG expander added to ORC is the first case.

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