GEOTHERMAL RESOURCE POTENTIAL OF THE REPUBLIC OF CROATIA

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ABSTRACT

In ihe Republic of Croatia, there are two regions having geothermal energy potential. The southem area (the Dinarides) with an average geothermal gradient of 0.018 °C m^{-1} has little geothermal energy potential. The northern part, which belong to the Panonian sedimentary basin, has an average g w t h d gradient of 0.049 °C m^{-1}. Several geothermal reservoirs, discovered during hydrocarbon exploration, have been extensively tested there.

Some recorded flow rates are 50 - 80 kg s^{-1}, with well head temperatures 80 - 152°C. Geothermal energy (80 - 96° C) from three geothermal fields is utilized (reinjection is applied). Installed thermal power is 15 MWt, but the load factor is too low. It has been estimated that the total thermal power from tested reservoirs could be 815 MWt (outlet temperature 50°C).

1. INTRODUCTION

Parts of two sedimentary basins: Panonian and the Dinarides, cover nearly all the Republic of Croatia (Fig. 1.). There is a great difference in their geothermal characteristics, which haw been studied *on* the basis of numerous temperature surveys in *many* hydrocarbon (and some geothermal) exploratory and production wells, as well as via temperature surveys of the soil (Jelić, 1979). In the Dinarides, the average geothermal gradient and heat flow are:

$$G = 0.018\ ^{\circ}C\ m^{-1}$$
$$q = 29\ mW\ m^{-2}.$$

It is obvious that the Dinarides has no significant geothermal resources potential. *On* the contrary, in the Croatian part of the Panonian basin, the average geothermal gradient and heat flow is much higher, that is:

$$G = 0.049\ ^{\circ}C\ m^{-1}$$
$$q = 76\ mW\ m^{-2}.$$

Similar results have been obtained for the Hungarian part of the Panonian basin (Boldizsar and Korim, 1975). The main reason for such great contrast can be explained by the difference of the Mohorovičić discontinuity depth (Jelić, 1979). The depth of Mohorovičić discontinuity in the Panonian basin (Croatian part) is about 28 km, but in the Dinarides it is much deeper (50 km). Increased natural radioactivity was observed m tho wells m m e localities in the Panonian basin. This heat generator increases geothermal gradient (Jelić,1979). The Croatian part of the Panonian basin *consist* of a series of depressions filled with younger sedimentary rocks, predominantly of Neogene age, like clays, shales, sandstones, breccias, limestone, arcoses and quartzites.

Within the sedimentary complex, there an some intercalated igneous rocks like lavas and tuffs. The tectonics structure is mostly blocklike with prevailing vertical faults, which enable water communication and thereby a convective hut transport. Recent magmatism has not been recorded, so that kind of the heat source docs not haw *any* influence *on* the g e o t h d gradient and heat flow. There are several local positive anomalies recorded in the geothermal (and hydrocarbon) reservoirs, whose geothermal gradients (0.055 - 0.075 °C m^{-1}) are significantly higher than average. Čubrić (1993) found that such positive anomalies resulted from the spontaneous convection in the reservoirs characterized by their thickness and high vertical permeability.

The Croatian geothermal reservoirs can be divided into two groups. The first is connected with natural springs in carbonate rocks' *outcrops.* Most of them haw temperature below 40°C, whereas, in two localities the water temperature reaches 60°C (Topusko and Varaždinske Toplice). The thermal water of the natural springs has been uscd for balneology *since* ancient time, whereas, more recently, in Topusko and Varaždinske Toplice, it is also being used for heating purposes.

The second group *of* geothermal reservoirs an those discovered during hydrocarbon exploration. From a hydrogeological point of view, they are closed *or* semiclosed hydrodynamic units, without *or* with inadequate natural recharge. For this reason, in three out four reservoirs that are under production, reinjection is being *applied.* More information *on* the second group of reservoirs is given in the next chapters.

2. CHARACTERISTICS OF THE RESERVOIRS

Fig. 1. shows the locations of the geothermal reservoirs in Croatia Tabk 1 contains data regarding the reservoirs where geothermal energy has been used. For the reservoirs whose data are shown in Tabk 2 the reservoir evaluation study has been compkted in 1994 while the pre-feasibility study will be completed during 1995. To collect data for these two groups *of* reservoirs, complex logging, hydrodynamic and thermodynamic testing methods haw been used.

To predict long-term change of a reservoir temperature, the Gringarten-Sauty (1975) method has been used in the reservoir evaluation studies.

2.1. Reservoirs In production

Bizovac

It is **interesting** that at **Bizovac there is an** oil-bearing **reservoir** in a separate lithologic **and hydrodynamic** unit.

Thus at the same **field there** is *oil* **and** geothermal **energy production.** The water from Biz-gneiss reservoir contains 30 g/l **dissolved solids and** 1.5 m^3/m^3 **hydrocarbon gas.** Balneology **is** the **main** *to* use of this water, but it is **also used** for space hcating. The water **from** Biz-sandstone reservoir contains 2 g/l **dissolved** solid8 **and** 1.3 m^3/m^3 hydrocarbon gas. **This** water **is** used for space beating. **Gas is used** in a hotel kitchen. The well Biz-2 has been **used for fresh** water injection *into* **a** gneiss-IS—— so **far,** waste **gwthermal** water has **been discharged** into surficial **streams.** Separate **treating** of waste water has **been** planned. **Treated** water will be injected through tubing into

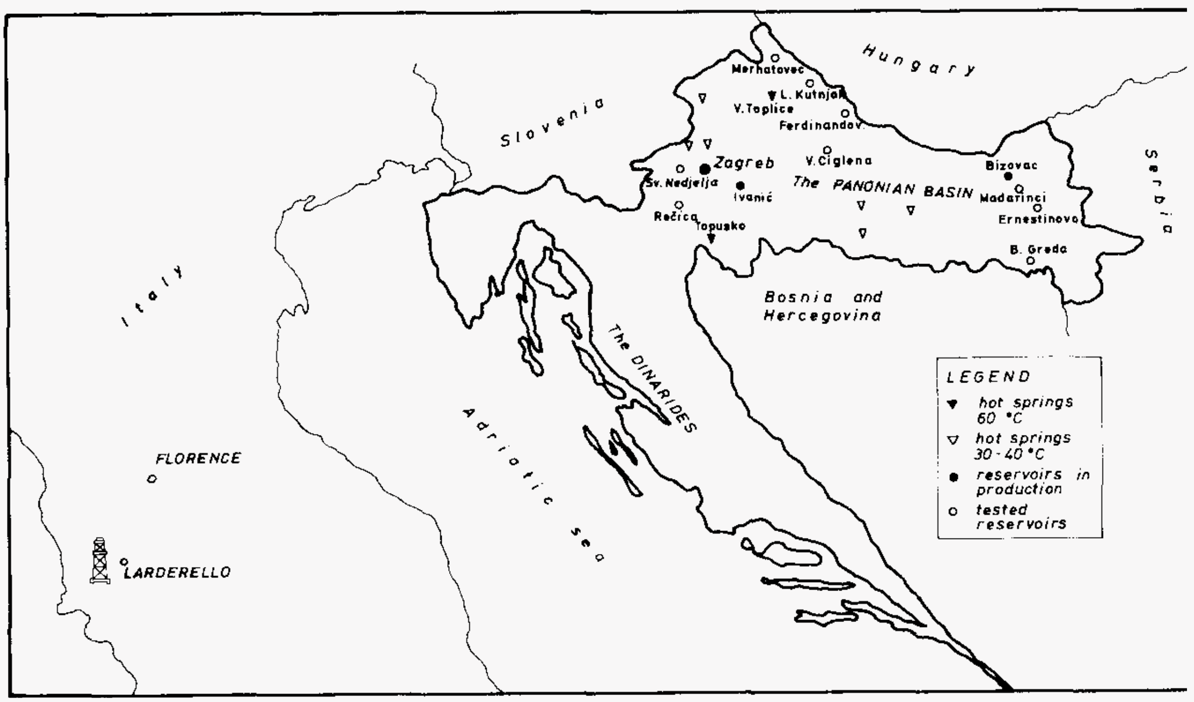

Figure **1.** Location **of geothermal reservoirs** in Croatia

Gneiss and through annulus into sandstone. **The** initial **reservoir** pressure **in** the **gneiss was** 30 ham **above** hydrostatic, but rapidly **dropped** about **30** bar **in the** first year of **production.** In the **sandstone** reservoir pressure (initially hydrostatic) **declines slowly.** Scale **appeared** m the **upper part (30 m)** of the production wells **and** in the surface facilities. Now it **is prevented** by **an** inhibitor.

Ivanić

In Ivanić locality, the water (10 **g/l dissolved** solids) is used for **balneology**. ***The reservoir pressure*** (*initially* hydrostatic) **declines slowly.**

Zagreb

In Croatia's capital - Zagreb, a very **interesting geothermal aquifer has been** discovered **by an** (unsuccessful) **oil** exploratory well (a ***total*** of **17** exploratory **and** development wells **have** been **Wed).** Biogenic limestone of **the** Miocene age underlies **the entire** town **and** the **suburbs (200** km^2), but its permeability in the major part is not high enough for reasonable g w t h d **development.** In **some** parts of the aquifer, *just* below **under** limestone, highly permeable **dolomite** has **been found.** Note, that **using** interference **tests** hydrodynamic connection **between** limestone **and dolomite** has **been proved.**

The geothermal water contains 2 **g/l dissolved solids, 0.1** m^3/m^3 CO_2 **and traces** H_2S. The very permeable part of **the aquifer** (which could **be** defined **as reservoir) covers an** area of **10** km^2 in the southwest part of the t o m (sublocalities Blato **and Mladost).**

Initial **reservoir pressure** was 106 **bars** (at **1000 m**). **Reservoir** temperature is **55-82 °C and** it depend8 *on* the natural convention, which is higher in the zones of high thickness **and** high vertical permeability (Fig. 2).

In **the** Blato sublocality, a **University** hospital was **under** construction **several** years *ago,* but *it* **has** *not* been **completed** *so* **far**

The planned t h d power (direct use) is **7** MW_t, but with heat **pumps** (which is **also planned)** it **will** be much higher.

In Mladost, then are several large **buildings** *for* **sports activity (indoor and outdoor** *swimming* **pools and two other halls),** heat for which is **etirely** supplied **by** g e o t h d energy, including peak consumption.

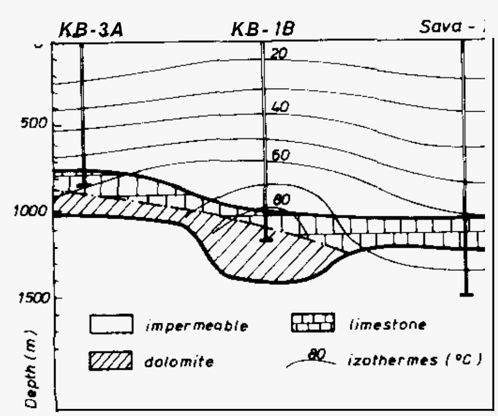

Figure **2.** **Temperature cross section** in **the** Zagreb ***geothermal field***

There are no technical problems at this site. Geothermal water flow through a closed system including the cascaded heat exchangers and the injection on-line pumps, without any contact with air. Because *of* that (and low content of dissolved solids and gas) there are no corrosion and scaling problems. Reservoir pressure dropped four bars. During reinjection it has ban maintained at 102 *bars*.

Table 1 Data of the reservoirs in the production

		Name of a (av. depth,m)	Well Name	Rate, kg s^{-1}		WHT °C	WHP	
				Prod.	Injec.		Prod.	Injec.
Bizovac	Bizovac	Biz-gneiss (1800)	Bu-2		5			50
			Biz-4	5		96	2	
	Bizovac	Biz-sandstone (1600)	Biz-2*		3			20
			Slk-1	3		85	2	
Zagreb	Mladost	Zagreb - carbonate (1000)	Mk-3	50		80	3	
			Mla-2		50			10
			Mla-1		8			15
Zagreb	Blato	Zagreb - carbonate (1000)	KB-1A	5		70	2	
			KB-1B*	50		80	3	
			KB-2A*		25			15
			KB-3A*		25			10
Ivanić	Ivanić	IK-sandstone (1200)	IvaT-1	2		62	2	

The surface facilities *make* possible to produce (and to use during summer) injected water from the well Mla-2, and to inject it into the well Mla-1. It could help to control cold front movement (in the reservoir) when the annual average flow-rate will be much higher than now. The theory is based *on* the facts that well Mla-2 has high injectivity (50 kg s^{-1} at 10 bar WHP - well head pressure) and lime thickness (fissured), but the well Mla-1 has low injectivity and high thickness (mostly intergranular porosity). Installed thermal power at Mladost site is 6.3 MW_t (direct use with outlet temperature 50 °C) and 0.86 MW_t using two heat pumps. But, even during peak consumption, *only* 40% of the available power *(direct)* is used, while the heat pumps do not work at all.

2.2. Reservoirs in the pre-feasibility study stage

Lunjkovec Kutnjak

At the Lunjkovec-Kutnjak locality, a geothermal reservoir has been tested by two exploratory *(oil)* wells. The distance between wells is 4.1 km, and an interference test proved their hydrodynamic connection.

The water contains 5 g/l dissolved solids and $3m^3/m^3$ gas (85% CO_2, about 15% hydrocarbon and traces *of* H_2S). Scale appears, where pressure is below 10 *bars*.

The reservoir rock is carbonate breccia (net pay, 80-150 m) with average porosity 7.5%. The average reservoir pressure is hydrostatic. The estimated pore volume, by a reservoir limit test, is about $10^9 m^3$ and the reservoir area about 100 km^2. The reservoir temperature varies depending *on* the depth of the top of the geothermal reservoir (Fig. 3).

In the impermeable rocks, between the geothermal reservoir and the earth's surface, the temperature gradient is higher than 0,06 °C m^{-1}. It is interesting to note that the measured static temperature in the gas reservoirs corresponds with the estimated isotherm's profile. So, it could be possible that a region of the wells Vot-1,2,4 ha a high permeability. Therefore this region will be considered in pre-feasibility study together with the regions of the tested wells Kt-1 and Lunj-1. A region of the well Leg-1j ha high temperature, but permeability probably is not high enough and the well needs some kind of stimulation.

Also, its long distance from a central region *(6 km)* is the reason that the well Leg-1j will not be involved in the first stage of pre-feasibility study.

In Table 2 one can see basic test data. The measured productivity index is 450 m^3/d bar. In the reservoir evaluation study, predictions have been for an average flow rate 80 kg s^{-1} with WHP 3-5 bars and WHT 125 - 140 °C.

To ensure such convenient flow rate for each well, the reservoir evaluation study has suggested highly slanted boreholes through the reservoir. Joshy (1984) found, that slanted boreholes with an angle of 70 degrees in a 120 m thick reservoir, increases productivity index three times compared with vertical borehole.

A reservoir development plan considers five drilling clusters with four production and two injection wells in each In the reservoir the well bottoms will form an inverted seven spot pattern, with a distance between wells of 1.2 km.

The pre-feasibility study objectives are to analyze geoheat transport to the towns (10 km distance) and possibility to convert geothermal energy into electricity by a binary process. Our preliminary calculations based *on* methods described by Ungemach (Economides and Ungemach, 1985) *shows* that single well, with 80 kg s^{-1} and inlet temperature 125 °C (outlet, 70 °C) could produce power of 1.5 MW_e, while in the case of an inlet temperature of 140 °C, produced power could be 2 MW_e.

Table 2. Tested data of the reservoirs in the pre-feasibility study stage

Location	Sublocation	Name of a reservoir (average depth, m)	Well Name	Prod. or injec. rate kg s^{-1}	WHT °C	WHP bar	
						Prod.	Injec.
Lunjkovec - Kutnjak	Lunjkovec	LK-carbonate (1800)	Lunj-1	23	120	12	-
	Kutnjak	LK-carbonate	Kt-1	23	131	14	-
Velika	Velika	VC-carbonate	VC-1	30		-	1

Velika Ciglena

This reservoir was discovered in 1990, by the exploratory (oil) well VC-1. The first indication of very promising geothermal potential was a total lost circulation of drilling fluid (in spite of hydrostatic reservoir pressure) and a high temperature (172 °C) at the top part of the reservoir (2550 m). The geothermal gradient was 0.062 °C m^{-1}.

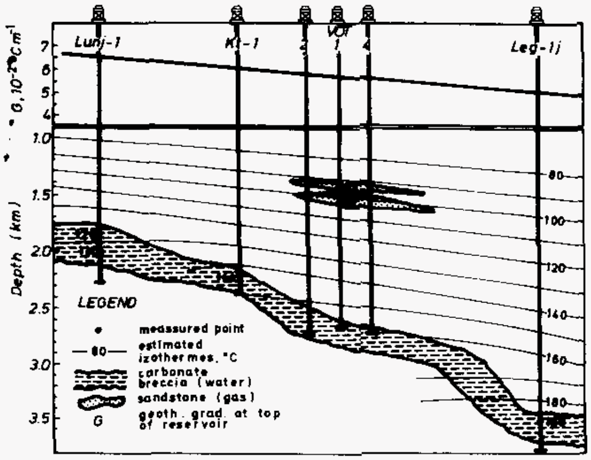

Figure 3. Temperature cross section In the **Lunjkovec-Kutnjak geothermal field**

To prevent lost circulation, aerated drilling fluid was used to the depth 3200 m when a short blowout of a hot wata, steam and CO_2 occurred. Then, drilling continued with total lost circulation to the depth 4000 m, where a 7 inches ha was set and partly cemented (Fig. 4).

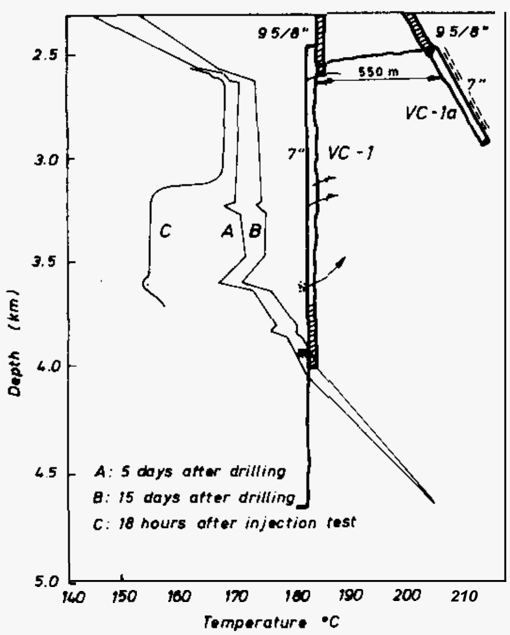

Figure 4. Temperature survey in the well VC-1

To a total depth of 4790 m, the borehole was drilled through several relatively low permeable zones without lost circulation problems. Two temperature surveys, 5 and 15 day after drilling operation, showed several very permeable (fissured) zones, which were cooled by lost drilling fluid. Nearly equal temperature from 3600 m to the top of reservoir implied that these zones were connected by other permeable zones that made possible natural convective circulation in the reservoir for millions of years. The log analyses showed several permeable zones in the interval 2550 - 2900 m, with total net pay 170 m and 16% porosity. It was estimated (Relić, 1991) from lost circulation data (*rate and level* in an annulus) that a productivity index was higher than 5000 m^3/d bar. A special geothermal well, VC-1A completed early 1991, has confirmed predicted temperature and the productivity index (about 10 000 m^3/d bar). Unfortunately, a reservoir limit test and an interference test haw indicated relatively small pore volume (200 - 250. *Id* m^3). It is thin volume of high permeable zones, which could creat short circuits during future production/injection process.

A pressure response in an interference test appeared in an unusually short time (less than one second). It also indicated possible short circuits. This is a serious uncertainty in a reservoir evaluation *study*, therefore no new well is being considered in a reservoir study. Water from the dolomite reservoir contains 24 g/l dissolved solids and 30 m^3/m^3 CO_2 with 59 ppm H_2S. The radioactivity of the water is high, but separated gas is not radioactive. Scale appeared below 20 bars. In Table 2, test data are given; the predicted production well performance is: flow rate 110 kg s^{-1} with WHP 20 - 25 bars and WHT 165 - 170 °C. The objective of the pre-feasibility *study* is to analyze a heat transport to the town Bjelovar (10 km) and a g w t h d energy conversion into electricity. Two existing wells would be considered (VC-1 88 injection and VC-1A as production).

2.3. Other tested reservoirs

Six localities (Fig. 1) haw been incompletely tested, by one well each. The wells at Sveta Nedjelja and Ferdinandovac haw been drilled as geothermal exploratory web, and others for hydrocarbon exploration.

These wells were tested simply. The artesian flow rate and well head temperatures have been recorded during several day (4 - 15 kgs^{-1} and 65 - 100 °C).

3. DISCUSSION

Data given in thin paper show significant geothermal potential in the north part of Croatia. Čubrić (1993) made a preliminary thermal power estimation of the localities mentioned in this paper. The estimate was based *on* the assumption that the flow rate in m e localities (Biz-sandstone, Ernestinovo, Rečica, Sveta Nedjelja) wuld be significantly increased by submersible pumps *andlor* by hydraulic fracturing.

The recent advances in hydraulic fracturing technology, like "tip screenout method" (Hanna, 1992) make it possible to improve well productivity in the reservoirs which permeability is relatively high (petroleum classification) such as the Croatian sandstone g w t h d reservoir ($60 * 10^{-15}$ m^2) Such a value is low for geothermal reservoirs.

Highly slanted web (Joshy, 1984) *or* an ultrashort-radius radial horizontal well *system* (Dickinson et al., 1989) could also improve the geothermal well's productivity.

Taking into consideration the mentioned possibilities to improve productivity and consequently WHT, total estimated flow rate in Croatia is 2607 kg s^{-1} and t h d powa is 815 MW_t (outlet temperature 50 °C). About 77% of the total t h d power comes from only two large reservoirs, Lunjkovec-Kutnjak (57%) and Velika Ciglena (20%). The estimated number of w e b is 79 (including 29 injection).

It is difficult to predict the future utilization of geothermal energy in Croatia. There are several problems, like the relatively long distance (10 - 15 km) of the geothermal fields from potential consumers. In addition, towns (and their industry) in north part of Croatia, are well supplied by a natural gas pipeline network. Therefore, in the very near future, geothermal energy *may* not make a major contribution to energy consumption in Croatia. However, it can be of great importance for the future economical development of certain subregions.

4. CONCLUSIONS

In the north part of Croatia, the Panonian basin has favorable natural conditions for geothermal energy development.

Most geothd reservoirs have been discovered during hydrocarbon exploration Preliminary estimated total thermal power is 815 MW_t (outlet temperature 50 °C).

So far, geothd energy is utilized at three localities, where installed thermal power is 15 MW_t, but load factor is too low.Croatian oil company INA (in cooperation with experienced international experts) has started to make pre-feasibility studies for geothermal energy utilization at the two most promising localities.

We suggest *speeding* up such studies for the other localities, as well. Also, it will be necessary to provide energetic market research as a part of the economic development studies of the subregions where the geothermal reservoirs are located.

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