GEOTHERMAL ENERGY UTILIZATION OF ABANDONED PETROLEUM INDUSTRY WELLS; CASE STUDY: THE POTENTIAL OF HOT WATER PRODUCTION IN TISZATARJAN HUNGARY

Darana, Arif Rahmansyah[1], Szuch Peter[1], Nyiri Gabor[1]

[1]Faculty of Earth Science and Engineering, University of Miskolc

darana.arif@gmail.com

Keywords: *Geothermal, direct use, abandoned petroleum industry well*

ABSTRACT

Abandoned petroleum industry wells can be harmful to the environment by effects such as the leakage of oil, natural gas and brine into soil and drinking water (Will Downey, 2016). Despite the possibility of several dangerous effects they still have some potential to be useful. One of the potential uses is the extraction of geothermal energy from this kind of well. By using an abandoned hydrocarbon well to extract geothermal energy, besides saving the environment, it also can save the cost of drilling for the project. The project cost can be reduced by up to 60% (Toth et al, 2019). However, this utilization technique requires several conditions such as a good thermal gradient. In Hungary due to the thin crust, the heat flow makes it possible to make use of geothermal energy. In the study area, the temperature of the sediment can reach 60-70°C with the thermal gradient of approximately 6°C/100 m (Less Gyorgy, 2011). Thus, the temperature will increase with depth (Jordan Hanania, Kailyn Stenhouse, 2015). The well in the study area has 2,794 m MD and it has five good aquifer zones from 867 m to 1310 m. Based on the theory and the uniqueness of the area, this abandoned hydrocarbon well meets the conditions for having geothermal energy potential. Due to those factors, the utilization of geothermal energy from this well can be achieved by mining the hot water. Based on calculations, the well can give a maximum temperature of hot water of approximately 70°C. Thus, the abandoned hydrocarbon well in the study area can be a productive geothermal resource, especially hot water production.

1. INTRODUCTION

The increase of population and the development of technology in the world has consequences, one of which is the increasing demand for energy. This is the case worldwide and also in Hungary. Based on the Hungarian Energy Strategy 2030 (Ministry of National Development, 2012), the energy consumption in 2030 is expected to increase by approximately 23%. The authority said that one type of increasing demand is for heat energy, especially hot water (Ministry of National Development, 2011). The number of dwellings connected to a hot water supply in Hungary, according to a recent report (Office, 2012), from 2010 to 2017, has increased by 4724. The report said that Hungary needs thermal water for several uses such as balneology, thermal bath (spa), green houses, and miscellaneous. In 2015, Hungary produced a volume of hot water of around 79.46 Million m^3, representing 863.80 MWt / 12,819TJ/y, from 877 active thermal water wells (Toth Aniko, 2016). As the hot water demand increases Hungary needs to find another way to meet the demand and to meet the aims of the Hungarian Energy Strategy. However. dealing with energy production has several consequences such as environmental, sustainability, and economic issues. Those factors are always taken into consideration in both the energy trilemma (Diána, 2018) and the pillar of the energy strategy (Janos and Kovacs, 2012).

In terms of sustainability and environmental issues, Hungary has several problems. One of them is old petroleum industry wells, abandoned either due to the depletion of the hydrocarbons making them no longer viable to be exploited, or the infeasibility of the prospect (Will Downey, 2016). Besides the sustainability issues, there are serious environmental problems such as:

- Groundwater

  Oil, gas and saline water can leak into fresh water aquifers. In the well operation phase some extraction methods such as hydraulic fracturing and well injection are used to increase well pressure, thus making groundwater contamination a likely consequence (Will Downey, 2016).

- Methane emissions

  A previous study said that 2-4% leakage of methane gas is expected from an abandoned well (Townsend-Small, A. et al. 2016 in Allison and Mandler, 2018).

- Surface Environment

  Oil, gas, drilling mud and saline water can rise to the top of the well and spill to the surface. The problem is even worse if it happens in offshore wells, because then those contaminants leak into the open water.

An abandoned petroleum industry well needs treatment in order to prevent those effects. Economically speaking, if after the treatment has been applied the well still has capability to produce another type of energy, then it will provide a solution for the trilemma and provide a the pillar for the energy strategy. Based on previous research, this solution can be implemented. For example (Kujawa et al in Cheng et al., 2013) have investigated how to utilize existing deep wells for extracting geothermal energy. Experiments on extracting geothermal water from oil wells for power generation were carried out in the Huabei oil region in China and resulted in a mass flow rate of hot water of 1932 t/d at a temperature of 116°C (Cheng et al., 2013). Furthermore, as mentioned above, the use of an abandoned oil well for geothermal energy extraction can cut the cost of a hot water supply project by up to 60% (Toth et al., 2018).

In Hungary, particularly in Tiszatarjan, geothermal energy has good potential due to several factors, such as the good thermal gradient (approximately 5°C/100m due to the thin earth's crust (Toth, 2016)) and the abundance of water, e.g., more than 10^9 m^3 of water are stored in the deep sedimentary layer of the Pannonian basin (F Pikler, 1980), where the study area is located. Hence, the production of thermal water from an abandoned oil well could be possible. Due to this possibility this country has a target of achieving 5 MWe from this type of source by 2020 ((Bertani, 2015)). This target indeed can be achieved by utilizing abandoned wells to extract the geothermal energy. Therefore, an investigation of hot water production must be conducted first as the part of preliminary step of the long research project.

2. OVERVIEW

Carpathian Basin is where Hungary is located and more than 70% of Hungary is classified as lowland. There are two types of lowland: the great Hungarian plains and the little plains. Those lowlands were formed at around 19 million years ago (Miocene),

The formations in Carpathian basin, especially in Hungary, were controlled by an earlier extensional lengthening crustal mantle lithosphere, and a late mantle was pressed. Those events interacted with the sinking of an isostatic. Thus, the continental crust in this area is thin.

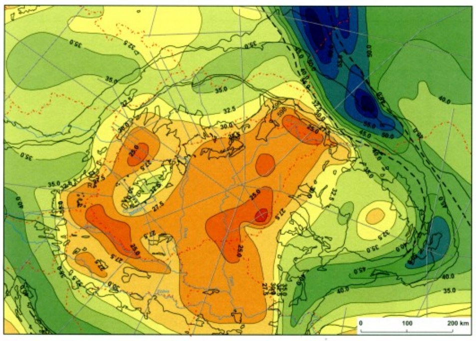

Figure 1: The thickness of the crust in Hungary (Less Gyorgy, 2011).

Due to the thinning of the lithosphere the average thickness of the Earth's crust in Hungary is around 25-28 km (Fig. 4). This unique condition makes the geothermal gradient favorable at approximately 5-6°C / 100 m. These two planes are filled by Quaternary, Pliocene and Upper Miocene (Pannonian) sediments (Less Gyorgy, 2011).

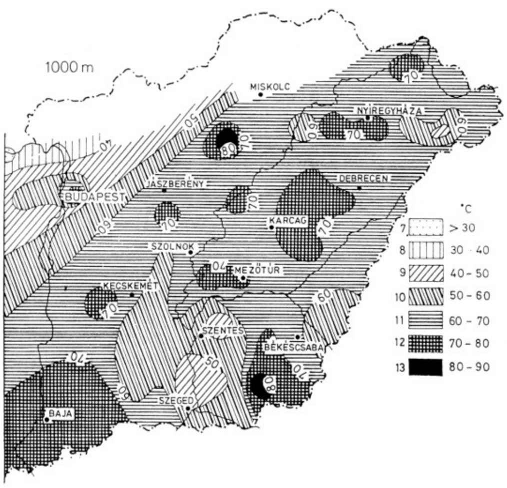

Figure 2: Temperature in Carpathian Basin in Hungary (Less Gyorgy, 2011).

Furthermore, Hungary is located on the Pannonian Basin which is surrounded by the Carpathian Mountains and it has a thin Earth's crust due to sub-crustal erosion. This thin crust has sunk so slowly that mostly tertiary sediments fill this basin, composed of sandy, shaley, and silty beds and can be classified into the following formations (Lorberer, 2003):

1. The Lower Pannonian sediments are mostly impermeable. This sediment consists of only a thin sandy layer in the clayey material. The porosity of it is low along with the salt and gas content

2. The upper Pannonian and Quaternary formations contain vast porous, permeable sand and sandstone beds.

3. The latter forms the upper Pannonian aquifer, the most important thermal water resource in Hungary. This sediment covers a broad area and is transgressing into all types of older sediments.

High-temperature volcanic steam or hot-water geothermal resources do not exist in Hungary. However, a considerable quantity of moderate temperature (< 100 °C) thermal water is available. Hungary, like many other countries which lack sources of conventional energy, has long been forced to utilize geothermal energy. The first plants of this type were established in Budapest around 40 - 50 years ago. But more uses of this form of energy have been developed over the last 15 years.

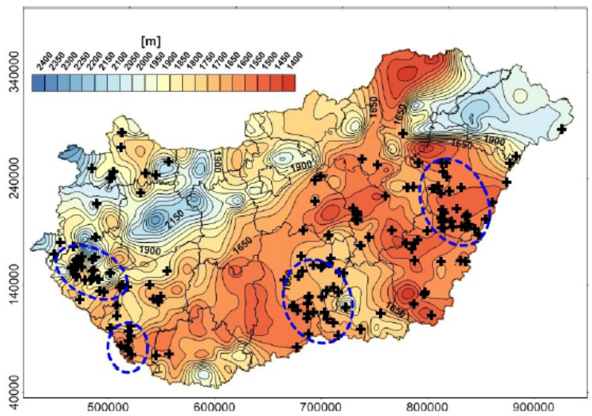

Figure 3: Isotherm map of 90 °C in Hungary, overlaid with the well distribution (Toth et al, 2018)

Many deep petroleum wells have been drilled in Hungary (Fig. 3). The map below shows the abandoned oil area overlaid on the 90 °C geo-isotherm map. Those wells are proof that high temperatures exist, and the impermeable basement rock is also delineated. The measurements show the temperature of the rock is 22 °C at a depth of 6 km which is favorable for geothermal energy production and utilization. The heat flow is around ~0.09 W/m^2, there is a high geothermal gradient (~0.04°C/m), and extensive deep aquifers with geothermal potential. The sandy layers have various thicknesses of between 1 m and 30 m. The sand lenses are interconnected, and thus form a unified hydraulic system, even though the horizontal extent is not too large. The upper Pannonian aquifer has an area of 40,000 km^2, the average thickness is around 200-300 m, with bulk porosity of 20-30%, and the permeability is approximately 500-1,500 mD. The hot water reservoir has almost the same hydrostatic pressure distribution everywhere, however local recharge or discharge plays a role in modifying this pattern (Toth Aniko, 2016).

Another type of geothermal reservoir is found in the Triassic age carbonate rocks. These can be fractured or karstified rock masses, with secondary porosity and with continuous recharge and important convection. Previous research (Bobok *et al*., 2003 in Toth Aniko, 2016) state that about 20% of Hungarian geothermal wells are situated in this kind of rock formations, with most of them in the western part of the country.

The thermal springs in Budapest are one of the well-known surface manifestations, and have been in use since the days of the Roman Empire. The exploration for geothermal energy to supply thermal water began in 1877, with the drilling in Budapest of the deepest well in Europe, at 971 m. Furthermore, during World War 2 a huge thermal water reservoir was discovered during exploration for oil. That discovery has high heat flux and geothermal gradient in Pannonian Basin (Boldizsár (1944, 1956), in Toth Aniko, 2016).

The geothermal potential in Hungary has been assessed for more than 10 years. According to the last study, the heat available down to a depth of 10 km was estimated to be around 375,000 EJ. For a depth of 5 km it was estimated to be 105,500 EJ, with probable reserves of around 60 PJ/y for the porous layer and 130 PJ/y for the basement reservoirs, with full re-injection (Zilahi-Sebess *et al.* 2012 in Toth Aniko, 2016).

Hundreds of geothermal wells were drilled in the late 1950s, mainly for agricultural purposes. At the peak of geothermal activity, a total of 525 geothermal wells were registered and 30 of them had a production temperature which exceeded 90 °C. Those wells have a 1,540 MW thermal power capacity; however, the utilization is seasonal, and the efficiency is low. The thermal water above 60 °C is used for heating purposes only.

3. METHOD

The research starts with simplifying the Lithology log which comes from the mud logging report on the well. Thus, simplifications are made to the hydrostratigraphy. The zone of interest for water extraction is chosen, and then an estimate of water extraction is calculated.

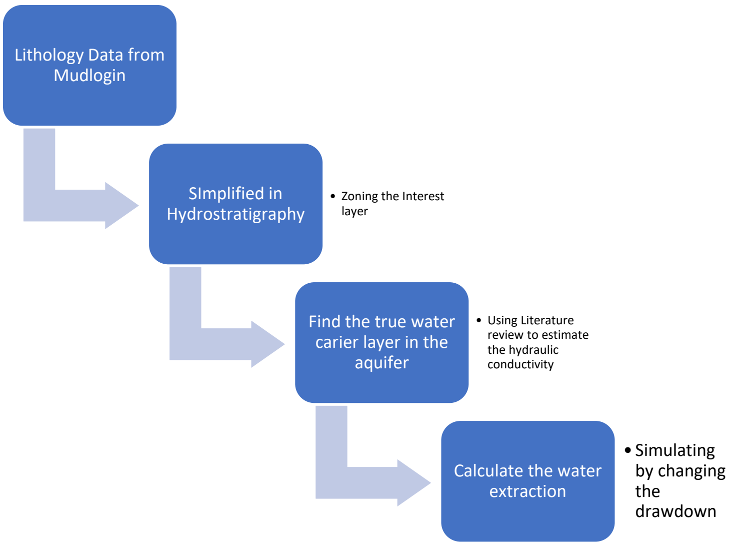

Figure 4: Workflow of the research

i. Critical velocity

$$V_{critical} = \frac{\sqrt{k}}{15}$$

ii. Radius

$$OD = 127\ mm$$

$$ID = OD - 2m = 127 - (2 \times 5.59) = 115.82\ mm$$

$$r = 115.82/2 = 57.91\ mm \approx 0.05791m$$

iii. Maximum velocity

$$V_{max} = \frac{Q}{2\pi rm}$$

iv. Operational water level

$$Q = 2\pi mk \frac{H - h_0}{ln\, {}^{R}/_{r_0}}, \qquad R = 5000 \times S_0 \times \sqrt{k}$$

$$h_0 = H - S_0$$

v. Bottom Hole Temperature (BHT)

$$\boldsymbol{BHT} = ST + (GD\ x\ TD)$$

Where GD = Geothermal gradient
BHT = Bottom Hole Temperature
ST = Surface Temperature
TD = Total Depth

vi. Average Temperature of the exploited layer (T)

$$T = ST + [(BL - UL)xGD]$$

Where T = Average Temperature of exploited layer

BL= Bottom of exploited layer

UL = Top of exploited layer

GD = Geothermal gradient

ST = Surface Temperature

4. RESULT AND DISCUSSION

The abandoned well studied is located in the Tiszatarjan Block in north-eastern Hungary. The well, with code HHEN Tiszatarjan-1, has a Total Depth of 2,794 m MD. It is an exploratory well with a static water table at 146.7 mbsl, the surface temperature is 15°C, the thermal gradient is 6°C/100m and the inner diameter of the well is 3”.

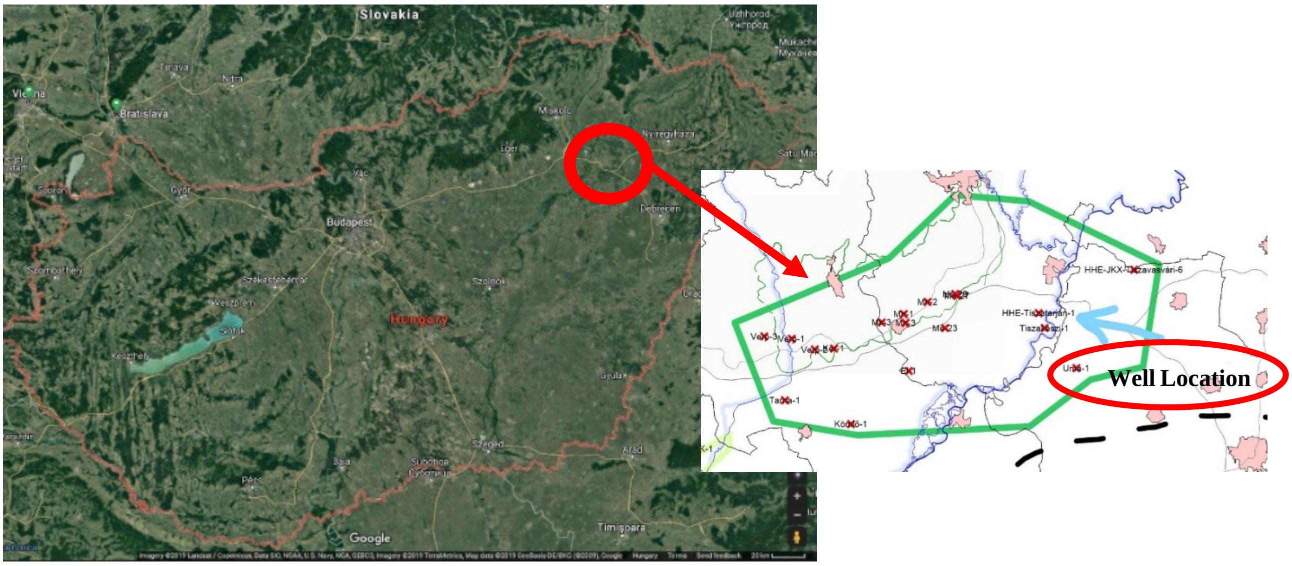

Figure 5: Location of the well

The geological formation of this well obtained from mudlogging data and the resulting lithology log has been simplified into hydrostratigraphy log below:

Table 1: Hydrostratigraphy of the well

Type of Formation	Depth MD (m)		Description	Notes
	From	To		
No Data	0	500	No Data	Quartenary to Pliocene Sediment
Upper Pannonian Aquitard 1	500	630	Lignite interbedded with sand and clay streaks	
Upper Pannonian Aquifer 1	630	760	Sand Interbedded with lignite and clay streaks	
Upper Pannonian Aquifuge	760	860	Claystone and lignite alternate with sandstone streaks	
Upper Pannonian Aquifer 2	860	970	Sandstone occasionally with lignite and claystone streaks	
Upper Pannonian Aquitard 2	970	1020	Lignite alternate with claystone and sandstone layer	
Upper Pannonian Aquifer 3	1020	1100	Sandstone interbedded with claystone and lignite strikes; and sandstone alternate with claystone occasionally with lignite strike	
Lower Pannonian Aquitard 1	1100	1282	Claystone Interbedded with sandstone and lignite streaks; claystone interbedded with thin sandstone and thin lignite strikes; and shale and	

			siltstone alternate with lignite interbeds and sandstone stripes	
Lower Panonnian Aquifer 1	1282	1360	Shale and sandstone alternate and siltstone with lignite stripes; shale interbedded with sandstone and siltstone stripes	
Lower Pannonian Aquifuge	1360	1420	Shale interbedded with siltstone strikes sandstone and lignite strings; shale, lignite and siltstone alternate with sandstone strings.	
Lower Pannonian Aquitard 2	1420	1565	Sandstone siltstone and shale alternate; shale interbedded with sandstone and siltstone streaks lignite streaks; sandstone siltstone and shale alternate, trace with lignite strings; siltstone interbedded with shale and sandstone streaks	
Lower Pannonian Aquifer 2	1565	1595	Sandstone interbedded with shale and siltstone streaks trace with lignite strings	Gas Peak at 1580-1582
Lower Panonian Aquiclude	1595	2435	Siltstone and shale alternate with sandstone, trace with lignite strings; Siltstone interbedded with shale; Shale with thin tuff strings; shale with siltstone streaks and thin tuff strings; shale with marl streaks and thin tuff strings; marls alternate with shale and with thin tuff strings; Shale interbedded with thin tuff and siltstone.	Gas Peak at 1981-1992
Miocene Aquiclude	2435	2794	Shale, tuff and limestone alternate; tuff interbedded with shale streaks and upper part thin limestone strings tuff; shale alternate with tuff layers and interbedded siltstone strings; Tuff interbedded with shale streaks tuff; tuff interbedded with shale and thin siltstone streaks; Tuff interbedded with limestone; Tuff interbedded with shale and thin siltstone streaks; Volcanic rocks/tuff; extrusive volcanic rock/tuff.	Gas Peak at 2458-2459 and 2580-2585

Based on the data above, there are five aquifers. However, there are only four which have potential for the mining of relatively clean hot water, these are: Upper Pannonian Aquifer 1; Upper Pannonian Aquifer 2; Upper Pannonian 3 Aquifer; and Lower Pannonian Aquifer 1. Meanwhile, the Lower Pannonian Aquifer 2 theoretically can produce hot water, but in this zone, there is a gas peak which can be entering the hot water. This table below shows the details of selected aquifers.

Table 2: Aquifer properties

Hydrostratigraphy	Depth		Description	Aquifer Materials	Materials Description	Total Thickness (m)	Lit. Hydraulic Conductivity (Domenico and Schwartz 1990 in Glenn M. Duffield, 2019)	Top Temp	Bottom Temp	Avg. Temp
	From	To								
Upper Pannonian Aquifer 1	630	760	Sand Interbedded with lignite and	Sand	very fine-fine grained	22.5	2.00E-07	52.8	60.6	56.7

			clay streaks	Sandstone	very fine to very coarse grained	55	4.50E-06	52.8	60.6	56.7
Upper Pannonian Aquifer 2	860	970	Sandstone occasionally with lignite and claystone streaks	Sandstone	Fine to very coarse grain, with quartz pebble	68	5.00E-06	66.6	73.2	69.9
Upper Pannonian Aquifer 3	1020	1100	Sandstone interbedded with claystone and lignite strikes; and sandstone alternate with claystone occasionally with lignite strike	Sandstone	Fine to very coarse grain, with quartz pebble	46	5.00E-06	76.2	81	78.6
Lower Pannonian Aquifer 1	1282	1360	Shale and sandstone alternate and siltstone with lignite stripes; shale interbedded with sandstone and siltstone stripes	Sandstone	Fine to medium grained	22	4.00E-06	91.92	96.6	94.26

In order to estimate the mining of the hot water from this abandoned well a simulation must be conducted. The simulation is conducted in the water carrier layer from each aquifer such as sand and sandstone. Table 3 shows the results of the simulation from each layer.

Table 3: Result of the simulation of water extraction

Sand Aquifer 1											
K (m/s)	m (m)	r (m)	H (m)	R (m)	s(H-ho) (m)	Q (m3/s)	Q(m3/day)	h0 (m)	T	Vcrit (m/s)	Vmax (m/s)
2.00E-07	22.5	0.0381	146.15	96.15092	43	0.000155	13.40975818	103.15	56.7	2.98142E-05	2.88151E-05
Sandstone Aquifer 1											
K (m/s)	m (m)	r (m)	H (m)	R (m)	s(H-ho) (m)	Q (m3/s)	Q(m3/day)	h0 (m)	T	Vcrit (m/s)	Vmax (m/s)
4.50E-06	55	0.0381	146.15	95.45942	9	0.001788	154.5105151	137.15	56.7	0.000141421	0.000135824
Sandstone Aquifer 2											
K (m/s)	m (m)	r (m)	H (m)	R (m)	s(H-ho) (m)	Q (m3/s)	Q(m3/day)	h0 (m)	T	Vcrit (m/s)	Vmax (m/s)
5.00E-06	68	0.0381	146.15	89.44272	8	0.002202	190.2554168	138.15	69.9	0.000149071	0.000135273

Sandstone Aquifer 3											
K (m/s)	m (m)	r (m)	H (m)	R (m)	s(H-ho) (m)	Q (m3/s)	Q(m3/day)	h0 (m)	T	Vcrit (m/s)	Vmax (m/s)
5.00E-06	46	0.0381	146.15	89.44272	8	0.00149	128.7021937	138.15	78.6	0.000149071	0.000135273
Sandstone Aquifer 4											
K (m/s)	m (m)	r (m)	H (m)	R (m)	s(H-ho) (m)	Q (m3/s)	Q(m3/day)	h0 (m)	T	Vcrit (m/s)	Vmax (m/s)
4.00E-06	22	0.0381	146.15	90	9	0.000641	55.35360114	137.15	94.26	0.000133333	0.000121648

The simulation was conducted by changing the value of drawdown (s) and with the rules that v max must be less then v critical but to make it efficient and effective the v max should be close to v critical. Hence, after the calculation given in Table 3, the estimate of hot water extraction from this well is shown in Table 4 below.

Table 4: Water extraction estimates

Q Total	0.006279	(m^3/s)	542.5327	m^3/day
T of exploited water	74.865	^{0}C		

The estimated hot water extraction from the abandoned hydrocarbon well, is based on hot water extraction at the depth of approximately 1,400 mbsl. This depth is chosen, because after 1,400 mbsl there is a gas peak and also there is hydrocarbon zone after that depth. Indeed, the well must be re-engineered to be able to extract 542.53 m^3/day, with an estimated average temperature of 74. 9 °C, from this well.

5. CONCLUSION

This abandoned hydrocarbon well has 5 aquifers, but the hot water can be extracted from only 4. These are:

- Upper Pannonian Aquifer 1
- Upper Pannonian Aquifer 2
- Upper Pannonian Aquifer 3
- Lower Pannonian Aquifer 1

The materials of the aquifers are sand and sandstone. The maximum depth for extracting hot water is 1,400 mbsl, due to presence of hydrocarbons at deeper levels. The estimated potential for hot water mining from this well is 542.53 m^3/day with an approximate temperature of 74.9 °C for the extracted hot water.

6. RECOMENDATION

This study is preliminary and based on simple data. More advanced data are needed, such as wireline logging. More advanced analyses are also needed to calculate an accurate estimate of the amount of hot water that can be extracted. Furthermore, to modify the well a drilling engineer and petroleum engineer must be involved in the advanced study.

ACKNOWLEDGEMENTS

This is a part of project funded by European Union through University of Miskolc.

REFERENCES

Allison, E. and Mandler, B. (2018) *Petroleum and the Environment*. doi: 10.1016/S0140-6701(01)80154-5.

Bertani, R. (2015) 'Geothermal Power Generation in the World 2010-2014 Update Report', *World Geothermal Congress 2015, (April), p. 19*.

Cheng, W. L. et al. (2013) 'Studies on geothermal power generation using abandoned oil wells', *Energy*. Elsevier Ltd, 59, pp. 248–254. doi: 10.1016/j.energy.2013.07.008.

Development, M. of N. (2012) *National energy strategy 2030*. Ministry of National Development.

Diána, S. (2018) '*Energy Policy Goals and Challenges for Hungary in the 21st Century*', E-2018/16(Institute for Foreign Affairs and Trade, 2018).

F, P. (1980) '*Geothermal Energy in Hungary'*, (State Office of Technical Development, Budapest).

Glenn M. Duffield (2019) *Hydraulic Properties :. Aquifer Testing 101*. Available at: http://www.aqtesolv.com/aquifer-tests/aquifer_properties.htm (Accessed: 4 September 2019).

Goals, E. P. (2018) '*Diána szőke'*.

Jordan Hanania, Kailyn Stenhouse, J. D. (2015) *Geothermal gradient.* Available at: https://energyeducation.ca/encyclopedia/Geothermal_gradient (Accessed: 23 October 2018).

Less Gyorgy (2011) *Geology of Hungary* | Digital Learning Library. Available at: https://www.tankonyvtar.hu/hu/tartalom/tamop425/0033_SCORM_MFFTT600231-EN/sco_01_01.htm?fbclid=IwAR03_Ql7DRaHWXLTWC2kcWmWXQP0Z4_u1FST6s-1SYIs26KkdKcCCwHO1vU (Accessed: 13 October 2018).

Lorberer, Á. (2003) '*Hydrogeological characteristics of thermal water bearing Plio-Pleistocene basin sediments in Hungary'*, pp. 1–9.

Office, H. C. S. (2012) '*Hungary in figures 2012'*.

Toth, A. N. et al. (2018) '*Converting Abandoned Hungarian Oil and Gas wells into Geothermal Sources'*, pp. 1–8.

Toth Aniko (2016) 'Geothermal Energy in Hungary', *GRC Transaction, 40.*

Will Downey (2016) (1) *Decommissioning and Abandoning Petroleum Wells in New Zealand*. Available at: https://www.linkedin.com/pulse/decommissioning-abandoning-petroleum-wells-new-zealand-will-downey/ (Accessed: 5 October 2018).