Evaluation of Geothermal Potential and Geothermal Energy Production Sustainability from Oil and Gas Fields in Western Ukraine

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ABSTRACT

Western Ukraine (Zakarpattya, Ivano-Frankivsk, Lviv and Chernivtsi regions) as well as Crimea peninsula are well known for their geothermal potential. In Zakarpattya, the presence of geothermal anomaly with temperatures around 60 degrees at the depth of 1200 m, represents a significant energy resource. According to a study conducted in the late 1990s, based on the evaluation of 20 exploration wells, 7 geothermal fields were identified with total flow rate capacity of 100 km^3/day and energy potential of 182.7 MW, stored in the aquifers within 400 – 2300m and temperatures up to 90°C.

Geological setting indicates possibilities for energy production from low enthalpy geothermal reservoirs. The classic low enthalpy geothermal project is based on the construction of a binary power plant, and includes recycling of water through one or several doublets of wells; produced hot water is directed to a heat exchanger (vaporizer), in which a secondary (working) fluid with low boiling point and high vapor pressure vaporizes and rotates a turbine to produce electricity.

The highest risk for the project is associated with drilling new wells, that may not hit the target or not have the required productivity.

Western Ukraine is one of the oldest oil and gas production regions in Europe. The majority of the fields are on a late stage of the development that is characterized with high produced volumes of water, that after separation is being reinjected back for pressure support.

In this paper we evaluate the possibility of sustainable energy production from produced oil and gas water based on numerical reservoir simulation model for a typical reservoir.

1. INTRODUCTION

Within Ukraine, Western part (Zakarpattya, Ivano-Frankivsk, Lviv and Chernivtsi regions) as well as Crimea peninsula are well known for their geothermal potential. In Zakarpattya, the presence of geothermal anomaly with temperatures around 60 degrees at the depth of 1200 m, represents a significant energy resource. According to a study conducted in the late 1990s, based on evaluation of 20 exploration wells, 7 geothermal fields were identified with total flow rate capacity of 100 km^3/day and energy potential of 182.7MW, stored in the aquifers within 400 – 2300m and temperatures up to 90°C (Petryashkevych M., 1998; Rudko Y., 1975; Rudenko F., 1971; Zharnikov A, 2002; Zapinska-Silwa A., 2012).

Another global estimate of the Ukrainian geothermal potential was done by Fomina O., 2005 (Table 1).

High level estimates of geothermal resources were also performed by Gordienko et al., 2005 for the depths 3, 4.5 and 6 km.

Natural heat flow here varies from 35-40 mW*m^{-2} in the southwestern part of the East European craton and Precarpathian deep, 50-60 mW*m-2 in the outer Carpathians up to 80-120 mW*m-2 in Pannonian Basin (Figure 1) (http://wdc.org.ua/en/node/147).

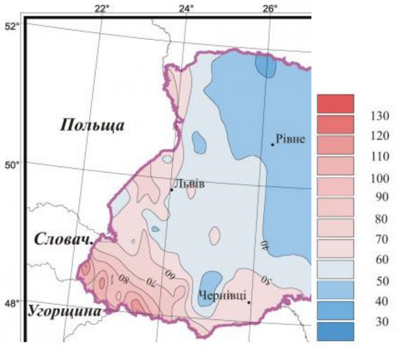


Figure 1: Density of heat flow map (http://wdc.org.ua/en/node/147).

Table 1: Estimates of Ukrainian geothermal energy potential for power generation.

Region	Depth interval, km	Average resource temperature, °C	Area, km^2	Nominal capacity of geothermal power station, 10^3 MW
Zakarpattya (Transcarpathian)	3 – 6	210 – 250	50 – 130	5.8
Prykarpattya (Precarpathian)	4 – 7	200	600	4.6
Crimea	4 – 7	200 – 220	300 – 500	10.5
Eastern Ukraine	5 – 7	185 – 217	660 – 2800	48

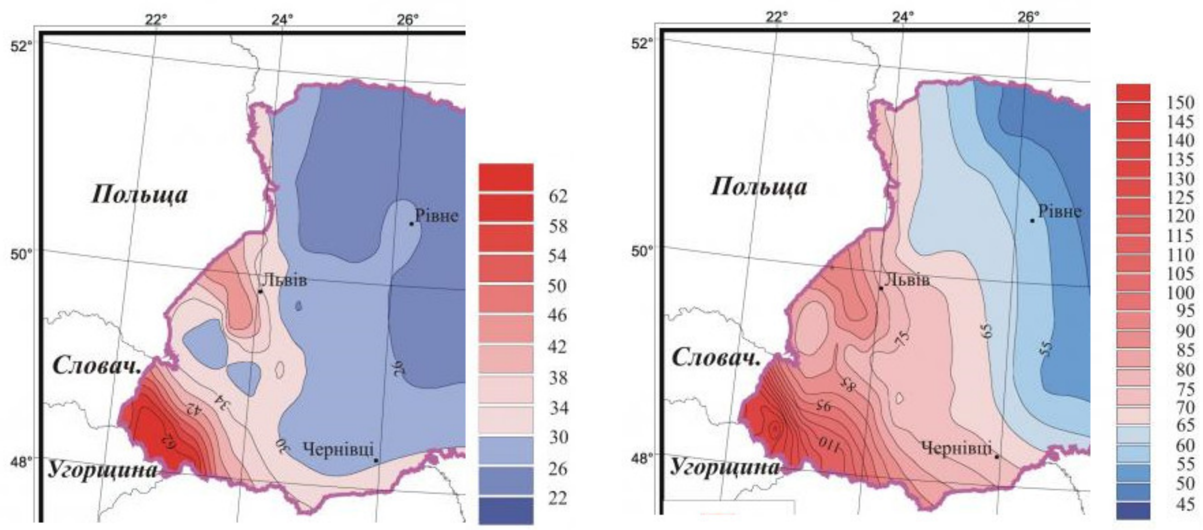


Figure 2: Temperature distribution map at 1000 m (left) and 3000 m (right) depth (http://wdc.org.ua/en/node/147).

Temperature maps at -1000, -2000 and -3000 m show significant variations in temperatures and presence of local geothermal anomalies, particularly high in Transcarpathia and Lviv regions (Figure 2) (Gordienko et al., 2005).

The peculiar geothermal regime of south-western part of Precarpathian deep and overlapping with the thrust from Folded Carpathian Mountains resulted in great variation and gradual increase of heat flow with depth. That is well observed almost in all oil and gas fields (Zapinska-Silwa A. et al, 2012).

2. OIL AND GAS FIELDS GEOTHERMAL POTENTIAL

The significant geothermal potential of the Western region is related to presence of oil and gas deposits. In Boryslav (Lviv region) oil production started in 1865, while in Prykarpattya active exploration for oil and gas initiated in mid-1950s and resulted in the discovery of more than 100 oil, gas and gas-condensate fields.

The deposits are accumulated within the depth intervals from 500 to 4800 m (Ivanyuta M. et al., 1998) and associated with clastic rocks, mainly sandstone. Reservoirs are producing under natural depletion, natural water drive or waterflooding drive. Reservoirs are on different stages of the development; some of them are on initial stage while some are already on the final one with low oil rates and high water-cuts. Water for pressure support and oil displacement is either taken from surface sources or re-injected after production. The later ones are ideal candidates for geothermal operation because they eliminate the need of drilling well doublets and could be immediately utilized for geothermal energy production.

In this paper we performed a numerical study on a synthetic model of quarter-spot pattern for a typical oil field parameters and settings to evaluate the sustainability of hot water production and its sensitivity on variability of reservoir properties and operational constraints.

3. SIMULATION MODEL SETUP

A set of synthetic simulation models with quarter-five spot wells (one injector and four producers placed in the corners) were created. Our task was to perform a sensitivity of typical reservoir and operating conditions on water breakthrough and sustainability of energy production for

- different well spacing;
- net formation thickness;
- permeability;
- porosity;
- reservoir temperature;
- production and injection rates;
- re-injected water temperature.

Different well spacing (150, 250, 350 and 450 m) and different effective net thickness (20, 50 and 100 m) were created. The cell dimensions were kept constant in all the cases at 10x10m laterally and 2 m cell thickness. Example of the model for 150 m spacing and 20 m net thickness is given in Figure 3.

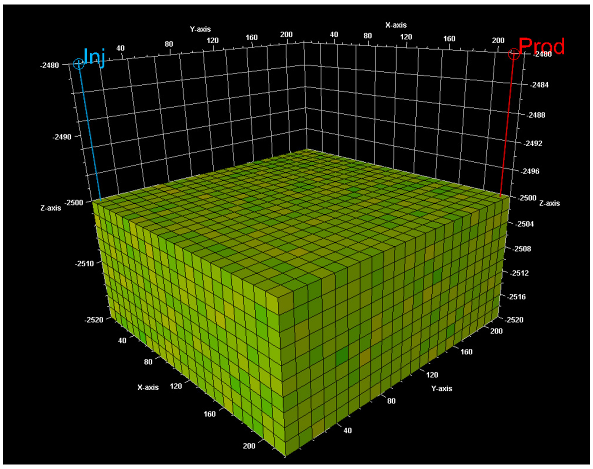


Figure 3: Example of numerical simulation model grid

Grid was populated with porosity and permeability assuming their stationarity for the commonly faced values within the area of study. For porosity, 4 cases were evaluated with a mean of 6, 8, 10 and 12 %, following a normal distribution truncated at 4% and 20% and standard deviation of 0.05. The histogram with distribution is shown on Figure 4. Horizontal permeability was also populated for 4 different mean cases of 5, 10, 20 and 50mD based on truncated log-normal distribution at 1 and 100 mD and standard deviation of 2 (Figure 5). Vertical permeability is reduced by 10 times with respect to horizontal.

Relative permeabilities were created based on Corey function for water-wet sandstones with Corey water exponent of 5 and Corey oil-water exponent of 2.5. Initial water saturation varied between 0.16 and 0.22 (Figure 6).

Oil viscosity and other PVT properties are generated with the help of correlations for the oil densities of 750, 800 and 850 kg/m^3 (Figure 7).

The sustainability of energy production was evaluated for different initial reservoir temperatures, injection rates and re-injected water temperatures that are summarized in Table 2.

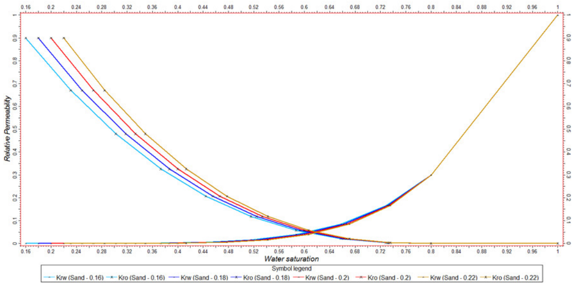


Figure 6: Oil-water relative permeabilities for initial water saturation of 0.16, 0.18, 0.2 and 0.22

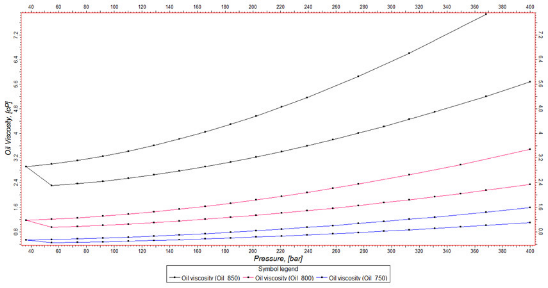


Figure 7: Oil viscosity for oils with 750, 800 and 850kg/m^3.

4. SENSITIVITY RESULTS ANALYSIS

In our analysis, first we will concentrate on response of production temperature and water break-through from injection to production well.

The worst-case scenarios are representing minimum formation thickness of 20 meters and minimum well spacing of 150 m (Figure 8). The high injection rates of 50 and 75 sm^3/day lead to quick water break-through in about 2 years for all permeability ranges (black lines), injection at 25 sm^3/day delays it to 4 years, and low injection rate case at 5 sm^3/day depending on permeability happens after 21 or 23 years. At the same time breakthrough of cool front, and as a result, decrease of produced temperature is observed only after 10 years for the maximum injectivity case (purple lines on the bottom plot). For the mid injectivity cases of 25sm^3/day production at constant temperature is sustained for 20-25 years (green lines) as well as for low injectivity (orange line).

The next thing to evaluate is the influence of injection rates and well spacing in the case of maximum permeability (50 mD) and minimum formation thickness (20 m) on the produced fluid temperature and water break-through time. From the plot on Figure 9, is clearly seen that water temperature is only affected by the smallest spacing, while injection rate and small spacing has also the biggest influence on water break-through. For maximum spacing of the wells and injection rate, water-free production is greater than 20 years.

Effect of formation thickness on production temperature is shown on Figure 10 – smaller the thickness, faster the break-through at the same limiting injection rate of 50 sm^3/day.

Effect of re-injected water temperature on produced water for the case with minimum formation thickness (20 m), well spacing of 150 m, maximum permeability

50 mD and high injection rate 50 sm^3/day is shown on Figure 11. In 50 years the reservoir is cooled down almost to the temperature of re-injected water (10, 20, 30 and 40 °C respectively). On Figure 12 we see progression of cooling front in time when re-injected water temperature is equal to 20 °C.

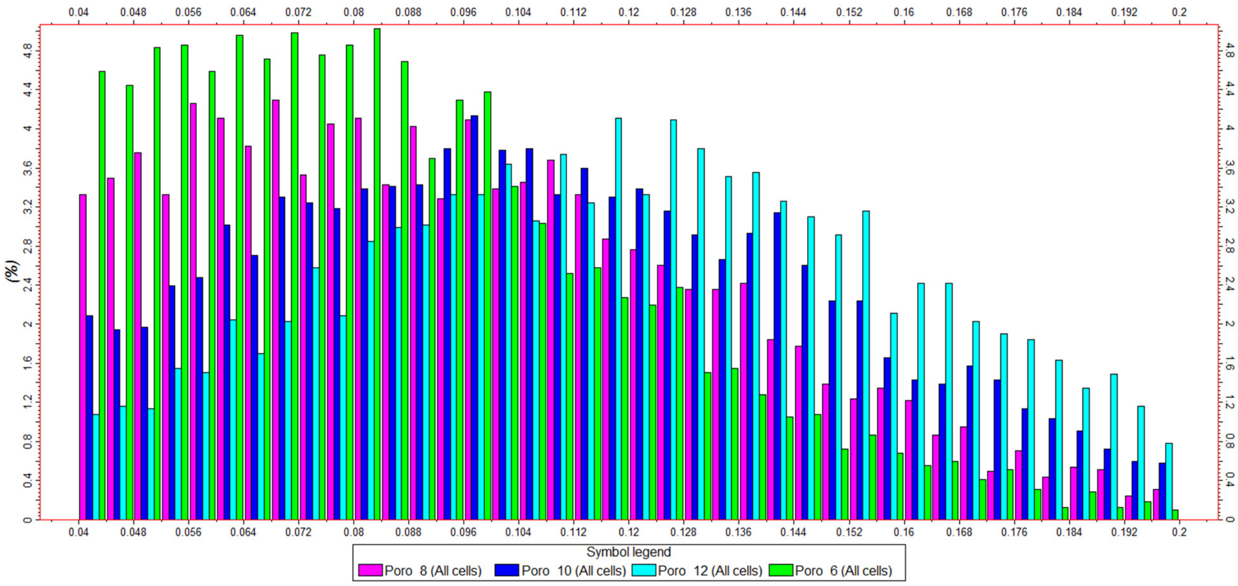


Figure 4: Porosity distributions for the mean values of 6, 8, 10 and 12 %.

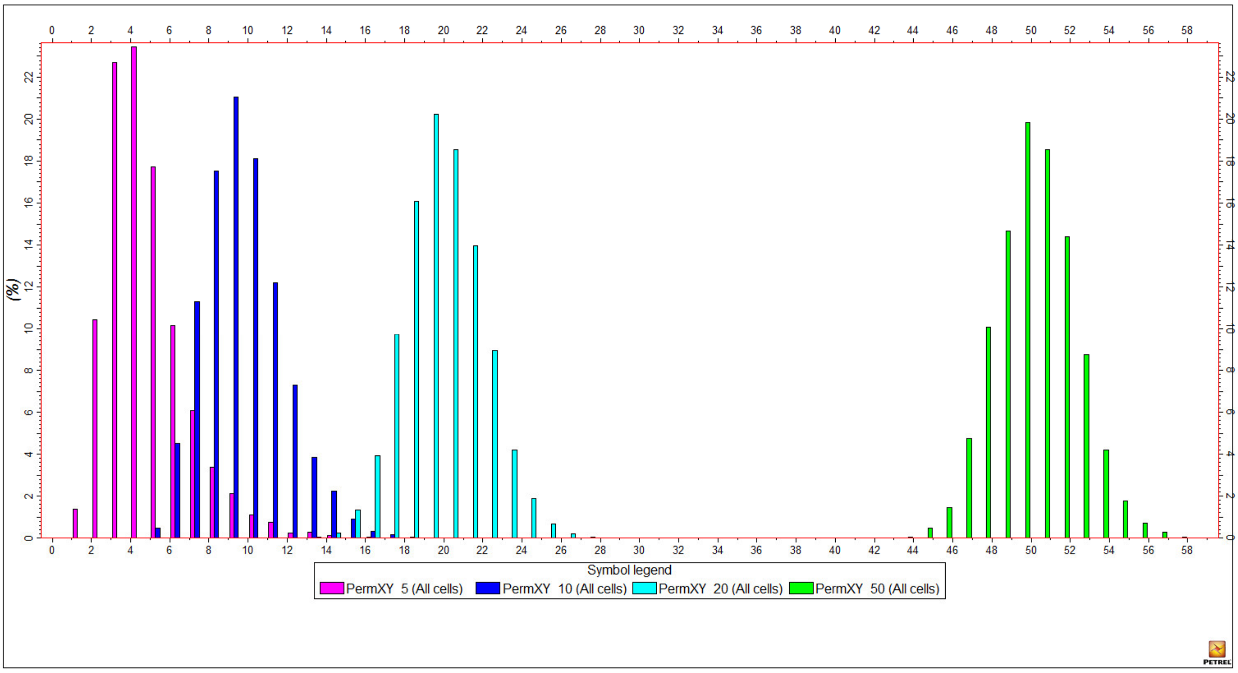


Figure 5: Permeability distributions for the mean values of 5, 10, 20 and 50 mD.

Table 2: Uncertain parameters that control sustainability of energy production.

Parameter	**Parameter value**			
Reservoir temperature, °C	50	60	70	80
Production/injection rate, sm^3/day	5	25	50	74
Re-injected water temperature, °C	10	20	30	40
Mean porosity, %	6	8	10	12
Mean horizontal permeability, mD	5	10	20	50
Initial water saturation, frac.	0.16	0.18	0.2	0.22

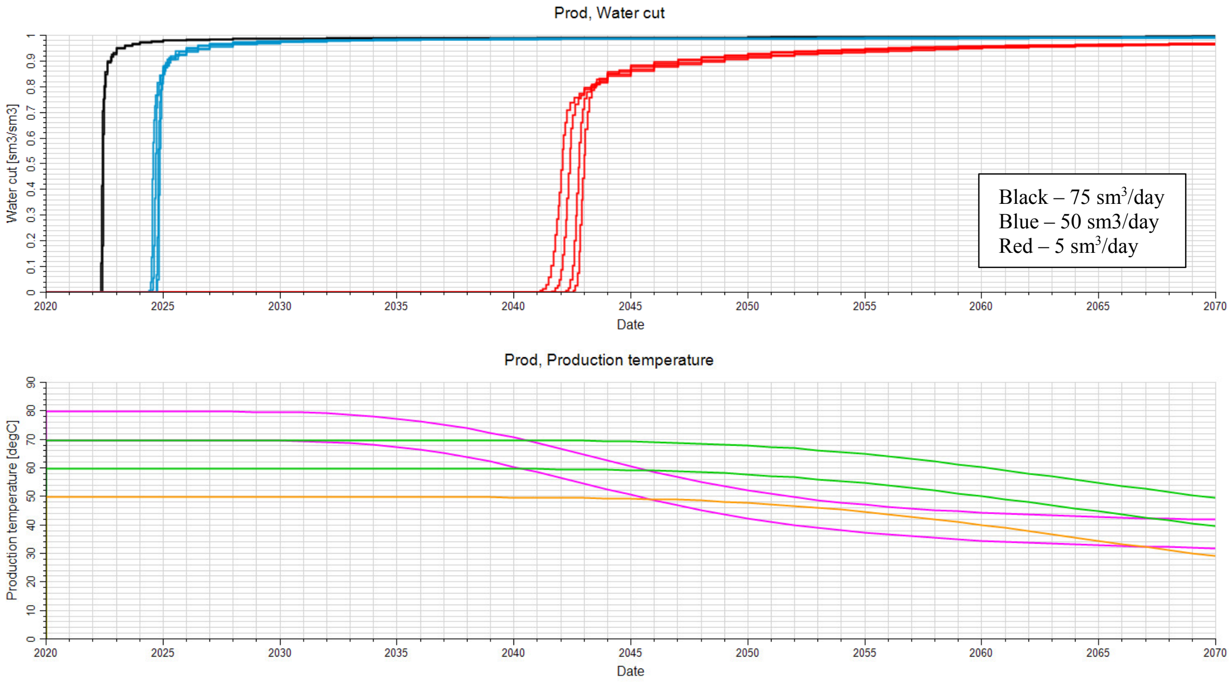


Figure 8: Sensitivity of water and cold front breakthrough time on different injectivity and reservoir permeabilities.

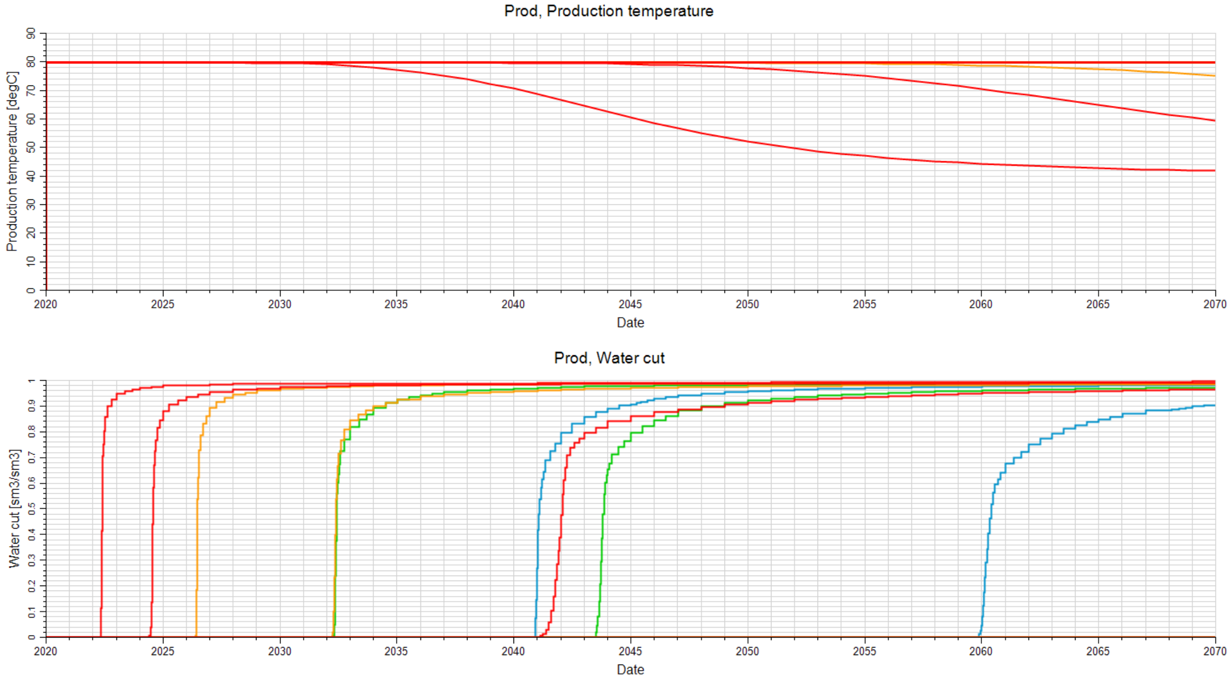


Figure 9: Sensitivity of water and cold front breakthrough time on different injectivity rates and well spacing (red – 150 m, orange – 250 m, green – 350 m, blue – 450 m).

Simulation results indicated that produced fluid temperature is not sensitive either to initial water saturation or to porosity. The primary reason is related to the small variation range.

Now let us move to the key objective of this synthetic study – energy production from produced water which is a by-product during the oil production. Therefore, here there is a conflict of interest, because the ideal situation for maximum energy production is early water breakthrough with delayed arrival of cool-front. While in the oil industry the maximum non-water production period is always preferred and maximized, in our case we are concentrating on heat extraction from produced reservoir water, therefore, early break-through time should give higher energy production. Figure 13 shows the change of energy production rate from water at 100% heat extraction for all simulated sensitivity cases, grouped based on formation thickness (a – 20 m, b – 50 m, c – 100 m). The most sustained production (early start, high energy rate, prolonged plateau before drastic decline) is observed for average reservoir thickness cases of 50 m.

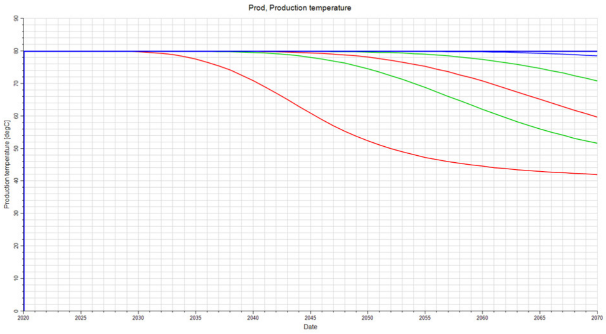


Figure 10: Change of production temperature as a function of formation thickness for minimum well spacing of 150 m and maximum permeability of 50 mD (red – 20 m, green – 50 m, blue 100 m).

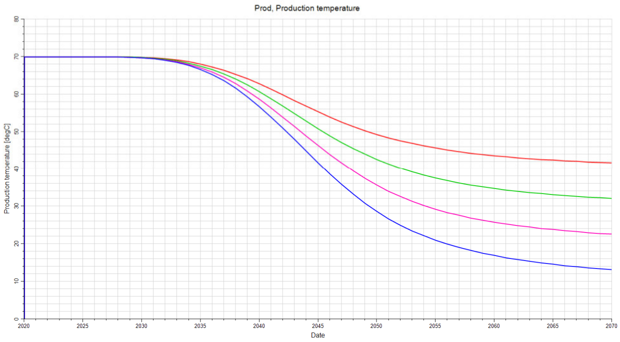
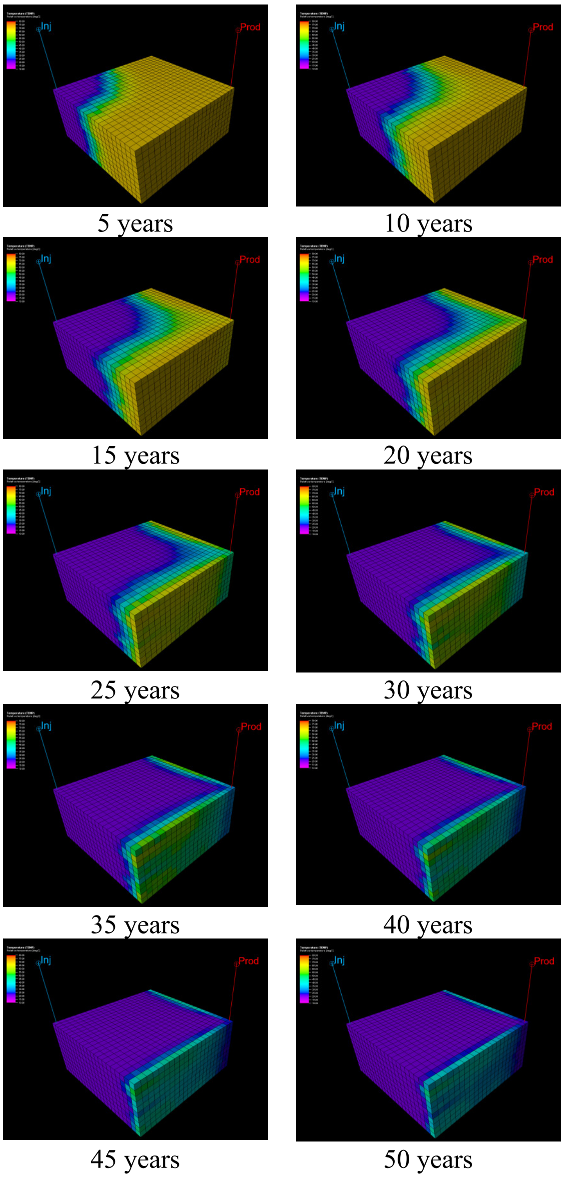


Figure 11: Change of produced water temperature as a function of re-injected water temperature (blue – 10 °C, pink – 20 °C, green – 30 °C, red – 40 °C)

Table 3 summarizes sensitivity parameters that gave highest cumulative energy production at 100% extraction for the 10 best cases, grouped based on the reservoir thickness. The maximum cumulative energy of 261.18*10E6 GJ is generated for 100 m thickness with minimum spacing of 150 m and the rest of the parameters at their maximum values. For 50 m thick reservoir, the optimum is 250 m spacing with the rest of the parameters at their maximum values. For the minimum thickness cases (20 m) the maximum energy is also generated when the distance between the wells is 250 m but the rest of the parameters are not at their maximum values. It is necessary to note that total generated energy for 100 m and 50 m are very comparable resulting in a difference of about 15*10E6 GJ, while for the minimum thickness we can produce 1.7 times less.



5 years 10 years
15 years 20 years
25 years 30 years
35 years 40 years
45 years 50 years

Figure 12: Example of cooling front progression in time

3. CONCLUSIONS

- In this synthetic study performed for the general reservoir conditions of oil fields in Western Ukraine we assumed that the wells are completed within the total formation thickness represented by clastic sandstone, where heterogeneity is defined via randomly populated porosity and permeability following stationary distribution.
- In total 1344 numerical cases were simulated for evaluation of the key parameters. Quarter-five spot models with one injector and producer in the corners were used with different standard average spacing between the wells.
- Analysis was performed from 2 points of view: a) water break-through with progression of cooling front, b) energy rate generated from water production as a by-product of oil.
- Energy production from newly drilled wells can start after 2 – 7 years, depending on the thickness of the formation and its permeability, once the water from injector reaches the producer.

- Constant energy production when the cool front has not reach the producer is between 7 to 25 years depending on reservoir parameters.
- For optimum energy generation we should target the reservoirs with maximum net thickness, high permeability and minimum well spacing of 150 m.

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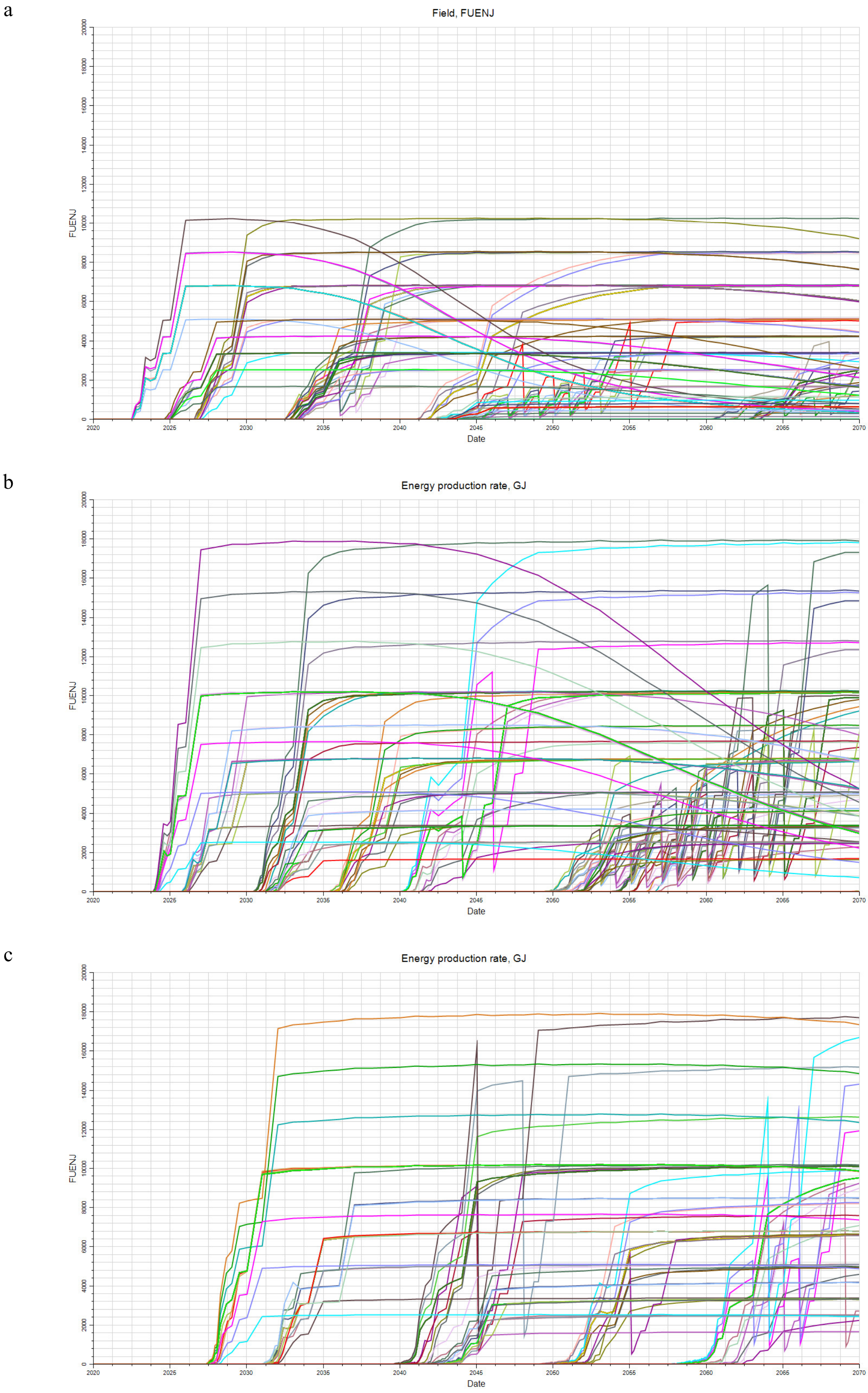

Figure 13: Combined plots for energy production rates, grouped based on formation thickness (a – 20 m, b – 50 m, c – 100 m).

Table 3 – Summary of sensitivity for 10 best energy production cases for each evaluated reservoir height

#	Produced energy, 10E6 GJ	Reservoir height, m	Well spacing, m	Injection rate, sm3/day	Injection temperature, C	Reservoir temperature, C	Permeability, mD	Porosity, %	Initial water saturation, frac.
1	153.56	20	250	50	30	70	20	10	0.16
2	128.03	20	250	50	40	70	20	10	0.2
3	127.87	20	250	50	30	70	20	10	0.18
4	126.91	20	350	50	30	70	5	10	0.2
5	105.76	20	350	50	30	70	10	10	0.2
6	102.89	20	350	50	30	70	20	10	0.22
7	102.31	20	250	75	40	80	20	12	0.22
8	102.18	20	250	50	30	50	20	10	0.2
9	102.18	20	250	50	30	60	20	10	0.2
10	102.18	20	250	50	30	70	20	10	0.2
1	244.75	50	250	75	40	80	50	12	0.22
2	231.35	50	150	75	10	80	50	12	0.22
3	209.82	50	250	25	40	80	50	12	0.22
4	198.14	50	150	75	20	80	50	12	0.22
5	174.86	50	250	50	40	80	50	12	0.22
6	172.56	50	350	75	40	50	5	12	0.22
7	164.66	50	150	75	30	80	50	12	0.22
8	151.05	50	150	50	10	70	50	10	0.2
9	147.92	50	350	75	40	60	50	12	0.22
10	139.90	50	250	75	40	80	5	12	0.22
1	261.18	100	150	75	10	80	50	12	0.22
2	223.88	100	150	75	20	80	50	12	0.22
3	186.57	100	150	75	30	80	50	12	0.22
4	161.81	100	250	75	40	50	50	12	0.22
5	151.01	100	150	75	40	80	5	12	0.22
6	151.01	100	150	75	40	80	10	12	0.22
7	151.01	100	150	75	40	80	20	12	0.22
8	151.01	100	150	75	40	80	50	12	0.22
9	151.01	100	150	75	40	80	50	12	0.22
10	151.01	100	150	75	40	80	50	12	0.22