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DESIGN OF A RE-INJECTION WELL USING NUMERICAL MODELLING TECHNIQUES

Miklos Antics

GEOFLUID S.A.
11, Parc S. Petofi
Oradea, 3700, ROMANIA
e-mail: geofluid@texnet.ro

ABSTRACT

Re-injection of cooled geothermal brines is an urgent prerequisite to present geothermal exploitation and future developments in the Pannonian Basin, not only to maintain the reservoir pressure over a long term exploitation, but also because it is requested by the legislation in many countries in the area in order to prevent potential thermal and mainly chemical pollution.

The selected sites are located in SE Hungary and thus, from a geological point of view, in the central part of the Pannonian Basin, a group of lowlands and subdued mountains framed by the Carpathian arc, the Eastern Alps, and the Dinarides. The geothermal fluids are produced from the Upper Pannonian sandstone reservoir.

Currently efficient re-injection is practiced on limited scale due to restricted design/demonstration experience in the area.

The numerical simulation exercise carried out (using TOUGH2) reveals the most sensitive parameters that should be considered in the well design, especially when developing the filter area that interfaces the well and the reservoir.

GEOLOGICAL BACKGROUND

The selected site Szentes, located in SE Hungary (Figure 1), and from geological point of view, in the central part of the Pannonian Basin, a group of lowlands and subdued mountains framed by the Carpathian arc, the Eastern Alps, and the Dinarids. The geothermal fluids are produced from the Upper Pannonian sandstone reservoir.

The Pannonian Basin was formed as a result of a southward subduction of an oceanic lithosphere. When considering it in the geological framework, the Pannonian Basin represents an element of the subsequent tectonics formed upon completion of the alpidic orogeny. At the apsis of Oligocene/Miocene, the alpidic orogeny of its edging was essentially completed, only in the molasse foredeeps folds were still formed by the end of the Miocene, and at most by that of the Pliocene. The orogens partly ascended to mountains, and partly collapsed in interior depressions, such as the Old Red depressions after the Caledonian, and the New Red depressions after the Variscan orogenies.

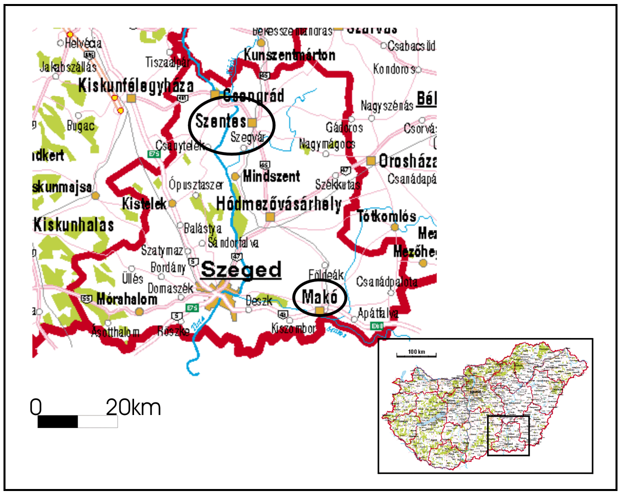


Figure 1. Location map

Phenomena of this kind occurring in the alpidic Neo-Europe are those sedimentary basins which had been extending since the Lower Miocene – partly as new formations, and partly consisting of already older marine zones – from the Vienna Basin, via the Pannonian Basin, the Euxinic Basin, the Manyc Lowland, to the Carpathian and Aral Basins. This "Parathetys" was separated from the Mediterranean Thetys – or better from its remainders in the Mediterranean – by a mountainous rise (Alps – Dinarids – Balkan Mountains – Pontian Mountains in northern Turkey – Elburz Mountains in northern Iran). At the apsis of Miocene/Pliocene, it broke up into the above individual basins (Teleki, 1994).

The actual formation of the Pannonian Basin started in the Upper Miocene (Helvetian), when the sea transgressed in the western and northern parts, and finally covered the entire basin in the Tortonian, including the Styrian part in the west and the Transsylvanian part in the east. However, the most significant subsidence took place in the top Miocene only, in a time unit called "Pannonian Stage". Solely in this period, up to 3,500 m thick sediments deposited under the brackish or freshwater conditions. This subsidence continued even in the Pleistocene, of which the maximum 1,000 m thick sediments in east Hungary give proof.

The collapse of the Pannonian Basin was connected with subsequent volcanism of a huge extent. It is assumed that on the overall area of 50,000 km^2 of the Pannonian Basin there is the largest concentration of Tertiary volcanism on the European territory.

The crustal structure of the Pannonian Basin shows peculiarities, i.e. the Mohorovicic area ascends up to 24 km. The rising contact of the mantle with the crust resulted in crust thinning by extension and erosion. This caused a higher than average terrestrial heat flow in the region, due to the closer proximity to the hotter mantle. The geothermal gradient is in large parts of the basin about 50ºC/km, locally it rises up to 100ºC, and about 140ºC are given as the maximum. The terrestrial heat flow in the areas in question is between 70-80 mW/m^2.

The subsidence which took place mainly during the Neogene-Quaternary age, resulted in sedimentation of sandstones, clays and marl. The Pannonian formations overlie rocks of Miocene age or older. The latter are often referred to as basement and consist of both sedimentary and igneous rocks, including limestones, dolomites, sandstones, conglomerates, as well as igneous and metamorphic rocks.

The stratigraphy of the selected area corresponds to fluvial-terrestrial deposition consisting in multilayered channel deposits of mud, silt and sandstone. The depositional layers are almost horizontal (Juhasz, 1991).

MODELLING OBJECTIVES

Reinjection of cooled geothermal brines is an urgent prerequisite to present geothermal exploitation and future developments in Hungary, not only to maintain the reservoir pressure over a long term exploitation, but also because it is requested by the Hungarian legislation in order to prevent potential thermal and mainly chemical pollution. Currently efficient re-injection is practiced on limited scale due to restricted design/demonstration experience in the area.

The selected test area is the most important from the point of view of the simulation exercise since on the respective area operates the largest geothermally heated greenhouse outfit in Hungary. The geothermally heated greenhouse complex is divided into two farms named Alkotmany and Szentlaszlo.

The location map of the proposed test site (Alkotmany) together with the main greenhouse farm (Szentlaszlo) are presented in Figure 2. The total area of the glass and plastic greenhouses is 46 ha of which one half is geothermally heated by 14 wells. The wells are producing from the Upper Pannonian geothermal reservoir with wellhead temperatures varying between 74-98°C.

The selected production / injection test triplet consists of two producing wells 5-66 and 5-96 and a future injector well (INJ01) that will be drilled close to well 5-66. Well design characteristics are presented in Table 3. In case that the re-injection test will be proved to be successful injection well array formed by six wells is planned to be drilled on the Szentlaszlo farm site (Figure 2, labelled INJ01-INJ06).

The aim of the reservoir simulation exercise carried out for the area in question was to develop a reservoir model for the selected production / injection test site in order to accurately reproduce, based on the available data, the reservoir behaviour during production / injection. Special attention was paid to the variable permeability structure of the filter area of the injection well. The main idea was to study what are the most sensitive parameters in designing the injection well in order to limit re-injection pressure.

The computer code employed for simulation was TOUGH2 PC Version developed by Karsten Pruess at the Earth Science Division, Lawrence Berkeley Laboratory, University of California.

RESERVOIR MODEL

Based on the available geological description presented earlier, was considered a 3D model (Figure 3) for the area with nine horizontal layers. Table 1 shows the characteristics of the layers. The permeability structure of the layers was chosen according to both geological description and correlation with the available well test data and available output curves of the wells. In order to accurately reproduce the wells, the well blocks were discretised with radial grid in logarithmic progression from the diameter of the casing to an outer radius of 62.5 m (Table 2).

Boundary conditions were assigned as being constant pressure type at all sides of the model.

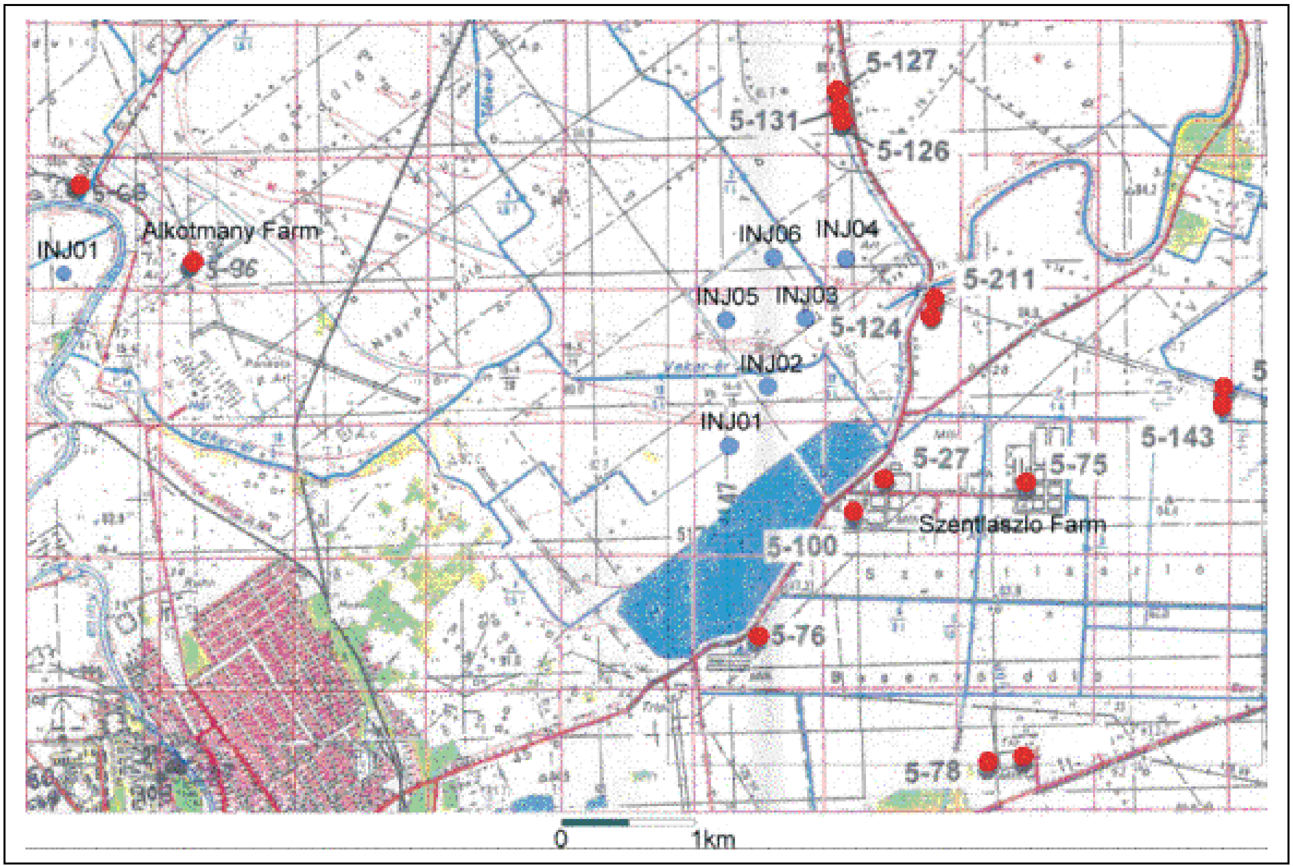


Figure 2. Location map of the proposed production/injection development in the Szentes area

Table 1. Rock properties of the reservoir model

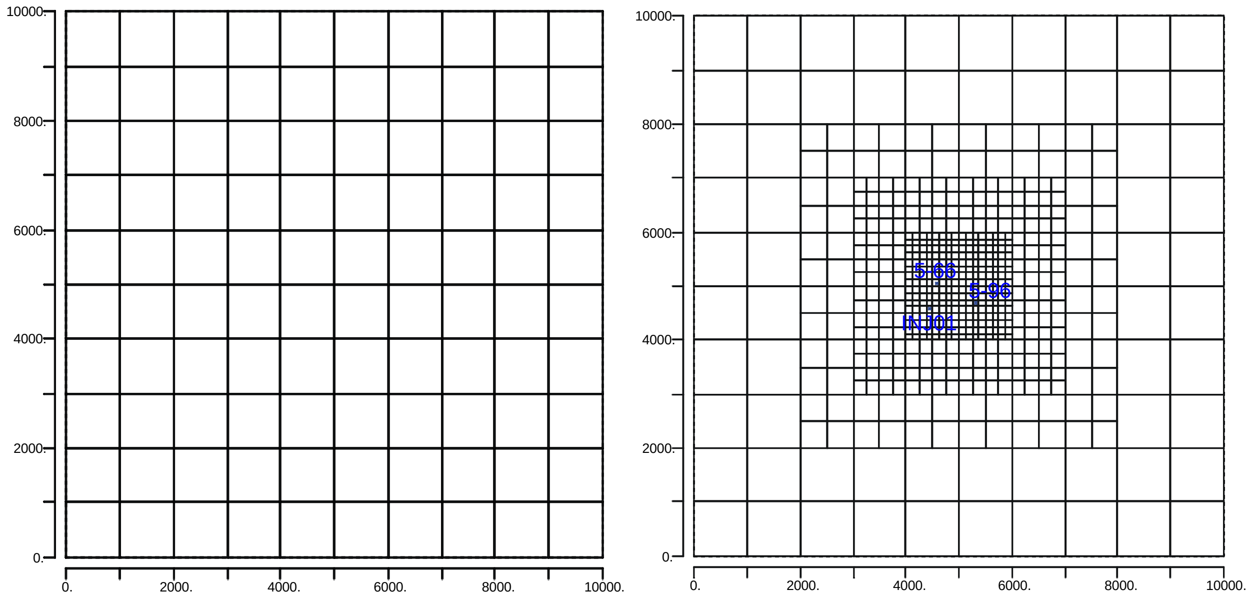
Layer name	Interval, m	Rock	ρ, kg/m^3	ϕ	k, mD	K, W/mK	c, J/KgK
AI	0-700	Pleistocene	1800	0.3	1000	2.1	872
AH	700-1100	Levantine	1950	0.1	5	2.0	886
AG	1100-1600	Upper Pannonian	2700	0.2	50	1.64	840
AF	1600-1700	Upper Pannonian	2700	0.2	50	1.64	840
AE	1700-1800	Upper Pannonian	2700	0.2	50	1.64	840
AD	1800-1900	Upper Pannonian	2700	0.2	50	1.64	840
AC	1900-2000	Upper Pannonian	2700	0.2	50	1.64	840
AB	2000-2100	Upper Pannonian	2700	0.2	50	1.64	840
AA	2100-2400	Lower Pannonian	2750	0.1	5	1.75	890

Table 2. Mesh geometry of the production/injection blocks for height of 1 m

ELEM	REL, m	RCON, m	D, m
1	0.0610	0.1220	0.0610
2	0.2263	0.3306	0.1043
3	0.5088	0.6871	0.1783
4	0.9919	1.2967	0.3048
5	1.8177	2.3387	0.5210
6	3.2294	4.1201	0.8907
7	5.6428	7.1656	1.5227
8	9.7687	12.3720	2.6032
9	16.8220	21.2720	4.4502
10	28.8800	36.4880	7.6079
11	49.4940	62.5000	13.0060

Table 3. Existing wells design characteristics

Well label	Depth, m	Casing interval			Opened interval	
		Diam, mm	top, m	bottom, m	top, m	bottom, m
5-66	2026	349	0	37	1801	2019
		244	0	655		
		178	0	2025		
5-96	2401	350	0	3	2063	2266
		244	0	796		
		168	0	2140		
		114	2135	2401		



Discretisation of layers AA, AB, AG, AH, AI

Discretisation of layers AC, AD, AE, AF

Figure 3. Reservoir discretization grid

A natural state model was used to reproduce the undisturbed pressure and temperature fields in the reservoir prior to exploitation. To the selected grid was added a heat source of $8x10^6$ W (corresponding to a heat flow of 80 mW/m^2). The pressure and temperature values for each layer are shown in Table 4. The resulted pressure and temperature fields match the recorded pressures and temperatures in the selected wells i.e. 5-66 and 5-96 respectively.

Table 4. Temperature and pressure conditions resulted from natural state modelling

Layer name	Interval, m	T, °C	p, bar
AI	0-700	31.37	35.36
AH	700-1100	52.71	88.97
AG	1100-1600	72.90	132.51
AF	1600-1700	87.53	161.29
AE	1700-1800	92.41	170.83
AD	1800-1900	97.29	180.35
AC	1900-2000	102.17	189.83
AB	2000-2100	107.05	199.29
AA	2100-2400	116.34	218.11

The production wells are producing in a cyclic manner with average flowrates of 20 kg/s during 180 days/year. Another aim of the simulation exercise was to study the reservoir behaviour since 1970 when the wells were commissioned. The results showed that the reservoir is very stable mainly due to its infinite extent and the simulated pressures reproduce the observed drawdowns in the production wells. It was also observed that the reservoir pressure is recovering during the summer period close to its initial value, fact confirmed by practice.

INJECTION WELL DESIGN

In order to investigate the evolution of the injection pressure during the injection test it was considered an injection well (generically named INJ01) in which will be the cooled geothermal brine (produced by wells 5-66 and 5-96) at 30°C with a flowrate of 40 kg/s in the interval of 1600-2000 m depth injected. The reason for selecting this interval was the geological information from the area that confirms the presence of the Upper Pannonian formation in the aforementioned interval. The injection well was discretised similarly with the previously presented mesh. The duration of the injection test was assumed to be 180 days, which corresponds to a heating season.

The scope of the simulation was to investigate the permeability/porosity distribution of area in the vicinity of the injection well (up to 1 m radius) in order to minimise injection pressure. Basically this area should correspond to the filter area that is built up in front of the reservoir area. There were twenty models investigated. The characteristics of these models are presented in Table 5. The simulation results are presented in Figures 4 and 5.

Table 5. Characteristics of the models employed for the injection test simulation

radius, m	0.061		0.2263		0.5088		0.9919	
Model	ϕ	k, D	ϕ	k, D	ϕ	k, D	ϕ	k, D
1	0.9999	1.00E+05	0.3	100.0	0.2	50.0	0.2	25.0
2	0.9999	1.00E+05	0.3	50.0	0.2	25.0	0.2	10.0
3	0.9999	1.00E+05	0.3	25.0	0.2	10.0	0.2	5.0
4	0.9999	1.00E+05	0.3	10.0	0.2	5.0	0.2	1.0
5	0.9999	1.00E+05	0.3	5.0	0.2	1.0	0.2	0.5
6	0.9999	1.00E+05	0.3	1.0	0.2	0.5	0.2	0.1
7	0.9999	1.00E+05	0.3	0.5	0.2	0.3	0.2	0.2
8	0.9999	1.00E+05	0.9999	1.00E+05	0.2	25.0	0.2	1.0
9	0.9999	1.00E+05	0.3	100.0	0.2	0.1	0.2	0.1
10	0.9999	1.00E+05	0.3	50.0	0.2	0.1	0.2	0.1
11	0.9999	1.00E+05	0.3	25.0	0.2	0.1	0.2	0.1
12	0.9999	1.00E+05	0.3	5.0	0.2	0.1	0.2	0.1
13	0.9999	1.00E+05	0.3	1.0	0.2	0.1	0.2	0.1
14	0.9999	1.00E+05	0.3	0.5	0.2	0.1	0.2	0.1
15	0.9999	1.00E+05	0.3	0.1	0.2	0.1	0.2	0.1
16	0.9999	1.00E+05	0.3	25.0	0.2	0.1	0.2	0.1
17	0.9999	1.00E+05	0.3	25.0	0.2	0.5	0.2	0.1
18	0.9999	1.00E+05	0.3	25.0	0.2	1.0	0.2	0.1
19	0.9999	1.00E+05	0.3	25.0	0.2	10.0	0.2	0.1
20	0.9999	1.00E+05	0.3	25.0	0.2	10.0	0.2	1.0

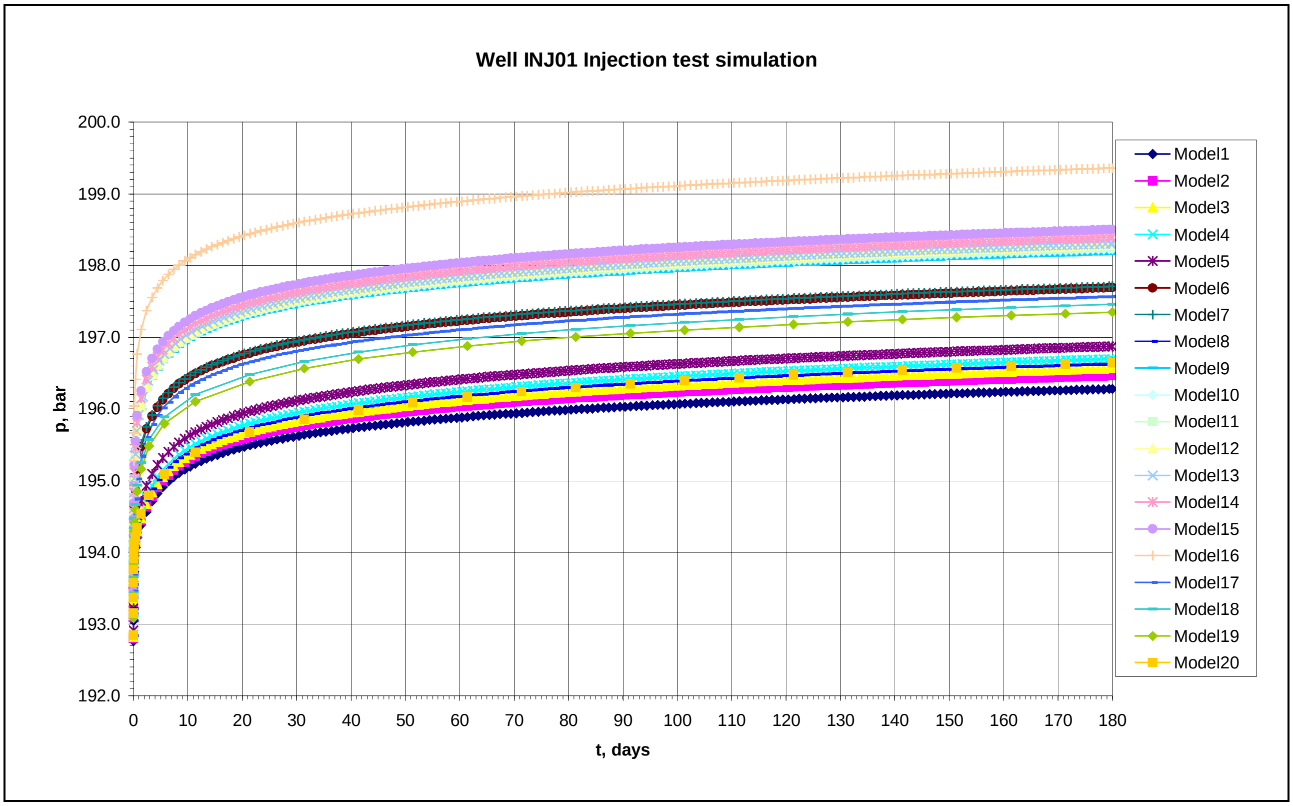


Figure 4. Injection test simulation. Evolution of pressure for the considered models at reference depth of 1950 m

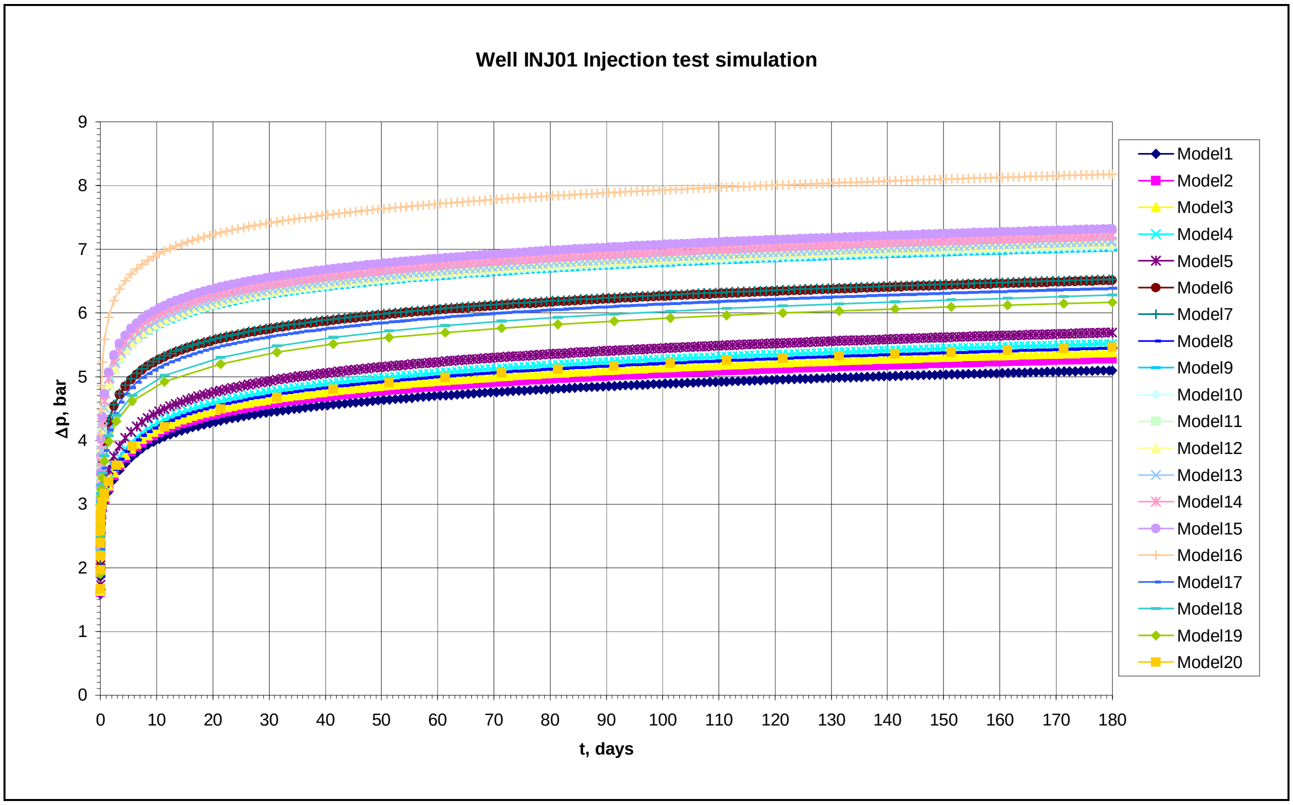


Figure 5: Injection test simulation. Evolution of pressure difference between injection pressure and static pressure for the considered models

Since the simulator was designed to simulate flow in porous media and the first well block corresponds to the hole it was modelled as a media with porosity close to 1 (this was selected due to numerical restrictions of the simulator) and very high permeability. The second block corresponds to the filter area that generally has high porosity and permeability. The permeabilities of the third and fourth well block were selected arbitrary. Models 1-8 are ideal models which technologically are unlikely to be achieved however this models would be the most suitable in order to minimise injection pressure.

It was considered that model 17 would be the most reasonable model that could be achieved by existing technologies i.e. high permeability filter area and increase of permeability in the vicinity of the well by acidising/hydraulic fracturing.

The next step was to investigate the evolution of the pressure / temperature fields during long term production / injection for the selected injection well model.

It was considered that wells 5-66 and 5-96 will produce in a heating season of 180 days with a flowrate of 20 kg/s each and the whole amount of cooled geothermal water will be injected in well INJ01 i.e. 40 kg/s at 30°C.

The conditions simulated for the production history for the past 30 years were assumed as being initial conditions for simulation forecast.

For the injection well INJ01 the permeability distribution of the vicinity of the wellbore was selected according to model 17 among the injection test models. The simulation results are presented in Figures 6 and 7.

From the simulation results was observed that there will be no thermal breakthrough after 20 years of operation. The pressure will gradually increase in the injection block from 191.9 to 198 bar at the reference depth of 1950 m.

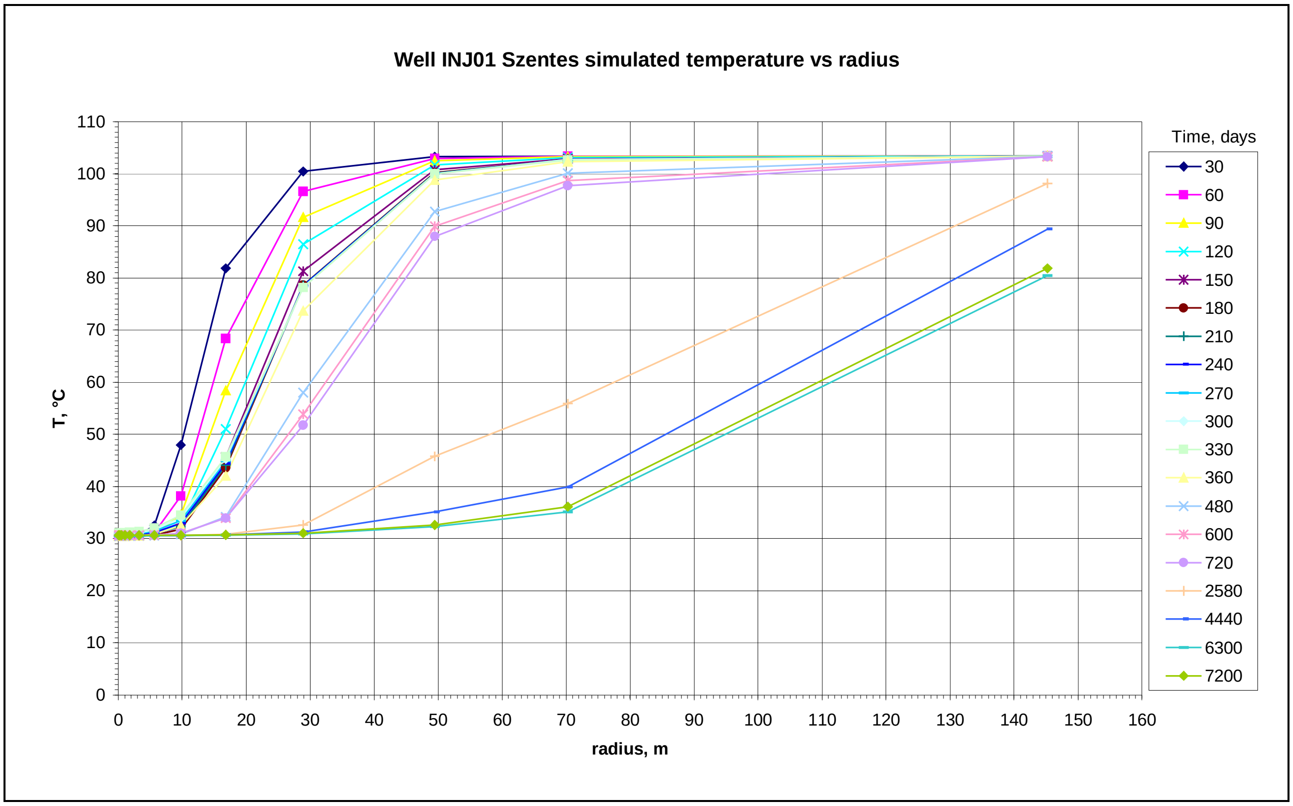


Figure 6. Well INJ01 Simulation. Evolution of temperature vs. radial distance at reference depth of 1950m

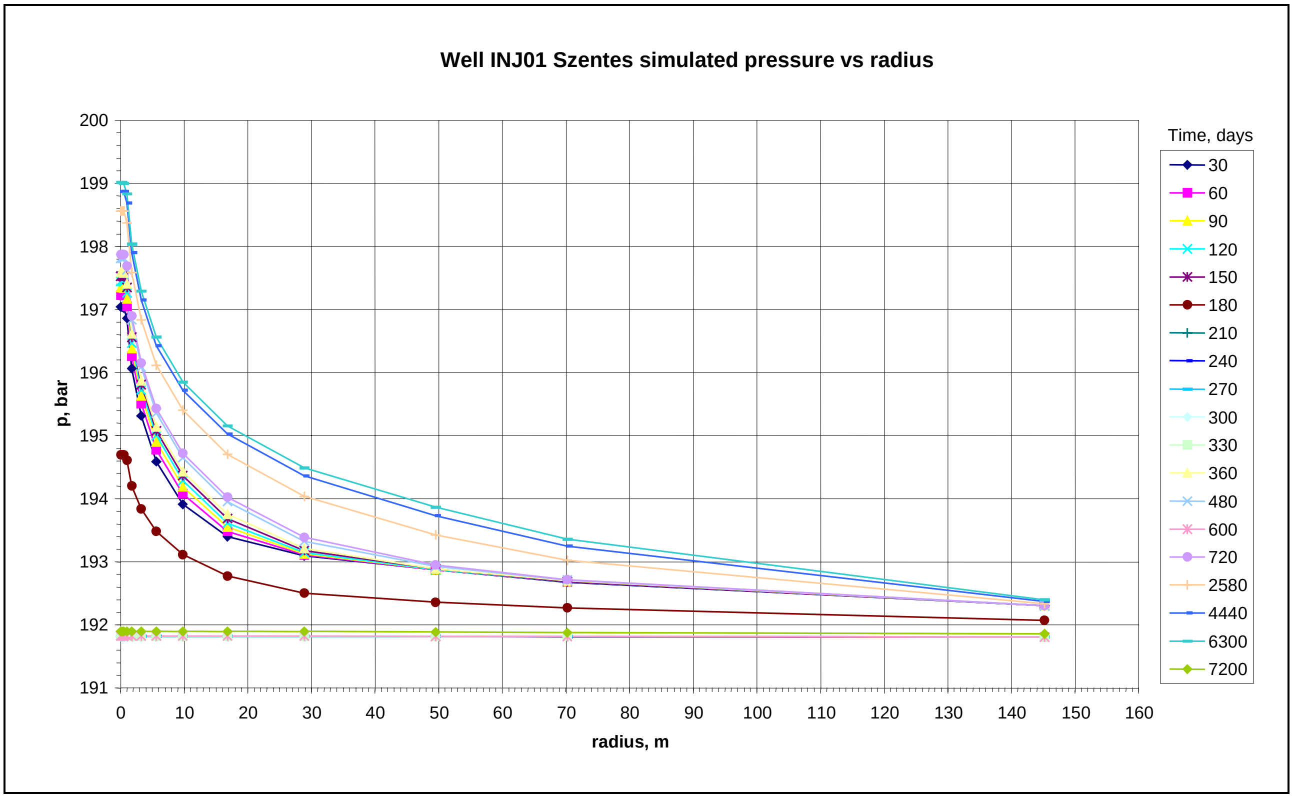


Figure 7. Well INJ01 Simulation. Evolution of pressure vs. radial distance at reference depth of 1950m

While designing well completion, emphasis has been placed on its injective capacity aimed at routinely accommodating a 40 kg/s injection rate under well head pressures not exceeding 10 bar. The simulation exercises carried out suggested that this objective can be achieved by a well completion given by the following (Figure 8) programme:

- a 9"5/8 casing set at top reservoir depth (ca 1450 m)
- a screen / gravel pack completion over the target pay interval (ca 370 m) combining a 10"/6"5/8 gravel packed annulus and a 6"5/8, stainless steel wire wrapped screen / blank liner assembly
- a careful design and implementation of the mud programme, particularly during the reservoir drilling phase, owing to the multilayered and clayey nature of the geothermal aquifer
- a sound monitoring and testing of the fluid and reservoir rocks in view of properly assessing well injectivity and formation injectibility which are vital data for further optimisation and operation of replicate injection wells.

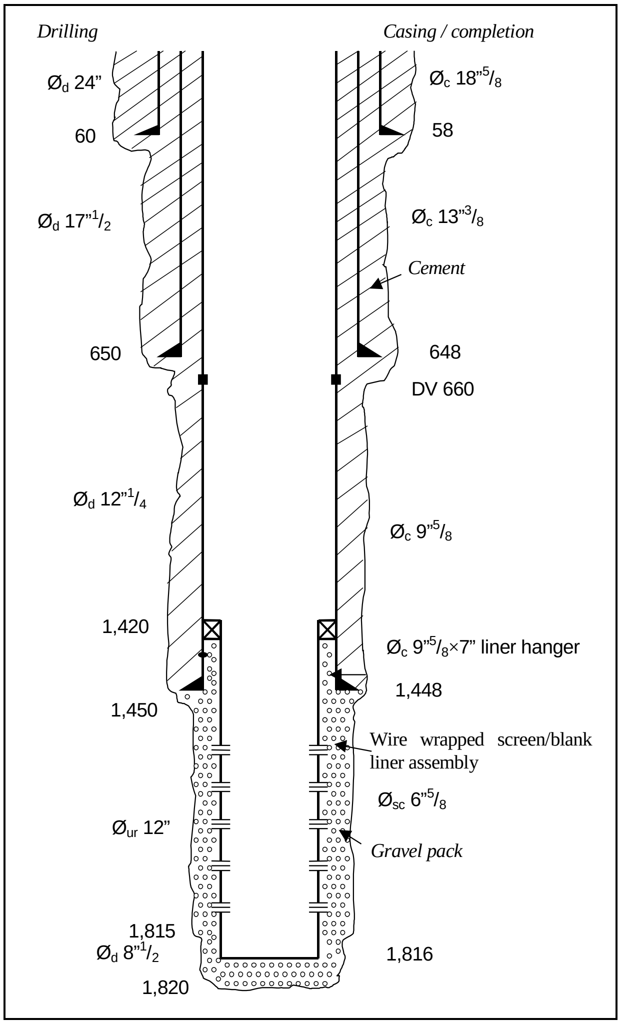


Figure 8. Injection well design

CONCLUSIONS

The simulation exercises carried out on the porous permeable sand/sandstone reservoir in the Szentes, area lead to the following conclusions:

- The reservoir may be assumed as multilayered with constant thickness, horizontal, homogeneous by layers and with infinite extent.
- Injection in the reservoir may be possible provided adequate well completion consisting in an increased permeability of the vicinity of the injection well (up to a radius of 1 m).
- The total injection reservoir thickness assumed to be 400 m is somehow generous but conservative permeability values were taken for the reservoir which creates realistic model of the production/injection behaviour.
- The intrinsic permeability of the reservoir influences very much the injection pressure that will by all means increase during the time.
- The distance between the production and injection well should be at least 500 m in order to avoid thermal breakthrough.
- The simulations carried out for the above areas showed that the injection flowrates up to 40 kg/s can be accommodated by an injection well thus achieving injection pressures of 7-8 bar after 20 years.

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REFERENCES

Juhasz, G. (1991): Lithostratigraphical and sedimentologica framework of the Pannonian (s.l.) sedimentary sequence in the Hungarian Plain (Alfold), Eastern Hungary. – AGH, 34, 53-72, 14 fig., Budapest.

Teleki P., Mattick R., Kókai J. –editors- (1994): Basin analysis in petroleum exploration: A case study from the Békés basin, Hungary. Kluwer Academic Publishers, p39-65, p.67-82, p.99-110, p.201-210.