SIMULATION OF GEOTHERMAL REINJECTION PROCESSES

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ABSTRACT

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

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.

The numerical simulation exercise carried out (using TOUGH2) focused on the hydraulic and thermal behaviour of the area interfacing the wellbore with the reservoir, in order to provide some ideas required to develop the filter area between the wellbore and the reservoir.

Keywords: Pannonian Basin, simulation, reinjection, sandstone reservoirs

INTRODUCTION

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 Dina rids. The geothermal fluids are produced from the Upper Pannonian sandstone reservoir.

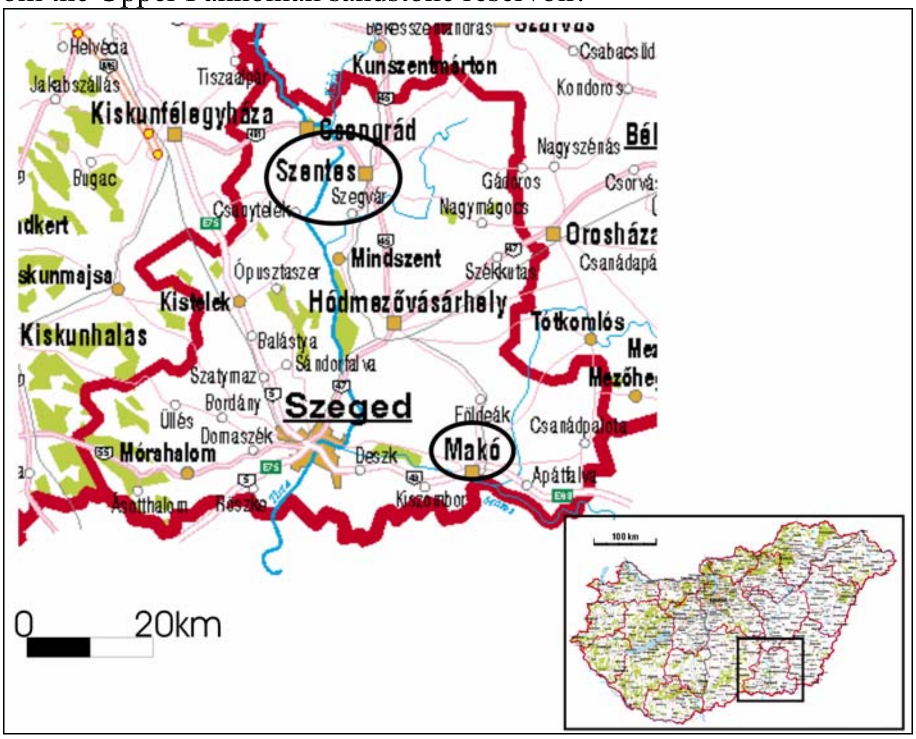

Figure 1: Location map

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 molasses fore deeps 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. [1].

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 [2].

SIMULATION EXPERIMENTS

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 Szent Laszlo.

The location map of the proposed test site (Alkotmany) together with the main greenhouse farm (Szent Laszlo) 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.

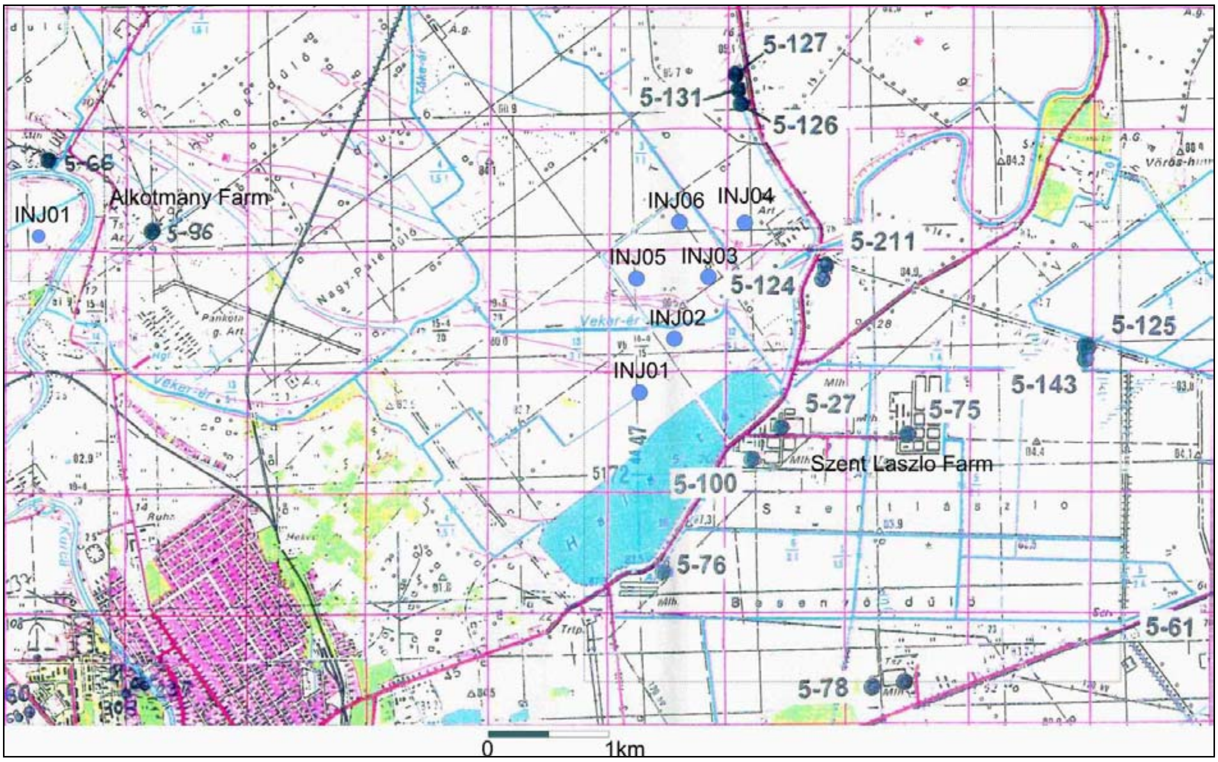

Figure 2. Location map of the proposed production/injection development in the Szentes area

Based on the available geological description presented earlier, was considered a 3D model (plan view presented in 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 125 m (Figure 4). Boundary conditions were assigned as being constant pressure type at all sides of the model.

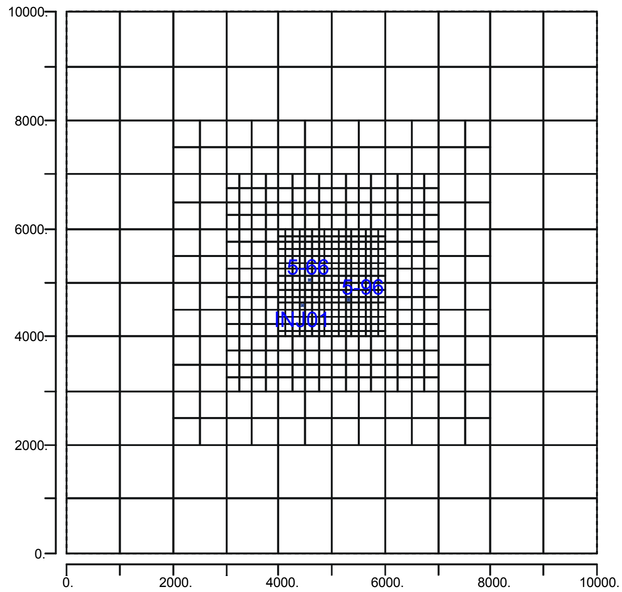

Figure 3. Plan view of the discretization grid

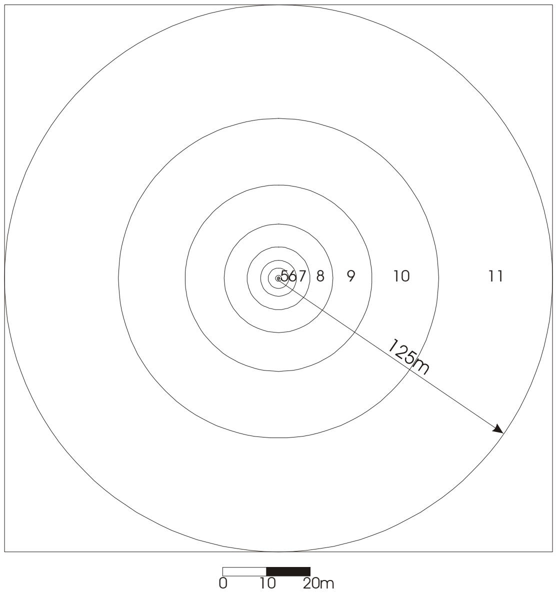

Figure 4. Production/injection block

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 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		

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	Depth of the centre of the block, m	T, °C	p, bar
AI	0-700	350	31.37	35.36
AH	700-1100	900	52.71	88.97
AG	1100-1600	1350	72.90	132.51
AF	1600-1700	1650	87.53	161.29
AE	1700-1800	1750	92.41	170.83
AD	1800-1900	1850	97.29	180.35
AC	1900-2000	1950	102.17	189.83
AB	2000-2100	2050	107.05	199.29
AA	2100-2400	2250	116.34	218.11

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 injected, in the interval of 1600-2000 m, the cooled geothermal brine (produced by wells 5-66 and 5-96) with the flowrate of 40 kg/s and temperature of 30°C. 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 find out what would be 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 developed 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 Figure 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

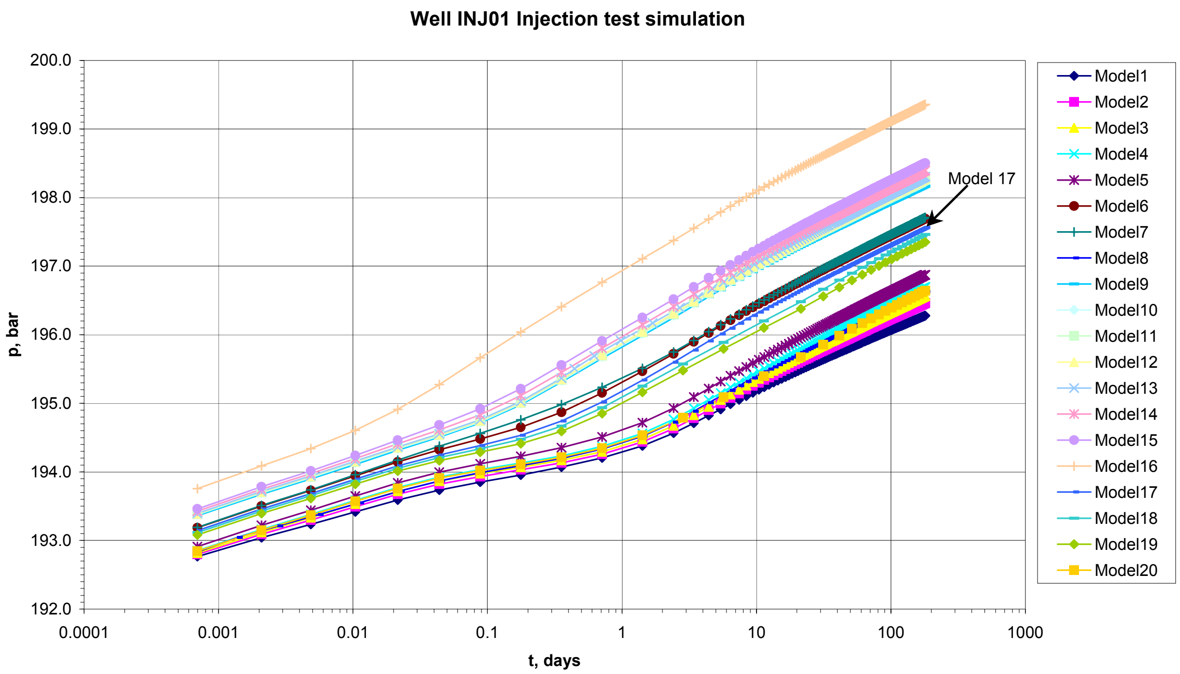

Figure 5. Injection test simulation. Evolution of pressure for the considered models at reference depth of 1950 m

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 no. 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.

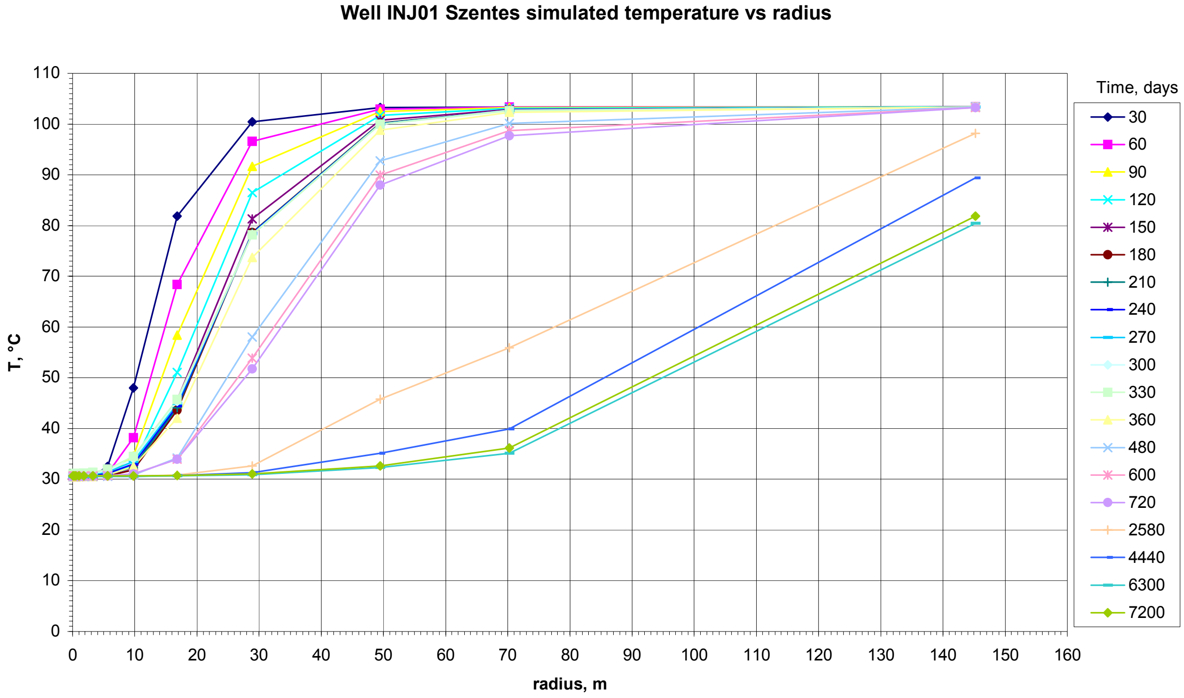

Figure 6. Well INJ01 Simulation. Evolution of temperature vs. radial distance at reference depth of 1950m

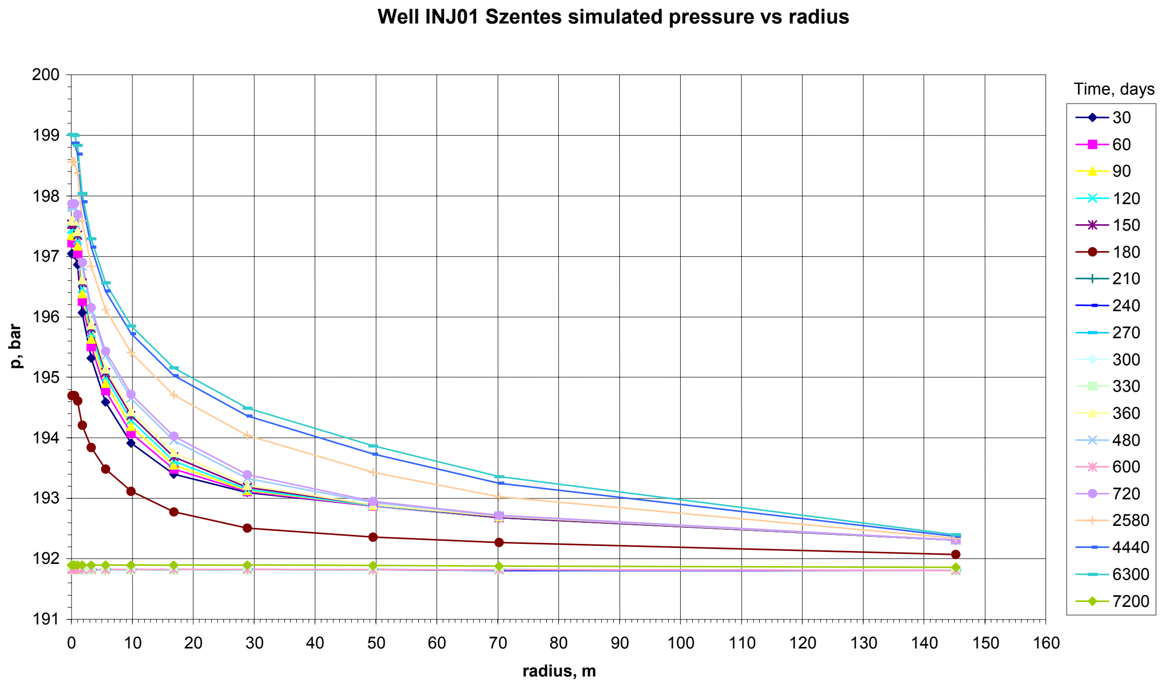

Figure 7. Well INJ01 Simulation. Evolution of pressure vs. radial distance at reference depth of 1950m

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 layers of constant thickness, horizontal, homogeneous by layers and with infinite extent.
- The simulation exercise carried out did not take into account particle invasion and chemical transport phenomena.
- The sole objective of the simulation was to investigate the hydraulic and thermal behaviour of the injection well/reservoir interface.
- 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 simulations carried out for the area 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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