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COMPUTER MODELLING OF AN OVER-PRESSURED MEDIUM ENTHALPY GEOTHERMAL RESERVOIR LOCATED IN DEEP SEDIMENTARY BASIN

Miklos A. Antics

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

ABSTRACT

Over-pressure conditions occur in the south-eastern region of the Pannonian Basin due to the reversal of the regional tectonic stress beginning in the Middle Miocene. Exploratory wells in the area discovered well head pressures close to 350 bar and high temperatures exceeding 190°C at depth of 3,500 m.

These promising shows, based on early appraisals, require thorough in depth investigations in terms of reservoir size, recoverable reserves, well deliverabilities in order to assess whether the resource could sustain feasible development issues for electricity production.

The paper reviews the results of the preliminary reservoir simulation studies carried out for the area in question addressing reservoir evaluation: i.e. lateral extent, thickness and volume, tectonic features, governing boundary conditions, porosity/ permeability patterns, reservoir compartments and continuity between these compartments.

INTRODUCTION

The Pannonian Basin was formed as a result of a southward subduction of an oceanic lithosphere. The rising contact of the mantle with the crust resulted in crust thinning by extension and erosion. This caused a higher than average heat flow in the region, due to the closer proximity to the hotter mantle. The subsidence which took place mainly the Neogene-Quaternary age. resulted in sedimentation of sandstones, clays and marl. The Pannonian formations overlie rocks of Mocene 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 basement rocks are the main target of exploration for geothermal resources suitable for electricity production.

Many of the deep geothermal reservoirs in the Pannonian Basin are overpressured with pressure gradients exceeding 21 MPa/km. Exploratory wells drilled in the south-eastern part of Hungary discovered high pressures exceeding 62 MPa and temperature of 190°C at depth of 3200m.

The primary mechanism for the existence of overpressured conditions (Horvath, 1995) is the reversal of the regional tectonic stress field in the area beginning in the Middle Miocene. The tensional forces prevailing throughout the region in the Lower Miocene initiated the formation of the Pannonian Basin by sedimentation over the Mesozoic carbonate and granitic basement, with up to 6500m thick of deltaic and basinal sand and clay deposition. In the Middle Miocene occurred a reversal in the stress field whch lead to the compression of the Pannonian Basin in north-east direction. In the central part of the Pannonian Basin further subsidence occurred resulting in increased thickness of Plio-Pleistocene clastic sediments. The margins of the Basin were uplifted. Movement on normal and growth faults within the Pannonian were reversed while Mesozoic thrust faults were reactivated.

Alternative explanation (Spencer et al., 1994) to potential sources of overpressured conditions in the sedimentary rocks of the area may be: (i) dewatering of shales and siltstones, (ii) hydrocarbon generation. (iii) aquathermal heating, and (iv) generation of carbon dioxide as result of thermal decomposition of carbonate rocks in the presence of silica. Clay mineral transformations, that release water may also contribute to abnormally high pressures.

Overpressuring in basement rocks, most of which are fractured may be caused by: (i) aquathermal heating and (ii) thermally generated carbon dioxide in the basement rocks simultaneously with downward migration of fluids from overpressured Mocene and lower Pannonian basal clayey marl and marl.

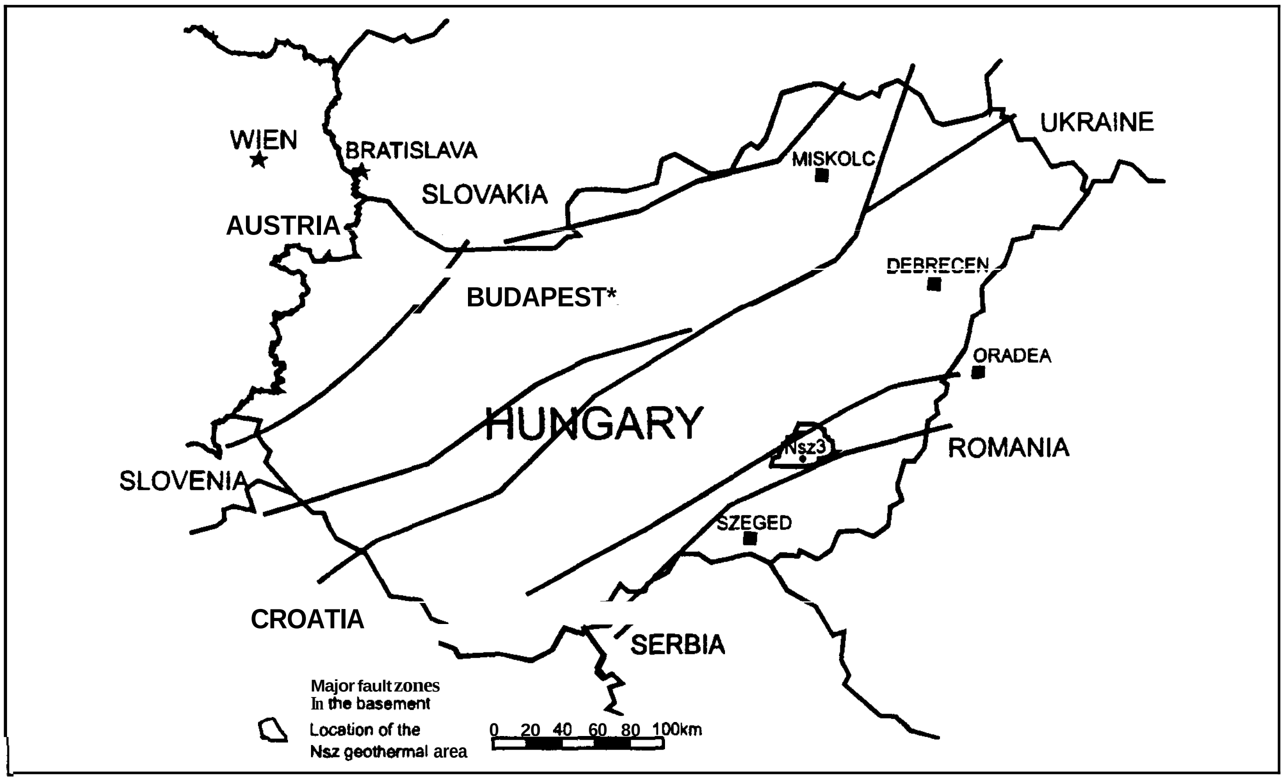

***Fig.* 1** *Location map showing the Nagyszénás area and major fault zones in the basement of the Pannonian Basin*

GEOLOGY

The studied area is located in the southeastern part of the Pannonian Basin, in Bekes county, Hungary (Figure 1). The area is part of the Bekes Basin, a north-west trending Neogene basin with an aerial extent of **3900 km^2**. The basin is filled with about 6500m thick of synrift and postrift sedimentary deposits. The synrift deposits of Middle Miocene age are relatively thin and Paleogene rocks have not been encountered by exploratory drilling yet. The prerift section (often referred as basement) is formed by Mesozoic carbonate and clastic rocks and Paleozoic and older volcanic, igneous and metamorphic rocks. The Mesozoic rocks mainly belong to shallow-water environment and may be up to 5000m thick in the Bekes-Doboz Mesozoic Through (BDT) and up to 2000m thick in the Battonya-Pusztaföldvár Mesozoic Through. As reported by exploratory wells, numerous examples of repeated sections occur in the basement rocks and these are inferred as being a result of overthrusting.

Mesozoic napes in the basement occur mainly in two parallel north-east-south-west trending belts. Rock units of the southern belt (Battonya-Pusztaföldvár Mesozoic Through) can be correlated to lithologic successions in the autochtonous Codru napes of the Apuseni Mountains of western Romania. Rock units in the northern belt (Bekes-Doboz Mesozoic Through) can be correlated to lithologic successions in the Bihor autochton of the northern Apuseni Mountains (Grow et. al. **1994).**

The Nagyszénás area belongs to the southern belt of the Bekes Basin i.e. to the Battonya-Pusztaföldvár Mesozoic Through. The first exploratory wildcat oil well was completed in **1954** at a depth of 3009m During **1978-1988** six more exploratory wells were drilled in the area with final depths of **2800-4200m**. These wells confirmed the existence of medium-high enthalpy overpressured geothermal resources below depth of 3000m. The steam blow-out of Fábiánsebestyén **4** well and the flow test of well Nagyszeniis **3** (Nsz3) confirmed that geothermal overpressured resources nestled in fractured Mesozoic formations which may be suitable for power generation exist in the area. The geological structure of the area is shown in Figure 2. The rock formations encountered by the lower part well Nsz3 (final depth 3500m) are presented in Figure 3.

The magneto-telluric survey carried out during 1989-**1991** gave more information about the location, and approximate size of the geothermal resources discovered in the area. Moreover many deep tectonic fractured zones were evidenced in the area.

The average value for porosity compiled from the well data from south-eastern area of the Pannonian basin by Spencer (1994) for depths below 3000 varies between 5 and 7%. Below 4250m depth there is an anomalous increase of about 2% over normal porosity that may be possible due to dolomitisation, karstification, fracturing of carbonates.

The Lower Pannonian sandstones below 3500m depth have very low permeability, averaging 0.1-10mD (Spencer et. al 1995). The carbonate formations of the Bekes Basin have much higher permeability within a range of 20-120mD. This may be due to the preserved secondary porosity from karstification or dolomitisation in combination with a dense fracture network observed on many core samples. On the major fault zones much higher permeabilities may be encountered.

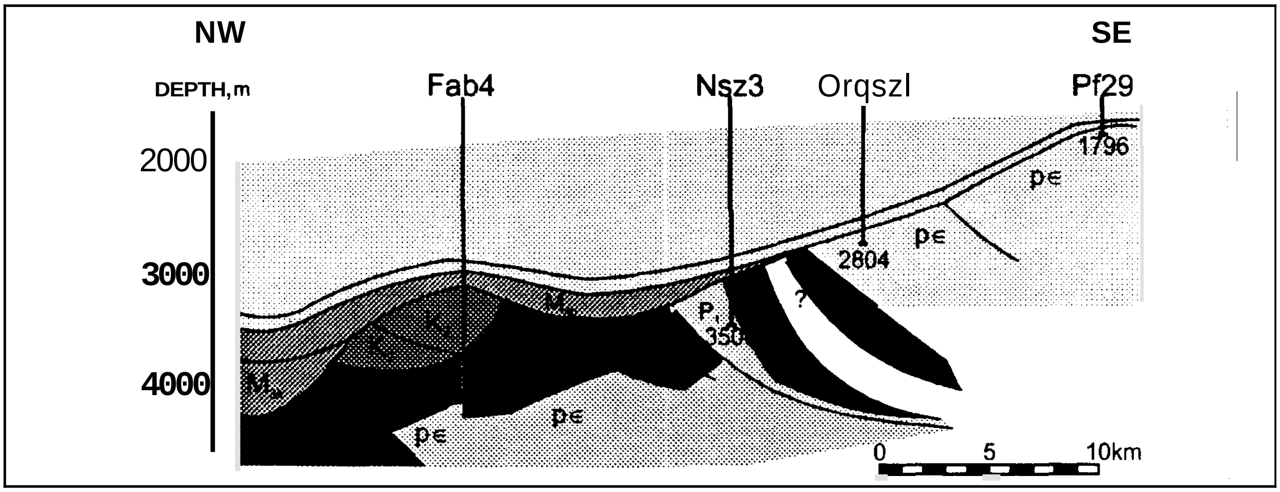

Fig. 2 *NW-SE Cross section through the Nagyszénás-Fabiánsebestyén area (source MOL Geothermal)*

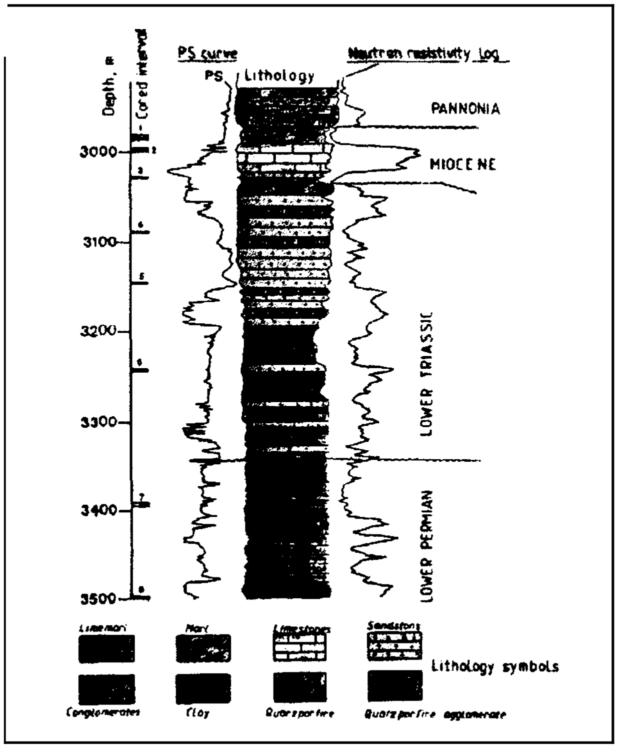

Fig. 3 ***Formations encountered by the lower part of well Nsz3***

COMPUTER MODELLING

The preliminary numerical simulation studies carried out for the Nagyszenas area were addressed **mainly** to reservoir evaluation i.e.: lateral extent, thickness and volume, tectonic features, governing boundary conditions, porosity / permeability patterns. The main idea was to set up a numerical model that can reproduce the recorded reservoir pressure build-up behaviour after the flow test carried out in 1991.

Flow test description

The Nsz3 well was completed in 1981 at a final depth of 3500m with a production casing of $9^{5/8}$" at 2922m and open hole below. In 1991 the well was recompleted with a slotted 7" liner between 2793-3984m and a 7" cemented tie-back liner to 2793m with the top of cement at 740m. After recompletion a short time flow test was carried out. The well was produced through a $2^{7/8}$" tubing fixed with a packer at 3000m. The flowrate was adjusted by varying the choke diameter. The flow history is presented in Figure **4.** The liquid and separated gas flowrate was measured at the gas liquid separator installed at the surface. **At** the end of the flow test the pressure build-up was recorded by downhole gauge set at 3006m (Árpási, 1996).

The inflow zone in the well was identified based on temperature logs as being between 3115-3l65m. The reservoir temperature at 3165m is 190°C.

The reservoir fluid contains significant mount of gas mainly CH_4 and CO_2. The GWR is about 5.41 m^3N/m^3.

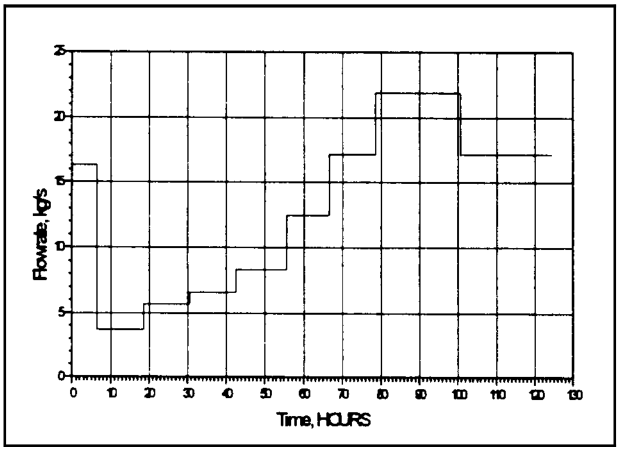

Fig. 4 Flowrate history recorded during the test

The results of the interpretation of the build-up test are presented in Table 1. Figures 5 and 6 show the log-log and Horner plots for the build-up. All recorded build-up pressures at 3006m were recalculated for the depth of 3140m.

Table 1 Estimated parameters from build-up curve

Parameter	Unit	Value
kh	mD·m	564
skin factor, s		-4.7
radius of investigation	m	819.7

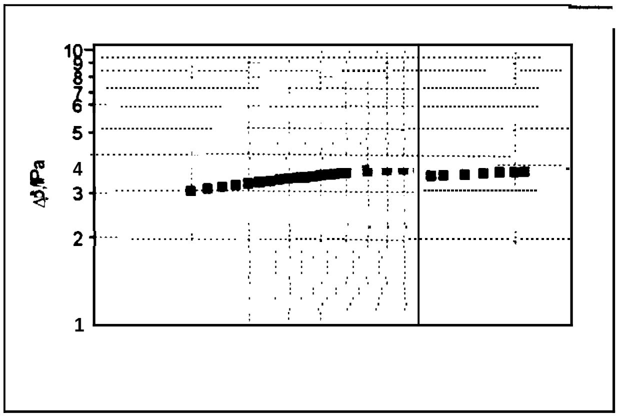

Fig. 5 Log-log plot of Nsz3 well build-up data

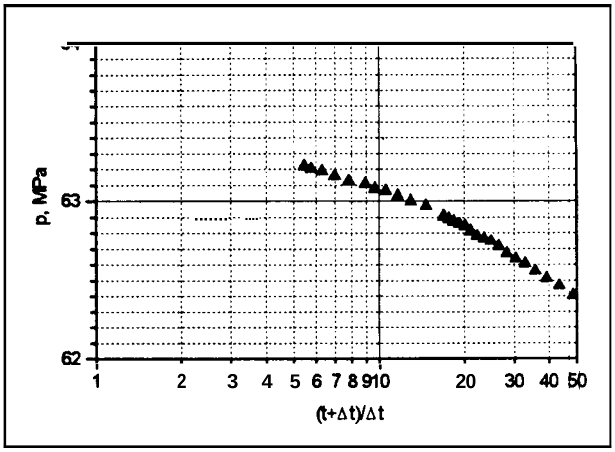

Fig. 6 Horner plot of Nsz3 well build-up data

Reservoir model

The computer code employed for simulation was TOUGH2 PC version developed by Dr. Karsten Pruess at Lawrence Berkeley Laboratories.

Based on the available geological model and rock properties a 3D model was set up considering that the productive geological formation belongs to Lower Triassic. From the cross section of the area (Figure 2) and the results of the magneto-telluric survey the reservoir considered that has a rectangular shape with the dimensions of 15x2km and thickness of 950m. The grid set-up is shown in Figure 7. For simplicity the grid describes in vertical direction only the part between 3050-4000m corresponding to the Lower Triassic formation. Furthermore it was assumed that in plan view the well is located in the centre of the grid and in the centre of the third layer in vertical direction (Figure 7).

With respect to permeability / porosity structure of the grid four models were considered:

1. Uniform model with constant thickness of 950m (labelled Uni 1)
2. Uniform model with constant thickness of 50m (labelled Uni2)
3. Fractured model consisting of one vertical fracture from East to West 50m wide and 950m thick interacting with the rest of porous medium. The porosity of the fractured medium is higher than of the porous medium (labelled Fra1)
4. Fractured model consisting of one vertical fracture from East to West 50m wide and 950m thick interacting with the rest of porous medium. The porosity of the fractured medium is same as of the porous medium (labelled Fra2)

The main assumption for each model is that the reservoir is sealed on each side.

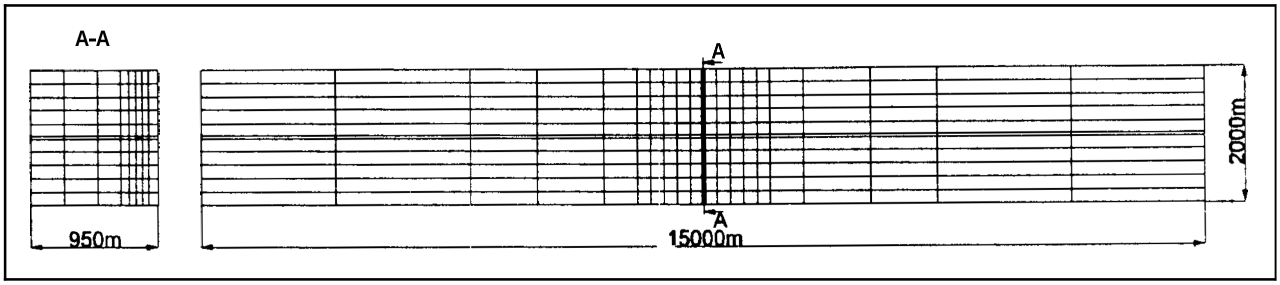

Fig. 7 Gridset-up

The main properties of the four models considered are shown in Table 2. For the case of fractured models, where no separate properties are listed for the fractured and the porous medium they are assumed to be the same.

Table 2. Main rock properties

Parameter | Model	Unil	Uni2	Fral	Fra2
Rock density, kg/m^3	2650	2650	2650	2650
Matrix porosity	0.03	0.03	0.03	0.03
Fracture porosity	-	-	0.1	0.03
Matrix permeability, mD	11	11	1	1
Fracture permeability, mD	-	-	11	11
Rock heat conductivity, W/m°C	3	3	3	3
Rock grain specific heat, J/kg°C	1000	1000	1000	1000
Compressibility, m^2/N	10^{-9}	10^{-9}	10^{-9}	10^{-9}

The initial temperature was considered 190°C. All models were run first under no flow conditions until hydrostatic equilibrium has reached corresponding to the observed 63.8 MPa at 3165m.

Each model was run for the simulation of the flow test described earlier. The main objective of each simulation was to find a candidate model which is able to reproduce the build-up pressure data recorded at the end of the flow test. The results of these simulations are presented in Figure 8. Figure 9 shows the Homer plot for the measured / simulated pressured build-up for each model.

The obtained results lead to the idea that there are two candidate models: **Uni2** and Fral respectively which closely reproduce the measured data. Another conclusion **that** can be draw is **that** the reservoir's aerial extent has been correctly estimated from the geological data therefore no further sensitivity studies regarding the aerial extent of the reservoir are required.

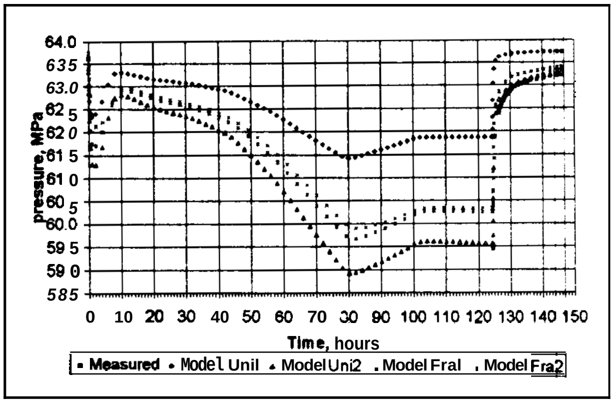

Fig. 8 Model calibration results

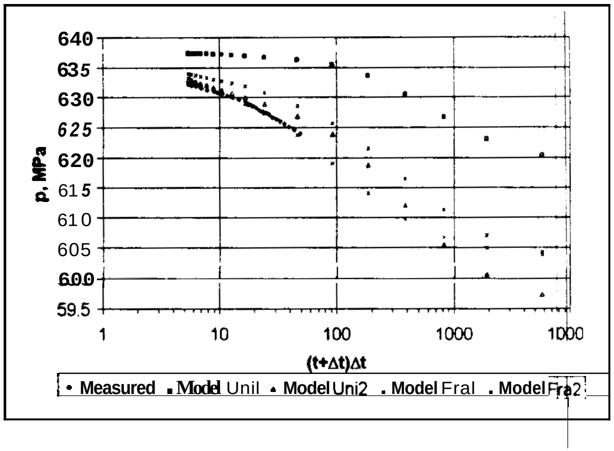

Fig. 9 Horner plot of measured and simulated build-up

The next step was to examine how the two candidate models **Uni2** and Fral would describe reservoir behaviour for two long term production scenarios.

The first scenario assumes that the well would be produced with a flowrate of 16kg/s corresponding to **1MW** for **25 years.** The purpose of this simulation was also to examine the reservoir behaviour in case of a long term flow test and to find ideal duration for a long term flow test.

The second scenario assumes that the well would produce 80kg/s (5MW) for 25 years.

In spite of the fact that there are only two candidate models, simulation of both **scenarios has** been carried out for all models. The results are presented in Figures 10,11 and 12 respectively.

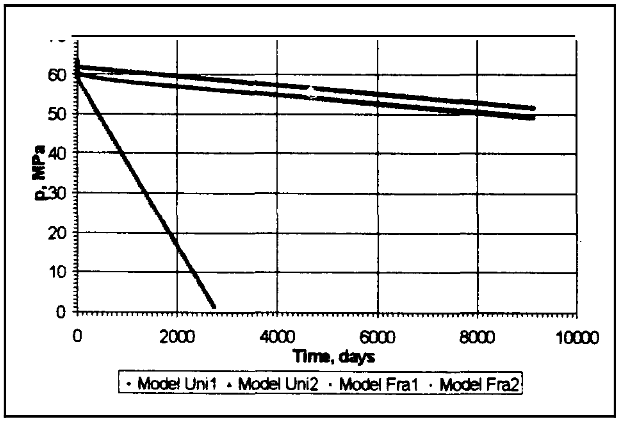

Fig. 10 1MW production simulation

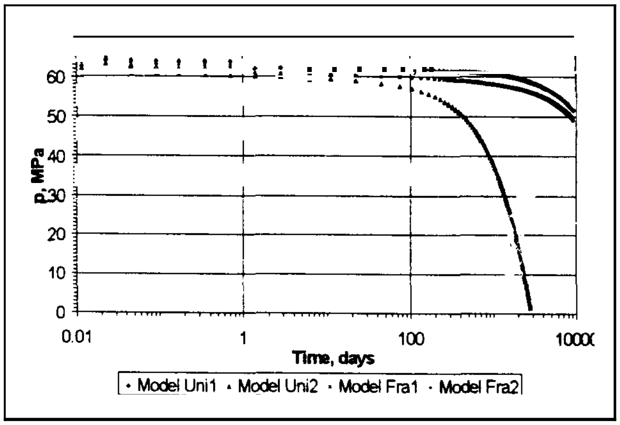

Fig. 11 1MW production simulation semilog plot

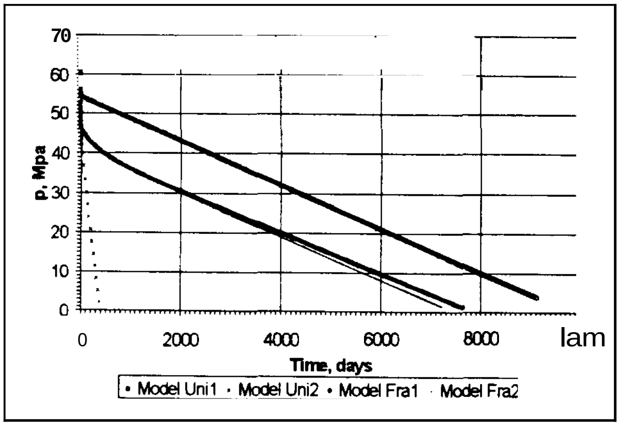

Fig. 12 5MW production simulation

The long term production simulation for 1MW suggests that out of the candidate models, **the** reservoir which could sustain ***25*** years production corresponds to the Fra1 model.

As shown in Figure 11 the ideal duration for the long term test would be over 100 days. This time would be sufficient to obtain an accurate reservoir response.

None of models studied would be able sustain a production of 5MW for 25years. **This** suggests that the reservoir in question is a small sealed compartment of Lower Triassic formations.

CONCLUSIONS

The **best** reservoir model that was able to reproduce the pressure response of the reservoir in the Nsz3 area is a fractured double porosity model. This model is in very good agreement with the geological description of the area.

The preliminary modelling studies carried out for the Nsz3 area revealed that the overpressured medium-high enthalpy reservoir is small and is not suitable commercial operation. However a **demonstration** project for 1MW would be **welcome as it could** provide the necessary **long term production** behaviour data for such type of overpressured reservoir.

It is obvious that a long term flow test is absolutely necessary in order to improve the reservoir model.

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Last but not least special **thanks** are expressed to Geoproduction Consultants (GPC), France for making the TOUGH2 computer code available for the modelling studies.

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