Hydrodinamic tests in well-pairs producing geothermal energy

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Abstract

It is by application of instruments and evaluation methods used in the petroleum and gas industry, that the hydrodinamic tests of geothermal energy-producing wells provide qualified basic data for planning. In order to protect both reserves and environment, squeezing back the cooled-down waters into the reservoir formations is expedient. Oil-industry experience has shown that 'heat mining' by production and injection wells may economically be performed from fractured-karstified carbonates.

Introduction

An environment-preserving way of geothermal energy production infers that production and water-reinjection wells [5, 11] are to be operated. Economical operation of the producing and water-handling systems is of the highest importance [7].

The decisive part of the realization costs of the whole system is related with the production and re-injection wells, the costs of which – on return – depend on the reservoir parameters and, especially, on the well–reservoir contact.

As hydrodinamical tests have to do with the wells and the perforated intervals of the formation [2, 8], the obtainable parameters and their proper use will essentially influence the profitability of the project.

Because of the high temperatures at levels of the target formations of geothermal energy-producing wells, their testing tools differ remarkably from those of 'normal' water-producing wells, and also from the equipment for checking in them environmental protection nowadays. But temperatures and pressures of geothermal target layers [4, 6, 11] count as common in oil and gas wells; therefore, testing tools and methods of the latter can be applied [2] provided that specific needs of geothermics are kept in mind.

Re-injection/squeezing of fluids into reservoirs is a general practice in oil- and gas-production: water injection enhances oil recovery, gas injection is a basic operation of underground gas storage.

Considering the oilfield experience of the latest years and some re-injection tests performed for geothermal applications [5, 6, 11], it can be stated that fractured, karstified carbonates are the best target objects for energy (= heat) production by circulation. The main problem, in this type of formations, may be the shortcircuiting of the production and injection well(s).

In the following, we give an account of the hydrodinamic tests needed when preparing circulating production of geothermal energy – pressure build-up tests, production rate tests and pulse (interference) tests.

Experimental, Results, Discussion

Pressure Build-Up Measurement and Evaluation

The overwhelming majority of reservoir parameters can be determined from pressure build-up measurements. While producing from the well, we lower the required downhole pressure meter/gauge to, or suitably below, the level of the inflow and then, by shutting in the well-head, we stop production. The gauge records transient pressure variations against time; evaluation means the processing of these variations [2]. In case of pressure build-up measurements in ideal reservoirs (fractured–cavernous carbonates) we can expect best results if we use electronic memory manometers with a resolving power of 70 Pa, because of the high over-all permeability [9]. The power of memory manometers is supplied by batteries; therefore, the way of running in such meters is the same as that of the mechanical ones [2], i. e. lubricator, solid wireline and winch are needed. The memory pressure tools compensate for temperature, based on their built-in thermometer. As a function of depth and time, any changes of temperature within well can be measured. Sample taking frequency of pressure and temperature data can be programmed for 0.1 second or more.

The processing of the enormous quantity of data recorded by electronic manometers demands modern software. The PanSystem programme package [9] we have used since 1990 contains a selection of the evaluation procedures deemed most necessary and useful from the published supply throughout the world [1, 3].

The joint application of memory manometer and software gives the flow parameters of both reservoir and the near-well zone; relying upon them, if justified, the friction pressure loss in the near-well zone can – by means of acidizing – be eliminated.

From the pressure build-up test of a high-temperature well one can obtain information about heterogeneities of the reservoir – fractures, linear flow, reservoir boundary – at distances from well ranging up to several hundred meters.

It is reasonable to have pressure build-up testing done in each well of the producing/injecting system. This is the basis also for planning and executing pulse tests.

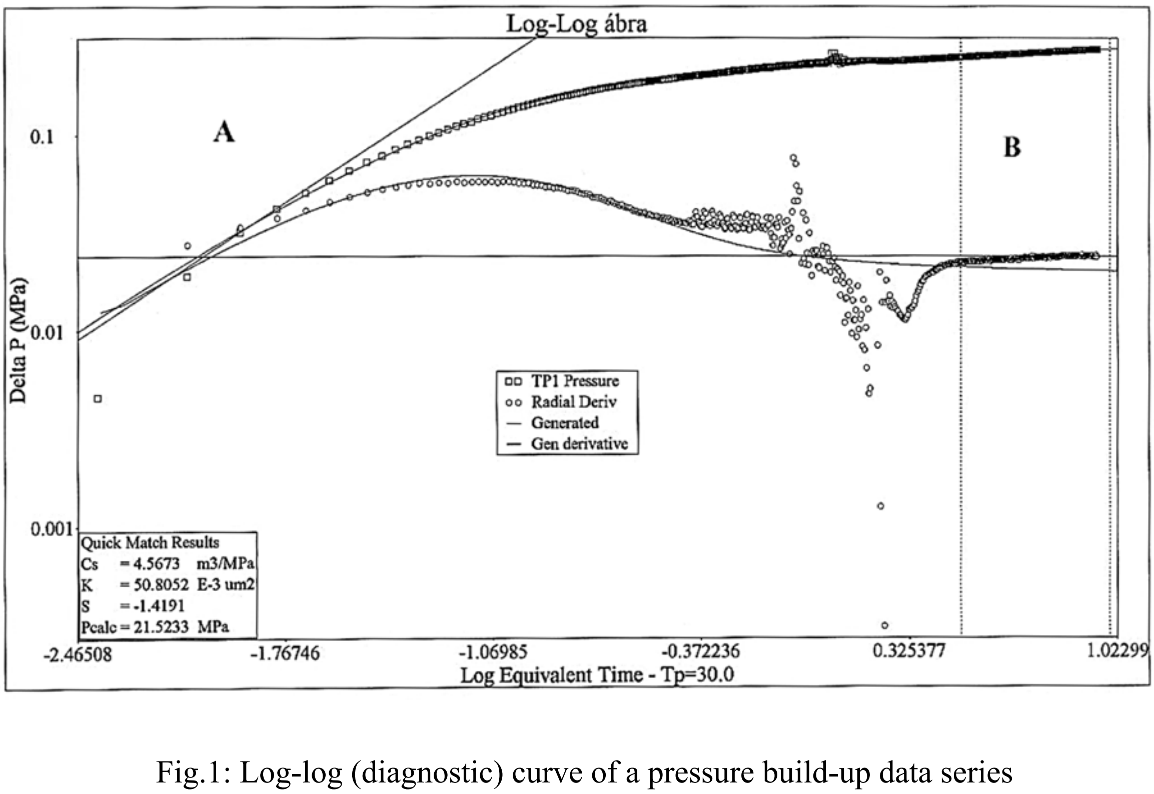


Fig.1: Log-log (diagnostic) curve of a pressure build-up data series evaluated with PanSystem software [9].

In Fig.1., the log-log (diagnostic) evaluation results of a pressure build-up data (PBU) series, measured in a thermal water well are shown; evaluation model: radially homogeneous

medium of infinite extent. The test was made on Sep. 18–21, 1996 at a depth of 2300 m, the static pressure of the reservoir was 21.523 MPa, temperature: 124 °C.
The straight line with the unit slope fitted to the initial section of the PBU curve marks out the after-flow section A. The horizontal straight line fitted to the derivative (d*p*/d(logΔt)) identifies the interval (B) which can be interpreted as the interval of radial flow.
The model results gained from the HORNER procession of the points of interval B were used – as starting values – for the automatic fitting (= parameter optimization by non-linear regression). The reservoir and well completion parameters (permeability k, skin factor s) are shown in the results box of the Figure.

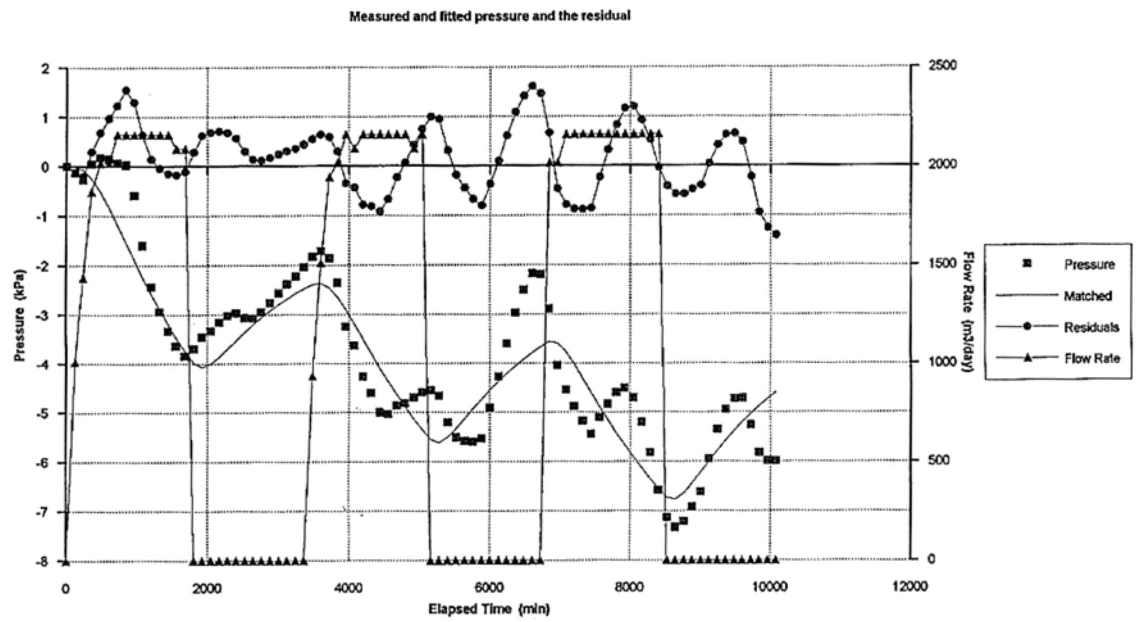
Capacity (Producibility) Tests

After successful perforations, the execution of capacity tests in at least 4 cycles is advisable. On their basis the production rate equation of the given well can be defined; under given limiting conditions this can give the 'produced fluid rate – bottom pressure under production' relationship. Capacity tests start usually with shut-in well state, and are performed in steps of gradually increasing rate of production. Recorded temperature changes during properly chosen production rates and rate changes can give information about heat conductivity at given depths of the well, and wellhead temperature data make possible calculations of heat losses along the whole well equipment [12].
Pressures and pressure changes during re-injection may – even in case of fractured and cavernous/karstified reservoirs – differ from those during production. Such differences in injection wells can be investigated by means of, and their reasons concluded from, capacity and pressure drawdown tests made during injection. Temperatures and temperature differences measured while injecting constitute the basis of planning comprehensive measures for heat-household managing [12].

Pulsation Interference Measurements

On the basis of pressure build-up tests in production and injection wells the distance of flow heterogeneities from well axes can be calculated, their impacts estimated, but their setting (orientation) is uncertain.
As for hydrodinamical connection of production and injection wells and its extent, the pulsation interference tests are capable of providing that information.
The measurements with high-resolution pressure gauges have shown that the measured pressures contain noise components, the order of magnitude of which is about the same as that of the interference signals to be expected. We measure the pressure resultant of overall pressure changes within the reservoir, of atmospherical pressure and temperature, and of the tidal effect of Earth's crust [10].
The generation of pulsed signals, meaning equal production and shut-in time periods, filters in itself the overall pressure changes; however, only the evaluation method with noise filtering – which can detach stochastic changes – has significantly improved evaluability: by experience in Hungary: from 17 to 78 per cent [10].
The evaluation results of the test are: transmissibility ($k.h/\mu$) and storage ($\Phi.c_t.h$), where

k	is effective permeability
h	effective bed thickness
μ	viscosity of the flowing fluid
Φ	porosity
c_t	total compressibility related to the fluid-filled porosity



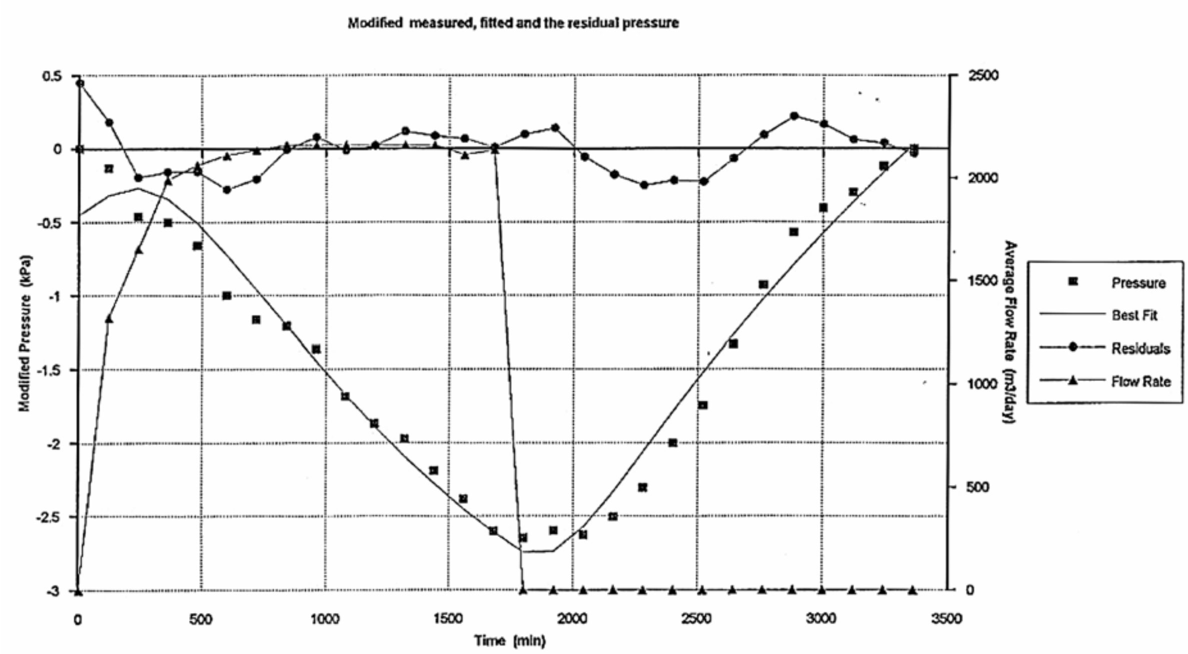


Fig.2: Evaluation of a pulse test executed on a pair of thermal water wells with PulsEx software (noise-filtered evaluation) [12].

In Fig. 2, the evaluation results of a thermal water well-pair with PulsEx software (noise-filtered) are presented [2, 13].

Assumptions:

- the hydrodinamical system is homogeneous, isotropic, isothermal, of infinite extent; the flow pattern is radial,
- the flowing medium is slightly compressible, its parameters are pressure-independent, the distribution of the pressure differences (anomalies) is normal.

Twofold transformation of the measured pressure data series was executed [10]:

- We broke up the measured data series by test cycles, and summed up the pressures within the individual cycles.
- From the data obtained like this, we subtracted the linear pressure trend (the monotonous noise component), defined by the straight line connecting the first and the last point of the transformed pressure series.

The first transformation filters out higher-frequency noises, the second will drop out those having larger time constants.

By the least squares method we have found the theoretical curve having the best fit to the filtered pressure changes (automatic fitting); from its parameters we calculated transmissibility ($T = 4.20 \cdot 10^5\ \mu m^2 \cdot m/Pa \cdot s$) and storage ($S = 2.48 \cdot 10^{-2}$ m/MPa).
For guidance, readers should know the following test parameters:

- distance between wells, a = 1508 m
- pulsation-related change of the production rate, $\Delta q = 2100\ m^3/d$
- amplitude of the pulsed pressure wave, $\Delta p = 2.80$ kPa
- depth and temperature of the reservoir: 2500 m and 96.6 °C.

By comparing for well-pairs (a) the transmissibility as calculated from the pressure build-up curves, and storage as calculated from 'working' (= effective) bed thickness and porosity from geophysical (electrical etc.) well logs with (b) the same parameters as evaluated from the pulse tests, one can draw conclusions about the heterogeneity of the reservoir. From the point of view of geothermal energy production it is very important to know the existing flow pattern, because if outstandingly high transmissibility was found between the two wells, the cooling effect of the cooled-water-swallowing injection well can quickly appear also at the production well. We experienced this phenomenon in a well-pair, being 700 m apart and hitting the same fractured and karstic reservoir at a depth of 2000 m. Both wells were filled with oil and well-head pressures were recorded. Eight seconds(!) after the active well was set into production by opening the two-way cock, we already perceived its impact in the observation well; then, after quick shut-in, a pressure-oscillation of 7.5 s periodicity was observed in both wells.

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