

ANALYSIS OF PRESSURE TRANSIENT DATA OF VERKHNE MUTNOVSKY SITE MUTNOVSKY GEOTHERMAL FIELD, KAMCHATKA, RUSSIA

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ABSTRACT

Long term (well 049N) and short term (wells 049N, 055, 048) flow tests and pressure monitoring (well 30) were performed in Verkhne Mutnovsky site Mutnovsky geothermal field during **September, 1995 - September, 1996** period.

Average pressure in Verkhne Mutnovsky geothermal reservoir (well 30, depth 950 m) is 45.0 - 46.0 bars. The long term flow test data shows clear interference between the observation well 30 and the flowing well 049N.

The observed pressure data has oscillations which make interpretation of short term flow test data very difficult, but some information of the reservoir could be obtained.

INTRODUCTION

New production wells (048, 049N and 055) were drilled last years in Verkhne-Mutnovsky site of the Mutnovsky geothermal field, where pilot plant 12 MWe was decided to build based on wells aforementioned above (Fig. 1).

To understand pressure response and hydrodynamic properties of geothermal reservoir the following studies were carried out:

1. Pressure monitoring in observation well #30 (capillary tubing Pruet type system was installed to measure pressure at depth 950 m, pressure records were obtained since **Sept. 13, 1995** until **Dec. 30, 1996**);

2. Long term flow test from well 049N was performed since **Nov. 27, 1995** until May 7, 1996; Discharge rate 13 kg/s, enthalpy was estimated as 1260 kJ/kg.

3. Short term flow tests of wells 049N (**Sept. 13, 1995**), 055 (**Sept. 13-14, 1995**), 048 (**May, 6-7, 1996** and **Sept. 14-15, 1996**) with corresponding pressure monitoring in well 30 were performed.

1. PRODUCTION ZONES DISTRIBUTION IN GEOTHERMAL RESERVOIR

According to flow tests data of production wells we can assume **Uhodyashy-2** fault, which controls **some feed-zones** of wells 055, 048, 30, 037 and Verkhne-Mutnovsky natural steam manifestations. **Top** plane of **Uhodyashy-2**, which intersects top levels of **feed-zones** mentioned wells and low level of natural steam manifestations is shown in Fig. 1. According to this **Uhodyashy-2** fault has a NE strike and **SE60°** deep.

Another production zone we can assume is horizontal and penetrated **below - 700 masl** by wells 047, 049N, 037 (H-reservoir).

2. LONG TERM FLOW TESTS FROM WELL 049N INTERPRETATION

2-1. LINE-SOURCE MODEL APPLICATION

Analysis of long-term pressure transient data during flow tests of well 049N (Nov.27,1995 - May.7, 1996) using inversion program DIAGNS of S-Cubed , was performed. Matching between the data and an analytical solution of a line source model by inversion calculation , the estimated parameters of the reservoir are : permeability-thickness $kH = 4.8 \text{ D}^*m$, storativity $\cdot 7.2 \cdot 10^{-7} \text{ m}^2/\text{Pa}^2$, and initial undisturbed pressure 46.1 bars (see Fig.3)

2.2 3D MODEL APPLICATION

2.2.1 GRID IMPROVEMENT

Analysis of long-term pressure transient data during flow tests of well 049N (Nov.27,1995 - May.7, 1996) using existing 3D model of the Mutnovsky geothermal field (Kiryukhin, 1996) with some modifications was made too . Fig.2 shows 2D implementation in the 3D Model to represent NE strike fault zone Uhodyashy-2.

Note two modifications of 3D model which were performed (Fig.2), so it evolve to 3D+2D model :

1. Additional 2D sub-grid consist of 91 elements $236 \text{ m} \times 191 \text{ m}$ each marked as FFK J , where $K=1, \dots, 9$ corresponding to X- position (local X axis choosed along NE direction) , $J=1, \dots, 9$ corresponding to Y- position (local Y axis choosed along subvertical fracture deep axis 60° SE). All elements of 2D grid were connected to corresponding elements of former 3D model grid (main-grid). For example, elements FFK J ($K=1,2,3$, $J=7,8,9$) were connected to element A46 7 of 3D model grid , ..., elements FFK J ($K=7,8,9$, $J=1,2,3$) were connected to element A2A 9 of 3D model grid. Two domains FFF 1 and FFF 2 with specified rock properties were assigned in 2D sub-grid. Initially , all properties of 2D sub-model were the same as corresponding elements of 3D model.

2. To represent more realistic boundary conditions in the NE of the 3D model the liquid discharge element (A2A10) was transformed from "inactive" to "active", new inactive element B2A10 with coordinates corresponding to Nizhne-Zhировsky hot springs at elevation +70 masl and corresponding connections with elements A2910, A2A10, A2A 9, A3910, A3A 7 , A3A 8, A3A 9 , A3A10 was installed (distance 8 km) .

After that a new natural state runs were performed to maintain reliability of the 3D+2D model (see Fig.2).

2.2.2 PRESSURE TRANSIENT DATA MATCHING

initially , to calibrate 3D+2D model against pressure transient data we used compressibility of rocks as a calibration parameter , no any other changes in the elements corresponding to 2D sub-model (Uhodyashy-2 fault zone) or other domains of the existing 3D model were made. As a result of calibration studies compressibility value $5.0 \cdot 10^{-9} \text{ Pa}^{-1}$ for all reservoir was obtained (Fig.3). Note the most reliable pressure monitoring data are corresponding to He purge periods (triangles in graphs), so some pressure drops were not taken in account during matching procedure.

3. SHORT TERM FLOW TESTS FROM WELL 049N & 055 MATCHING AND INTERPRETATION

Analysis of short-term pressure transient data during flow tests of well 049N & 055 (Sept.13 -15,1995) using mentioned 3D+2D model of the Mutnovsky geothermal field was performed . It was obtained , that there is no any pressure response to well discharge (sources were installed in the elements FF7 6 (well 055) and A49 8 (well 049N)) in the 3D+2D model element FF4 6 (well 30 pressure chamber element) if model parameters mentioned in 222 used.

A reasonable response in well 30 from well 055 discharge may be detected in the model, if the following parameters domain FFF 1 (Fig.2b) were used: fracture thickness 0.1 m, fracture porosity 0.5, permeability 20 Darcy, compressibility 10^{-7} Pa⁻¹ (Fig.4).

Meanwhile the model we used was not able to explain pressure oscillations of real data, so really we can say about "matching in average" only. It will be discussed in Appendix.

4. SHORT TERM FLOW TESTS FROM WELL 048 MATCHING INTERPRETATION.

Analysis of short-term pressure transient data during flow tests of well 048 (May 7, 1996 and Sept. 14-15, 1996) using 3D+2D model of the Mutnovsky geothermal field was performed. We did not find at current time the way on 3D+2D model to explain strong drawdown in well 30 more than 1 bars about 24 hours after well 048 discharge with the rate 8-15 k/s on May 6-7, 1996 (Fig.2, time about 3900 hr). So, we assume now this is false "pressure drawdown" caused by long time without He purge in well 30, and probably water entered capillary tubing chamber because of some pressure build-up after long term flow tests 049N shut-down on May 7-th, 1996. Next time, flow test from well 048 on Sept.14-15, 1996 was made more carefully, with He purge before and after flow test, so there is a reason to refer last flow test data as more reliable.

To calibrate 3D+2D model against pressure transient data (Fig.5) the source was installed in the element FF4 4 (well 048), and the following parameters of domain FFF 2 (Fig.2b) were obtained: fracture thickness 10 m, fracture porosity 0.5, permeability 5 Darcy, compressibility $6 \cdot 10^{-7}$ Pa⁻¹.

5. RERUN OF THE 3D MODEL

We rerun long term flow test from well 049N in the model with parameters updated in the elements of the grid,

correspondingly to results of short term flow tests matching. As a result of recalibration studies new compressibility value in the 3D+2D model 10^{-7} Pa⁻¹ was obtained in domains outside of Uhdoyuashy-2 fracture zone, all other parameters remain unchanged.

CONCLUSIONS

1. Pressure monitoring data during long term flow test (well 049N) and matching with additional calibration of the numerical 3D + 2D model reveals that Verkhne-Mutnovsky reservoir behavior may be explained based on average compressibility $5 \cdot 10^{-9}$ Pa⁻¹, and permeability distribution generally corresponding to 3D numerical model (Kiryukhin, 1996) (3.0 - 4.5 mD at -1000 masl - +500 masl). Consistent estimations of permeability-thickness 52 Dm and storativity $7.8 \cdot 10^{-7}$ m/Pa were obtained using Line-Source model.

2. Pressure monitoring data during short term flow test (well 055 and 048) and matching on 3D+2D model reveals that the following parameters of fracture domains FFF 1 (lower part of fracture) and FFF 2 (upper part of fracture) are needed to explain pressure response:

FFF 2: fracture thickness 10 m, fracture porosity 0.5, permeability 5 Darcy, compressibility $6 \cdot 10^{-7}$ Pa⁻¹,

FFF 1: fracture thickness 0.1 m, fracture porosity 0.5, permeability 20 Darcy, compressibility 10^{-7} Pa⁻¹.

Total fracture area - 1720m (sub-vertical) * 2125 m (horizontal) = $3.655 \cdot 10^6$ m².

3. Continuation of pressure monitoring in well 30, and additional long term flow tests from wells 048 and 055, as well as additional modeling studies may be useful for better understanding of geothermal potential and nature of the Verkhne Mutnovsky reservoir.

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APPENDIX

Let's consider one of the possible mechanism of pressure oscillations in monitoring well 30. Conceptual model of such oscillations (nine of high amplitude pressure oscillations are shown in Fig.4) may be the following. Water levels in most of wells in Mutnovsky field are located at depth 500 - 600 m below surface. That mean boiling conditions at water level. So, pressure P (bottomhole pressure) we monitor in capillary tubing chamber is:

$$P = P_s(T(L)) + L \rho g$$

, where P_s - saturation pressure at given temperature, $T(L)$ - temperature distribution along the well depth, and $L \rho g$ - is the weight of water column. If reservoir pressure decline, some water from monitoring well is going to reservoir, decreasing L (water column height). Declining, top of the water column reached more highest temperatures and saturation pressures P_s (because of temperature gradient) - which may result P increase, despite reservoir pressure decrease (e.g. L decrease).

so $SP > 0$ if

$$\frac{\delta P_s(T(L))}{\delta T} + \frac{\delta(L \rho g)}{\delta L} > 0 \text{ or } \frac{\delta P_s}{\delta T} + \frac{\delta T}{\delta L} \cdot \rho g > 0$$

Having parameters appropriate for water level zone of well 30 (temperature 222 °C, $\delta T / \delta L = 0.75$ °C/m, $\delta P_s / \delta T = 0.465 \cdot 10^6$ Pa/°C, $\rho = 840$ kg/m³) the following estimations may be obtained:

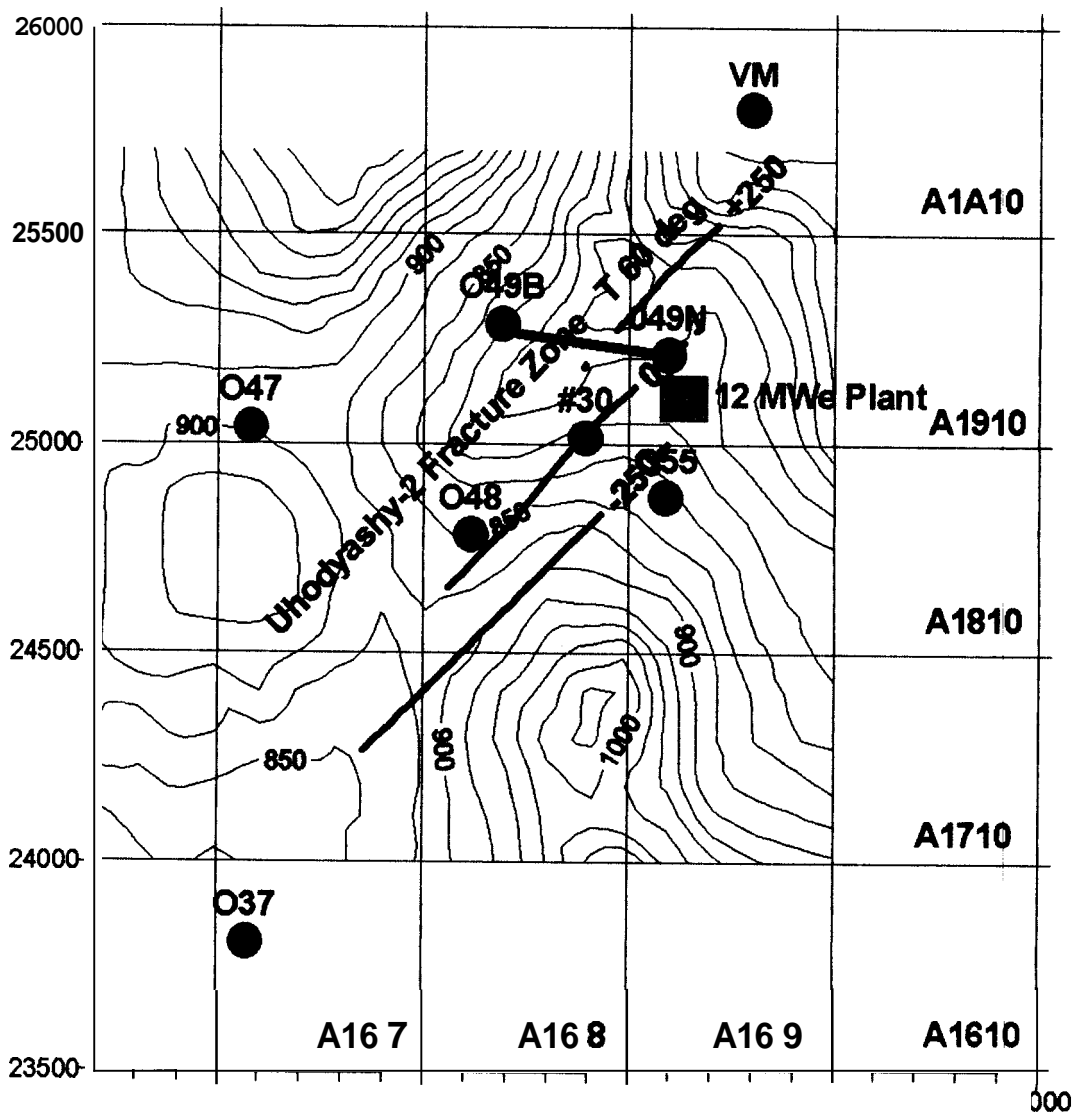
$$\frac{\delta P_s}{\delta T} + \frac{\delta T}{\delta L} \cdot \rho g = 26634 \text{ Pa/m} > 0$$

that is why bottom hole pressure may increase, while reservoir pressure decrease (1-st phase of oscillations - bottomhole pressure increase).

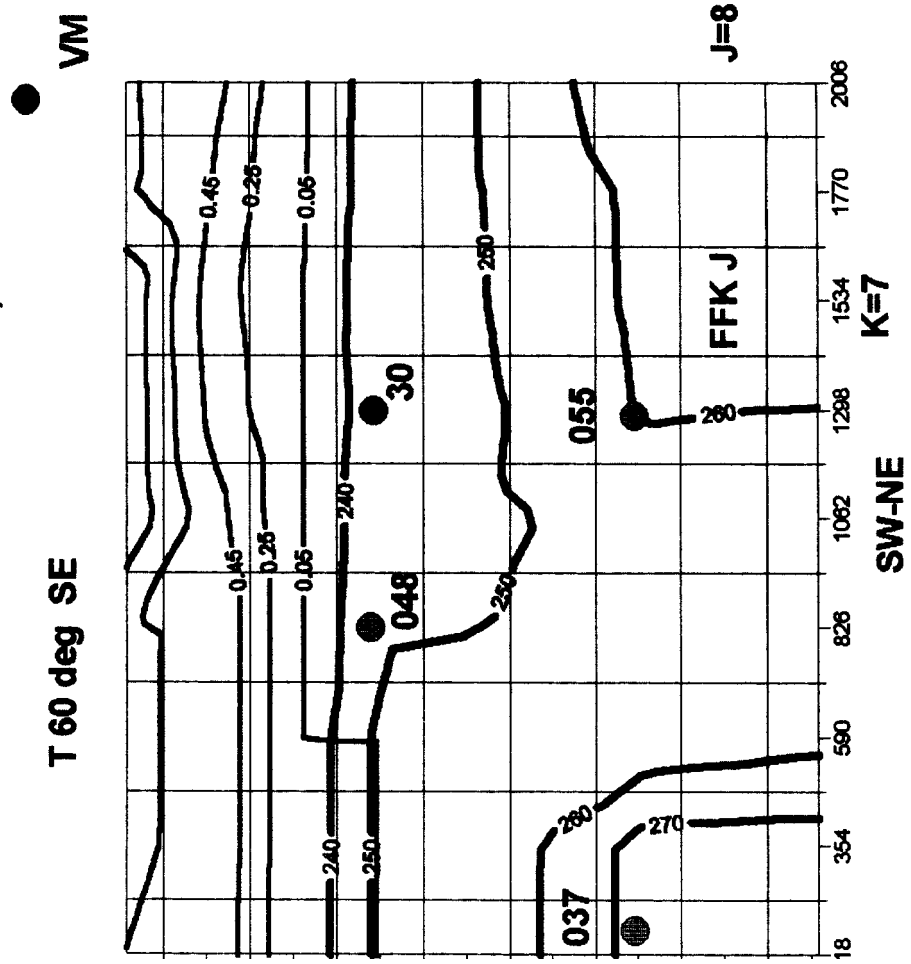
As temperature increase at water level during drowdown, some additional boiling took place and steam goes up resulting cooling of water level zone and saturation pressure drop. That is why bottom hole pressure may decrease some time later (2-nd phase of oscillations - bottomhole pressure decrease).

Note, simple calculations shows that heat conduction speed is enough to heat water level in time scale of 10 minutes, and time intervals ratio between 1-st phase of heat extraction from rocks (10 min) and 2-nd phase of heat recover (50 min) are in accordance with heat conduction solutions (its known, that degree of temperature recover defined by $\log(t/t_0)$ parameter, so if $t=50$, $t_0=10$, we will get 82% recover of initial temperature of rocks, so the cycle may start again ... etc ...

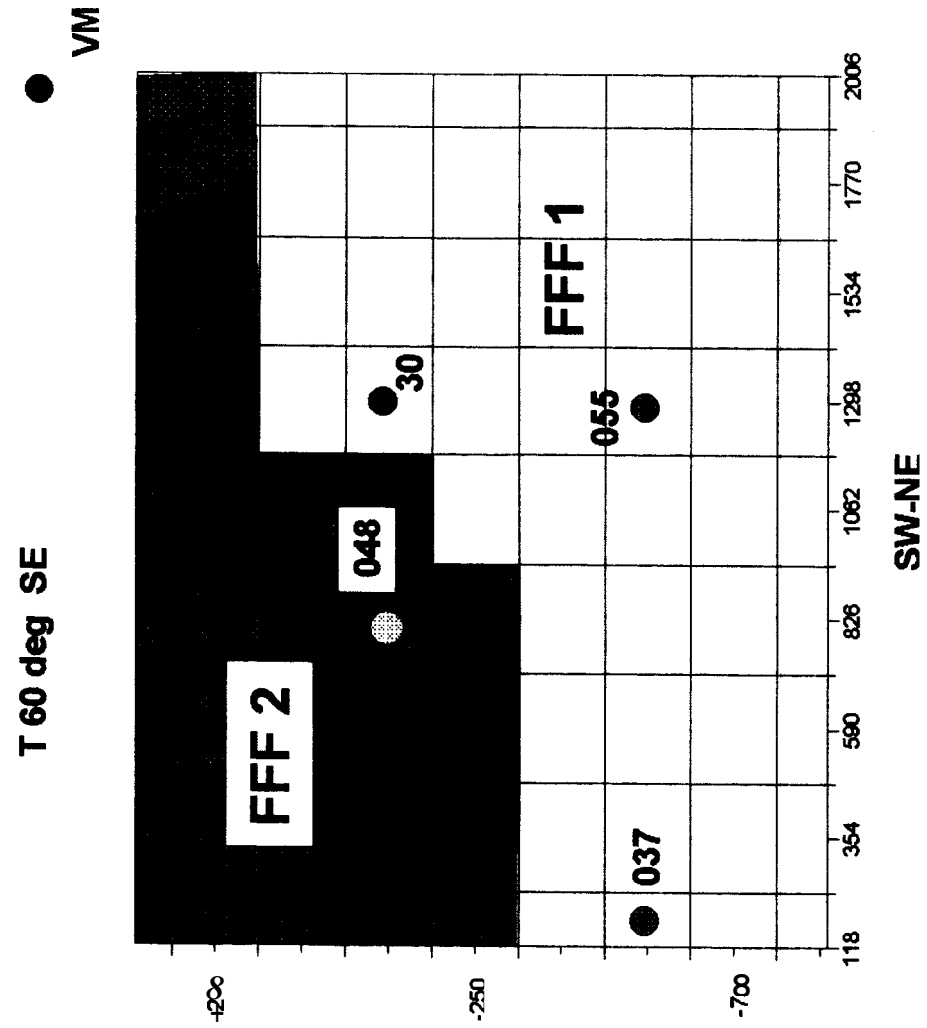
Fig.1 Verkhne-Mutnovsky Site of the Mutnovsky Geothermal Field. Grid Corresponding to 3D Model (Kiryukhin, 1996)



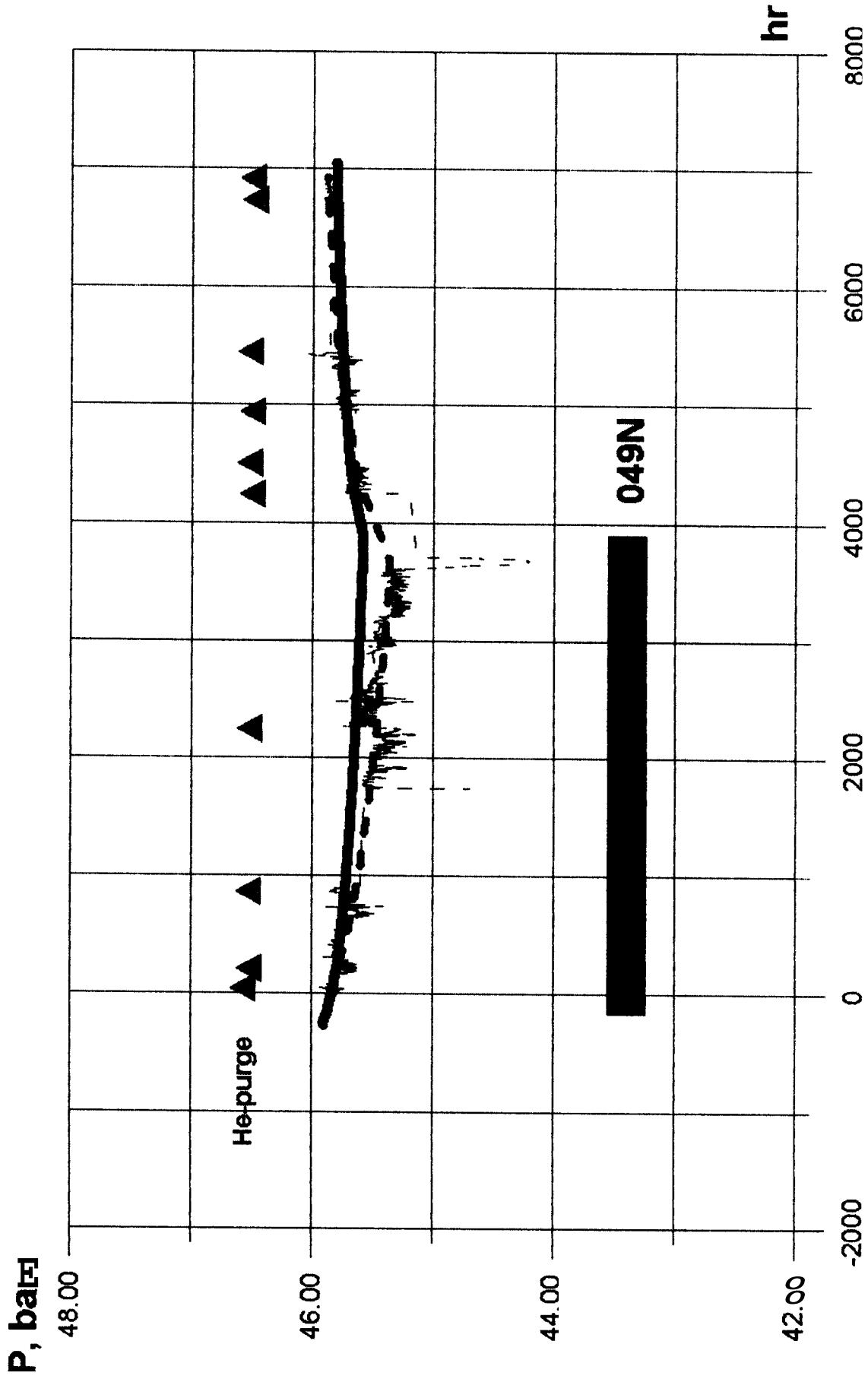
**Fig.2a Uhodyashy-2 Fracture Plane
2D-implementation in 3D Model
(Temperature & Phase Distributions,
Feed Zones Locations)**



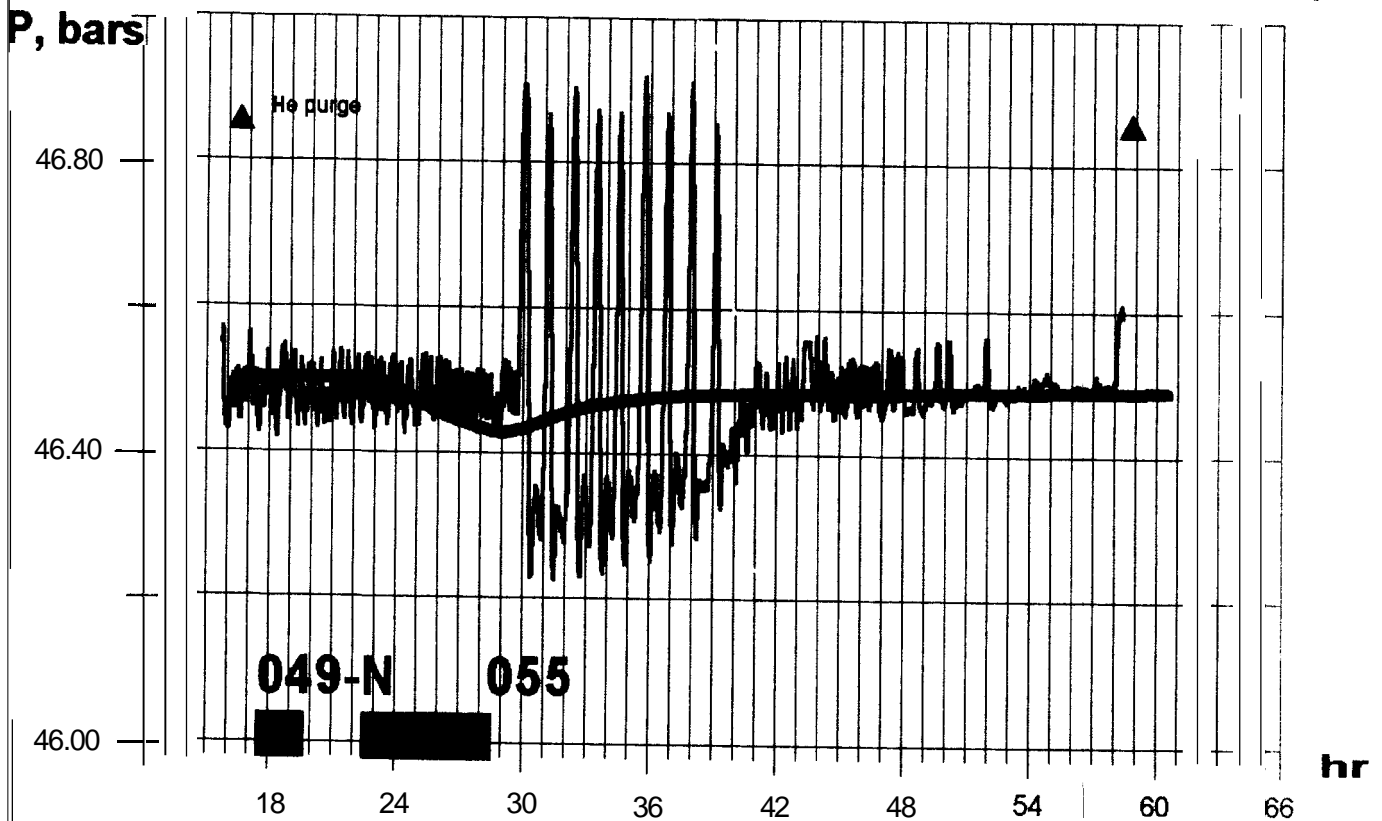
**Fig.2b Uhodyashy-2 Fracture Plane
2D-implementation in 3D Model
(Rock Properties Distribution)**



**Fig.3 Pressure Match in Well #30 During Long Term Flow Tests from Well 049N (27 Nov. 1995 - 7 May 1996).
 Thick line - 3D Model Output, Thick Dashed line - Line Source Model
 Thin line - Pressure Monitoring Data (Running Average,21).**



**Fig. 4 Pressure Match in Well #30 During Short Term Flow Test from wells 049N and 055 (13 - 15 Sept. 1995).
 Thick line - 3D Model Output,
 Thin line - Pressure Monitoring Data(Running Average,11).**



**Fig.5 Pressure Match in Well #30 During Short Term Flow Tests from well 048 (Sept.14 - 15 ,1996)
 Thick line - 3D Model Output ,
 Thin line - Pressure Monitoring Data (Running Average,21)**

