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Interpretation of the Short Term Production Test of Seferihisar Geothermal Field

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ABSTRACT

A flow test was conducted in Seferihisar (Turkey) geothermal field. The pressure response of the observation wells is modeled using a double porosity model with variable storage and skin. The results indicate that the permeability thickness product is larger at sections of the reservoir that are close to Aegean Sea. In these parts, porosities are somewhat larger compared to the rest of the reservoir.

1. INTRODUCTION

Seferihisar geothermal field is located 40 km south of İzmir, Turkey and 17 km south of Seferihisar town (Figure 1). The area is rich with geothermal manifestations such as natural springs that have temperatures ranging between 36 °C and 72 °C. These natural manifestations historically have been used by Romans and then Ottomans for balneological purposes. Twenty gradient wells with depths of 56 – 171 m and ten deep exploration wells (Figure 2) with depths between 151 m and 2009 m have been drilled in the area since 1972 by General Directorate of Mineral Research and Exploration (MTA). The field operation has been transferred to İzmir Geothermal Inc. which was established by Governorship and Municipality of İzmir in 2006. Since then several new wells have been drilled to further explore the geothermal potential of the reservoir. Several geothermal surveys that mainly deal with site descriptions, general geological and hydrogeological properties of the area and geochemistry of geothermal waters of Seferihisar geothermal field were carried out in the past (Esder and Simsek, 1975; Esder and Simsek, 1977; Filiz, 1982; Esder et al, 1983; Esder et al, 1988; Esder et al, 1997; Canbolat, 1986; Esder, 1990; Filiz and Tarcan, 1993; Filiz et al, 1997; Conrad et al, 1997; Tarcan et al, 1999).

2. GEOLOGY

The basement rock that forms the reservoir of Seferihisar geothermal field is Menderes Massif metamorphic rock (Precambrian to Paleocene), which is made up of schists and marbles. Bornova melange (Upper Cretaceous to Paleocene) that consists of interbedded conglomerate, sandstone–shale, limestone lenses, limestones and serpentinite bodies, mafic volcanics, chert and their complexes overlies the Menderes Massif rocks along thrust fault zone. Bornova melange rocks located close to the fault zones are highly fractured and extremely hydrothermally altered. The heat source is the high geothermal gradient caused by graben tectonics of the area. The clay-rich zones of the overlying Neogene terrestrial sediments which consist of interclated lacustrine and stream sediments formed by interbedded conglomerate, sandstone, claystone, mudstone, and marl and limestone lenses cap the system. The average thickness of Neogene terrestrial sediments is approximately 400 m and is overlain by rhyolitic Miocene volcanics. Unconsolidated granular sediments form the Quaternary alluvium that covers all the units. Holocene travertine and saltpan formations are also observed in and around the thermal springs. (Esder and Simsek, 1975; 1977)

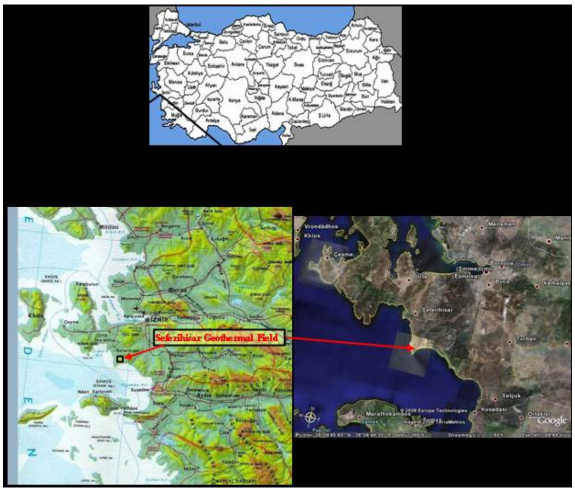

Figure 1: Location map of Seferihisar geothermal field.

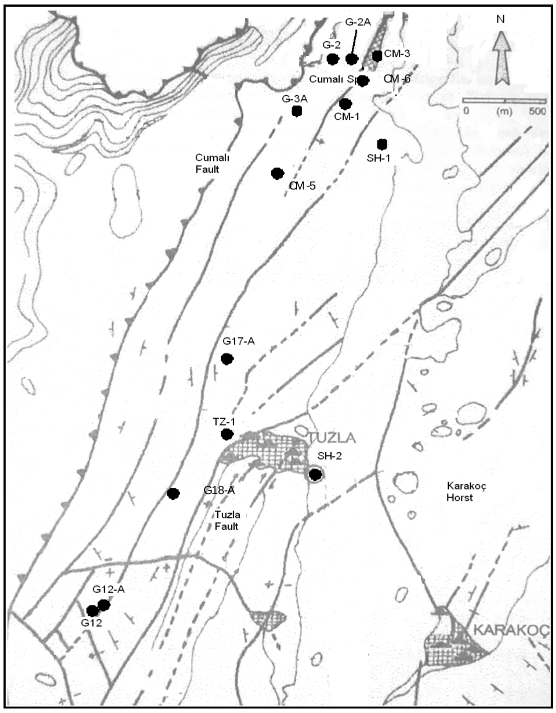

Figure 2: Deep exploration wells in Seferihisar geothermal field (modified after Esder et al, 1988).

Na and Cl ions mainly dominate the chemistry of thermal waters (30-153°C, and 7400-55200 µS/cm) of Seferihisar. Thermal waters of the Seferihisar area are believed to be mixtures of groundwaters and seawater (10% to 80%). Empirical chemical geothermometers, mineral equilibria and silica-mixing model results suggest that the temperature of the Seferihisar geothermal area reservoir systems vary between 60 and 180°C (Tarcan and Gemici, 2003).

3. FLOW TEST

All wells have been tested individually after their drilling by carrying out the following tests: static temperature and pressure, water loss, multi rate injection, dynamic temperature and pressure and pressure build-up. It has been observed that productivity index and the permeability of the wells changed between 45.56 and 349.72 ton/hr/kPa and $2.7x10^{-13}$ and $2.4x10^{-12}$ m^2. The productivity index measurements showed that the most productive well is G3-A (349.72 ton/hr/kPa) whereas the least productive well is CM-6 (45.56 ton/hr/kPa). The highest and lowest injectivity was observed in G17-A (131.77 ton/hr/kPa) and CM-6 (9.69 ton/hr/kPa) respectively.

Table 1: Flow rates during the production test.

Duration	Flow rate (m^3/hour)		
(min)	G18-A	CM-3	CM-6
3998	0	0	0
2906	294.2	0	0
60	0	0	0
2914	294.2	0	0
4140	148.21	0	0
15	106.71	0	0
5	59.28	0	0
25	41.50	0	0
5925	0	0	0
4330	0	154.13	103.35
5750	0	71.14	54.71
7343	0	0	0

The flow test was carried out in February 2009 by using six wellbores; three of them as production (G18-A, CM-3 and CM-6) and remaining three as observation (G17-A, G3-A and CM-5). Prior to opening the wells for production the static water level of all three observation wells were recorded for three days (6 – 9 February 2009). Then the well G18-A in Tuzla region was opened to flow in 9/2/2009 while G17-A, CM-5 and G3-A were used as observation wells. Wellhead and line pressures and temperatures, lip pressure of the production well were recorded during the test. Weir box levels were also continuously monitored. Weir box water flow rates were converted to total flow rates and reported in Table 1. Pressure and temperature changes in observation wells were continuously recorded using a pressure transmitter and a temperature sensor with accuracies of 0.01 bar and 0.01°C. After producing G18-A for a week, the well was shut and the weir box was transported to Cumali area. Similarly, CM-3 and CM-6 wells were produced simultaneously for a week. A chemical scaling inhibition system was used to prevent scaling in CM-3 and CM-6. The aforementioned measurements were also conducted in production and observation wells of this period of the flow test.

4. RESULTS AND DISCUSSION

It was observed that prior to flow test water level oscillates in observation wells which results from the straining of the surrounding formations by forces of tidal origin. Daily water level changes of G3-A are given in Figure 3 as an example. As discussed by Bodvarsson (1977) the water level oscillations represent breathing of the formations through the borehole. The volume amplitude of the oscillating fluid must therefore give clues as to the local strain amplitude and the formation volume in direct contact with the borehole. In this regard, the diffusion of low frequency pressure fields in natural formations must be considered. Hydraulic properties of aquifer systems have been determined by analyzing periodic water-level fluctuations. Rock compressibility and porosity have been related to barometric loading (Bodvarsson, 1970; Rojstaczer and Agnew, 1989). Specific storage has been estimated by analyzing water-level fluctuations that were induced by earth and ocean tides (Bredehoeft, 1967; Robinson and Bell, 1971; van der Kamp and Gale, 1983; Hsieh et al, 1988). It is reported by Halford (2006) that periodic water-level fluctuations and trends typically can be ignored where drawdowns are great and pumping periods are short.

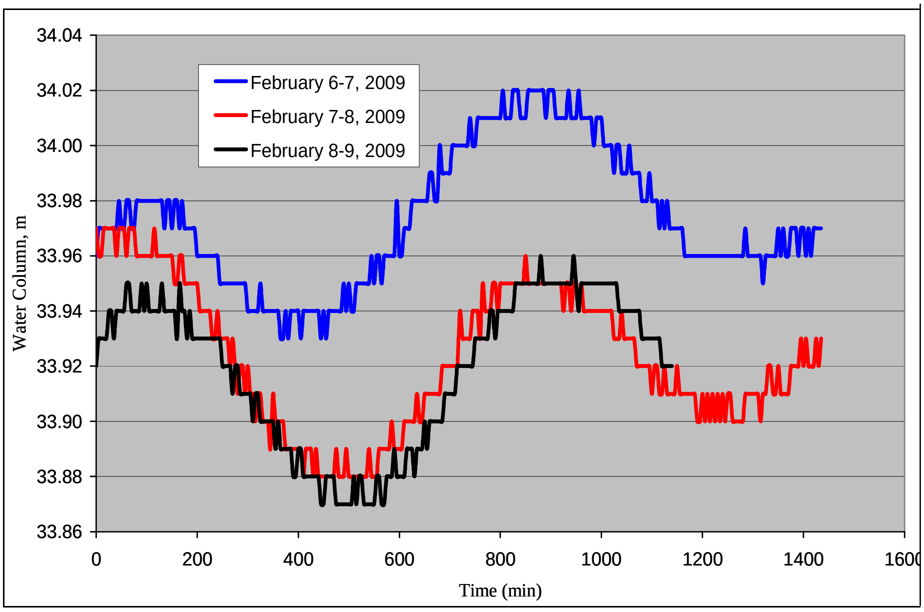

Figure 3: G3-A water level change prior to flow test.

Assuming that lunar principle (Θ_{M2} = 4.5x10^{-8}) with ½ day period causes the largest dilation it is possible to obtain porosity of the reservoir using Bodvarsson's (1970) static solution (Equation 1). The pressure level difference can be obtained from water level measurements; however it is more accurate to obtain this difference in Fourier space where it corresponds to twice the amount of peak to peak Fourier magnitude. Using Equation 1 and assuming that c_f is 3.6x10^{-6} 1/psi the porosity near the vicinity of G17-A can be found as 8.64%. Note that G17-A is closer to Aegean Sea compared to other wells (corresponding porosities for G3-A and CM-5 are obtained as 5.02% and 1.97% respectively) in Seferihisar reservoir.

$$\Theta = \phi c_f \Delta p \quad (1)$$

Figures 4 and 5 give the wellhead pressure and temperatures measured in the production wells CM-3 and CM-6 during the test. It can be observed that wellhead temperature and pressure measurements follow rate changes. Tidal effects are also observed when the well is not flowing (i.e. see shut in data for CM-3).

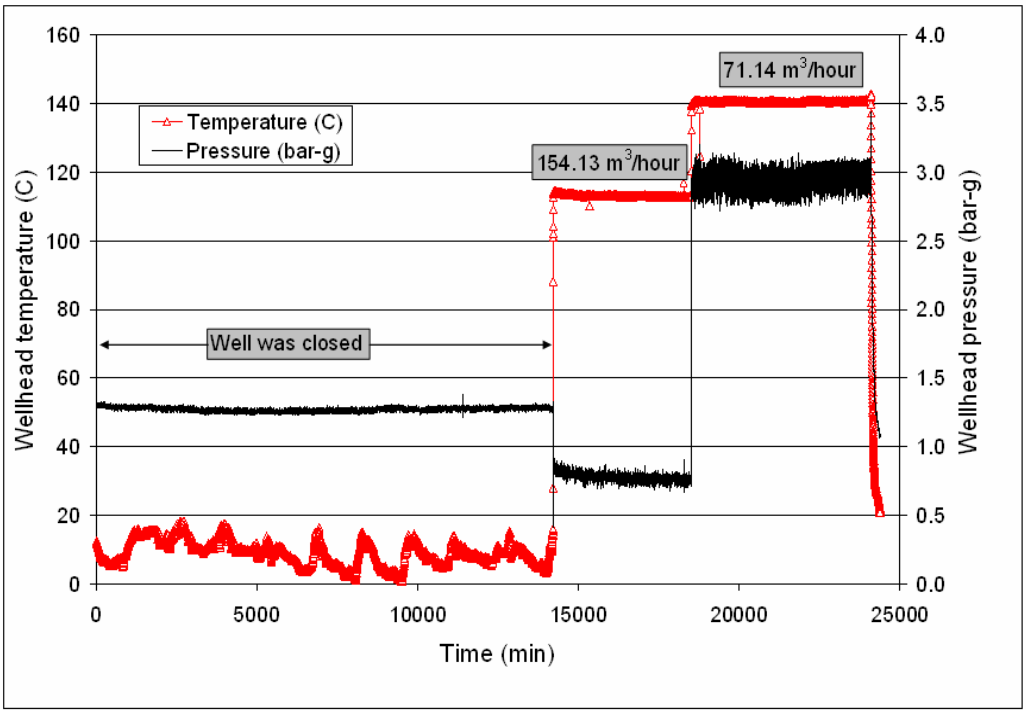

Figure 4: CM-3 wellhead temperature and pressure changes during the flow test.

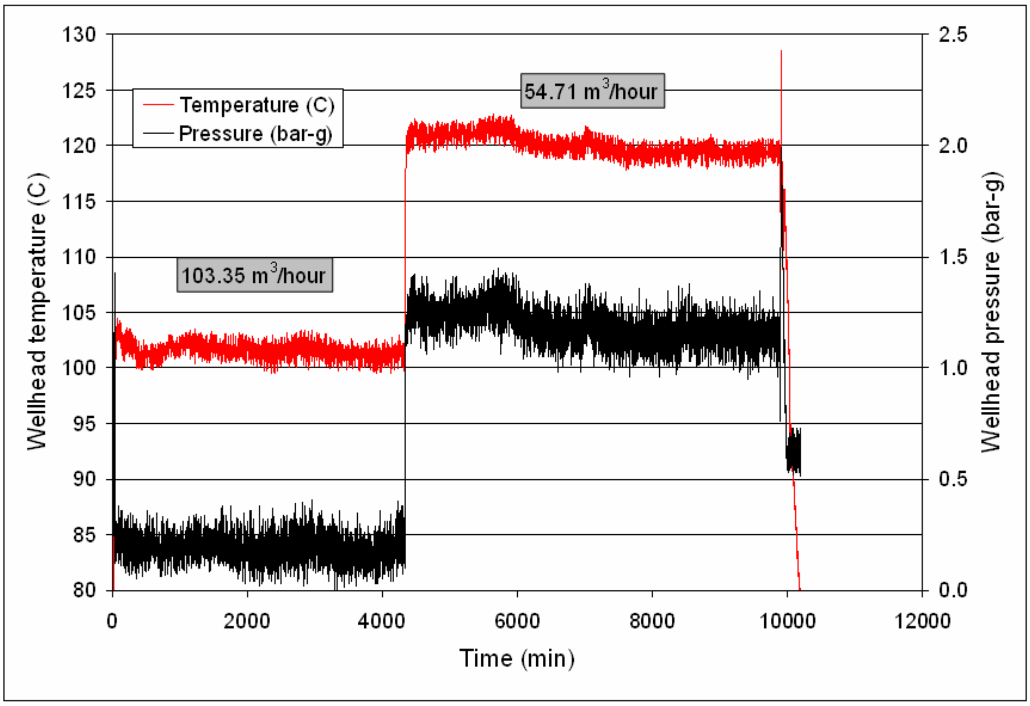

Figure 5: CM-6 wellhead temperature and pressure changes during the flow test.

Figures 6 through 8 give water level measurements in the observation wells during flow test, G17-A, G3-A and CM-5. The largest water level drop during the flow test occurs in G3-A (~13 m) due to productions of CM – 3 and CM – 6. The water level change in G17-A is smaller (~1.4 m) compared to the one observed in CM-5 (~4 m).

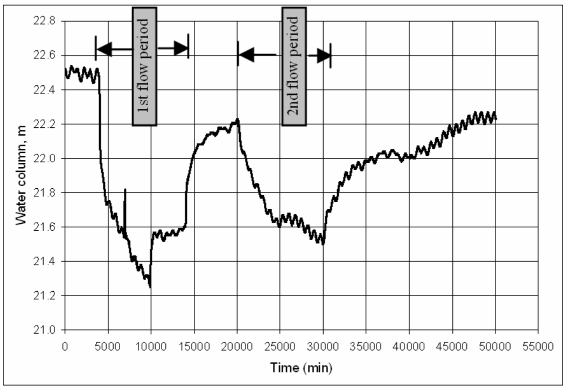

Figure 6: G17-A water level change during the flow test.

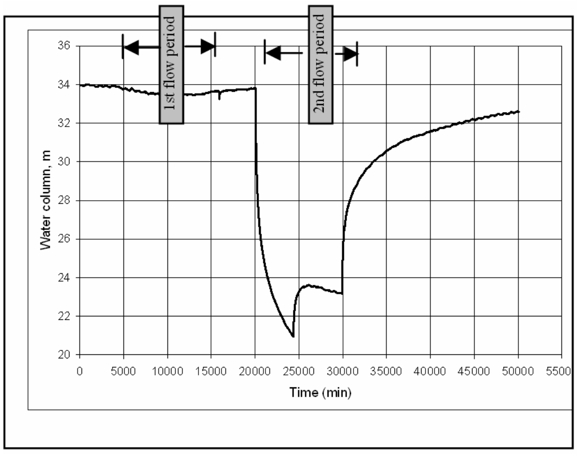

Figure 7: G3-A water level change during the flow test.

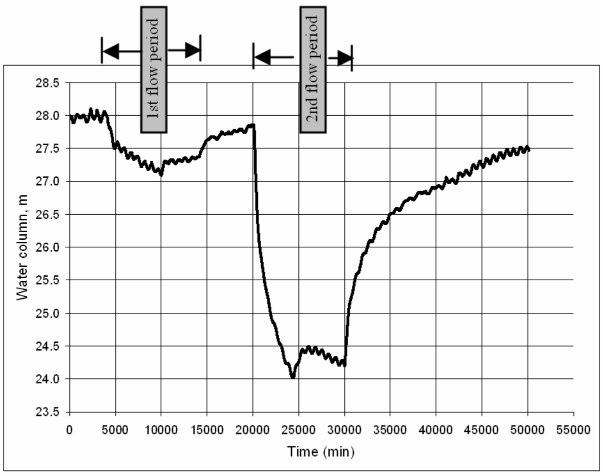

Figure 8: CM-5 water level change during the flow test.

Yet another important issue during a flow test is temperature changes. Figure 9 shows temperature measurements acquired in the observation wells during the flow test. G3-A has the highest temperature followed by CM-5 and G17-A respectively. Sudden changes observed in temperature of G3-A is due to placement of sensor at a different level in the wellbore after taking the sensor out of wellbore to transfer the data. The sensor was stuck at a level higher than previous runs. The pressure recordings were corrected by adding the difference between the end of previous run and the beginning of new run, but the temperature data was not corrected. Slight increase during the test indicates that there is no cold water encroachment from colder nearby, shallow aquifers. The temperatures measured in other wells do not change significantly which is encouraging.

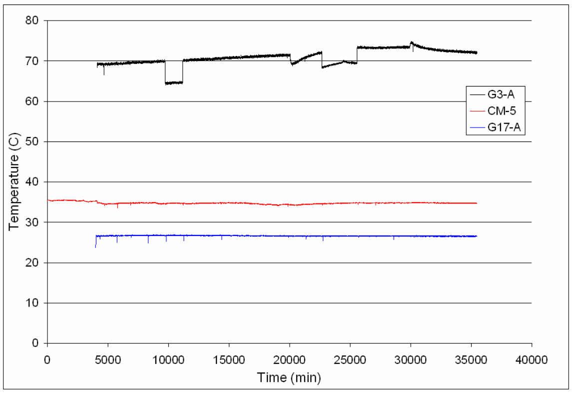

Figure 9: Change in temperature in the observation wells during the flow test.

The pressure data acquired in observation wells during the flow test were analyzed using a double porosity pseudo steady state model. One important deviation from the basic single well model involves cases where there is more than one well opening into the reservoir. This situation may lead to a well-well interaction and pressure field scattering. The practical criterion for interaction is obtained by comparing the well to well distance to the skin depth *d* of the medium. Wells will interact noticeably if the distance between the well –reservoir cavities is approximately equal or less than the skin depth at tidal frequencies (Bodvarsson, 1977). Assuming that this assumption is valid for Seferihisar reservoir, in order to tackle the effect of production in wells superposition principle was used. Note that neglecting well to well interaction in multi-well situations will lead to underestimation of the reservoir flow properties such as the permeability. Figure 10 shows the pressure and pressure derivative match obtained using double porosity pseudo steady state model. Common to all analyses a model with variable wellbore storage and skin in an infinite reservoir is considered. A standard analysis procedure is followed. The final shut in pressure data is used to carry out a manual log – log match. After that non-linear regression is used to improve the match until satisfactory results (i.e. confidence intervals less than 10%) is achieved. The quality of the match is checked with the remaining pressure data (i.e. the pressure data taken prior to shut in). Once again a satisfactory match is required at this stage. Figures 10 and 11 show matches obtained for G17-A pressure data. The pressure derivative plot shows a characteristic "v" shaped restricted interporosity flow behavior. Although not shown here, it is observed that the other analyses also have the same characteristic behavior. Following that the derivative plot does not show a radial flow stabilization. There is a ½ slope increase showing a possible fault boundary. The derivative plot makes a minimum when the Cumali test begins. Table 2 shows the results obtained using the data acquired in observation wells during the test. It can be seen that the results are in accord with the tidal pressure analyses. It must be noted that well test analyses show the dynamic reservoir behavior as opposed to the static conditions considered in tidal pressure analyses. Unfortunately, a comparison with static log values is not available. Large negative skin values are obtained for almost all cases. Since geothermal reservoirs produce from fractured formations large negative skins are quite common unless a drilling induced damage is present in the fracture system (i.e. interporosity skin). The interporosity flow coefficient values are somewhat smaller than what is commonly seen for fractured formations. Likewise, storativity values are small except for that of CM-5. Note that large storativity values may indicate multiphase flow.

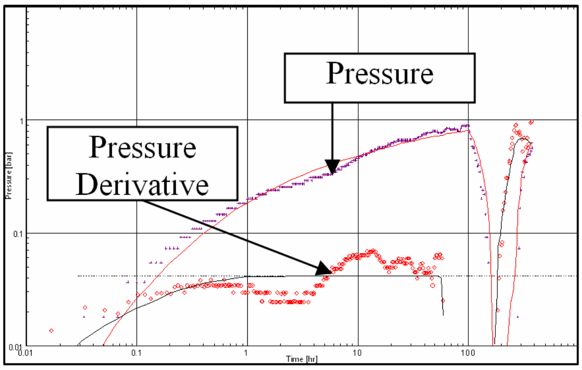

Figure 10: G17-A pressure – pressure derivative match.

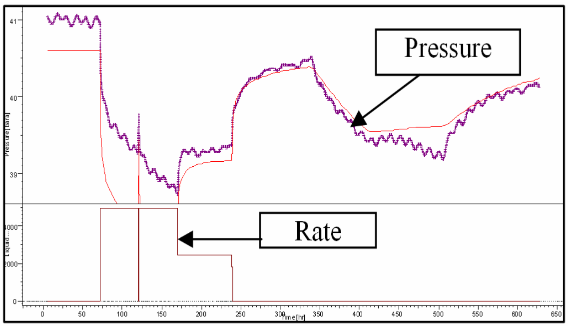

Figure 11: G17-A rate history plot and pressure match.

Table 2: Results of flow test analyses.

	G17-A	CM-5	G3-A
Permeability – thickness, m^3	$5.32x10^{-11}$	$1.26\ x10^{-11}$	$6.33\ x10^{-13}$
Porosity, %	5.11	6.1	2.21
Interporosity flow coefficient	$1.97x10^{-8}$	$2.47\ x10^{-8}$	$4.07x10^{-8}$
Storavity ratio	0.00819	0.196	$1.5\ x10^{-4}$

5. CONCLUSIONS

A flow test conducted in Seferihisar (Turkey) geothermal field. The static part of the flow test is analyzed using a static tidal model. The dynamic data is modeled using a double porosity model with variable storage and skin. The results indicate that the permeability thickness product is larger at sections of the reservoir that are close to Aegean Sea. In these parts, porosities are somewhat larger compared to the rest of the reservoir. Dynamic porosities obtained using dynamic analyses have the same magnitude but the values of porosity are somewhat different than the static ones.

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