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ASSESSMENT OF WELL TESTS IN SALAVATLI-SULTANHISAR GEOTHERMAL FIELD OF TURKEY

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ABSTRACT

This paper presents our analysis of several well tests performed for the formation evaluation in the Salavatli geothermal field Turkey, by using the data accumulated over 20 years since the drilling of the first well. Available geological information about the area has been included. Three specific studies were conducted within context of this work. First, qualitative analysis has been carried out to identify permeable zones. Then, conventional pressure transient analysis methods have applied to this liquid dominated geothermal reservoir to determine transmissivities of the reservoir around the wells drilled. Finally, modern well test interpretation techniques have been used to obtain both reservoir parameters and suitable models, and the results were reported.

INTRODUCTION

Salavatlı geothermal field is located in one of the most promising geothermal regions, namely on the northern flank of B. Menderes graben of Menderes Massif. The Salavatli-Sultanhisar geothermal system known with two hot springs was delimited after a resistivity survey conducted by MTA Institute of Turkey. Two wells (AS-1 and AS-2) were drilled in 1987 and 1988 to 1500 m and 962 m, and temperatures of 169.5°C and 172.5°C were recorded, respectively. In the past two years, two more wells were also drilled to the depths 1300 and 1430 m for reinjection and stand by production, and both have struck similar temperatures. The geothermal fluid contains an average of 1% of CO_2 by weight, which is similar to that of other geothermal fields encountered in the B. Menderes region. An air cooled binary power plant with 7.35 MW_e gross power is being installed and power generation will start soon.

First well tests (injection and fall-off) were carried out after completing first 2 wells in 1987 and 1988. A production well test campaign was conducted on the first two wells for about 2 months in 1999. Recent tests have been carried out as completion tests after the drilling of the last two wells. After mechanically cleaning scaling occurred in the wellbores, new tests have been conducted the first two wells. The well tests were evaluated qualitatively and quantitatively. Qualitative evaluation focused on identifying permeable zones in long open sections of wells. On the other hand, well tests were quantitatively evaluated to obtain information on transmissivity of individual wells and formation damage. The pressure surveys, injectivity, multi-rate injection and fall-off, build-up and drawdown were screened and analyzed. Conventional and modern test methods are used in this study. Results of interpretations for these tests are discussed and reported.

GEOLOGICAL SETTING

The geothermal field is situated within the B. Menderes graben. Stratigraphy of the Menderes Massif covers old Paleozoic age metamorphic units and Cenozoic age sedimentary units. Metamorphic units are composed of gneisses, several types of schist and marbles, in which geothermal reservoir is located. Sedimentary units consist of clayey formations, silts and gravels which serve as caprock for the geothermal reservoir. The wells drilled (AS-1, AS-2 and ASR-2) in the northern section of the field intersected only marbles as thick as 800 m due to intense folding. On the other hand, a southern well (ASR-1) intersected no marbles but only gneisses and schists.

Tectonically, SWW-NEE oriented two major faults that could be related to the formation of graben in the north of the field and an older major inferred fault with NWW-SEE orientation crossing through the center of the field control geothermal system. There are several secondary faults within the structure with SWW-NEE direction.

QUALITATIVE EVALUATION OF SURVEYS

Several temperature surveys that have been run during water loss tests and heating up periods have been evaluated to locate different fractured zones within the geothermal reservoir.

Fig. 1, Fig. 2 and Fig. 3 illustrates temperature surveys run during water loss tests and heating-up periods in northern wells AS-1, AS-2 and ASR-2, respectively. As seen in Fig. 1, Fig. 2 and Fig. 3 there is a major fractured interval between 750m and 950 m. This fractured interval detected by water loss tests is confirmed by fast heating due to convection and substantial circulation losses occurred during drilling at those levels. Minor fractured horizons can be observed from water loss tests in deeper sections of AS-1 and ASR-2 (Fig. 1 and Fig.3). Small temperature reversals are observed in wells AS-1 and ASR-2 in stabilized temperature profiles, and dynamic temperature profiles of these wells indicate that deeper horizons also contribute to the production of these wells.

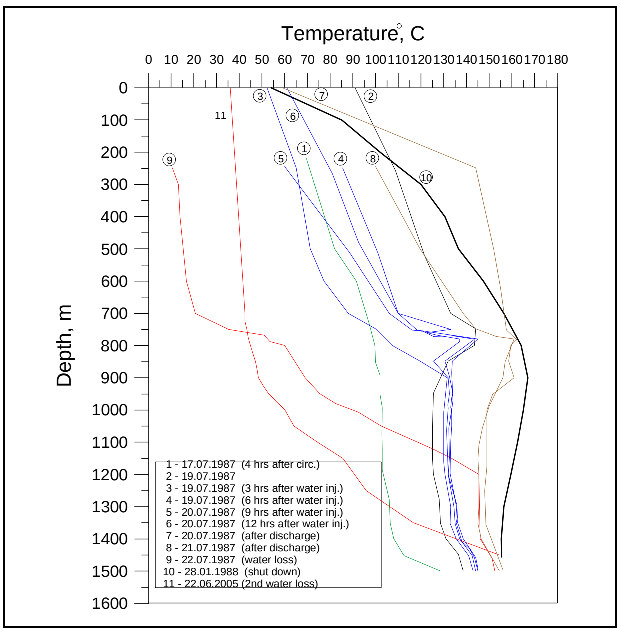

Fig. 1.Temperature surveys run in AS-1 well.

No temperature reversal is observed in the well AS-2, which is relatively shallower than the AS-1 and ASR-2 wells. The AS-2 well is located on the same geological structure where other two are situated and intersects the same major fractured interval. If this well had been drilled as deep as the others the same temperature reversal might have been observed. This well is considered as reinjection well since it has better injectivity than the others (Serpen and Aksoy, 2004). A deeper AS-2 might have better permeability thickness since it might have intersected similar minor fractured intervals encountered in other wells, and it might have absorbed more disposal water than the actual one.

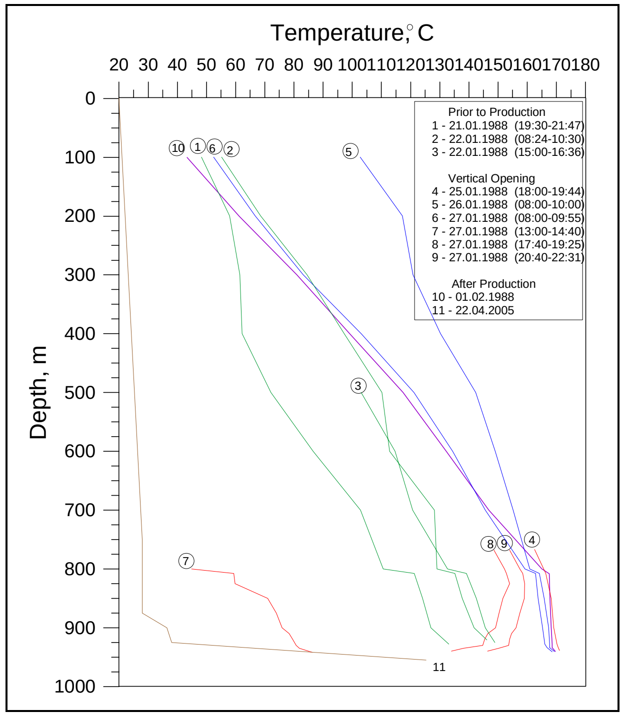

Fig. 2. Temperature surveys run in AS-2 well.

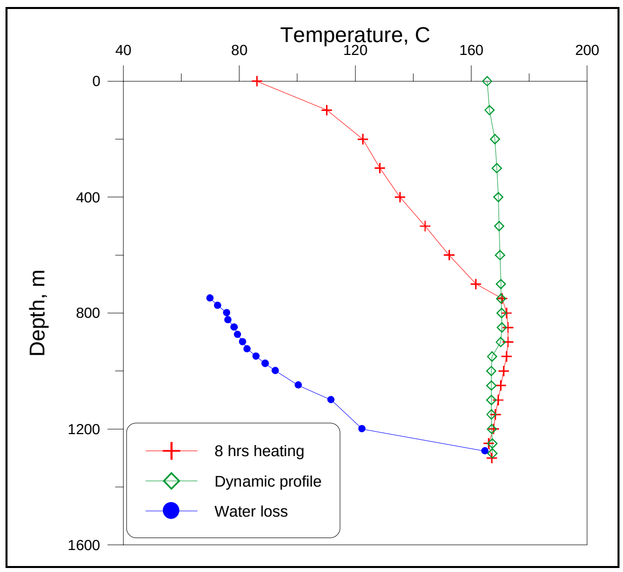

Fig. 3. Water loss test in ASR-2 well.

As seen in water loss and heating-up temperature profiles of ASR-1 well (Fig. 4), major fractured zone slides down to a deeper interval between 1000-1200 m, which is an expected situation, since this well is situated toward the center of graben. There are minor fractured zones around 800 m and 1300 m. No circulation losses were observed during drilling in this well and only schichts were cut, marbles were not encountered. Paradoxically, productivity of this well is individually almost twice the other wells while its injectivity seems to be poor. Similar temperature reversal exists at bottom of this well, but as dynamic profile indicates deeper sections with relatively lower temperatures also contributes to the production.

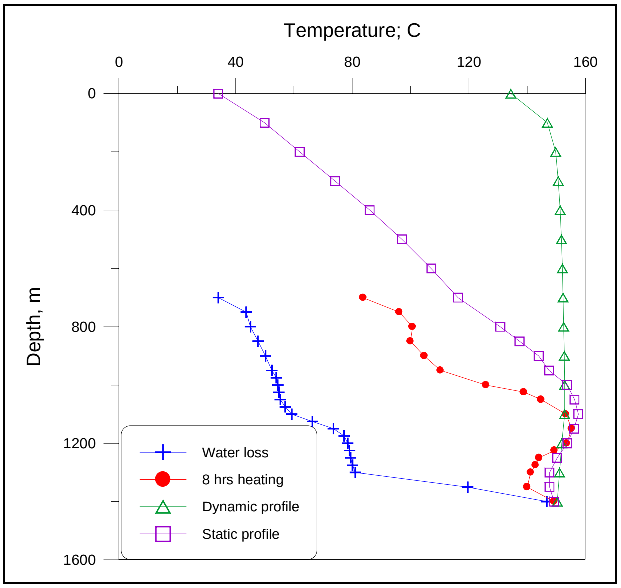

Fig. 4. Water loss test in ASR-1 well.

QUANTITATIVE EVALUATION OF WELL TESTS

Well tests have been evaluated by using conventional and modern interpretation techniques.

Conventional Well Test Interpretation

Well tests conducted in the Salavatli geothermal field were evaluated to obtain information on transmissivity of individual wells, and skin damage caused by mud circulation. Database for this study have been obtained from the reports of Özüdogru and Yeltekin, (1999) and Bayramer and Kucuk, (2005). The pressure surveys, injectivity, multi-rate injection and fall-off, build-up and drawdown tests were screened and analyzed. Results of these tests are reported and discussed in the following sections.

Build-up and Drawdown Tests

Table 1 shows the results of analysis of build-up and drawdown tests. As can be observed from the Table 1, although transmissivity values belonging to all wells are of the same order of magnitude, they differ markedly. Maximum transmissivity values obtained in ASR-2 well, but it's skin values are very high and therefore, though this well was originally intended to be a reinjection well, turned out to be a production well because of high skin. But, its productivity is not as high as it is expected from its high transmissivity due to high skin effect values that have been probably caused by mud solidification during long waiting periods taken place in this well. At initial development stage of Salavatli geothermal field, it has been thought that mud solidification issue was not likely due to relatively low reservoir temperatures. However, it is a well known fact that fresh water bentonite mud solidifies after 170°C if it remains in fractures of geothermal reservoirs, and Salavatli reservoir temperatures reach 172°C.

Table 1. Build-up and Drawdown Test Results.

Wells	Test Type and Analysis	Transmissivity, kh, (d-m)	Skin Factor
AS-2	BU, MDH	20.1	-1.4
ASR-1	BU, MDH	16.9	-1.8
ASR-2	BU, MDH	53.9	18.2
ASR-2	BU, Horner	49.3	10.2
AS-1	DD, MDH	3.6	-4.2
ASR-1	DD, MDH	11.9	-0.7
ASR-2	DD, MDH	47.7	13.6

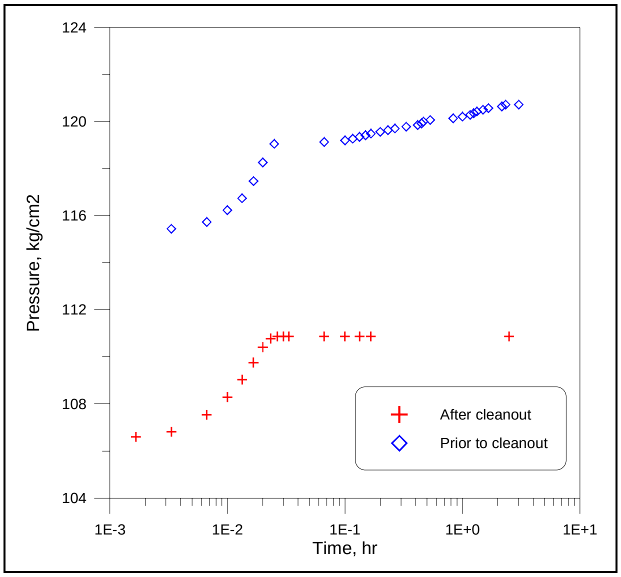

Fig. 5. Build-up test conducted prior and after cleanout of ASR-1 well.

Another mud solidification case might have occurred during the completion tests of ASR-1 well drilled with mud. This well discharged spontaneously before it was properly wash up, and as a result, amerada gauge could not be lowered below 1075 m in a 1430 m deep well equipped with slotted liner. Repeatedly discharging this well for about 20 days, it was cleaned up to 1230 m depth. Finally, a workover operation was conducted, and the well was washed up to 1420 m. Fig 5 and Fig.6 illustrate build-up and drawdown tests conducted prior and after the workover operation, respectively. As seen in Fig. 5, while the pressure recovery takes 2.5 h in the build-up test prior workover, it takes 2 minutes after the cleanout operation. Similar trend can be observed in drawdown test (Fig. 6). Peculiar behaviors of pressure response in both build-up and drawdown tests prior to cleanout operation are very much marked. Especially, rising pressure after stabilization in drawdown test presents very particular situation. On the other hand, pressure responses of build-up and drawdown tests seem to be normal after cleanout.

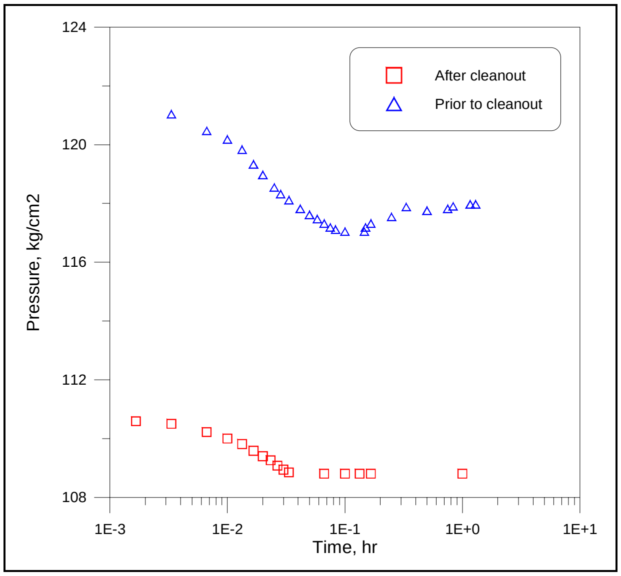

Fig. 6. Drawdown test conducted prior and after cleanout of ASR-1 well.

Injection and Fall-off Tests

Injection tests have been especially conducted on all wells in the last two years in order to be able to select best well for this purpose. Although ASR-1 and ASR-2 wells have been drilled for reinjection purpose AS-2 well was found the most suitable well from the injectivity point of view (Serpen and Aksoy, 2004).

Table 2. Injection and Fall-off Test Results.

Wells	Test Type and Analysis	Transmissivity, kh, (d-m)	Skin Factor
AS-1	Inj. (34 l/s)	6.9	-4.2
AS-2	Inj. (50 l/s)	14.7	-3.5
ASR-1	Inj. (22.5 l/s)	4.6	-1.6
ASR-2	Inj. (two-rate)	25.3	
ASR-2	FO (27 l/s)	23.5	11.9
ASR-2	FO (11 l/s)	19.6	2

As for the interpretation of injection and fall-off tests, unlike stated by Grant (1982), lower transmissivity values have been obtained in these tests than the build-up and drawdown tests.

Negative skin factors are normally calculated in injection and fall-off tests, but curiously, positive skin factors for ASR-2 well have been obtained in these tests, as they were found in build-up and drawdown tests. This confirms formation damage occurred in this well during drilling operation. Fig. 7 illustrates semi-log graphs of injection and fall-off test in ASR-2 well. While drawdown part of the test seems to be all right pressure response in the injection part looks like irregular and analysis of this part is very difficult. On the other hand, very close values of transmissivity have been obtained in injection and fall-off tests with different injection rates confirm each other.

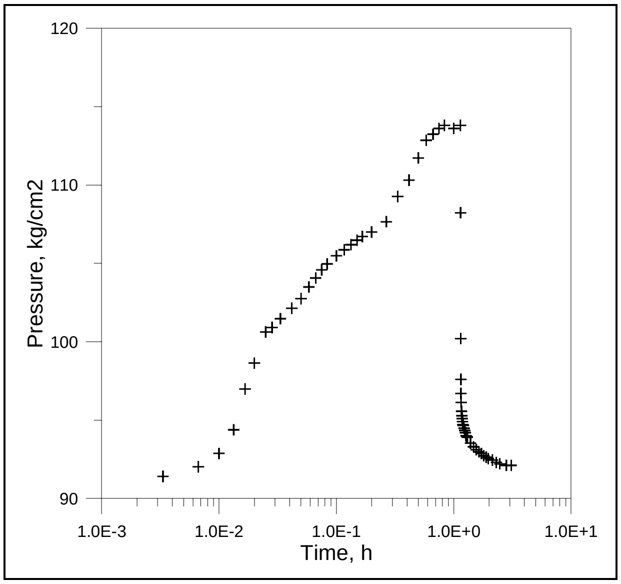

Fig. 7. Injection and Fall-off test results with 26.5 l/s in ASR-2 well.

An interference test was conducted in 1999 between AS-1 and AS-2, which are 1400 m apart. While AS-2 was set as production well, Amerada was run into AS-1, which was used as observation well for 6 days. Interestingly, no interference was observed between two wells.

<u>Modern Well Test Analysis</u>

In order to be able to explain some unusual behavior encountered in the tests modern test methods have been introduced for the interpretation. Saphir software was utilized for model matching and subsequent simulation.

Wellbore storage-homogenous-infinite models have mostly been tried since Salavatli geothermal system formed a big geothermal reservoir. Fig. 8 illustrates such a model matching for ASR-2 well.

For injection and fall-off tests radial composite models have been matched. Fig. 9 shows composite model matching for ASR-2 well.

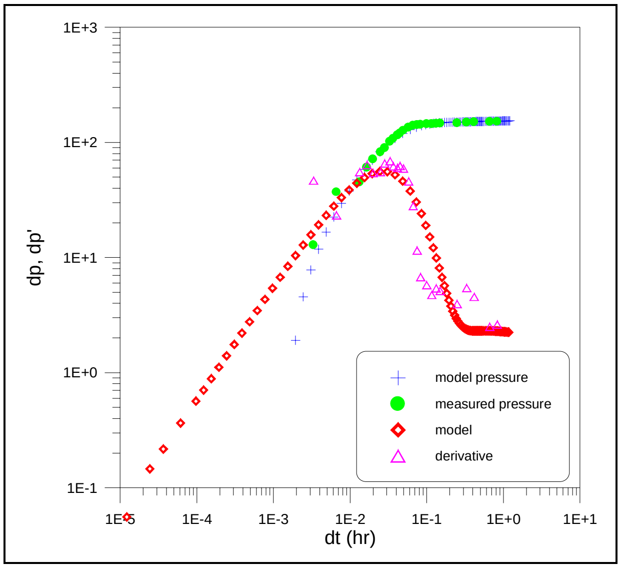

Fig. 8. Model results for drawdown test in ASR-2 well.

Fig. 10 illustrates model matching for AS-2 well. As seen, a no-flow boundary in model matching and a sealing fault is identified.

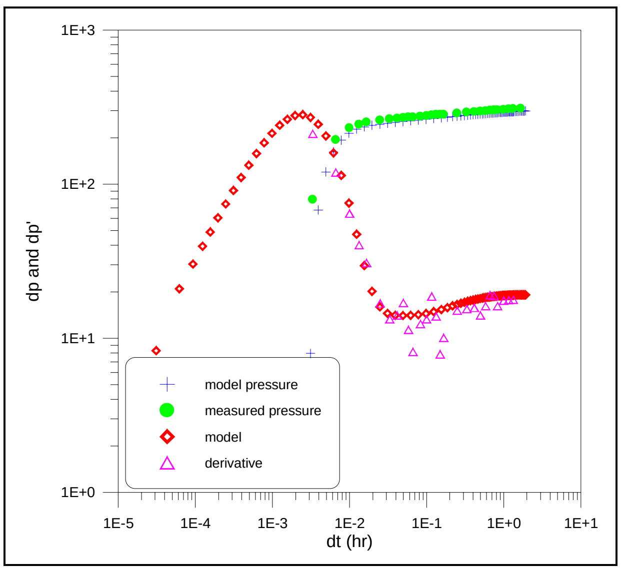

Fig. 9. Modeling results for injection test in ASR-2 well.

A limited entry model was tried for the well ASR-1 prior to cleanout with no results. On the other hand, some test data produces noisy derivative as seen in Fig. 11, and therefore, obtained results from model matching are not meaningful.

Table 3 summarizes some model matching results. Some of the results are similar to the ones obtained from conventional analysis. As in conventional analysis, it is interesting that ASR-2 well produced very high skin values.

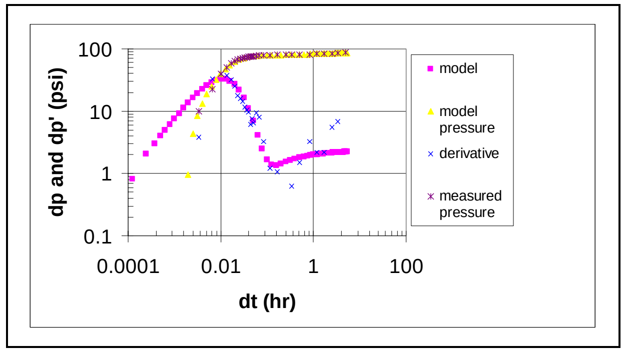

Fig. 10. Modeling results for build-up test in AS-2 well.

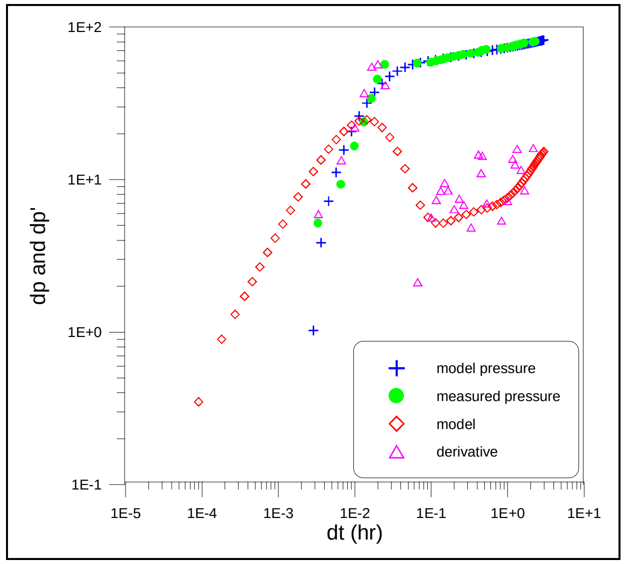

Fig. 11. Model results for build-up test in ASR-1 well.

Table 3. Model Matching Results.

Wells	Test	Model	Transmissivity (d-m)	Skin
AS-1	BU.	SSHI	11.8	+50
AS-1	DD.	SSHI	10	+30
AS-1	INJ.	SSRC	9.6	-3.9
AS-2	BU.	SSHFNF	19.6	+30
AS-2	DD.	SSHI	10.5	+20.5
AS-2	FO.	SSHI	15.3	-1
ASR-1	BU.	SSHI	7	0.3
ASR-1	DD.	SSHFNF	7.1	+31.8
ASR-1	INJ.	SSRC	6	-1
ASR-1	INJ.	SSHI	5.4	-4.5
ASR-2	BU.	SSHI	10.4	+13
ASR-2	INJ.	SSRC	10.4	26
ASR-2	INJ.	SSRC	11.5	20

SSHI: Storage+Skin, homogenous and infinite model.
SSRC: Storage+Skin, radial, composite model,
SSHFNF: Storage+Skin, homogenous, fault with no flow boundary model.

DISCUSSION AND RESULTS

Of the several tests examined, only a handful single rate tests have been found worth analyzing due to short duration and very fast recovery of reservoir pressures. In highly permeable wells as encountered in Kizildere geothermal field by Serpen et al., (1998), fast pressure stabilization (within few minutes) has been observed, especially when corresponding production and injection periods are of short duration, and the tests are dominated by wellbore storage effects. Had the tests been conducted for longer periods, more meaningful results could have been obtained. Tests that have been planned and conducted by ourselves for longer periods provided better results (Satman et al., 2005).

On the other hand, nonisothermal effects might be influencing injection and fall-of periods. This phenomenon may be complicating analysis of these tests. Besides, composite systems forming during injection tests might be further complicating the analysis. Moreover, there might have been mechanical problems related to equipment and survey itself, such as difficulties arising running surveys in wells during production or equipment failures in hot temperature environment that might be affecting and resulting in unusual test behaviors encountered.

Some of the derivative data obtained from model matching in short term tests indicated clearly that test had not terminated, and eventually ending up with an inconclusive test. Some other derivative data seemed to be not stabilized and noisy, because the data recorded by strain-gauge instruments may not be reliable and sensitive enough.

As known, there are several fractured zones feeding geothermal wells, and therefore, layered models could be more suitable for Salavatli wells and such models should be tried for model matching. But in this case, the contributions of each layer should be provided for good model matching. In order to be able to obtain the layers share, a flowmeter survey should be run in the well. Unfortunately, we have no flowmeter instrument available in Turkey's geothermal industry for such a measurement.

Following results are obtained form this study:

- Permeable horizons were identified in open sections of the wells.
- Transmissivity values were computed for individual wells.
- Formation damage by mud use was detected for certain wells in both conventional and modern analysis methods.
- Model studies mostly indicated a homogenous infinite geothermal system.
- In two cases, no-flow boundaries were also indicated by model studies.

In the light of above mentioned the following recommendations could be given:

- Strain-gauge instruments do not always provide sufficiently sensitive data therefore, quartz-gauge instruments should be especially used for model analysis.
- Transient tests should be planned long enough to have better data for the analysis.
- Layered models should be tried for Salavatli geothermal well test analysis.

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