

Enhancement of Geothermal Reservoir Through Varying Acidizing Operation Procedures in Aydın Kuyucak Geothermal Field

Arif Mert Eker¹, Gözde P. Yal², Selim Cambazoğlu², Osman Şen², Hüseyin DÜNYA³

¹HD Consultant Energy, İzmir, Turkey

²SDS Energy, Ankara, Turkey

³General Directorate of Mineral Research and Exploration, Aegean Regional Directorate, İzmir

merteker@gmail.com

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ABSTRACT

This study is conducted in order to assess the efficiency of the acid operations for the enhancement of a geothermal reservoir. The study area is located in Kuyucak geothermal license owned by SDS Energy where two production wells, namely KS-1 (3232 m) and KS-2 (3614 m) were drilled. The area is located at the northern flank of the Büyük Menderes Graben. Generalized stratigraphical succession of the area from bottom to top is Menderes Massif, Neogene sediments and Quaternary deposits. The marble unit of the Menderes Massif is the reservoir rock throughout the Büyük Menderes Graben which is also the case for KS-1 and KS-2 wells drilled at Kuyucak geothermal area. At KS-1, following the well completion operations, dynamic PT logging and water loss test has been conducted where at this stage no artesian flow was observed. The results of the water loss test were used to identify the section(s) to perform the acidizing operation. Two reservoir sections were identified and a one-stage acidizing operation using 38 tonnes of 26% HCl was performed at the section with higher temperature values. The operations were performed while drill rig is at the site, allowing high pumping rates. After the operation, artesian flow was observed and the well was left for production for a certain period of time. At this stage, dynamic PT logs were taken and a build-up test was performed. However, in order to further enhance the well, an additional acid operation was performed at the same reservoir using 39 tonnes of 20% HCl. In order to assess the performance of the acid operation, another build-up test was performed. The analysis of the pressure transient curves indicated that the acid operation was successful which was further supported by the enhanced productivity index values. For KS-2 well, a similar operation schedule was employed. However, instead of performing two separate acidizing operations, a two stage acidizing operation with 37 tonnes of 20% HCl and 30 tonnes of 20% HCl was performed at different depths at the same reservoir. As a result of these two different operation schedules at these two wells penetrating the same reservoir, effect of acidizing operation on the enhancement of the reservoir was assessed.

1. INTRODUCTION

Nowadays, acid treatment become a standard procedure for almost all wells in geothermal sector in Turkey to enhance the reservoir conditions in order to increase the production parameters (especially flow rate and well head pressure). The role and the impact of the different reactants [e.g., hydrochloric acid (HCl), hydrofluoric acid (HF), Acetic Acid (CH₃COOH), Formic (HCOOH), etc.] or their mixed compounds can be used for the chemical treatments. An acidizing job at the geothermal wells, especially located in Aydın Province, should be planned by considering the calcium carbonate acidizing techniques, since most geothermal reservoirs are composed of marbles of Menderes Massive in this region.

During an acid job for the geothermal wells, typical acid additives (corrosion inhibitor, inhibitor intensifier and iron control agent) should be utilized during the preparation of acid solution. The correct selection of a corrosion inhibitor retards the reaction time of the acid with the rock. Therefore, the acid can penetrate deeper into the formation. Another reason of utilizing the inhibitor is to protect the tubings or drill pipes against a possible corrosion during acid pumping. Based on bottom hole temperature, inhibitor intensifier can also be used to increase the performance of the corrosion inhibitor. Beside these additives, the well should be cooled down as much as possible by pumping cold water to well since reaction time of the acid increases with temperature. Additionally, iron control agent is the other essential additive in the preparation of the solution for the acid treatment. During acidizing operation, high amount of iron content and other metal ions can be dissolved, and this amount can increase with temperature. The iron control agent react with the dissolved metals, preventing the precipitation of these by maintaining metal cations in the solution.

When the literature is examined, it can be observed that the thickness of the pay zone is dominant parameter in the estimation of the pumping acid volume according to Malate et al. (1997), Barrios et al. (2002), Gdanski(2005). However these researchers propose their suggestions with respect to oil wells having reservoir zones accessed with controlled fashion by perforation operations. However, this situation is different in a geothermal wells since typically the wells have long liner-completed intervals. Therefore, the reservoir section of a geothermal well where the acidizing operation is performed may be much more longer than that of an oil well. Due to this condition the aforementioned suggestions are not applicable in the geothermal industry (Akin et al., 2015).

An acid operation is commonly carried out by using two alternatives (i.e., drill rig plus cement unit or coiled tubing unit) in the geothermal industry. The main advantage of coiled tubing unit is that the acidizing job can be held throughout a large interval by reciprocating the tubing. However, the major disadvantages are the limited pumping rate (i.e., 2-3 bbl/min) and limitation on acid concentrations (< 15%) due to possibility of significant damage to the CT string due to corrosion.

2. STUDY AREA

The study area is located about 2 km north of Kuyucak Village, on the northern flank of Büyük Menderes Graben in Aydın, Turkey. East of the study area lies the well known Pamukören geothermal field where several geothermal power plants are in place. The elevation varies between 55 m to 1580 m asl mainly from south to north. The location map of the study area can be seen on Figure 1 where the drills conducted in the study area (KS-1 and KS-2). The air distance between these wells is approximately 2 km.

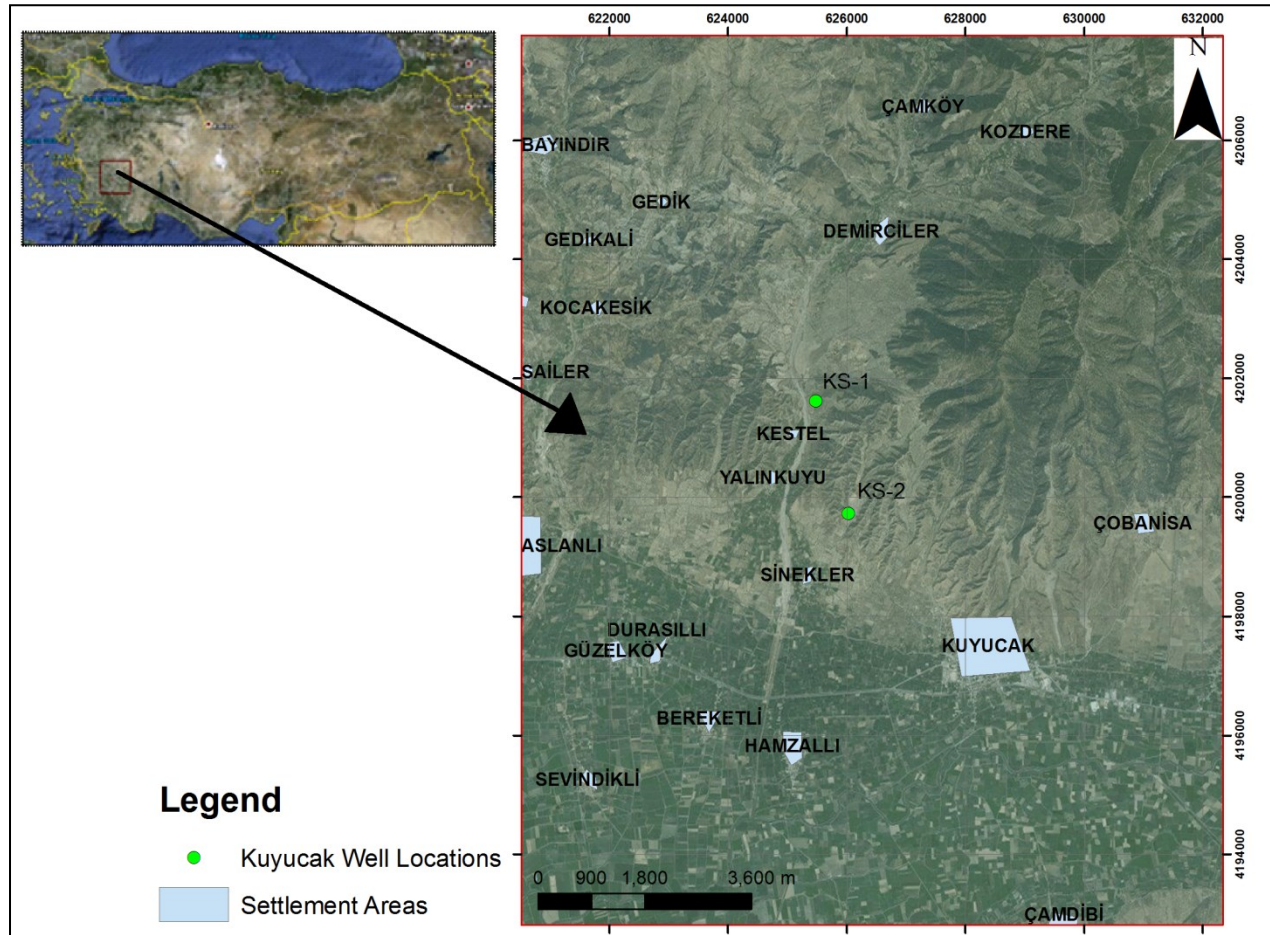


Figure 1: Location map of the study area.

3. ENCOUNTERED LITHOLOGIES

The Paleozoic-Mesozoic Menderes Metamorphics (Massif) are the basement of the study area. They are unconformably overlain by the Neogene deposits and in turn overlain by the Quaternary graben fills. The Menderes Massif is composed of "core" and "cover" rock assemblages. Core is composed of augen gneiss, metagranite (granitic gneiss), schist and metagabbro whereas the cover is composed of metapelites, amphibolite with dolomitic marble intercalations and marble dominated re-crystallized sedimentary sequence. In Menderes Massif the highly fractured augen gneisses, quartzites and marbles present high porosity due to the multiphase brittle deformation and underground dissolution openings form the geothermal reservoir while the schists, such as the mica and chlorite schists represent the cap rocks of the geothermal system at places (Koçyiğit, 2015). The marble unit of the Menderes Massif is the reservoir rock throughout the Büyük Menderes Graben which is also the case for KS-1 and KS-2 wells drilled at the licence area (Figure 1).

At both wells the transition between Neogene and Paleozoic units of the Menderes Massif were observed at around 700-800 meters. At KS-1 well, based on the lithological log, loss in circulation depths and results of PT logs, two reservoir sections were identified divided by a layer of graphite-schist. The upper reservoir section was encountered between 2558-2942 m depth with a thickness of 384 m and the lower reservoir section has been encountered at 3029 m following a 90 m graphite-schist unit. A similar situation was observed at

KS-2 well as well. The upper reservoir and lower reservoir sections were encountered between 2530-2897 m (thickness 367m) and after 3150 m (thickness > 464 m) respectively with graphite-schist layer in between. The schematic drawing in Figure 2 shows the reservoir depths and positions with respect to each other.

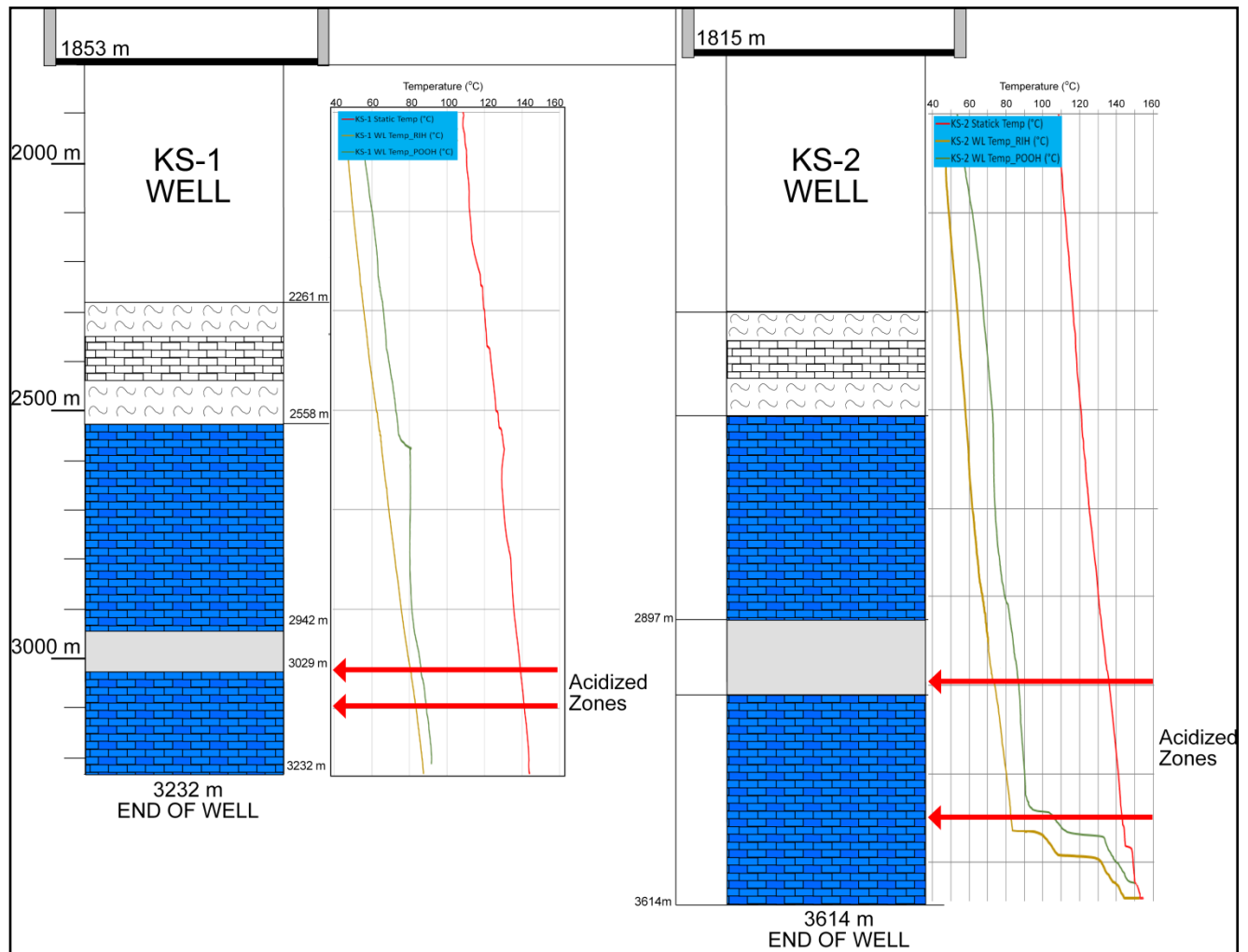


Figure 2: Encountered reservoirs during the drillings, temperature variations with respect to the depth after static and water loss tests and acidized zones.

4. FOLLOWED METHODOLOGY

After drilling of KS-1 well to maximum well depth of 3232 meters, 7" liner was hanged at 1807 m within 9^{5/8}" casing and casing shoe was set at the depth of 3231 meter. 7" liner was inserted within well as solid liner down to the depth of 2216 m and as slotted liner between the depths of 2216 m and 3219 m. Also liner was inserted as closed liner at the final depth of 11 m at the well. Silencer and wier box was connected to the wellhead and necessary measurement gauges (temperature and pressure) was installed on the horizontal production line for the flow tests. The water was displaced at the depths of 966, 1680, 2350 and 3220 m, respectively. At 3220 m, a compressor was connected to kill-line, pressurized air was applied and well was tried to be rejuvenated via blow-off from production line. After this operation, no flow was observed. After this, the drill string was pulled up to 205 m depth and water column within the well was displaced via a compressor having a capacity of 25 bar. This operation was performed at the depths of 292 m and 311 m as well. Compressed air lift operation at 311 meter depth was repeated by pouring sulfatex to the well, but the artesian flow was not observed. After this, it was decided to take a static PT log measurement and perform water injection tests (Figure 2).

After the drilling of the first well (KS-1) of the license area, KS-2 was drilled down to the depth of 3614 m with in the same area. 7" casing was hanged within 9^{5/8}" casing at 1815 m. 7" liner was set in the well and hanged as solid liner until down to 2560 m. and slotted liner from the depth of 2560 m down to 3585 m. At the final 11 m of KS-2 well, soil liner was utilized. Due to the conditions encountered at the first well after completion of KS-1, at the second well, air lifting operation was not held and primarily static PT measurement and water injectivity tests were carried out (Figure 2).

Before acidizing of both wells, firstly injectivity and water loss tests were performed in order to determine the feeding zones throughout the wells and injection parameters for the acidizing operation. In order to carry out these operations, memory type down hole pressure and temperature recording device (Kuster and Datacan PT tools) were utilized. At KS-1, the water loss test was performed by pumping clean water with a rate of 15 lt/sec. Total of 250 m³ cold water was squeezed to the lithological units during this test. After a waiting period of 92 minutes at 3230 m, temperature rise of cooling zones were measured by retracting the tool with 30 m/min line velocity as a procedure of this test. Then, an injectivity test was tried to be implemented at same well, however; a drastic pressure increase at well head was observed, then this test was had to be cancelled for this well. During the water loss test, well head pressure (WHP) of 21.97 bar-g was observed and an average injectivity index was estimated as 1.9 (t/hr)/bar from the water loss test.

For KS-2, water loss test was also performed with an average injection rate of 16.6 lt/sec and approximately 158 m³ cold water was pumped throughout the test. During pumping, WHP of 37.23 bar-g was observed and due to the max pressure range of the Kuster K-10 geothermal PT tool (5000 psi), pumping was stopped at 3000 m and tool was run at the remaining section of the well without pumping. Tool was left at the well bottom for 10 minutes and temperature increases were measured while pulling the tool out of the hole with 30 m/min line velocity. Due to the observation of the high WHP during injection tests, the injectivity with a single injection rate was performed by setting the tool at the depth of 3100 m. As a result of this test, injectivity index (I.I.) was estimated as 0.89 (t/hr)/bar.

The intriguing issue is that, although the mud losses is very high (>50 bbl/min) at both wells, especially at KS-1 well, and drilling was finalized due to encountering total mud loss, the reservoir did not take in as much water as expected during injection and water loss tests. The reason for this phenomenon is that, during these tests the pressure within reservoir did not reach the critical values to re-open the fractures. Therefore, in the implementation of acidizing operations at both wells, it was decided to utilize a drill rig and cement unit in order to enable high pumping rates when compared to the capacity of coiled tubing unit. At both of these wells, each acidizing operations started with cooling down the wells by pumping fresh water more than three times of the well volume. When the acid solution was being pumped to the wells, fresh water was also pumped from annulus with the rate of idle running of the drill rig pumps (2-4 bbl/min). After pumping the entire acid volume, the acid in the well was displaced by 100-150 bbl fresh water. Thus excessive rise of the acid solution in the well was prevented by pumping fresh water. Additionally, all acidizing operations were performed by using injection jet (Figure 3) at the end of the drill string. The fundamental parameters and required information for the acidizing operations held at the both wells are summarized in Table 1.

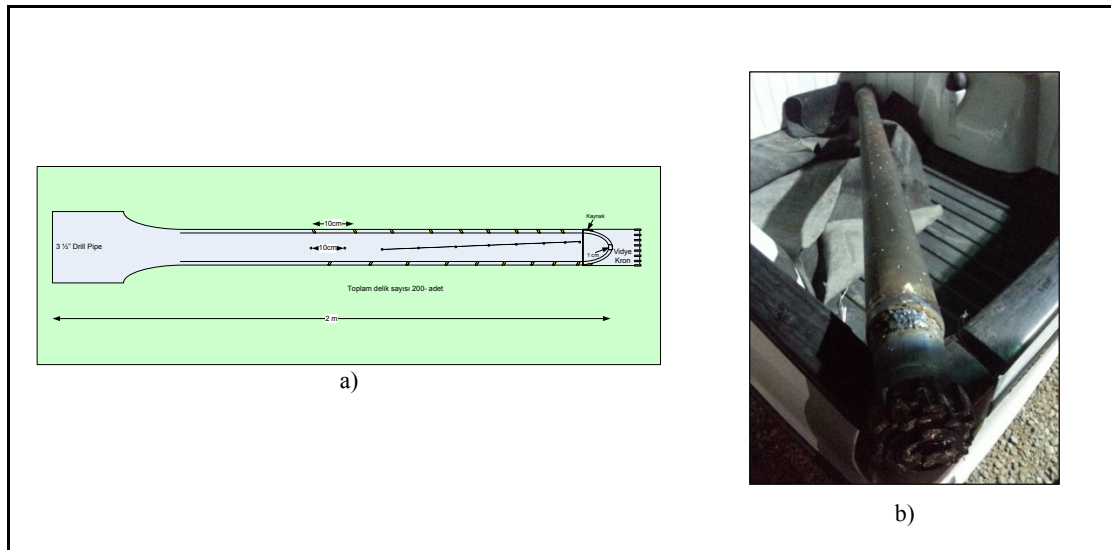


Figure 3: a) Schematic drawing of the injection jet, b) close-up view of the jetting tool.

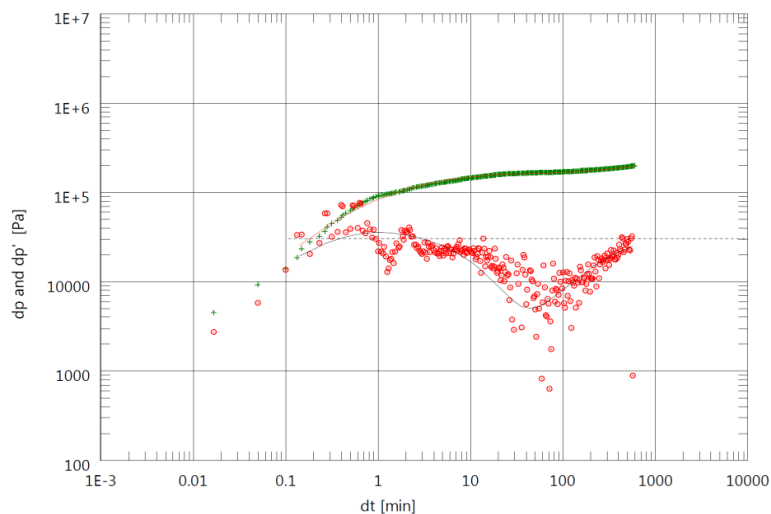
Table 1: Basic acidizing parameter and required information for the acidizing operations at both wells

Well Name	KS-1	KS-2
Utilized Unit	Rig+Cement Unit	Rig+Cement Unit
Operation #	2	2
Operation Sequence	Episodic	Sequential
Depth (m)	3097 (3020)	3408 (3098)
Acidizing order	From bottom to top	From bottom to top
Average Pumping rate (bbl/min)	5-6 (5-6)	5-6 (5-6)
Acid(%)	28 (20)	20 (20)
Acid Volume (ton)	38 (39)	37 (30)
Acid Inhibitor (gallon)	55 (55)	55(55)
Iron Agent (kg)	300 (600)	400 (400)
Parenthesis indicates the values for the second acid operation		

6. RESULTS AND CONCLUSION

After each acidizing operation performed at each well (i.e., KS-1 and KS-2), artesian flow was observed. As it was stated before, KS-1 was tried to be produced by air lifting from 300 m via a compressor immediately after completion of the drilling operation, but the wellhead temperature have not exceeded 87°C and no artesian flow was occurred at this well. Since, both wells are at the same area and the distance between the wells is not very long, in order to save time and resources, the air lifting procedure was not considered at KS-2 following completion of drilling operation. After the first acid job, the well flow rate of 168 t/h was observed with WHP of 44 psi and the well head temperature was recorded as 127°C. The productivity index of KS-1 was calculated as 23.78 t/hr./bar. The reservoir was enhanced by the application of the second acid job at the same well. Then the WHP increased to 58 psi and the productivity index was estimated as 51.61 (t/hr)/bar. KS-2 well production was obtained with a rate of 162 t/hr flow rate at WHP of 26 psi, and 116°C production temperature was observed. The productivity index of KS-2 was calculated as 9.9 (t/hr.)/bar after analysing the pressure build-up curve.

However, unavailability of data regarding the production parameters along with dynamic down hole measurements and tests data before the acidizing operations due to lack of artesian flow at the wells, the acidizing effects at the productions cannot be quantitatively compared and assessed. On the other hand, after each acid job at KS-1, the well was let to flow and the production parameters were recorded, and furthermore, dynamic PT logging and pressure build-up tests were also carried out at this well. Additionally, the same tests were conducted at KS-2 twice at different times. The final build-up tests at both wells were performed after completing short term flow test with duration of 10 and 7 days for KS-1 and KS-2, respectively. The log – log analysis of build-up tests were conducted in these wells by using double porosity reservoir behavior (Figure 4). When transmissivity values and skin effects were compared after analysing the both build-up curves for KS-1, it is observed that skin value was decreased from 0.04 to -9.21 and transmissivity value increased of nearly 3 order of magnitude. Therefore, it can be surely stated that the acid treatment has successfully resulted in improvements in characteristics of both wells such as reduction of skin, increase of injectivity and permeability-thickness product, and production output.

**Figure 4: Log – log analysis of pressure build-up test data of KS-1 after second acid job..**

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