ACID STIMULATION OF INJECTION WELLS IN THE LEYTE GEOTHERMAL POWER PROJECT, PHILIPPINES

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Abstract

Acid stimulation was applied in injection wells MG-7RD, 4R7D and 4R12D in the Leyte Geothermal Power Project, Philippines, to increase their injection capacities affected by mud during drilling. Several improvements were initiated in terms of well testing and analyses and acid treatment design to increase the effectiveness of the stimulation compared to previous acid stimulation jobs.

The use of electronic pressure-temperature-spinner logs and improved well test interpretation became essential for better candidate selection, acid treatment design, quantification of pre-acidizing well parameters and evaluation of acidizing results. Further improvements in acid treatment design were also achieved with the refinements in spotting the acid, increased injection rates and the use of chemical diverters. Post-treatment results showed a 77% to 357% increase in injection capacities.

1.0 INTRODUCTION

Injection wells have commonly been primary candidates for stimulation when PNOC-Energy Development Corporation (PNOC-EDC) started to undertake its acid stimulation program in 1993 (Buiiing, et. al., 1995). Majority of these injection wells were stimulated due to formation damage caused either by silica deposition in and away from the wellbore or mud during drilling. The experiences gained in acidizing these wells made PNOC-EDC refine and improve the acid treatment of future wells. This paper discusses the improvements made in stimulating some of the injection wells in the Leyte Geothermal Power Project (LGPP).

The development of LGPP has recently experienced a shortfall in injection capacity, particularly in the Mahanagdong and Upper Mahiao sectors of the field. Initial analysis of the wells drilled in these areas identified injection wells 4R7D and 4R12D in Upper Mahiao and well MG-7RD in Mahanagdong to may have been damaged by mud during drilling. Thus, PNOC-EDC programmed these wells for acid stimulation to improve their injection capacities and thereby reduce if not eliminate drilling of new injection wells.

2.0 CANDIDATE SELECTION AND EVALUATION

The parameters used in selecting the candidate wells for stimulation were similar to the previous acid stimulation jobs conducted by PNOC-EDC. These included the correlation of well test, drilling, petrological and geological data. The use of an electronic logging tool was also applied in refining the payzone targets for the selected wells. Moreover, PNOC-EDC has also initiated the application of a welltest interpretation software in improving the analysis of pressure transient data of the wells.

Well 4R7D was drilled in 1995 to a total depth of 2492 mMD (measured depth) while 4R12D, a more recent injection well was completed in 1996 to a depth of 2624 mMD. These wells, although targeted in the more permeable sector of Upper Mahiao, have shown marginal injection capacities. The injection capacity of 4R12D in fact was unexpectedly low compared with the other big holes drilled in the area. MG-7RD is another injection well in Mahanagdong area, completed in 1995 with a total depth of 1815 mMD. Its estimated injection capacity was also found to be low compared to its neighboring wells.

$170K excluding rig cost

Well	Total Mud Lost (barrels)
MG-7RD	7,210
4R7D	17,735

Table 1.* *Mud volume *lost during drilling.*

The major permeable zones found in these wells are postulated to have accepted most of the mud lost since these would have the least resistance to flow and so the greater capability of accepting the mud. Acid treatment of these payzones could substantially reduce if not eliminate the damage, thereby clearing the fluid flow paths and improve the acceptance of the wells. These payzones can be initially identified from drilling circulation losses correlated with geological and petrological records. To further refine the definition of such zones, downhole surveys and welltest results were utilized. These measurements are also intended to constitute the baseline data from which improvement in the wellbore due to acidizing might be gauged.

The pre-acid completion tests for wells 4R7D and 4R12D were performed using an electronic pressure, temperature **and** spinner (PATS) tool recently acquired by the company. PATS logging tool enables more precise definition of permeable zones with its built-in flow-metering capability. It permits real time downhole data acquisition during the tests, allowing immediate observation of results and modification of the test when necessary. A Kuster temperature-pressure mechanical gauge was used in MG-7RD due to the unavailability of the PATS tool.

The results of the PATS survey in 4R7D showed a thin major permeable zone starting from 1980 mMD where the spinner response starts to sharply decrease (Figure 1). This was matched by the temperature gradient that began to change from this depth and increased towards the bottom. Minor permeable zones appeared at around 2080-2120 mMD and at 2260 mMD to bottom. The temperature near the bottom remained steady even with increased pumping unlike at shallower depths which espectedly cooled suggesting that most of the fluid was lost at shallower levels.

A major permeable zone at around 1650-1790 mMD was distinguished from the logs in well 4R12D (Figure 2). **A** minor zone appeared likely at around 2550 mMD to bottom. These zones were marked by a drop in spinner response wluch were interpreted as fluid loss zones.

Kuster surveys at MG-7RD showed sharp increases in temperature at 1250-1300 mMD, 1650-1750 mMD and 1800-bottom which indicated permeable zones at these depths (Figure 3). This was evident from the. waterloss profile and even more prominent from the zero flow profile recorded.

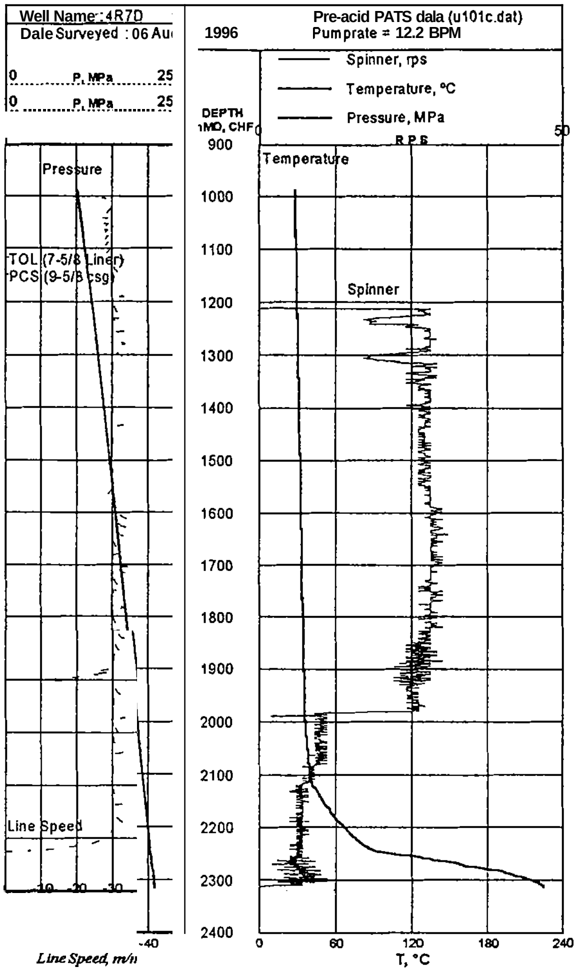

Figure 1. Pre-acid PATS log of 4R7D.

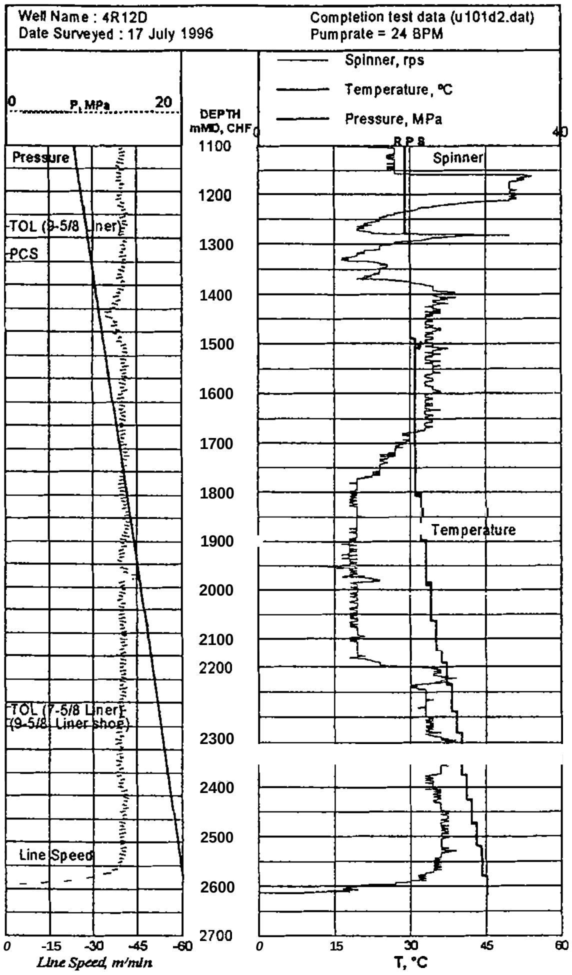

Figure 2. Pre-acid PATS log of 4R12D.

Well data from injection and pressure transient tests were analyzed to determine parameters such as injectivity, transmissivity, storativity and skin, which are essential in the evaluation of 'the acidizing candidates. A well test interpretation software called Saphir (Kappa Engineering, 1995) was used for the analysis. Saphir enables a computer aided approach to pressure transient analysis, automating such procedures as type curve matching and pressure derivative generation. Furthermore, the data can be easily tested under various combinations of well/reservoir models and boundary conditions so that the most appropriate conditions could be determined. For the wells in this study, a homogenous reservoir model with an infinite boundary and wellbore storage and skin was found to be appropriate. Results of the pre-acidizing pressure transient analysis are summarized in Table 2.

All the wells showed good permeability based on the transmissivity values derived, which indicated favorable acceptance. However, the injectivity which reflected the downhole pressure response to injection, was relatively low, particularly for MG-7RD and 4R7D. The true acceptance of the wells were therefore not being attained, likely due to mud damage. The high positive skin values obtained also supported the postulated damage initially created by the mud. Well 4R7D also exhibited an apparent decline in injection capacity prior to acid treatment. This was evident from the significant drop in injectivity index and a higher skin value calculated from the pre-acid test (05Aug96) compared to the original completion test (07May95). This was likely the effect of its use for waste fluid injection after drilling. The results obtained froin these welltest surveys have further reinforced the selection of these wells for acid stimulation.

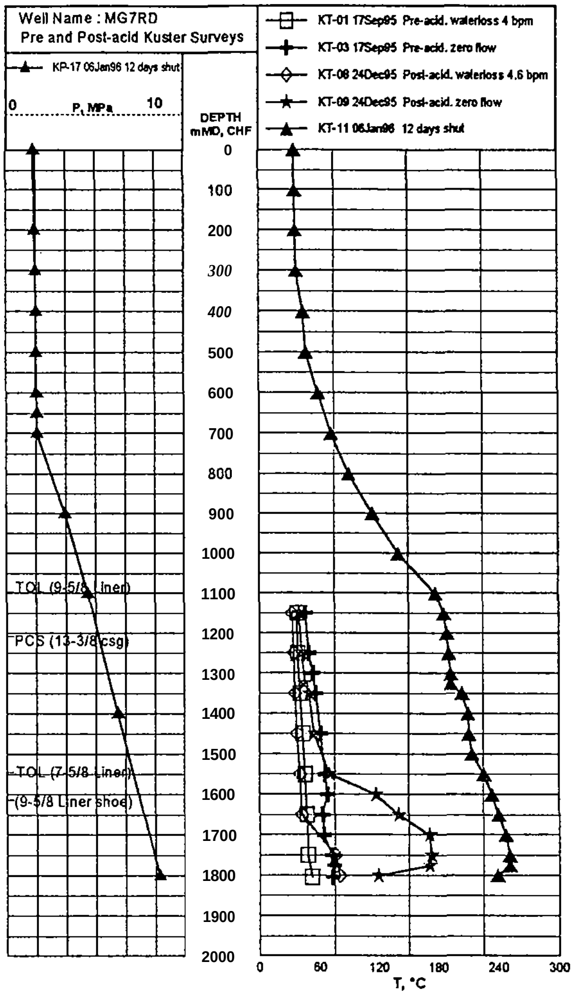

Figure 3. Pre and post-acid temperature and pressure profiles of MG-7RD.

Well	MG7RD	4R7D		4R12D
		(1)	(2)	
Date Tested	17Sep 1995	07May 1995	05Aug 1996	16Jul 1996
Injectivity Index (li/s/MPa)	15.2-15.6	12.5-12.9	6.8	30.1
Injection Capacity (kg/s)	81	70	36	149
Transmissivity (darcy-m)	2.8	1.9-2.4	1.1	9.6
Skin	+6.2	-0.3 to -1.0	+3.2	+9.9
Storativity (m^3/kPa)	0.0109		0.0062	0.0128

Table 2. Summary of pre-acid welltest analysis results.

3.0 ACID TREATMENT DESIGN

A matrix acid treatment procedure was applied for all the wells in this study as in the previous acid jobs of PNOC-EDC. A mixture of 10% hydrochloric acid (HCl) and 5% hydrofluoric acid (HF) was also used as the mainflush, which was primarily intended to dissolve the silicate and carbonate deposits. The mainflush volume was based on a dosing rate of 75 gallons per foot of target payzone. A preflush solution, injected prior to the mainflush, was also prepared consisting of 10% HCl. This removed the acid soluble deposits, minimized the loss of HF in the mainflush, and served as a spacer between the mainflush and the formation brine. The preflush volume was based on a dosing rate of 50 gallons per foot of target zone. The target payzones were determined from the permeable zones identified from the pre-acid completion tests.

The acid treatment was conducted by injecting the appropriate acid mixtures through an open ended drill string set at the targeted payzones. A combination of 5", 3" and 2-7/8". drill pipes were utilized. Preferably, the drill pipe sizes to be used should be maximized for better hydraulic efficiency. The injection process in this case was modified into stages so that the treatment could be applied more evenly across the payzones particularly for wells with multiple zones. This was done by segmenting the target zones into smaller sections (e.g. 50 meters) and treating each zone separately. The end of the drill string was spotted just above each section and correspondingly, the calculated volume of the acid injected into the section. Treatment started from the topmost target zone going down until the deepest zone. The injection rate was kept as high as possible below the calculated fracture pressure gradient to achieve better acid penetration into the desired targets. The results of acid treatments are summarized in Table 3.

An attempt to temporarily isolate the targeted payzone from the other zones of interest was applied in well 4R7D by using diverting agents. Benzoic acid flakes were initially used as the chemical diverting agent to determine its applicability. This chemical diverter is also used to achieve uniform placement of the stimulation fluid. The volume of diverter used was based on a dosing rate of 5 lbs of benzoic acid per foot of payzone. The diverter was injected prior to the preflush acid at every stage.

Well	Target Zones (mMD)	Main Flush Volume (barrels)	Average Injection Rate (bpm)	Average Treating Pressure (psig)
MG-7RD	1250-1300	294	10.0	1660
	1625-1675	308	8.0	1750,
	1675-1750	293	10.0	1600,
	1800-bot.	293	10.0	1650
4R7D	2000-2050	297	14.0	1025
	2050-2100	292	13.5	1400
	2150-2200	292	14.0	1800
	2250-2300	293	13.8	2100
	2350-2400	349	14.3	1900
4R12D	1650-1700	311	17.5	1790
	1700-1750	297	16.5	1640
	1750-1800	298	17.5	1740
	2500-2550	302	16.8	1740
	2550-2600	303	16.8	1745

Table 3. Acid treatment summary.

4.0 RESULTS OF THE ACID TREATMENT

Post-acid completion tests were conducted on these wells to determine improvement in the wellbore in terms of injectivity indices, changes in temperature and pressure profiles and payzone thicknesses and other reservoir parameters. These are basically waterloss, injection and pressure transient tests patterned after the pre-acid completion tests. PATS logging tool were also used in wells 4R7D and 4R12D while Kuster temperature and pressure gauges were used in well MG-7RD.

Results of the post-acid PATS survey in 4R7D showed a clearer definition of the permeable zones starting at 1980 mMD compared to the pre-acid logs (Figure 4). The section froin 1980 to about 2100 mMD now appeared to be composed of several discrete sections whereas before, only a thin zone near 1980 m was distinguished. Based on spinner responses, permeable sections were now discerned at around 1980-1985, 2030-2035, 2100, and 2210 mMD, with the last two sections appearing as minor zones. This indicated an opening up of previously blocked zones and clearing of fluid flow paths. Temperatures close to the bottom declined with increased injection unlike at shallower depths which expectedly cooled. This suggested that majority of the injected fluid was accepted at shallower levels (above 2330 mMD) thereby hardly affecting the temperatures close to the bottom. The prominent increase of the temperature gradient which started at 2100 mMD during the pre-acid completion tests, now began lower at 2240 mMD. This could be attributed to the clearing and opening up of zones above 2210 mMD.

The effect of the chemical diverter was not determined with certainty. However, the appearance of discrete permeable sections within the treated payzones can be attributed to the more evenly distributed acid treatment perhaps made possible by the diverter.

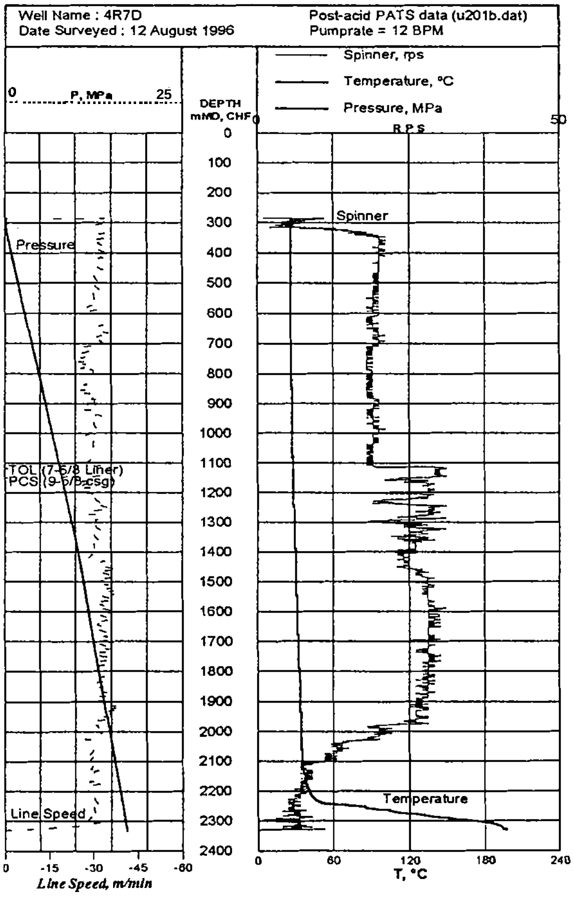

Figure 4. Post-acid PATS log of 4R7D.

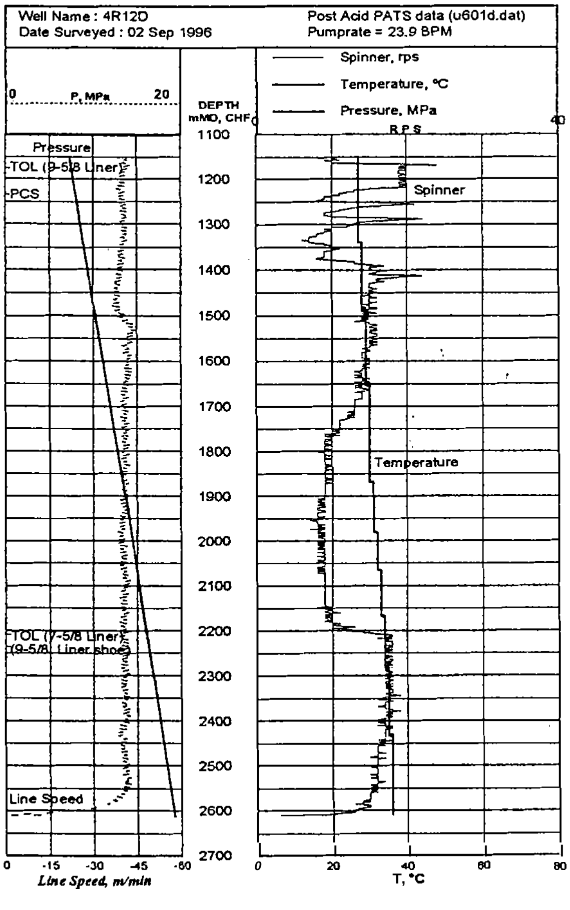

Figure 5. Post-acid PATS log of 4R12D.

The post acid completion test results for well 4R12D are presented in Figure 5. The permeable zones identified are similar to the pre-acid logs recorded except for a newly observed thin zone at around 2450 mMD. The slight increase in temperature gradient starting at about 1800 mMD coincided with the Occurrence of the major permeable zone (1650-1790 mMD). The temperature profile obtained from the post-acid Kuster surveys in MG-7RD showed a inore distinct major permeable zone at around 1650-1750 mMD (Figure 3). The increase in temperature gradient at around this depth was more pronounced compared to the pre-acid profiles as shown by the waterloss and zero flow surveys. Again, such a change could be attributed to the opening of zones previously obstructed.

The three wells also registered a decline in downhole pressures during the post-acid injection tests. The observed decline ranged from about 1 MPa seen in 4R12D to around 3.5 MPa in 4R7D. This signified a reduction in injection pressure which meant restriction to flow was lessened and hence'greater acceptance.

A decrease in water levels during injection was also observed in 4R7D and 4R12D. The water level in 4R7D reached a depth of 250 m while injecting at a maximum rate of 17 bpm during the post-acid tests compared with the water level recorded at 260 m during the pre-acid test at an injection rate of only 5 bpm. Similarly, the water level in 4R12D declined to about 450-470 m at 6-18 bpm compared to about 360-415 m at 6-12 bpm. This decline in water level was indicative of improved acceptance.

Post-acid pressure transient data were also analyzed using the welltest software Saphir. The results are summarized in Table 4 below.

Well	MG7RD	4R7D	4R12D
Date Tested	24Dec 1995	11Aug 1996	03Sep 1996
Injectivity Index (li/s/MPa)	108-120	17.7	58.4
Injection Capacity (kg/s)	370	91	264
Transmissivity (darcy-m)	11.3	2.8	14.8
Skin	-2.2	+1.8	+1.0
Storativity (m^3/kPa)	0.0159	0.0128	0.0258

Table 4. Summary of post-acid ***welltest*** *analysis* ***results***

Significant improvements in well characteristics were attained after the acid treatment as indicated by results of the post-acid welltest analysis. Transmissivity values of all the wells appreciated, most remarkably in MG-7RD and 4R12D. Enhanced storage capacity was realized with the improvement in storativity. High positive skin values were reduced, although only at MG-7RD was a negative skin achieved. The skin values of the other two wells were now only slightly positive. The damage attributed to mud was apparently reduced substantially if not completely eliminated. Increases in injectivity were achieved, by as low as 11 li/s/MPa for 4R7D to as high as 104 li/s/MPa for MG-7RD. Along with the decline in downliole pressures, this resulted to an overall improvement in injection capacity by a minimum of 55 kg/s for 4R7D and a maximum of 289 kg/s for MG-7RD. In relative terms, injection capacities increased from 77% for 4R12D to 357% for MG-7RD.

5.0 SUMMARY

Significant improvement in overall well characteristics were achieved through the application of acid stimulation on injection wells severely affected by mud. In wells 4R7D, 4R12D and MG-7RD improvements attained were increased transmissivity and storativity, reduction **of** skin, decline in injection pressures, higher injectivities and greater injection capacities. The effectiveness of the acid treatment was enhanced with better well testing and analysis before and after the treatment, proper candidate selection and evaluation, and appropriate acid treatment design. The use of PATS logging tool and well test interpretation software became advantageous for sound well test analysis. Acid stimulation techniques such as the staged spotting of the acid, and maximized injection rates were found to be beneficial in the treatment design. Although the effectiveness of the chemical diverter was not exactly quantified, the results were promising and its application is warranted.

6.0 REFERENCES

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