KS 14 PUNA Geothermal Venture: Flawless Execution of Aerated Mud Drilling with Mud Motor in Hostile Environment

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Keywords: Hawaii, Puna, Ormat, geothermal, aerated mud, drilling motor, fixed hole opener

ABSTRACT

The PUNA Geothermal Venture (PGV) wells are located on the Big Island of Hawaii near the Kilauea Volcano. This results in a highly fractured, hard, hot formation, challenging PGV with lost circulation, hole-cleaning, cooling and stuck pipe issues. With static formation temperatures of 600°F the traditional fluid system incorporates water-based mud, various cooling systems to maintain operation temperature limits < 300°F, micronized cellulose for lost circulation and mud-pulse measurement while drilling.

Although aerated mud is the preferred drilling fluid for operations performed in areas prone to lost circulation, there are certainly drawbacks and considerations to running aerated fluids.

- One of the industry standards, mud pulse telemetry better known as Measurement While Drilling (MWD), will not function in aerated fluid;
- Reduced fluid density hampers the ability to lift cuttings;
- Aerated fluid adversely affects the ability to power positive displacement mud motors;
- The thermal capacity of aerated mud is lower, reducing the cooling effect on the hole.
- Drilling equipment exposed to the high velocities can be quickly eroded; and
- The reduced hydrostatic head can have a detrimental effect on wellbore stability.

PGV along with its contractors managed to complete the 26" hole section flawlessly on aerated mud, which has not been part of the standard program. The following techniques were used:

- A pump rate of 350 GPM;
- Foaming agents supplemented with polymers were used to provide rheological properties and gel strengths to facilitate hole cleaning;
- A polymer was used for cuttings encapsulation and lubricity;
- A controlled rate of penetration (ROP) was employed to allow for proper cuttings disposal and hole cooling;
- A 9 1/2" performance mud motor equipped with high-temp stator elastomers, provided high torque drilling with temperature resilience;
- Fixed hole openers were used to further ream and condition the borehole. This section of the well was drilled successfully and 22" casing was landed with no problems. This is a significant improvement as compared to other offset wells in the area.

1. INTRODUCTION

Well KS-14 26" was scheduled to spud on the 7th of February 2010. In each section, improvements were planned to reduce the amount of overall drilling hours. The well was spudded on schedule and the hole was drilled to 123 ft. At this point, the supply of water was lost but drilling was continued to 140 ft. The drill string was pulled out of the hole (POOH) as it was found that the water- line from the well ruptured because the line was packed with cement. Under these circumstances, the water supply was not to be reestablished for at least 4 days. The rig was prepared to drill with aerated mud, and although the plan was to use it in the lower sections, the decision was made to proceed with the drilling operation using aerated mud.

We will describe the performance of previous wells, indicating the major drilling issues; also we will list and explain the action taken to improve performance in the 26" section and finally review the well operations and contrast them with offset wells.

2. OFFSET WELLS

The two reference wells were KS-5 and KS-6. Typical well profiles include a 26" vertical section down to 1000 ft, where 22" casing is set.

2.1 KS-5

The 26" inch section was drilled in approximately 50 days. Initially the well was drilled down to 599 ft and by the 5th day the drill pipe got stuck in the well. Different solutions were tried in an effort to fish the drill string for a period of 25 days but none were successful. A surface sidetrack was started and after 10 days TD was reached. 5 more days were taken to ream and cement the 22" casing. The major issues were: slow rate of penetration (ROP), poor weight on bit (WOB), lost circulation –partial returns, resulting in stuck pipe and a sidetrack due to tight hole conditions.

2.2 KS-6

With similar well profile to KS-5, the well was drilled in 8 days, washed and reamed for 1.5 days, then casing was run and cemented in 2 days. The major issues were: drilling blind (total loss of circulation), stuck pipe at 720ft, jarring and frequent washing and reaming due to tight hole conditions.

3. SOLUTIONS IMPLEMETED

From past wells, stuck pipe and tight hole conditions were major issues. The cuttings generated usually packed off around stabilizers, reducing the flow area. In this section lost circulation is always expected. It was anticipated that the wellbore would have ledges, due to low penetration rates in interbedded formations. These problems were addressed in the following way:

3.1 Bottom Hole Assembly (BHA)

Geothermal Resource Group designed a specific stabilizer for this well (Figure 1). The Stabilizer was designed to have as much surface area as possible, as reaming was considered essential to the success of the section. Therefore the transition from the collar OD to the maximum blade diameter was quite short. In contrast, the space between blades was also maximized not only in its width but in height. The idea was that the bigger the flow area the less prone the stabilizer would be to balling up with cuttings. This stabilizer was also built up in the upper part with tungsten carbide to give the stabilizer back reaming capability. Baker Hughes Drill Bit Systems analyzed bit performance, along with the engineering group in the offset wells and selected a bit with the objective to drill the section with only one bit.

Figure 43: Specific stabilizer designed by Geothermal Resource Group

3.2 Motor

The use of the motor was not standard in this application, due to the risk of sticking and losing the bottom hole assembly. These formations are very hard to drill, especially with a 26” bit diameter in the initial interval where there is very little drill collar weight available. The use of a motor made it possible to transform hydraulic into mechanical energy for breaking the formation. The motor was placed above the stabilizer and strapped to the motor (see photo 1) to prevent possible back off and loss of the stabilizer and bit.

The motor was selected based on its slow RPM, high torque capability and ability to handle the torque originated by having a stabilizer sub above the bit. Baker Hughes Drilling Systems selected an Ultramax motor to be used for this application

3.3 Mud

It was planned that the aerated mud would be used in other sections but this was implemented earlier as a solution due to the lack of water supply described before. Initial foaming of the mud system was achieved with mud detergent (MD). However, improved foaming was obtained when drilling fluid foaming agents were used. PHPA was used for drilled cuttings encapsulation and to provide lubricity for the drilling tools and wellbore. Xanthan gum polymer was used to increase low shear viscosity and gel strengths for hole cleaning and cuttings suspension. Adequate hole cleaning and lubricity were obtained with this drilling fluid system.

Air Drilling Associates installed their equipment (part of which, is shown in the Figure 2 below).

Figure 2: Part of the equipment installed by Air Drilling Associates

They designed an aerated mud specifically for this application and the consumables are listed in the table below.

Table 1: Consumable Items

Consumable Items	Amount Used
Foaming Agent A	18ea-55gal drums
Foaming Agent B	82ea- 5gal buckets
Drilling Detergent (MD)	24ea-5gal Buckets
PHPA liquid	12ea- 5gal Buckets
Xanthan Gum polymer	35ea- 25lb Sacks
Hydrated Lime	10ea- 50lb Sacks

4. SUMMARY OF OPERATIONS

The well was drilled from 110 ft to 140 ft. From 140 ft. to 1000 ft. it was drilled in 7 days. At 717 ft the Bottom Hole Assembly (BHA) was pulled out of the hole (POOH) to pump a water sample as required by regulations. Reaming of that section of the well took 2 days and 1 more day was required to set the casing and cement.

Day 1: Drilled 26” hole from 110 ft with mud motor. At 113ft, loss of water supply, pull up to 60” and the drilled blind to 140 ft. POOH and installed aerated system.

Day 2: Installed aerated mud system

Day 3: Completed air drilling rig up. Made up BHA, drilled 26” hole using motor and aerated fluid from 140 to 234’. Intermittent foam returns (pproximately 100 gpm).

Day 4: Drilled to 290ft with partial returns. Two singles of HWDP (Heavy Weight Drill Pipe) were laid down to pick up three 9” drill collars for additional weight. Continued drilling to 381ft, at 321ft lost total returns Two more HWDP were laid down and more drill collars and Jar were inserted in the drill string. Drilling continued to 400 ft,, still with no returns.

Day 5: Drilled 26” hole with locked up motor BHA, from 400’ to 590’. Three more drill collars are added.

Day 6: Drilled to 600’ with no returns. Reamed tight hole conditions from 600’ to 511’. Drilled 26” hole partial foam returns to 717 ft. using different foaming agents. At this depth there were no returns. The bottom hole assembly was extracted from the well bore to collect water sample.

Day 7: A water sample was taken from 640ft. Continued drilling 26” hole with motor utilizing air and foam from 717 ft. to 766 ft. with partial returns. Back reamed tight hole from 766’ to 726’. Continued drilling to 845 ft. with no returns. Back reamed tight area from 845’ to 813’ without returns.

Day 8: Drilled to 971 ft. without returns and back reamed from 969’ to 930’. After laying down a washed out joint of drill pipe the string packed off and stuck the BHA. The string was jarred down and down and free at 970’ regaining partial foam returns. Drilled to a depth of 1000’ circulated the well and pulled out of hole.

Day 9: Laid down motor and made up reaming assembly. Reamed the hole from 690 ft. to 898 ft. with no returns. Back reamed tight hole to 890 ft..

Day 10: Reamed from 898 ft. to 1000 ft. without returns. Short tripped to 557 ft. Reamed and tripped out of the well to run 22” casing.

Day 11: Ran and cemented 22”casing

Table 2: **Bottom Hole Assembly (BHA) used (from bottom to top)**

ADVANTAGE String Report							
Case PGV 17.5 - Air Drilling							
Operator		**PUNA GEOTHERMAL**			**Field**	**PAHOA HAWAII**	
Well		**KS-14**					
String Components							
Item	#	Component	Gauge OD in	OD in	ID in	Length ft	Total Len ft
	18	Drill pipe		5	3		
	17	HWDP		6 1/4	3 1/4	300.6	720.7
	16	Sub - other		6 1/2	3 3/4	2.5	420.1
	15	Sub - X/O		7 1/2	2 7/8	2.1	417.6
	14	Drill collar		9	2 7/8	91.8	415.5
	13	Jar		7 15/16	2 13/16	32.0	323.7
	12	Drill collar		9	2 7/8	90.7	291.7
	11	Sub - X/O		8 15/16	3 1/8	3.5	201.0
	10	Drill collar		9	2 7/8	59.6	197.5
	9	Drill collar		10	3 1/4	29.4	137.9
	8	Sub - shock		9 1/2	2 7/8	11.9	108.5
	7	Stab - string	25	10.938	3 1/8	5.8	96.6
	6	Drill collar		10	3 1/4	30.0	90.8
	5	Sub - shock		10.166	2 3/4	12.0	60.8
	4	Stab - string	25	10.166	2 3/4	6.2	48.7

	3	Motor		9 3/8	3	35.9	42.6
	2	Stab - string	25 1/2	9 3/4	3 1/16	4.8	6.7
	1	Bit - insert - roller cone	26	26		1.9	1.9
18 String components with a total length of 720.7 ft.							

5. RESULTS AND CONCLUSIONS

a) Drilling Days: By utilizing aerated fluid the well was drilled in fewer days than KS-5. It took a similar time compared to KS-6.

b) Utilization of a down hole motor: As a performance drilling application, the additional RPM and down hole torque of the motor provides energy to efficiently drill the upper shallow portion of the well bore, where there is not enough Drill Collars weight. The average WOB was below 10 klbs and maximum WOB no more than 22 klbs. The stabilized motor also allowed better vertical control, resulting in a better wellbore profile. Baker Hughes high performance motor was able to deliver despite the rough drilling environment.

c) Setting casing: The well was reamed, and the casing was at the targeted depth without problems. It took 13.5 hours to run casing.

d) Use of aerated fluid- The use of aerated fluid is possible in this application. Compared to offsets, the ROP was above average, we pumped less than 300 gpm with some returns to surface compared to 875 gpm and no returns without air. The motor was able to deliver the power required.

e) Quality Chemicals: It is critical to use a good quality foaming agent. Not only do you use fewer products, but get better quality foam. The quality of the foam will determine what size cuttings you can carry. Good foam should be able to carry cuttings immediately after being drilled. Otherwise the bit has to re-drill the material until it is small enough to be carried out. The drilling detergent used on this well worked as supplement until we reached the water table. It is not recommended that it be used again as alternative to foamer. We immediately saw a difference at surface once we switched to the Amber foam. Returns were re-established and the drillstring rotating torque was reduced by better hole cleaning.

f) Hole Cleaning Capacity: After some experimentation, we arrived at the optimum mixture worked adequately for hole cleaning. This information can be used on future wells but will need adjustments based on specific well requirements and the amount of water influx that is encountered.

g) Third Air Compressor: In a regular stiff foam operation, two 1256cfm air compressors would be ample. But since our operations required use of aerated fluid, a third compressor would be beneficial. Originally, we did not plan to use mud motor involved. This changes the volume requirements dramatically. A third air compressor would allow us to increase both air and pump volume; thus improving the efficiency of the mud motor. More air volume will improve our hole cleaning capabilities and may result in less chemical usage as well.

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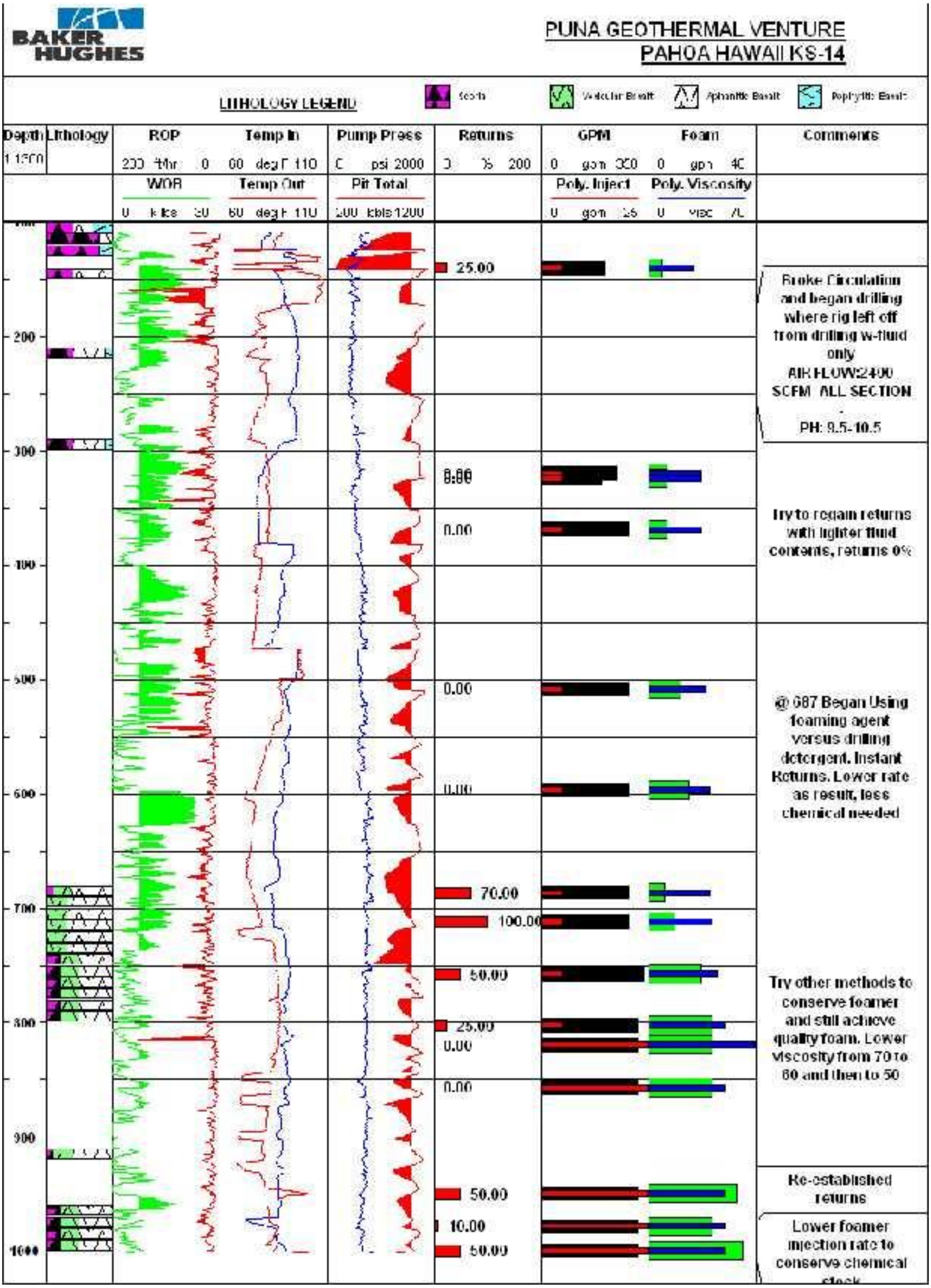
ACKNOWLEDGEMENTS

The authors appreciate PUNA Geothermal Venture, ORMAT Technologies, The Resource Group and Baker Hughes Incorporated for allowing this paper to be presented. The authors would like to thank the drilling staff Tom Atkison, Brian Watson, Mike Barry, Jeff Potter, Alan Bailey, Clarence Reams and Steve Nygaard. The drilling fluids staff Rusty Connell, Revius Green, David Moehlenbrock, and Terry Rowell.


BAKER HUGHES
PUNA GEOTHERMAL VENTURE
PAHOA HAWAII KS-14
LITHOLOGY LEGEND
Scoria
Vesicular Basalt
Aphanitic Basalt
Porphyritic Basalt
Depth
Lithology
ROP
200 ft/hr 0
WOB
Temp In
60 deg F 110
Temp Out
60 deg F 110
Pump Press
0 psi 2000
Pit Total
200 bbls 1200
Returns
0 % 200
GPM
0 gpm 300
Poly. Inject
Foam
0 gph 40
Poly. Viscosity
Comments
200
300
400
500
600
700
800
900
1000
25.00
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0.00
70.00
100.00
50.00
25.00
0.00
0.00
50.00
10.00
50.00
Broke Circulation and began drilling where rig left off from drilling w-fluid only
AIR FLOW:2400 SCFM ALL SECTION
PH: 9.5-10.5
Try to regain returns with lighter fluid contents, returns 0%
@ 687 Began Using foaming agent versus drilling detergent. Instant Returns. Lower rate as result, less chemical needed
Try other methods to conserve foamer and still achieve quality foam. Lower viscosity from 70 to 60 and then to 50
Re-established returns
Lower foamer injection rate to conserve chemical stock