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Successfully Applying Micronized Cellulose to Minimize Lost Circulation on the PUNA Geothermal Venture Wells

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Abstract

The PUNA Geothermal Venture wells are located on the Big Island of Hawaii. The project site is close to the Kilauea Volcano with a high geothermal gradient resulting in static bottom hole temperatures above 600˚F. As with most geothermal projects, lost circulation can be a problem in drilling these wells, as it is costly, resulting in drilling delays, hole instability and stuck pipe. These associated drilling problems can ultimately jeopardize the hole. By controlling mud losses, the amount of time combating lost circulation is reduced, providing a more stable wellbore. Controlling mud losses has also been helpful with logistics since Hawaii is 2,000 miles away from the closest drilling infrastructure.

The drilling, as with most geothermal wells, is conducted with unweighted drilling mud containing few solids to bridge the formation and limit fluid losses. To minimize lost circulation when drilling the intermediate hole intervals, micronized cellulose material is introduced into the mud system, which stops lost circulation and/or reduces mud losses to seepage. This ability to control mud losses in the intermediate sections provides improved wellbore conditions for directional drilling and benefits cementing operations. To minimize losses and protect the reservoir, the production interval is drilled with a high-temperature copolymer drilling fluid conditioned with micronized cellulose. The micronized cellulose material being used is a unique fibrous material that has been developed for controlling seepage and lost circulation while drilling depleted, fractured or other permeable zones.

This paper will discuss the drilling operation, drilling fluid and the application of micronized cellulose on these geothermal wells.

Introduction

The Puna Geothermal Venture (PGV) facility, in operation since 1993, is the first and only commercial scale geothermal plant in Hawaii. It currently produces about 30 MW of power with the reservoir's estimated potential between 500 to 700 MWe. The production wells supply geothermal water to the turbines; then the water is re-injected, resulting in power generation with zero emissions.

PGV is located in the Puna District at Kilauea Volcano's East Rift Zone. Kilauea is an active volcano in the southeastern part of the island of Hawaii. The geothermal gradient on these wells is approximately 7°F per 100 feet; a temperature profile of a typical well is listed in Table 1:

Lost circulation can occur from surface to total depth. Hole stability and hydrogen sulfide are concerns and have been encountered as a result of lost circulation and during work-over operations. Drilling large-diameter holes require good drilling practices to ensure adequate hole cleaning and to avoid lost circulation. Minimizing mud losses and special techniques facilitate high-quality cement jobs. This project requires directional drilling in the intermediate intervals to reach the production targets. Large drilling fluid surface volumes, good drilling practices and mud cooling equipment are required to facilitate an efficient operation.

Well Program

First a 30-inch conductor casing is set at 75 feet. Then 26-inch surface holes are drilled to ±1,000 feet and 22-inch casing is cemented. The formations are fresh basalt with massive lost circulation. In the shallow large diameter sections, hole cleaning is always a concern, therefore, circulation rates while drilling blind, penetration rates and sweep fluid viscosities are important operational parameters. When reaching interval total depth, holes are conditioned as necessary prior to running casing. Sodium silicate pre-flushes are used ahead of the cement to minimize lost circulation during cementing operations. Top outside cement jobs are used to bring the cement to surface in the annulus. After drilling out the casing shoe formation, integrity tests are conducted.

On a recent well, a unique approach was used to drill the surface hole due to severe lost circulation. A mud motor and an aerated mud were used to successfully drill the surface hole on the KS-14 well.

The first intermediate holes are drilled with 20-inch bits to ±2,000 feet and 16-inch casing is run and cemented. Rotary drilling and/or straight hole mud motors have been used to drill this interval. To minimize mud losses and maintain hole conditions, it is necessary to adjust drilling parameters and mud treatments. Reduced penetration rates and lower flow rates in conjunction with pro-active mud treatments have proven to be a successful combination. The hole and mud system are conditioned prior to running and cementing casing. This interval is usually drilled very trouble free and the casing is foam cemented to ensure a good cement job to surface.

The second intermediate intervals are directionally drilled with 14 ¾-inch bits and steerable drilling assemblies. To avoid and/or minimize lost circulation, micronized cellulose is added tourly. The pro-active LCM treatments help to minimize mud losses and improve hole conditions. Reducing mud losses help to minimize differential sticking, which is more of a concern during directional drilling. The improved well bore provided with mud and the use of foam cement result in high-quality cement jobs. Drilling techniques, large surface volumes and mud coolers facilitate circulating temperatures allowing conventional drilling tools to be used. In this interval, 11¾-inch intermediate casing is run and foam cemented to surface. If significant lost circulation has been encountered, the foam cement is reverse circulated to further ensure a good cement job. The use of micronized cellulose in conjunction with the foamed cement has resulted in total success to date circulating cement to surface from depths up to 5,000 feet.

The production interval is drilled with a 10 $^5/_8$-inch hole and total depth is determined by the formation and where the production fracture network is encountered. Some wells are drilled to approximately 6,000 feet while others are drilled to approximately 8,000 feet. The shallower wells are drilled with a low bentonite/polymer drilling fluid. The deeper wells require a high-temperature copolymer system to ensure stable drilling fluid properties are maintained for good hole conditions. Micronized cellulose is incorporated into both shallow and deeper production wells. See Figure 1 for an example of a casing program.

Directional Program

Directional well plans are designed with an objective to deviate the well bore from vertical in the intermediate portion of the well with enough maximum angle to intersect permeable production fractures in the high temperature (HT) reservoir. Typically the directional drilling is performed above the high temperature formations. Conventional steerable down hole motors are used with measurement while drilling (MWD) equipment to carry out the directional drilling process. The bend or offset of the steerable motors are usually set to deliver 2.5˚ degrees per 100 feet of dog leg severity. Limiting dog leg severity avoids excessive torque and drag as well as drill pipe and casing wear.

Typical geothermal wells have a build and hold or (J) profile. The KS 14 well had two bottom hole targets, so a 3D well plan was required to intersect both targets. New wells in this project are drilled vertically to approximately 2000 feet. After drilling out the 16-inch intermediate casing the 14 ¾-inch hole is directionally drilled as per the directional plan. The hole angle is built from vertical to approximately 16 to 20 degrees and steered towards the reservoir targets. Figure 2 provides an example of a directional plan and well path of a 3D well plan of KS 14.

Special temperature handling procedures are necessary when directional drilling operations are conducted in the reservoir section to avoid destroying the MWD and mud motor. The rigs top drive increases the ability to circulate when tripping. Staging in the hole to reduce circulating temperatures helps to minimize tool temperatures. The use of mud coolers while maintaining adequate mud volumes are also important for reducing circulating temperatures. On some of the wells directional drilling has been conducted in the reservoir with static temperatures of 620˚F.

While directional drilling it is helpful to minimize lost circulation for a stable wellbore with good hole conditions. The micronized cellulose has helped to minimize mud losses while conducting the directional drilling operations on this project.

Drilling Fluids

The surface hole is drilled with bentonite (gel) treated with lime to increase viscosity and carrying capacity. If formation stability becomes a concern, the use of a gel/polymer system similar to the mud used in the intermediate intervals is employed. The intermediate holes are drilled with gel/polymer drilling fluids with the components as described in Table 2. Concentrations are varied as dictated by the drilling operation, hole conditions and sometimes logistics. The polymers used provide cutting encapsulation (PHPA), filtration control (PAC), and increased low shear viscosity and weight suspension (xanthan gum). Caustic soda and lime are used for pH control.

The shallow production interval can be drilled with a lightly treated polymer fluid and reduced to polymer/water with sweeps when significant loses are encountered. When the production interval is at greater depths, a high-temperature copolymer drilling fluid is utilized to avoid problems that are associated with unstable drilling fluids on geothermal wells, such as:

- Lost circulation
- Stuck pipe
- Wellbore instability
- Tight hole
- Excessive torque & drag
- Difficulty surveying
- Inability to log
- Excessive pump pressures
- Formation damage

The geothermal copolymer fluid utilizes bentonite that is stabilized with a low molecular weight copolymer. The low molecular weight deflocculant is a sodium salt of sulfonated styrene maleic anhydride copolymer (SSMA). This SSMA has a high-charge density that enables it to remain adsorbed on the clay particles at high temperatures.[6, 7] On some of these wells a derivatized synthetic interpolymer has been used for thermal stability in place of the SSMA. High-temperature, high-pressure (HT/HP) filtration control and supplemental viscosity is obtained with variations of vinyl sulfonated copolymers[8]. Both the SSMA and vinyl sulfonated copolymers are also effective at maintaining properties even when exposed to contamination such as carbon dioxide, brine and cement.[4,5,6] The high-temperature fluid formulation is listed in Table 3.

Hydrogen Sulfide

Hydrogen sulfide can be observed at surface when severe lost circulation occurs during the drilling operation.[7] Sour gas must be abated when re-entering and working over wells, allowing for routine operations. The pH of the drilling fluid in conjunction with basic zinc carbonate is used to eliminate H_2S. Constant monitoring of the location is the standard practice by operator staff, safety personnel, drilling crews and service personnel. The basic zinc carbonate requires suspension so when using water as the drilling/completion fluid, it is viscosified with polymer. Prior to treating a waterbased drilling fluid, it is conditioned with a deflocculant/clay stabilizer to avoid viscosity increases. The basic zinc carbonate reaction and comparison to other alternative chemistries was discussed by Garrett et al. (1979)[8] and Bettge (1975)[9]. The papers point out that the basic carbonate provides a treatment that is non-corrosive and provides a reaction that forms ZnS, which is insoluble in a pH above 3.5.

Note: Basic carbonate is $3Zn(OH)_2 \cdot 2ZnCO_3$ which is not the same as the mineral smithsonite, $ZnCO_3$.

Lost Circulation and Micronized Cellulose

Lost circulation, stuck pipe and inadequate cement jobs are the most common severe problems encountered in drilling and completing geothermal wells. Lost circulation is the single most troublesome and costly problem and can result in stuck pipe and cementing complications. [10] Lost circulation can occur at induced fractures, natural open fractures and/or natural openings with low structural strength[11]. Lost circulation is the partial or total loss of whole mud (not filtrate) to the formation. Experience has shown that lost circulation is one of the top contributors to nonproductive rig time. [11]

Most geothermal drilling operations use unweighted low solids drilling fluids. Maintaining low mud weight and reducing circulation rates are effective practices for minimizing lost circulation in thief zones. It is also important to have solids in the drilling fluid to improve the particle distribution for bridging pore throats and/or fractures. Maintaining a concentration of bridging material in the drilling fluid is limited to the screen size of the shale shaker and solids control equipment. Conversely reducing the screen mesh size (increasing the openings) reduces the shale shakers ability to remove drilled solids so there are trade-offs. On these wells, a concentration of the fibrous micronized cellulose bridging material enhances the drilling fluids capabilities for sealing potential thief zones. Since the fibrous micronized cellulose is maintained in the mud at all times, it is available to mix with the various-sized drilled cuttings whenever losses are encountered and results in an immediate lost circulation treatment.

The particle size of the standard micronized cellulose is such that an effective concentration can be maintained in the entire mud system. A comparison of the particle size distribution of the base fluid and the base fluid treated with 10 ppb of the micronized cellulose can be viewed in Figures 3 and 4.

Note: The laser equipment used to evaluate particle size distribution calculates solids scanned as spheres. The micronized cellulose is a fibrous material; therefore, these results and other PSD results with this type of material will report larger particle size distributions than actually exist. Approximately 55% of the standard micronized cellulose is less than 74 microns, by API sieve analysis.

A high-temperature copolymer fluid was prepared in the laboratory to evaluate the effectiveness of the micronized cellulose-treated mud compared to the base mud. The HT/HP fluid loss results for the base mud compared to the treated mud on a 60-micron disc were 32 vs. 20 ml/30 min (Graph 1). The HT/HP fluid loss results for the base mud compared to the treated mud on a 120-micron disc were 60 vs. 30 ml/30 min (Graph 2). The filtration evaluation was conducted at 300°F, and 500 psi differential pressure. The mud formulation was also hot rolled for 24 hours at 400°F and then an additional 24 hours at 500°F. The test properties before and after aging are located in Table 4. The results indicate that the fluid had some thinning and an increase in fluid loss, but very acceptable for the severity of the test.

The base mud treated with the micronized cellulose fibers can work in conjunction with larger solids such as drilled solids and/or larger lost circulation material. The drilled solids and/or coarse lost circulation material can seal larger fractures. Maintaining a larger concentration of these coarse solids is desirable to seal off larger fractures, but would result in inefficient drilled solids removal.

When drilling the production interval, it is important the drilling fluid either thermally degrades or remains temperature stable so that fluid lost to the reservoir can be produced. To avoid production damage it is desirable on geothermal operations that the lost circulation material temperature degrades so that a temporary seal occurs in the reservoir's fractures and/or pore throats. The micronized cellulose comprises organic fibers that will degrade at the production temperatures of these wells. Cottonseed hulls and sawdust have also been used in conjunction with the micronized cellulose for sealing larger fractures. The effectiveness of cottonseed hulls and sawdust to seal larger fractures was reported by, Thomas et al. (1983). [13] The degradation of cottonseed hulls and sawdust at geothermal temperatures was researched and confirmed by Viv Kandarpa, Otto Vetter and reported to the GRC in 1980.[14]

Minimizing mud and solids invasion into the production reservoir is important. The mud cake and LCM particles normally flow back out of the reservoir when the wells are produced. However, if remediation is required, treating mud cake and LCM material close to the wellbore is preferred as it is best to minimize the depth of invasion. Lower temperature geothermal wells still have application for the micronized cellulose. The micronized cellulose would still be expected to flow back when produced; however, If remediation is required, our lab tests show that micronized cellulose is more responsive to treatment with sodium hypochlorite than acid. After exposure to treatment at 150˚F for 16 hours the micronized cellulose product was over 90% soluble in 12% sodium hypochlorite, but only 40% soluble in 15% hydrochloric acid.

The micronized cellulose is a water-insoluble, sized, complexed cellulosic material used for controlling seepage and loss of circulation while drilling through depleted or underpressured zones. It comes in three particle range classifications that are equivalent to (fine), (standard), and coarse. Figure 5 is a photograph comparison of the standard and coarse samples of the micronized cellulose. Figure 6 displays the fibrous and varied-sized particles of the micronized cellulose as viewed with a scanning electron microscope (SEM) at 200 x magnification with a 200-micron scale.

Bridging

The approximate fracture or pore throats that are being sealed with the micronized cellulose was determined by modeling fracture sealing requirements with a calculator that was developed to optimize bridging. The calculator enables the user to select from one of four rules:

- Abrams 1/3 rule states that 5% of the bridging materials should be greater than the mean pore opening.
- Kaeuffer rule states that to form a perfect seal, the cumulative volume of the bridging material should form a straight line when plotted against the square root of the particle size, where the D-90 of the bridging material is equal to the largest pore opening (D-100).

- Vickers rule[15.]
- Fracture Rule states that D90 of the bridging material should equal the fracture width.

With the determined pore size or fracture width, the model calculates an optimized product mix to be used from either the predefined tables or manually input of the particles size data for specific products.

Foamed Cement

Lost circulation is also more apt to occur during cementing operations. Lost cement returns can produce poor cement jobs, poor zonal isolation, increased casing corrosion and force expensive remedial cementing. Thermally stable mud properties and the micronized cellulose in conjunction with the foamed cement can be effective at obtaining quality cement jobs.

It is important that drilling fluid remains thin during cementing operations to minimize channeling of cement and to maintain low equivalent circulating densities. A mud with stable filtration control provides an annulus more conducive for obtaining a quality cement job. The micronized cellulose improves cake quality as the well is drilled in formations with higher permeability. Because the micronized cellulose is maintained in the drilling fluid, this tough cake is also available to bridge thief zones while the cementing operation is conducted.

Foam cement is a mixture of cement slurry, foaming agents and a gas (nitrogen). Figure 7 displays a foam cement sample viewed with a scanning electron microscope. When properly executed, the process creates extremely stable, lightweight slurry with low permeability and relatively high compressive strength. When foam slurries are properly mixed and sheared, they contain tiny (often microscopic), discrete bubbles that will not coalesce or migrate. The bubbles formed are not interconnected, which results in a low-density cement matrix with low permeability and relatively high strength.

The primary method of cementing the specific geothermal wells earlier has been the use of a lightweight lead cement using high-strength microspheres followed by a standard geothermal tail cement design. On most of the wells, this has produced good results. However, in certain cases, large top jobs have had to be performed resulting in excessive costs in rig time and non-productive time (NPT). A couple attempts have been made using a reverse circulation method to minimize ECD. However, due to the particular method used on these reverse jobs, there was still a high potential for formation breakdown and cement fallback. Several other risks included the possibility of trapping fluid behind casing, poor mud removal, and the inability to accurately predict the location of cement during the job. [16, 17]

Most recently, two foam cement jobs were performed on the well KS-14. Both jobs were highly successful and allowed the placement of 16-inch casing and 11 3/4-inch casing at depths of 2,201 feet and 4,878 feet respectively, and successfully bringing cement to surface. The casing setting depths on both of these casing sizes placed the casings within solid bedrock, potentially allowing better zonal isolation, and also improving the ability to perform more accurate leak-off and injection tests.

By using foam cement on this well, a lower cement density was achieved and was varied throughout the wellbore using just one base cement design. This lowered both the ECD during cement placement and the final hydrostatic pressures at the end of the job. By reducing the pressure exerted on the formation, not only was it possible to bring cement back to surface, but volume loss was minimized and smaller job excesses were needed than with conventional methods. In addition, the amount of cement fallback was minimized on 16-inch casing job, and completely eliminated on 11-inch casing. Despite the added benefits and success of these two jobs, the actual cost per barrel of foamed lead cement was less expensive than using a conventional high-strength microspheres lead cement design. Additional savings were also realized by reducing the size of, or eliminating the need for, a top job.

Conclusion

1. Micronized cellulose helps to reduce mud losses.
2. A concentration of micronized cellulose can be maintained in the mud system; therefore, improving the fluids particle size distribution for bridging potential thief zones.
3. Maintaining circulation is important for safe and efficient directional drilling operations. Directional drilling tools function properly while maintaining a concentration of micronized cellulose in the drilling fluid.
4. Basic zinc carbonate is an effective method for controlling hydrogen sulfide during drilling and workover operations.
5. Thermally stable mud properties and micronized cellulose benefit the drilling and cementing operations on geothermal wells.
6. Foam cement is effective at obtaining high quality cement jobs on geothermal operations. Foam cement helps to minimize lost circulation in formations that have severe loss of returns when conventional cement is used.
7. Laboratory testing and modeling assist in evaluating fluid bridging characteristics.
8. Micronized cellulose has been used in the production interval without impairing production.

Reference

1. Chesser, Bill G., Enright, Dorothy P.," High Temperature Stabilization of Drilling Fluid with a Low Molecular Weight Copolymer", SPE 8224, 1979

2. Darley; H.C.H., Gray, George R., "Composition and Properties of Drilling and Completion Fluids", Fifth edition, Gulf Publishing Company, February 1991, page 467-468

3. Perricone, A.C., Enright, D.P., Lucas. J.M.," Vinyl-Sulfonate Copolymers for High Temperature Filtration Control of Water-Base Muds", SPE/IADC, 1985

4. Connors, James H., II, Otto, Michael J.,"A New and Different Geothermal Drilling Fluid System", Geothermal Resources Council, Transactions Vol. 4, September 1980

5. Zilch, H.E. Zilch, Otto, M.J., Pye, D.S., "The Evolution of Geothermal Drilling Fluids in the Imperial Valley", SPE 21786, 1991

6. Darley; H.C.H., Gray, George R., “Composition and Properties of Drilling and Completion Fluids”, Fifth edition, Gulf Publishing Company, February 1991, page 467 – 468

7. Rickard, Bill, Livesay, B.J., Teplow, Bill, Winters, Steve, Evanoff, Jerry, and Howard, W.T., “ Control of Well KS-8 in the Kilauea Lower East Rift Zone, World Geothermal Conference, 1995, Florence, Italy.

8. Garrett, R.L., Clark, R.K., Carney, L.L., Grantham, C.K., “Chemical Scavengers for Sulfides in Water-Base Drilling Fluids”, Journal of Petroleum Technology, June 1979

9. Bettge, G.W., “Zinc Carbonate can control H_2S in drilling mud”, Oil and Gas Journal, August 18, 1975

10. SAND85-0109; Caskey, Bill C., “Lost Circulation Technology Workshop” Sandia National Laboratories Report, March 01, 1985

11. Baker Hughes / ARCO, “Prevention and Control of Lost Circulation”, Best Practices Reference Manual, 750-500-104 Rev B, February 1999

12. Darley; H.C.H., Gray, George R., “Composition and Properties of Drilling and Completion Fluids”, Fifth edition, Gulf Publishing Company, February 1991, pages 434 – 446

13. Hinkebein, Thomas E., Behr, Vance L., Wilde, Steve L. “Static Slot Testing of Conventional Lost Circulation Materials”, Sandia National Laboratories, January 1983

14. Kandarpa, Viv, Vetter, O.J., ”Degradation Characteristics of Cotton Seed Hulls and Sawdust in High Temperature Geothermal Brines”, Geothermal Resources Council, Transactions Vol. 4, September 1980

15. Vickers, S., Cowie, M., Jones, T. and Twynam, A. “A New Methodology that Surpasses Current Bridging Theories to Efficiently Seal a Varied Pore Throat Distribution as Found in Natural Reservoir Formations,” AADE-06-DF-HO-16, AADE Fluids Conference, Houston, Texas, April 11-12, 2006.

16. Rickard, Bill, “Application of Foamed Cement on Hawaiian Geothermal Well”, Geothermal Resources Council Transactions, Vol. 24, September 24-27, 2000.

17. Niggemann, Kim, , Samuel, Abraham, Morriss, Alexander V., “Foam Cementing Geothermal 13 3/8” Intermediate Casing NGP#61-22, Geothermal Resources Council 2009, Oct 4-7, 2009, Reno, Nevada, USA and WGC 2010, April 25-30, 2010, Bali, Indonesia

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Table 1

Depth Feet	Static Temperature Deg F
2,400	200
3,000	350
4,000	550
4,600	600
5,000	620

Table 2

Product	Description	Function	Concentration (PPB)
Gel	Bentonite	Viscosity and fluid loss control	10 to 20 ppb
PHPA	Partially hydrolyzed polyacrylamide	Cuttings encapsulation and lubricity	0.1 to 0.5
PAC	Polyanionic cellulose	Filtration control	
Xanthan Gum	Biopolymer for low shear viscosity	Viscosity and solids suspension	0.15 to 1.0
Polymer Thinner		Thinner	.1 to 0.5

Table 3

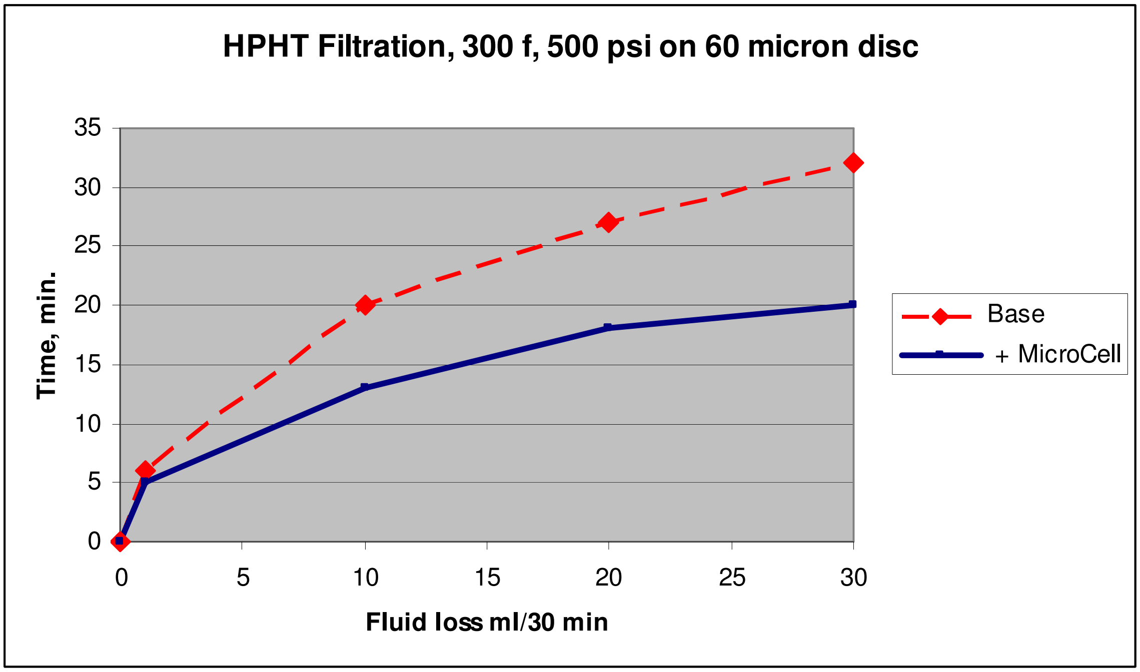
Product	Description	Function	Concentration (PPB)
Gel	Bentonite	Viscosity and fluid loss	10 to 20 ppb
HT Polymer Deflocculant – Bentonite Stabilizer	Sodium salt of sulfonated styrene maleic anhydride copolymer (SSMA) or a derivatized synthetic interpolymer	Deflocculation, high temperature stabilization and contamination resistance	0.2 to 0.5
HT Copolymers	Vinyl sulfonated copolymer	HT Filtration Control and Viscosity	0.25 to 2.0
HT Lignite	HT Lignite copolymer blend	HT Filtration Control	0.5 to 3.0

Table 4

Properties	Initial	Aged
Hot Roll Age Temperature	NA	400 / 500
Hours Aged	NA	24 / 24
Rheological prop test temp, deg F	120	120
Plastic Viscosity, cp	35	31
Yield Point, lb/100 ft^2	22	15
Gel Strength 10 sec., lb/100 ft^2	7	3
Gel Strength 10 sec., lb/100 ft^2	12	9
pH	10.8	8.2 to10.5*
API Filtrate, 30 ml/30 min.	4.4	7.0
HPHT Filtrate, ml/30 min	24.0	32

* pH adjusted from 8.2 to 10.5 with 0.25 ppb NaOH after aging

Graph 1



Graph 2

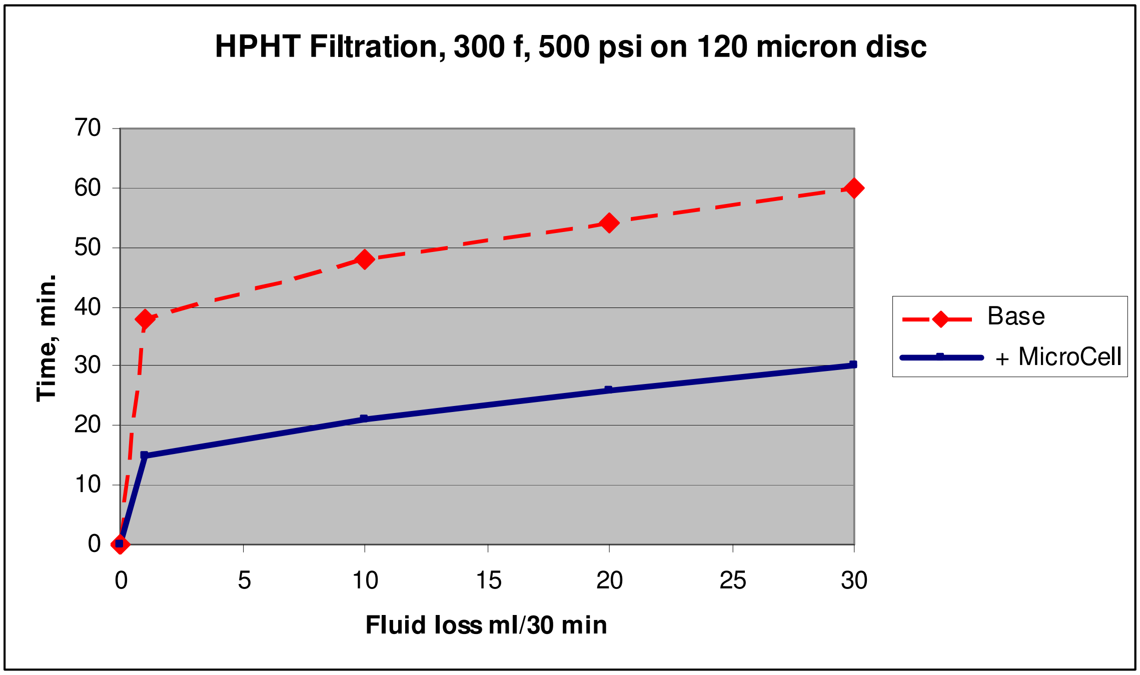

HPHT Filtration, 300 f, 500 psi on 120 micron disc
Time, min.
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Fluid loss ml/30 min
Base
+ MicroCell

Figure 1

Casing Program

Puna Geothermal Venture

Production Well Kapoho State 14

Drawn by S. Abraham, GRGI 6/26/2010 – Not To Scale

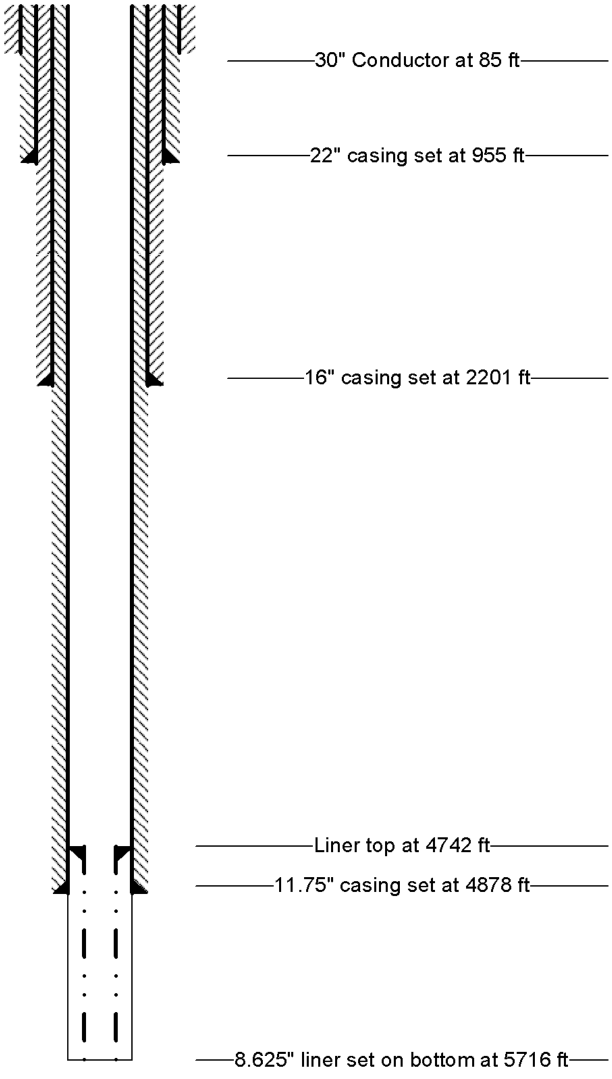
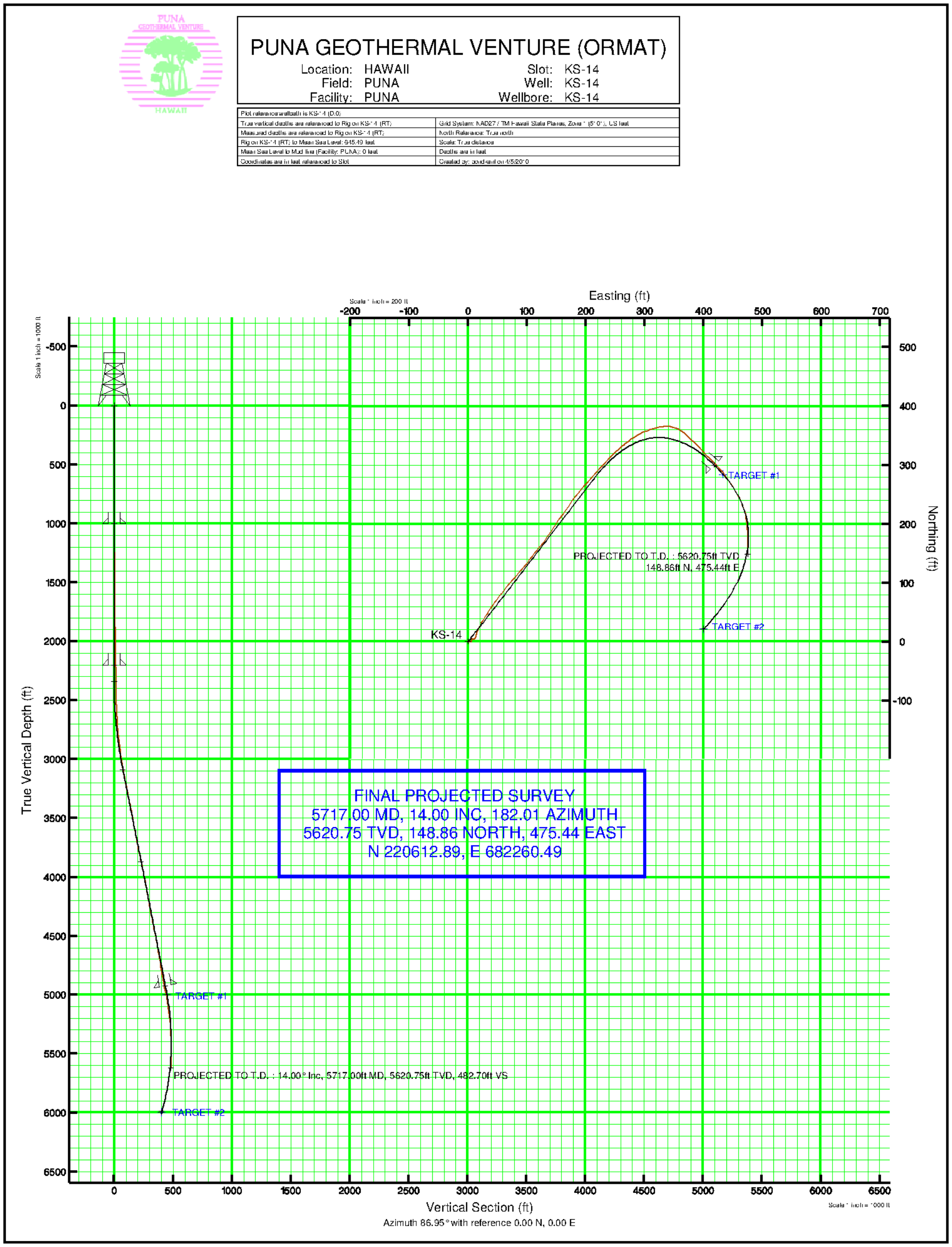


Figure 2

Directional Plan



PUNA GEOTHERMAL VENTURE (ORMAT)

Location:	HAWAII	Slot:	KS-14
Field:	PUNA	Well:	KS-14
Facility:	PUNA	Wellbore:	KS-14

Plot reference wellpath is KS-14 (D.0)	
True vertical depths are referenced to Rig on KS-14 (RT)	Grid System: NAD27 / TM Hawaii State Planes, Zone 1 (5101), US feet
Measured depths are referenced to Rig on KS-14 (RT)	North Reference: True north
Rig on KS-14 (RT) to Mean Sea Level: 645.49 feet	Scale: True distance
Mean Sea Level to Mud line (Facility: PUNA): 0 feet	Depths are in feet
Coordinates are in feet referenced to Slot	Created by: bondkent on 4/5/2010

FINAL PROJECTED SURVEY
5717.00 MD, 14.00 INC, 182.01 AZIMUTH
5620.75 TVD, 148.86 NORTH, 475.44 EAST
N 220612.89, E 682260.49

Figure 3

Results of a Particle Size Distribution (PSD) analysis performed on the geothermal drilling fluid.

Concentration:	**Span :**	**Uniformity:**	**Result units:**
0.0049 %Vol	7.756	2.58	Volume
Specific Surface Area:	**Surface Weighted Mean D[3,2]:**	**Vol. Weighted Mean D[4,3]:**	
1.71 m²/g	3.515 um	16.608 um	

d(0.1): 1.451 um **d(0.5): 5.405 um** **d(0.9): 43.374**

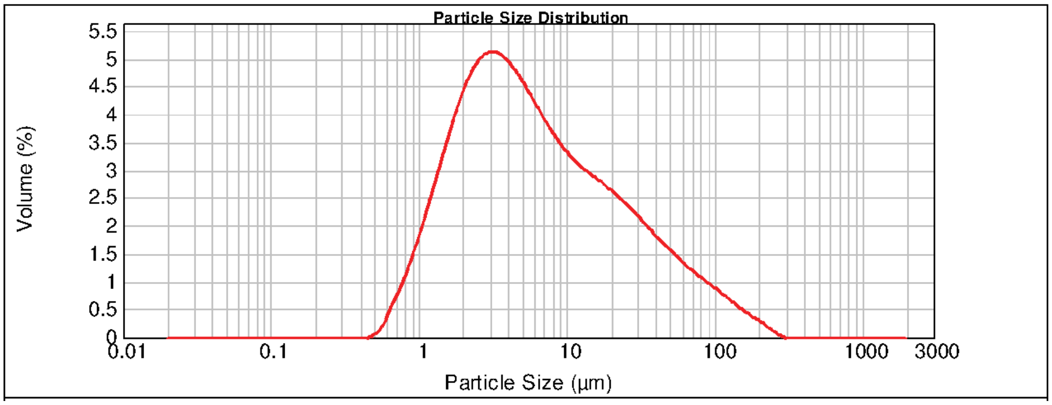


Figure 4

Results of a Particle Size Distribution (PSD) analysis performed on the geothermal drilling fluid after treatment with micronized cellulose.

d(0.1): 2.407 um **d(0.5): 54.407 um** **d(0.9): 219.190 um**

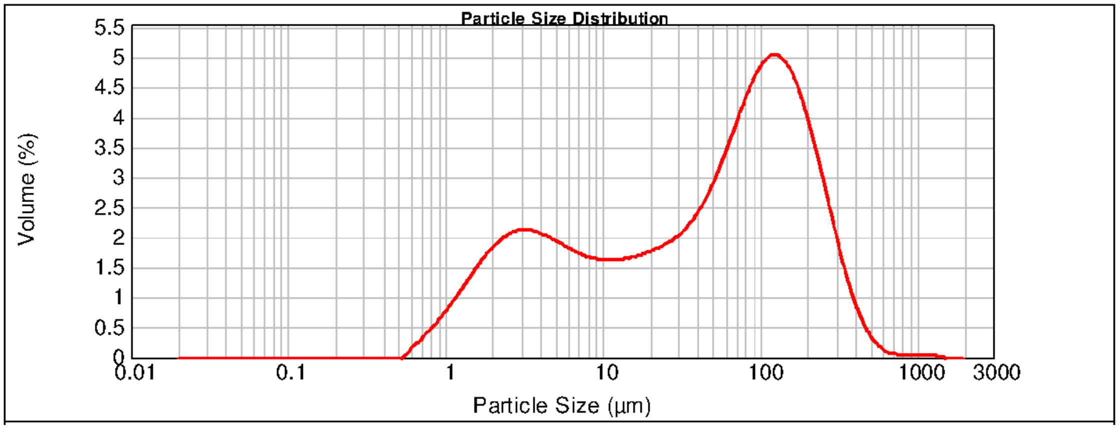


Figure 5

Photograph of two particle ranges of the Micronized Cellulose
Photograph from service company

Figure 6
SEM photograph of Micronized cellulose fibers at 200 X
Photograph provided by service company

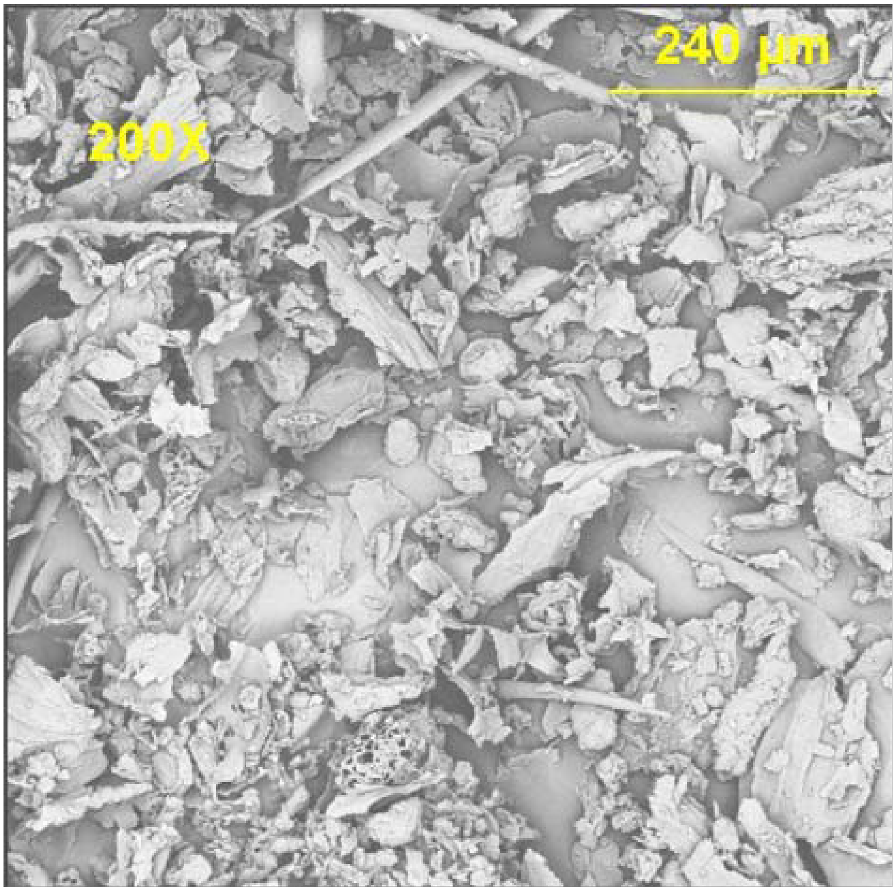


Figure 7

Foam cement viewed with a scanning electron microscope.