Reverse Foam Latex Cementing 11-¾ Inch Intermediate Casing in PGV Well KS-15

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Abstract

Many challenges arise when cementing geothermal wells. Lost circulation and temperature are the main culprits for increased cost when trying to achieve zonal isolation. At the Puna geothermal field, extreme lost circulation and bottom hole static temperatures in excess of 500°F are not uncommon. The extreme conditions, coupled with the remoteness to drilling service providers, represent a significant challenge. Reverse cementing was used to successfully complete a job in a challenging environment and also significantly reduce cost in the cementing phase of well completion. A demonstration of proper planning, designing, and execution of the job is presented.

Introduction

Hawaii is an excellent candidate for geothermal power, and active volcanism provides key indicators for a successful project. The Puna Geothermal Venture (PGV) project site is located within the Lower East Rift zone of the Kilauea volcano, which is a highly linear feature about 2 miles wide, has many surface features and vents. Geothermal power plants in specific areas can economically fill the power consumption gap. The PGV geothermal facility, located approximately 21 miles southeast of the city of Hilo, Hawaii, comprises two power plants, a binary and combined cycle system (flash and binary). The output capacity of the plants is ~38 MW_e. PGV operates the only geothermal plants on the Hawaiian Islands. There have been approximately 15 wells drilled in the project area, drilling in Hawaii has been challenging in the past and common problems of lost circulation, extremely hot formation temperatures, drill pipe sticking, and a lack of local drilling services and infrastructure make proper planning essential.

Reverse Cementing

Reverse cementing practices involve, as the name implies, pumping cement initially through the casing annulus instead of through the drill string. A key difference in the casing string assembly for reverse cement jobs is the absence of float collars and float shoes. However, certain float collars can be used through an inner-string method in combination with a sliding valve float collar. Float equipment is used to keep cement slurry in the annulus until the cement hydrates and sets. Without a check valve in place, the hydrostatic pressure difference occurring at the end of a cement job will equalize, resulting in what is called the U-tube effect, allowing cement in the casing annulus to migrate upward in the annulus. Therefore, for reverse cementing jobs, a valve is located on the top of the casing string and is closed at the end of the job to prevent U-tubing.

Reverse cement jobs are commonly used when wells are drilled in weak formations where lost circulation occurs. Advantages of reverse cementing include lower job equivalent circulating density (ECD), less slurry exposure time to formation temperatures (less retarder needed), assurance of continuous cement in the annulus, no need for tremie pipe if top jobs are required, and more excess can be run without having to handle excessive cement returns at surface. Drawbacks that need to be considered are the possibility of channeling due to poor mud removal and increased drill-out time due to more cement inside the casing then planned.

Designing a reverse cement job can be challenging and significant preplanning is needed to ensure a successful job is achieved. Ensuring that the job is properly designed can alleviate most reverse cementing drawbacks. Computer simulations are used to determine when cement is at, or near, the shoe. In some past reverse cementing jobs, radioactive tracers have been used in the spacer systems to determine when to shut the casing valve, ensuring cement placement at the casing shoe. This can be very costly because a logging tool has to be present at the desired depth to detect the radiation. Advances in cementing simulation software have eliminated the need to use a radioactive tracer, in most cases. The 11-¾ inch KS-15 reverse cementing job did not require the use of radioactive tracers, and an inner-string method was used to achieve the desired results. There is a gas-rich corrosive interval in the well bore from 1800 feet to 2400 feet; the gases are mainly carbon dioxide and hydrogen sulfide. The presence of these gases leads to a high probability of an acid attack on the cement in place. Latex cement impedes the rate of degradation when compared to conventional geothermal cement slurries.

Well Profile

Well KS-15 was drilled to a depth of 4709 feet with a 14-¾ inch bit (Figure 1). While drilling the 14-¾ inch hole, multiple lost circulations zones were encountered. The degrees of severity of the losses ranged from total to partial losses. Prior to cementing, full circulation was established through the use of lost circulation material.

Cement Details

Cement	Quantity*	Density	Yield	Water Req.
Lead	896 sacks	13.8 lb/gal	2.03 ft^3/sack	8.03 gal/sack
Latex	205 sacks	13.5 lb/gal	2.19 ft^3/sack	7.34 gal/sack
Tail	150 sacks	15.0 lb/gal	1.79 ft^3/sack	6.10 gal/sack
Cap	50 sacks	13.5 lb/gal	2.30 ft^3/sack	9.69 gal/sack

* 100% excess

Job Objectives

- Cement 11-¾ inch casing in 14-¾ inch open hole
- Circulate foam cement to surface with desired density of 11 lb/gal
- Spot latex cement in interval of 1800-2400 feet (suspected corrosive interval)
- Minimize losses during the cement job
- Eliminate the need for top job
- Effectively clean hole
- Preform efficiently to reduce cost and delays

- Control foamed returns

Job Design

Based on the case histories of surrounding wells and the losses experienced while drilling KS-15, a reverse-style cement job was an ideal choice for the 11-¾ inch casing string. An inner-string method was used and the overall goal was to cement reverse, knowing that we would be taking the entire excess volume of cement to the pit. By using an inner-string method, we were able to determine the height of cement inside the casing after job completion. This was achieved by pumping tail cement, a plug with a snap ring (shut-off plug), then displacing conventionally after the foam cement was pumped reverse. Knowing where the top of cement is inside the casing is a huge advantage when planning to drill out and start the next phase of drilling.

After drilling out of the 16 inch casing, a leak-off test at the shoe determined a 12.3 lb/gal equivalent mud weight. The shoe test confirmed that lightweight cement would be required. For geothermal wells there are two options for lightweight cements: high-strength microsphere (HSM) slurry, or foam cement slurry. Foam cement was the option chosen for a variety of reasons. Foam cement has a more favorable Young's modulus. The expansive nature and viscosity of foam cement are also extremely beneficial characteristics for this particular scenario. Using a local supply of nitrogen in Hawaii for foam cementing was more cost-effective than the high shipping charges required for HSM. For this particular job, nitrogen tube trailers were used as a nitrogen supply. The limiting factors of a tube trailer are pressure and volume. Nitrogen pumping begins with a fixed volume; the maximum possible injection pressure decreases as the nitrogen is consumed. This characteristic limits the usable volume of nitrogen to about half of the initial bulk truck volume. This is important because the nitrogen storage pressure must be ~800-1000 psi higher than the pumping pressure. A greater pressure difference creates more homogenous foam cement. Figure 2 show the difference in circulating pressure of a reverse and conventional cementing scenario. By doing a reverse job, the circulating pressure in this particular situation is reduced by ~640 psi. The maximum ECD for the reverse job was simulated at 11.3 lb/gal at 4700 feet. A simulation of the same cement products applied conventionally showed an ECD as high as 13.8 lb/gal. The simulations suggest that even with cement designed with a density lower than the shoe test density, a conventionally pumped job would result in lost circulation. The calculated pump pressure was also simulated at an average of 600 psi less in the reverse scenario, making the use of a nitrogen bulk truck feasible. The cost of using a nitrogen pump is at least three times higher than using a tube trailer.

The cement design consisted of two blends, a lead and a tail, both of which had 40% silica flour and micro-silica to protect against strength retrogression. Various other additives were used in the cement to ensure zero free water and adequate fluid loss control, while maintaining mixability. The designed densities were 13.8 lb/gal for the lead and 15 lb/gal for the tail. The lead slurry was designed to work as latex cement with the addition of liquid additives. A big challenge in designing the lead cement was ensuring that the latex version could be foamed without experiencing nitrogen breakout. The in-place foam density was designed to be 11 lb/gal, or ~23-25% foam quality. The excess cement was designed at 9.5 lb/gal, or ~38% foam quality. The thought process behind having the excess foam cement at a reduced density was that, in the event of lost circulation during the job, high quality foam cement will expand further into the voids. Also, the initial ECD and circulating pressure would be reduced, increasing the likelihood of a successful job. Foamed water at 4 lb/gal and foamed sodium silicate at 7 lb/gal was designed to be pumped as a spacer to ensure effective hole cleaning and minimize lost circulation. Foamed spacers have increased viscosity for better mud removal and decreased hydrostatic profiles. The cap cement was an accelerated version of the lead cement.

Job Summary

The job design and procedures were reviewed a few days prior to the job with the cementing and drilling engineers. At the KS-15 well site, a safety meeting was first conducted and then equipment was spotted and rigged up as shown in Figure 3. The extensive number of pipelines and valves were necessary to switch back and forth from a reverse- to conventional-type cement job. A detailed written procedure was distributed to personnel running the valves and all the valves were labeled in accordance with the design prior to the job. After the cementing equipment was rigged up, the rig reverse-circulated through the lines while a safety meeting was held. All the cement and nitrogen lines were tested to 2500 psi. Figure 4 shows the data acquisition chart for the job.

The rig then stopped circulating and the job was immediately started with a 40 bbl water spacer, foaming all but the first 5 bbls. Subsequently, 15 bbls of sodium silicate were foamed, followed by an additional 10 bbl of foamed water. Nitrogen was injected into the sodium silicate without the foaming agent due to a compatibility issue (the result was still a stable foamed product). After all the spacers were pumped, the automated foam controller system was activated for 75 bbls (unfoamed volume) of lead cement. This first cement was the designed excess and was foamed to a density of 9.5 lb/gal. The next fluid pumped was 153 bbls (unfoamed volume) lead cement foamed to a density of 11 lb/gal. This was followed by 80 bbls (unfoamed volume) latex lead, which only required the pump truck operator to switch his water supply and change the density to 13.5 lb/gal (all the liquid chemicals were pre-measured and mixed in a separate tank). The next step was to pump the remaining 97 bbls (unfoamed volume) of lead, which was foamed to 11 lb/gal. After all the lead cement was pumped, a shutdown was necessary to swap all the valves to pump the tail cement down the drill pipe conventionally. Then, 43 bbls of tail cement was pumped and a shut off plug was dropped. The drill pipe was displaced with water and the plug landed. While displacing, the returns were choked to establish a back pressure of ~150 psi as per the foam cementing design. After landing the plug, everything was shut in and the valves were switched to pump the cap cement down the annulus. At this point, the connection next to the annulus valve was disconnected and cement was pumped slowly until the line was entirely full of cement (ensuring no water would be trapped between casings). The line was then reconnected and 17 bbls of cap cement was pumped. After the cap cement was in place, the well was shut in to wait on cement hydration. At this point, another safety meeting was conducted and the cementing equipment was rigged down, except for pressure monitoring devices.

Post-Job Analysis

Foamed cement was observed at surface 48 bbls into the latex lead stage, indicating less than 10% washout in the open-hole section. Circulation was maintained during the entire job. Returns to the surface were treated by injecting defoamer directly into the return line before discharge into the sump. Defoaming the returns was a crucial step to keep the sump from overflowing in this environmentally sensitive area. While pumping the cap cement, the ending pressure from compressing the foam cement was 521 psi. The pressure eventually decreased to 305 psi over the course of 12 hours. After 12 hours, the pressure was manually bled off and cement was observed at surface. There was no need for a top job, which would have resulted in at least a 7-hour delay (3 hours to mix and get cement to location, and 4 hours to wait on set time). The job was executed as designed and the results mimicked the simulations.

Conclusion

Through the technique of reverse cementing, the 11-¾ in casing string in PGV Well KS-15 was successfully cemented in a cost effective and time-saving manner. All of the objectives of the job were achieved. Proper design and preplanning allowed for no losses in circulation during the job and eliminated the need for a top job. Furthermore, reverse cementing allowed the option of using nitrogen tanks as oppose to a liquid nitrogen pump truck (greatly reducing the cost of the job). In remote settings, the importance of avoiding non-productive time (NPT) is increased and, through the use of the foamed reverse cementing method, zero NPT was recorded for this aspect of the drilling operation.

References

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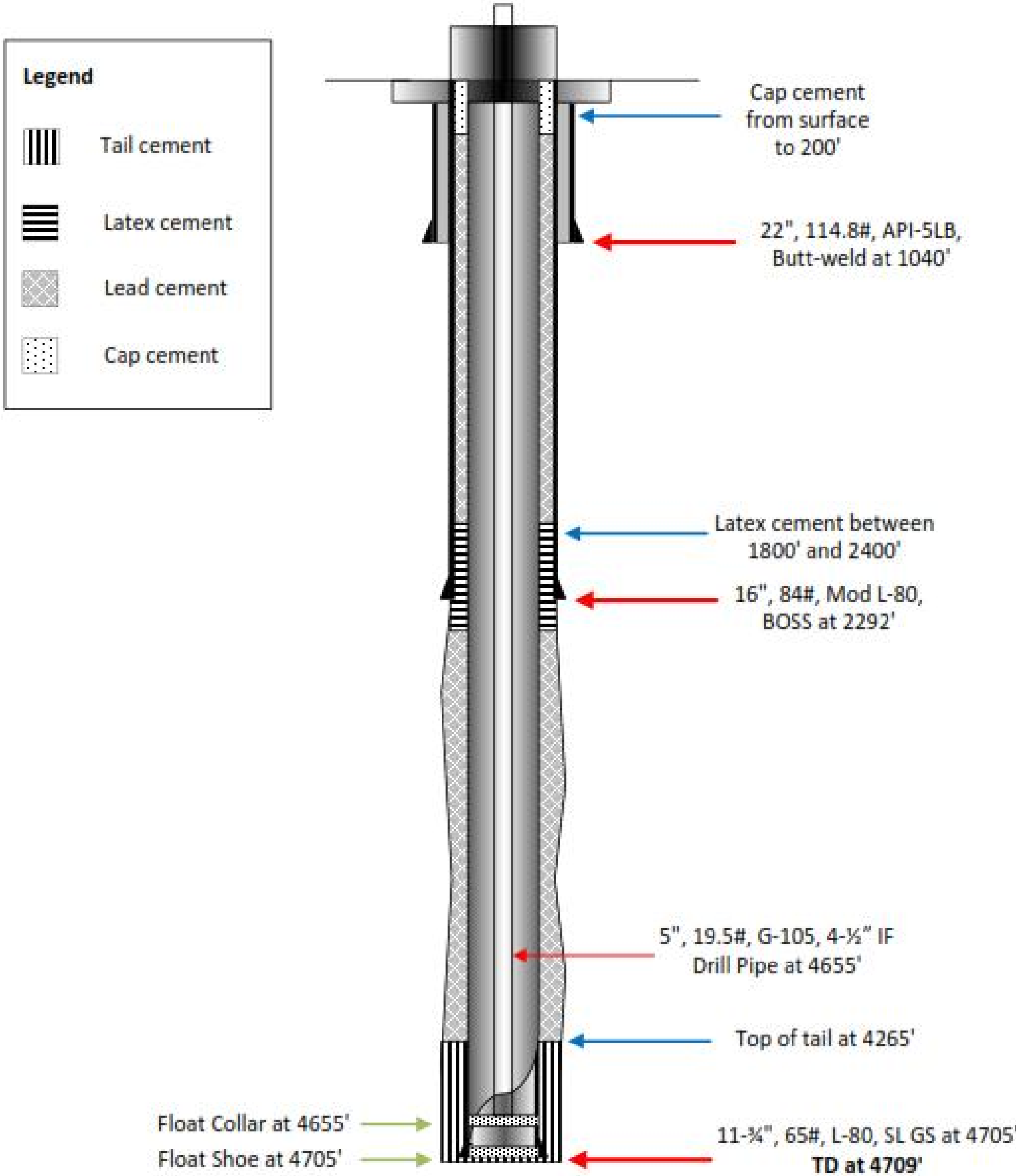

Figure 1 – KS-15 Reverse Foam Cementing Configuration

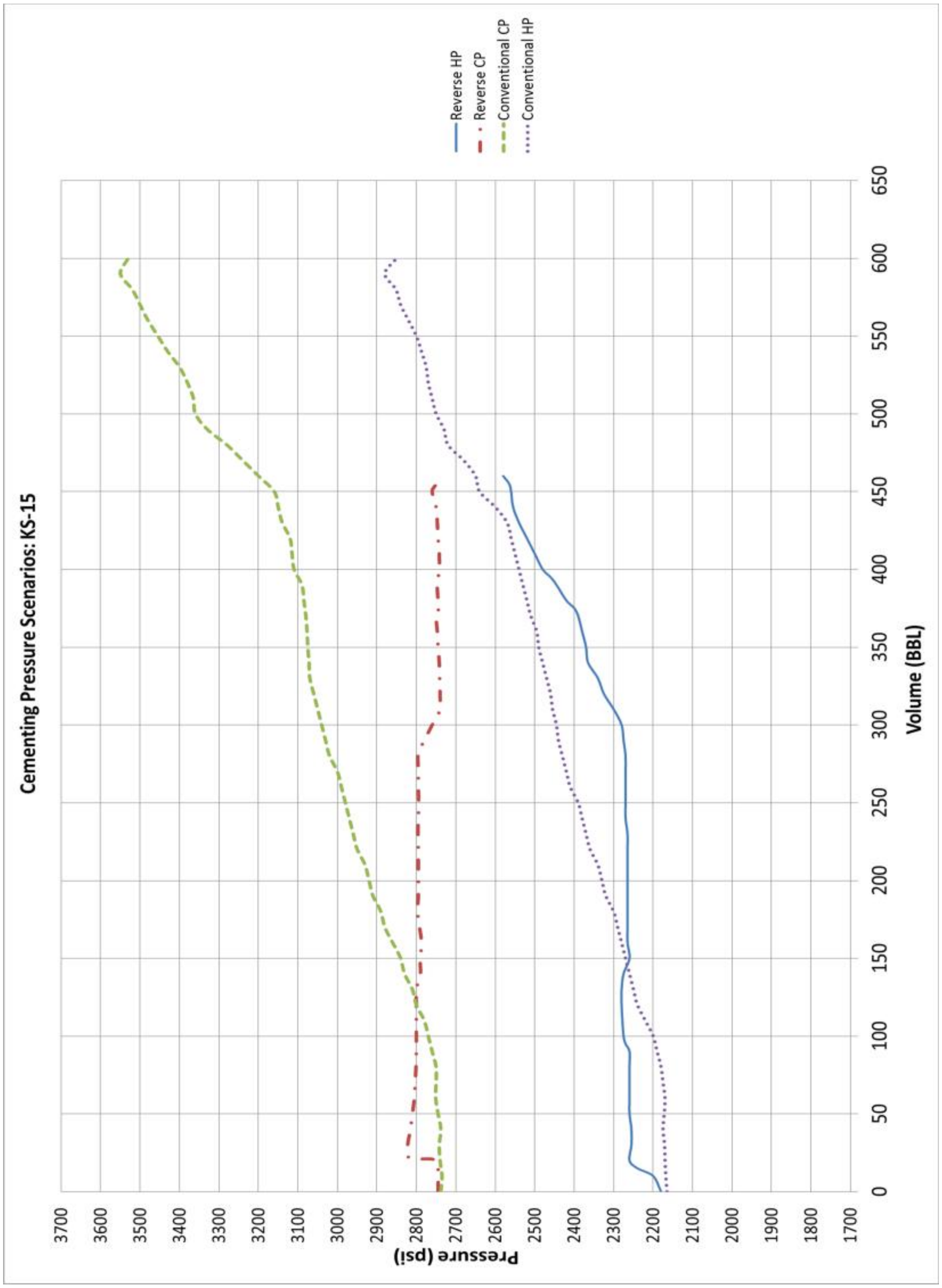

Figure 2 – Hydrostatic and Circulating Pressure Simulations - All Scenarios

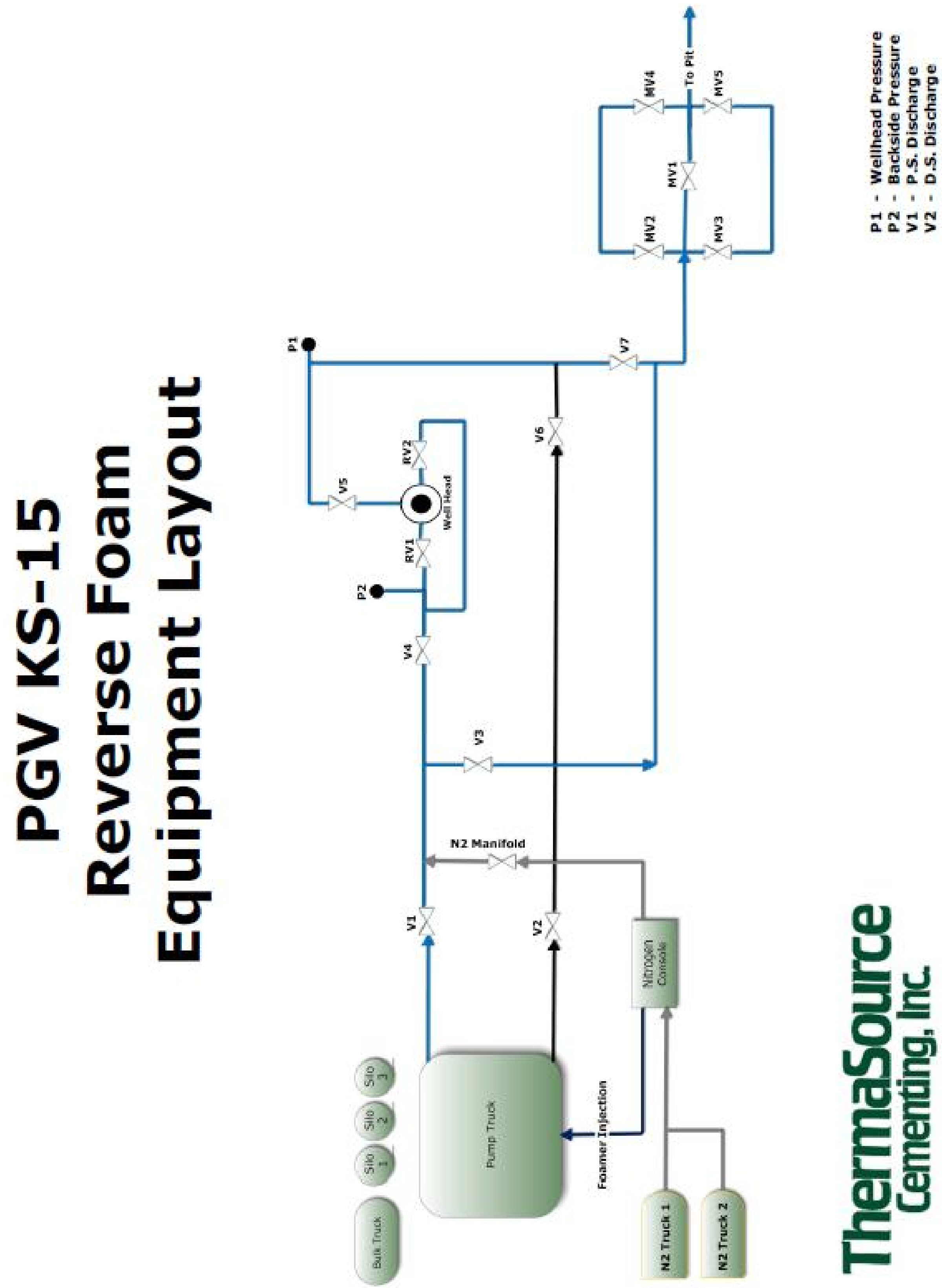

Figure 3 – Job Equipment Layout

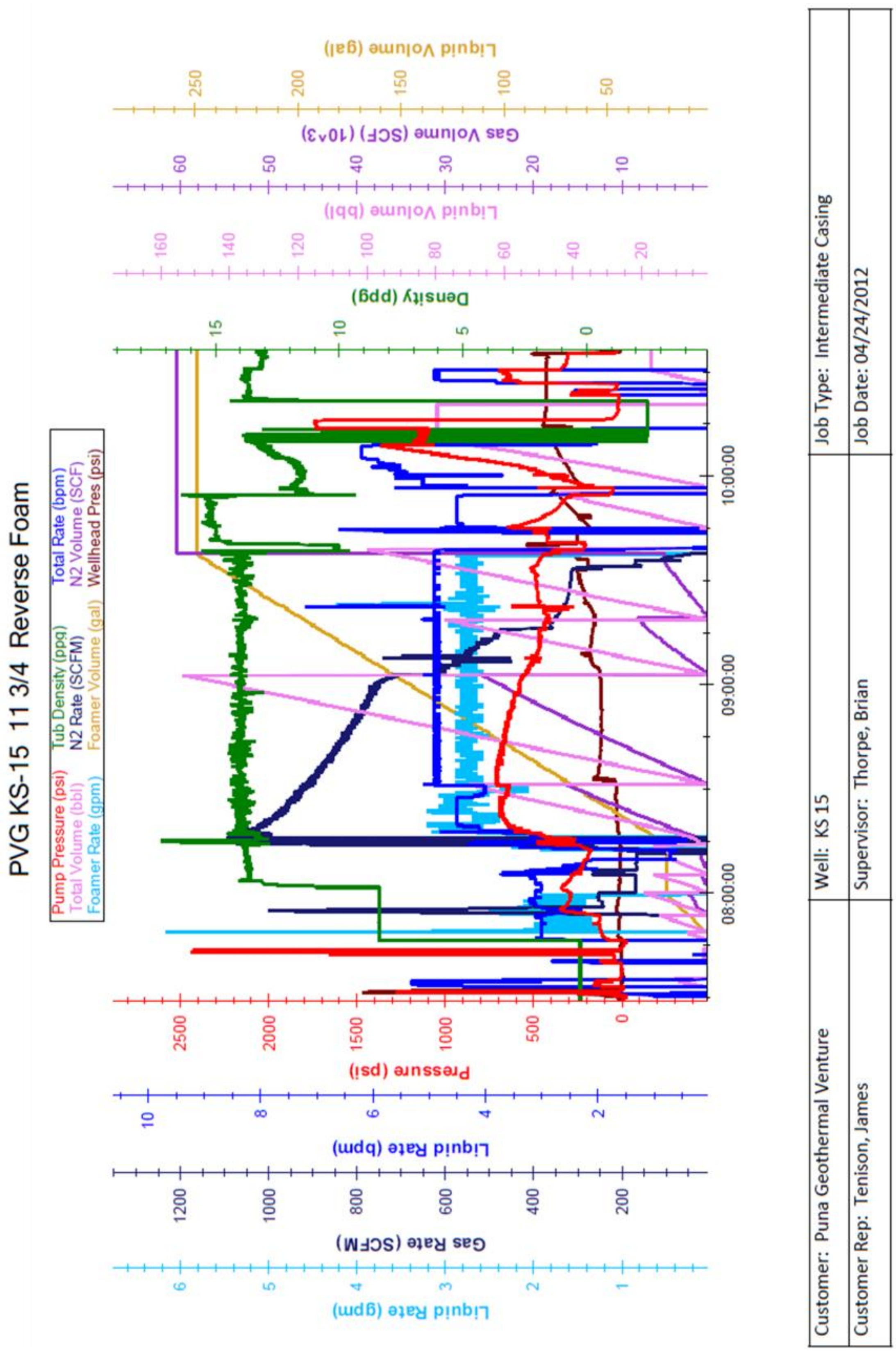

Figure 4 – Job Data