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Geothermal Aerated Fluids Drilling Operations in Asia Pacific

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ABSTRACT

Aerated fluids drilling is a widely accepted technique for drilling geothermal wells for a variety of reasons, which include but are not limited to minimization of circulation losses, increase in penetration rate, material savings, elimination of differential sticking, lesser water requirements, the ability to discharge during drilling, and the prevention of formation damage. The technique, which involves the application of air, mist, aerated liquid or foam fluid systems to lower the density of the drilling fluid and is mainly intended at reducing costs by drilling faster, has been proven to produce positive results in geothermal applications all over the world. As this paper shows, the same can be said for geothermal aerated fluids drilling operations in the Asia Pacific region. It provides an assessment of aerated fluids drilling projects performed in geothermal fields in the Asia Pacific region, as well as a comparative look at the equipment, technique, procedures and engineering involved in the same. Lessons learned and recommendations for the improvement of geothermal aerated fluids drilling operations are also included.

1. INTRODUCTION

Aerated fluids drilling, as defined by Weatherford (2006), is the application of air, mist, aerated liquid or foam drilling fluid systems with the end view of reducing costs by drilling faster. The key to success for this method is excellence in engineering and service delivery. **Figure 1** provides this definition in graphical format and **Figure 2** shows the four types of drilling fluid systems commonly used for aerated fluids drilling.

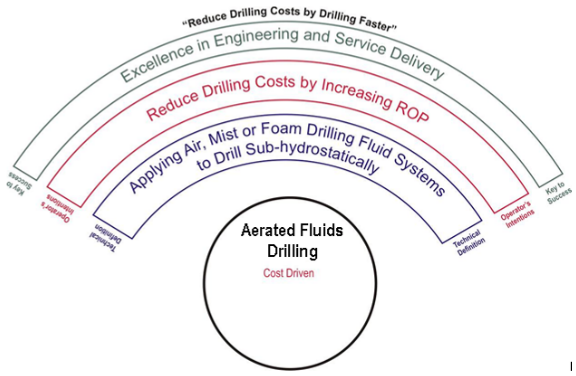

Figure 1: Definition of aerated fluids drilling

According to Russel (1987), "the use of aerated fluids as the drilling medium for geothermal wells is one of the more successful techniques for overcoming drilling problems and improving production" and its principal objective is to lower the density of the drilling fluid in order to reduce pressures in the annulus during drilling so that they "balance" formation pressures at potential loss zones.

The use of aerated fluids drilling in geothermal wells eliminates various drilling problems and improves well productivity. Some of the advantages that the technique provides are as follows: (1) minimization of circulation losses; (2) increase in penetration rate; (3) material savings; (4) elimination of differential sticking; (5) lesser water requirements; (6) the ability to discharge during drilling; and (7) the prevention of formation damage (Russel, 1987; Rehm, 2002; UNU-GTP, 1992; Rizo and Cuenca 1984).

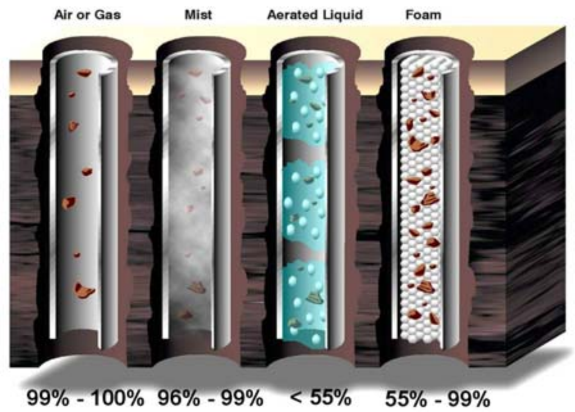

Figure 2: Four (4) different types of aerated drilling fluid systems and the percentage of air involved

Like any other drilling technique, geothermal aerated fluids drilling also has disadvantages, among which are the following: (1) higher cost for equipment and fuel costs for driving compressors; (2) noise of compressors and blooie line exhaust; (3) hot water disposal at the surface; (4) flashing; (5) corrosion; and (6) increased operational complexity. However, if aerated fluids drilling operations are planned and engineered properly, these disadvantages can easily be outweighed by the advantages that the technique brings to geothermal drilling operations.

2. GEOTHERMAL AERATED FLUIDS DRILLING APPLICATIONS

In Kirishima Geothermal Field, Japan, air was used to bring down the conductor hole to a depth of 47 m using an industrial air percussion hammer (Soda, 2000). In the Lund Geothermal Deep Drilling Project in Sweden, different aerated fluids drilling techniques were used in a deep (3701.8 m) exploration geothermal well that penetrated very hard and abrasive gneiss basement rock. The introduction of air drilling and percussion / hammer drilling increased the penetration rate to about 4 to 5 times in the same kind of rock formation. The testing of fracture zones while drilling was also deemed valuable as it saved time and money. The borehole walls were also found to be very clean due to air drilling and air lifting activities. This improved the electrical logging performance and the quality of logging data (Bjelm, 2006). Straight air drilling has been employed to drill dry steam and two-phase reservoirs in

Southeast Asia since the early 1980s (Russel, 1987; Rizo and Cuenca, 1984).

A comparative study using thermal transient simulators was performed in Las Tres Virgenes Geothermal Field, Mexico, to understand the thermal behavior of geothermal wells drilled using mists (air/water mixtures) or mud as drilling fluids and to predict the cooling of the surrounding rock during the drilling process. The results show significant cooling effects of the surrounding rock when mud circulates, but when mist is used, the surrounding rock temperature changes very little but matches well the temperature logs taken during the drilling of the well with mist (Espinosa et. al., 2000).

Compared to straight air drilling, the use of denser fluids, such as aerated muds, to drill in higher pressure reservoirs, is something more recent. In the 1980s, drilling using aerated mud / water was conducted in the Mak-Ban, Tiwi and Southern Negros geothermal fields in the Philippines. Advantages cited were: (1) save rig time on waiting on water; (2) ability to monitor cuttings during prolonged lost circulation; and (3) cleaner hole as compared with a blind drilled well, as during blind drilling, cuttings tend to return into the formation with possible plugging of production zones above the bit (Russel, 1987; Rizo and Cuenca, 1984).

In the Aluto Geothermal Prospect in Ethiopia, drilling of 4” 50-70 m deep temperature gradient wells was done with aerated foam as drilling fluid. A perched water table occurred below 50 m depth, and water was continuously lost in a concealed obsidian flow and a porous pumice layer. Use of aerated foam made it possible to complete the survey within a shorter period. Significantly less water was required for foam drilling (Hochstein, 1983). Severe circulation losses in the Olkaria Geothermal Field in Kenya occurred from some 30 m below ground level. Stable foam was used for the setting of the production casing shoe, at approximately 550 m depth, below which depth formation water flows and steam production create a "mist flow" situation in the return annulus. Aerated fluids drilling of geothermal wells was demonstrated to be an entirely practical operation in this field.

3. GEOTHERMAL AERATED FLUIDS DRILLING IN ASIA PACIFIC

The Weatherford Performance Tracking System (WPTS) collects information about all the projects that have been handled by Weatherford for the purpose of improving and optimizing succeeding projects. This database was utilized to determine the projects and, more specifically, wells located in the Asia Pacific region on which aerated fluids were utilized in drilling in the geothermal setting. Information gathered from this query was utilized, analyzed and compared for the purpose of this technical paper. It should be stated though that WPTS is still constantly being updated with entries coming from old and new projects that have not yet been included in the system, and as such, the data it provides is only reflective of those projects that have already been entered into the system.

As of February 2009, WPTS records show that Weatherford has participated in five (5) geothermal aerated fluids drilling campaigns in the Asia Pacific region and it has assisted in drilling a total of 78 geothermal wells using this technique. The first project, which lasted from 1990 to 1996, involved two locations, Laguna and Albay, Philippines and involved 26 wells. The second campaign was conducted in West Java, Indonesia and involved 11 wells and lasted from February 2004 until February 2005. The third campaign involved 3 wells in Leyte, Philippines and lasted from July 2005 until January 2006. Seven wells were drilled in the Taupo / Bay of Plenty areas in New Zealand spanning the years 2005 and 2006. The most recent campaign, in West Java, Indonesia, began on June 2006 and ended on January 2009, and involved 31 wells. **Table 1** shows these wells classified as to when and where they were drilled. The following sections provide a discussion and comparison of all these projects organized according to equipment used, applications intended, techniques utilized and operational parameters involved.

3.1 Equipment

A typical equipment lay-out for geothermal aerated fluids drilling operations is provided in Figure 3. A similar set-up was used for the West Java 2004-2005 project. In the project, air was compressed by four, but later on three, Quincy 1500 scfm / 200 psi air compressors to approximately 350 psi. Note that compressor output normally decreases as elevation increases. The air flow from the compressors was then fed to the low-pressure Joy WB-12 boosters where pressure was boosted from 250 psi to a maximum of approximately 2000 psi. The air was then injected into the drill string at the rig standpipe manifold and/or through the parasite string, where it then mixes with the drilling fluid. Aerated fluid with cuttings return from the well and are directed by the Model 9200 RCD to the flow line and the geothermal separator. Air was vented to the atmosphere and the liquid and cuttings continued to the shale shakers. At the shakers, the cuttings were separated from the fluid and the fluid was then recycled and reinjected down the string. Weatherford provided the compressors, boosters, RCD, non-return valves, meter runs and Barton recorders, air manifold, air flow lines, and chemical injection pumps. The client provided the geothermal separator, banjo box, and the two-phase flow line and the valves on it. In **Figure 3**, Weatherford equipment are in red while those of the client are in blue.

Table 1. Geothermal wells drilled using aerated drilling fluids

Year	Location	Country	Wells
1990-1996	Laguna / Albay	Philippines	26
2004-2005	West Java	Indonesia	11
2005-2006	Leyte	Philippines	3
2005-2006	Taupo / Bay of Plenty	New Zealand	7
2006-2009	West Java	Indonesia	31
		Total	78

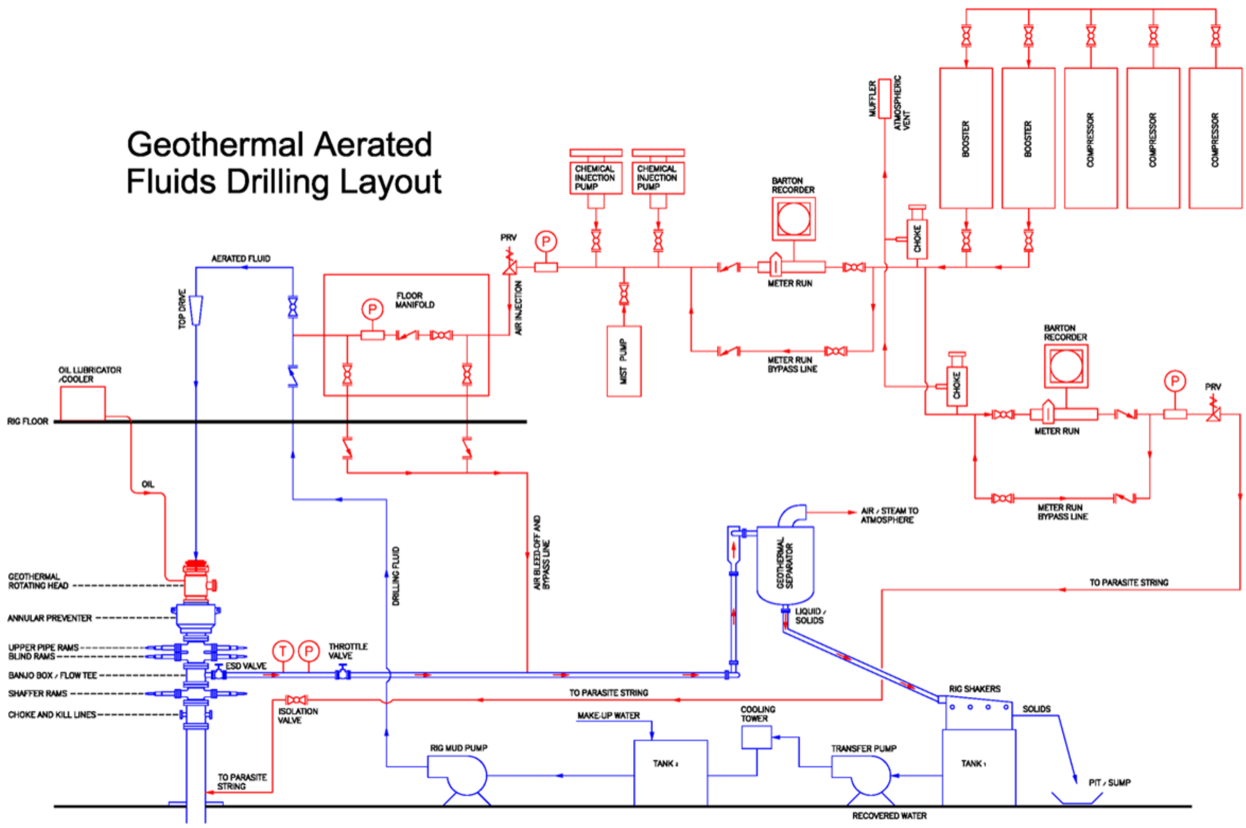

Figure 3: Typical geothermal aerated fluids drilling lay-out

In the Laguna / Albay 1990-1996 project, as much as three (3) Quincy 1500/200 compressors, three (3) Joy WB-12 boosters, two (2) National mist pumps (J-30 and J-60) and two (2) 5107 Texsteam chemical injection pumps were supplied during operations. The client provided a Grant RCD and the air / fluid separator for aerated fluids drilling operations. Operations in Laguna / Albay were conducted at an elevation of more or less 2000 ft (609.6 m) above mean sea level (AMSL).

Weatherford supplied all the equipment required for geothermal aerated fluids drilling in the Leyte 2005-2006 project, including three (3) 1500 scfm / 200 psi Quincy QSS primary air compressors, two (2) 1500 psi Joy WB-12 two-stage air pressure boosters capable of handling, with 165 psi suction pressure, a minimum of 2150 scfm at 1400 psi, and one (1) 500 psi Williams Model 9200 geothermal RCD. Leyte operations were conducted at an elevation range of 1876 to 2705 ft (571.58 to 824.69 m) AMSL.

A similar set-up was provided in the Taupo / Bay of Plenty, New Zealand aerated fluids geothermal drilling project that took place from 2005 to 2006.

In the recent project in West Java, the equipment involved are similar to the previous campaign in the area, with the exemption of the use of new compressor and booster models. Three (3) Sullair 1150 scfm / 350 psi two-stage, rotary-screw air compressors are providing the feed air, while two (2) Ariel JGJ/2 boosters increase the pressure of the feed air from 300 to 350 psi to a maximum of 2000 psi discharge pressure, with a maximum volume range of up to 3300 scfm, depending on suction pressure. Elevation ranged from about 3116 to 4920 ft (950 to 1500 m) AMSL. A data acquisition system (Data Pro) was also used. The system has sensors that measure the following parameters: gas injection meter run differential pressure, static pressure and temperature, wellhead pressure and temperature, and flow rates from the fuel line suction and return lines. The system can also be configured to capture and display other drilling operational parameters from other service companies.

3.2 Applications

Aerated liquid, particularly aerated mud, is the fluid system predominantly used in the geothermal aerated fluids drilling projects in the Philippines and Indonesia. In this system, it is common practice to put air online when a zone of total, severe or partial loss of circulation is encountered. At other times, it is used immediately at the start of the section being drilled. Air is also utilized at times to free stuck pipe. In Laguna / Albay, air was put offline and a switch was made to drilling blind with brine when a well started unloading or flashing. In subsequent projects, though, this was no longer the case, as improvements in technology and procedures have allowed for greater control over unloading and flashing, allowing aerated fluids drilling operations to continue up to the target depth (TD) of the wells.

In one of the wells drilled in Laguna / Albay, straight air (dusting) was used initially and as the level of fluid inflow increased, it was changed to a mist system, then subsequently to aerated mud. The switch from dusting to misting was based on the extent of formation fluid encountered, since continuing to use dusting at this point will cause cuttings to stick and build up on the drillstring.

The main reason for using aerated fluids drilling in Laguna / Albay was to balance the formation pressure so that drilling losses can be reduced alongside probable formation damage due to plugging of permeable zones. Though the method was able to restore circulation to a large extent in most of the wells drilled, its benefits in terms of reducing formation damage still has to be assessed in detail.

In Leyte, aerated fluids drilling was used to determine the feasibility of the technology in terms of minimizing well interference while conducting infill drilling within shallow to intermediate depths in an actively producing two-phase zone of a geothermal reservoir. Specifically, the objective of the project was to drill with bottomhole pressure as close as possible to the formation pressure (near balanced), low enough not to induce loss circulation, but high enough to minimize reservoir fluid influx, avoiding temperature problems on surface returns. The results of the well interference monitoring program revealed that aerated fluids drilling technology, by establishing good circulation during drilling even at loss zones, is capable of minimizing well interference during infill drilling (Ogena, et. al, 2007).

Minimal information can be found in the system as to the use of aerated fluids for geothermal drilling in Taupo / Bay of Plenty, New Zealand, including the reason/s why it was utilized.

The aerated fluids drilling application in the previous and current West Java projects aims to achieve three main objectives: (1) increase penetration rate, (2) minimize lost circulation, and (3) prevent differential sticking. In the wells that have been drilled so far, aerated fluids drilling has, to a certain extent, increased penetration rates for sections drilled with aerated mud as compared to those drilled using conventional mud, lost circulation has been minimized to a great extent, and no stuck pipe occurrence was experienced when air is online. Detailed studies on the effects of aerated fluids drilling on the penetration rate and on drilling hazard mitigation in West Java are currently being undertaken to further establish its benefits.

3.3 Techniques

In the projects involved in this study, the delivery of air was mostly done through the standpipe or drillstring, though delivery through the parasite string was also used at times. Jet subs of varying quantity, depth and jet size were also used to improve circulation in some instances.

In Laguna / Albay, a parasite string with an internal diameter of 1” was clamped to the side of the 11-3/4” casing and set at 1500’ in one of the wells. In a subsequent well, the internal diameter of the parasite string was increased to 1.6” and it was set deeper at 2000’. The logic behind the increase in diameter was to reduce the operating pressure on the booster, thereby increasing its reliability, and it was set deeper to negate the need for using jet subs. During operations, aerated fluids drilling equipment was attached to the parasite string and to the standpipe. This was accomplished by running two separate air supply lines with two separate air packs individually tied in. However, the parasite string, in conjunction with drillstring injection, was only used for three wells, as in subsequent wells, drillstring injection in conjunction with jet subs were utilized. As much as two jet subs were used to assist in regaining and maintaining returns. Jets used were #10, #12, #13 and #14. These subs were run in the 1500 to 3500 ft range of the casing. Short trips were required to raise the jet sub every 500 to 800 ft. Aerated fluids drilling was only used in assisting operations for either the 12-1/4” or 8-1/2” holes in Laguna / Albay.

The same two modes of air delivery into the wellbore were also utilized in the past and present West Java projects: drill string injection, which was predominantly used, and parasite string injection, which was also used in some of the wells drilled. Seven of the 11 wells drilled in the 2004-2005 campaign utilized a parasite string, and it was used mostly in conjunction with drillstring injection. It was largely used to assist in aerated fluids drilling operations in the 17-1/2” and 12-1/4” sections of the wells. Drilling mud and compressed air were utilized in the upper sections of the wells drilled, and a shift was later on made to aerated brine in the deeper sections of the wells. In the current West Java campaign, only seven (7) of the wells drilled were outfitted with a parasite string of 2” internal diameter, which was installed with the 20” casing. In the wells on which it was installed, only parasite string injection, without any assistance from drillstring injection, was used to deliver air during the drilling of the 17-1/2” section. The parasite string was not used in any other section of the wells drilled. Jets subs were not used in these wells. It should be stated that the generalizations provided below only apply for wells that have been drilled up to 2007, as more recent data still has to be analyzed and collated with the previous set.

Aerated fluids drilling was used in assisting operations in all the hole sections involved (26”, 17-1/2”, 12-1/4”, 9-7/8” and 7-7/8”) in the West Java 2004-2005 campaign, even in the reservoir section. It was used in the 12-1/4” section of all the wells involved and in majority of the 26” and 17-1/2” sections. The same can be said of the recent West Java campaign, where aerated fluids drilling has mostly been used to drill the 12-1/4”, 17-1/2” and 26” sections, where hole cleaning will be critical given the size of the hole. The reservoir section is usually drilled blind using brine. However, in each of the two campaigns, there has been one well where aerated fluids drilling was utilized to drill from the topmost section of the hole until the target depth of the well. In these wells, the lower sections were drilled blind using aerated brine, as circulation could not be immediately restored, probably due to the magnitude of the fractures.

In Leyte, since the surface and upper sections of the three wells involved have already been drilled beforehand, a parasite string could no longer be installed. Only the 12-1/4” and 8-1/2” holes were drilled using aerated drilling fluids. As to the type of fluids used, aerated mud was first used to drill the upper sections of the wells and aerated water was used when drilling reached the lower sections.

Table 2. Air / liquid volume and flowline temperature parameters

Project	Air Volume (scfm)				Liquid Volume (gpm)		Flowline Temperature (ºF)
	Min		Max				
	DSI	PAS	DSI	PAS	Min	Max	Max
Laguna / Albay 1990-1996	300	600	3800	2500	300	1000	-
West Java 2004-2005	300	300	4500	2500	200	1370	238
Leyte 2005-2006	400	-	3600	-	200	810	399
West Java 2006-2007	300	200	3000	1800	250	1700	161

Legend: DSI – Drill String Injection; PAS – Parasite String Injection

Table 3. Average penetration rate per hole section

Project	Average Penetration Rate (ft/hr)					
	26”	17-1/2”	12-1/4”	9-7/8”	8-1/2”	7-7/8”
Laguna / Albay 1990-1996	-	-	31.81	-	22.86	-
West Java 2004-2005	26.85	34.15	46.20	51.97	-	28.31
Leyte 2005-2006	-	-	20	-	12.63	-
West Java 2006-2007	54.3	46.42	59.08	49.8	-	51

In the West Java 2004-2005 campaign, 77 RCD stripper rubbers were used up, and eight were re-run, while in the recent West Java campaign, a total of 94 RCD stripper rubbers were used, or roughly an average of five per well, for both the past and present campaign. In Leyte, a total of 19 new RCD stripper rubbers were used and two were re-run. Stack misalignment was established as the main reason for increased wear on stripper rubbers. There are no records as to stripper rubber use in Laguna / Albay.

For corrosion inhibition during the Laguna / Albay 1990-1996 project, one part Barafilm 4/ Coat 415 / Conqor 202 and three to four parts diesel were pumped using the mist pump at values ranging from 12 to 20 gpm. Conqor 404 was also used. Chemicals used during aerated fluids drilling operations in West Java from 2004-2005 were a foamer and a corrosion inhibitor (WFT 9323). Foamer was pumped into the system using Texsteam pumps to stimulate circulation or to relieve tight conditions downhole. Corrosion inhibitor was introduced at the active mud tanks at a rate of 5 gallons per 100 barrels. In Leyte, a corrosion monitoring program was implemented involving Weatherford chemicals (WFT 9323, WFT 9386, and WFT 9368). Rates were varied depending on the rate of corrosion observed. Alkali foam was also used. Weatherford is not involved in corrosion control for the current West Java campaign.

4. CONCLUSION

Aerated fluids drilling technology has been successfully applied in the geothermal setting in various wells and projects in the Asia Pacific region. However, a review of the literature on how the technology has been used effectively around the world reveals that there are aspects of the technology that have not yet been tested and verified in this part of the world. Examples of this would be the use of foam for improving the rate of hole cleaning and the utilization of an air hammer for increasing the penetration rate. Another important observation is that aerated fluids drilling has been used in some of the wells to drill from surface to TD, thereby begging the concept of maximizing the utility of an air package by engineering applications that expand its usage to all the hole sections for a greater number of wells.

The applications of geothermal aerated drilling fluids in two of the largest geothermal producing countries, the Philippines and Indonesia, are broadening. Aside from the customary increase in penetration rate, other applications of the method are now being discovered, such as the prevention of well interference during infill drilling and an increasing emphasis in the use of aerated fluids drilling for drilling hazard mitigation. It is also worthwhile to note that the chronological presentation of the rates of penetration in all the geothermal aerated fluids drilling projects involved show an increase with respect to time. This conclusion excludes data from the Leyte project, where penetration rate was sacrificed in pursuit of the project’s main priority, the prevention of interference during infill drilling. More information needs to be gathered about geothermal aerated fluids drilling operations in New Zealand and other countries within the region.

On a cautionary note, it should be stated that aerated fluids drilling is not a panacea, and in order for its benefits to be maximized, it is important that the project and the methods it will entail be properly evaluated and engineered. Calculations must be made as what are the requirements of a particular project and this should serve as the main basis as to what and how much equipment will be provided. Modeling software must also be utilized to be able to estimate the volume of air and liquid needed to balance the formation pressure and minimize circulation losses. The modeling of surface temperature during aerated fluids drilling operations will be useful for controlling the extent of unloading and flashing during these operations. Other concerns that can be approached from an engineering perspective include aerated fluids drilling through multi-feed zones and crossflow, the effects of aerated fluids drilling on bit life, as well as a more in-depth statistical evaluation of the data on rates of penetration and drilling hazard mitigation in previous drilling campaigns.

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