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Corrosion Control in Geothermal Aerated Fluids Drilling Projects in Asia Pacific

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ABSTRACT

The introduction of air into the drilling fluid used for geothermal aerated fluids drilling operations brings with it an increased potential for the corrosion of the materials that it comes into contact with, particularly the downhole tubulars and the surface equipment involved.

It is therefore recommended that a corrosion control program be prepared when geothermal aerated fluids drilling operations are involved and this usually entails the monitoring of the level of corrosion and the introduction of corrosion inhibitors and other related chemicals into the drilling fluid.

This paper presents the corrosion control programs that have been put in place in selected projects in the Asia Pacific region that have utilized geothermal aerated fluids drilling and evaluates their effectiveness in addressing the level of corrosion in these operations. It also provides the common practices, equipment and materials used when corrosion control is utilized as well as recommendations as to how the system can be improved further for future projects.

1. INTRODUCTION

Aerated fluids drilling technology 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. The definition of this technology is best presented graphically in Figure 1, which provides the technical definition, the operator's intention and the key to success. Figure 2 presents the four types of aerated drilling fluid systems (air, mist, aerated liquid and foam) and the corresponding percentages of air involved.

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: minimization of circulation losses, increase in penetration rate, drilling material savings, elimination of differential sticking, lesser water requirements, the ability to discharge during drilling, and the prevention of formation damage (Russel, 1987; Rehm, 2002; UNUGTP, 1992; Rizo and Cuenca 1984).

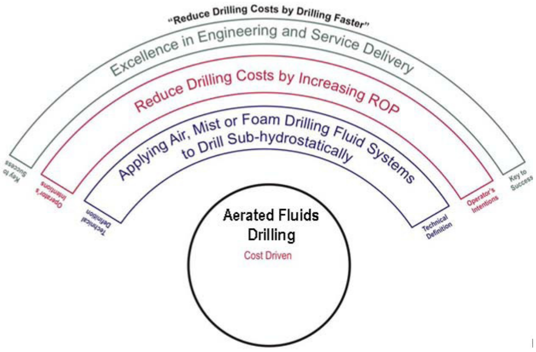

Figure 1. Definition of aerated fluids drilling

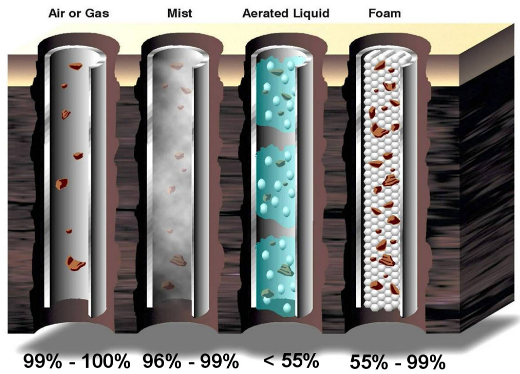

Figure 2. Four Different Types of Aerated Drilling Fluid Systems and the Percentage of Air Involved

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

Corrosion is a major concern when drilling in a geothermal environment especially when using compressed air. The combination of geothermal fluid's high temperature and pressure, dissolved and free H_2S and CO_2 gases and their associated compounds of sulfate and bicarbonates, elevated levels of chlorides and other anions, and the oxygen content from air can lead to severe corrosion and potential tubing and drill pipe failure. With this knowledge of the corrosion problems that will be encountered during aerated geothermal drilling, it is necessary that a good and solid corrosion management program be in place.

Laboratory simulations conducted at Weatherford Chemical Research and Development Center indicate that drilling without the proper corrosion management program will result in excessive corrosion [>270 mils per year (mpy) or 147 g/m^2/day] and severe pitting. Thus, the appropriate corrosion program must start with the treatment of the aerated drilling fluid. By implementing the proper corrosion chemistry, it is possible to lower corrosion rates, reduce metal loss, and reduce frequency of damage to downhole tubulars. Not only does this program help lower drilling costs it also provides an increased level of safety in geothermal drilling operations.

The objective of this paper is to present a corrosion management program specifically designed for the drilling of a geothermal well using aerated fluids.

2. GEOTHERMAL DRILLING USING AERATED FLUIDS

2.1 Geothermal Aerated Drilling Experience

Starting 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: savings on rig time on waiting on water; ability to monitor cuttings during prolonged lost circulation; and cleaner hole as compared with a blind drilled well, as during blind drilling, cuttings tend to move into the formation with possible plugging of production zones above the bit (Russel, 1987; Rizo and Cuenca, 1984).

Recent Weatherford engagement with geothermal aerated drilling mostly took place during the 1990s with projects in the Philippines, particularly in Laguna and Albay. From 1990 to 1996, it assisted in the drilling of 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. The most recent campaign in West Java, Indonesia, which started from June 2006 and concluded in January 2009, involved 31 drilling engagements (Toralde, 2008). As of January 2009, it has participated in four geothermal aerated fluids drilling campaigns in Indonesia and the Philippines and it has assisted in drilling a total of 71 geothermal wells using this technique. **Table 1** show these wells classified as to when and where they were drilled.

Table 1. Geothermal wells drilled using aerated fluids with Weatherford involvement

Year	Location	Country	Wells Drilled
1990-1996	Laguna / Albay	Philippines	26
2004-2005	West Java	Indonesia	11
2005-2006	Leyte	Philippines	3
2006-2009	West Java	Indonesia	31
TOTAL			**71**

2.2 Method of Geothermal Drilling Fluid Aeration

In all the projects involving Weatherford, aeration of drilling fluids is achieved by delivery of air through the standpipe or drill string in the rig. In addition, air delivery through the parasite string was also performed. The air supply used for aeration is initially produced from air compressors at 350 psi and eventually increased to high pressure (~2000 psi) using air boosters before it is injected into the rig standpipe manifold and/or parasitic line.

3. CORROSION IN GEOTHERMAL AERATED DRILLING

3.1 Corrosion Agents in Geothermal Drilling Aerated Fluids

Corrosion is an electrochemical reaction that causes the alteration and degradation of material by its environment. In the aerated drilling environment, the material altered or degraded is usually the steel components of drill pipes or tubulars and to some extent the casing. The principal corrosive agents affecting drill stem materials in aerated fluids are oxygen from air and gases from geothermal fluids (CO_2 and H_2S), chlorides, sulfates and bicarbonates. The degree of elevation of the temperature and pressure in mixed geothermal/aerated fluids also play a significant role in the degree of corrosion.

3.1.1 Oxygen

Oxygen is the main corrosive agent in aerated fluids drilling. In the presence of water, it promotes rusting of steel, the most common form of corrosion. With the presence of oxygen and water, corrosion in the drill stem is potentially high. With 20% concentration of oxygen gas in compressed air, traditional oxygen scavengers are not an option because oxygen scavengers eliminate only in a molecular weight-ratio basis. With the high flow rates of oxygen gas into the well of up to 3,000 scfm, scavenger volume requirement would have to reach tonnage levels to effectively remove all oxygen present.

3.1.2 Carbon Dioxide (CO_2)

Carbon dioxide dissolves in water to form a weak carbonic acid that corrodes steel by hydrogen evolution, unless the pH is maintained above 6.0. Carbon dioxide corrosion is similar to oxygen corrosion, but at a slower rate. However, when carbon dioxide and oxygen are both present, the corrosion rate is higher than the sum of the individual rates. Carbon dioxide is a naturally occurring gas in the geothermal environment. It is a major gas component in geothermal fluids. It is about 95% of the total gas composition.

3.1.3 Hydrogen Sulfide (H_2S)

Hydrogen sulfide dissolves in water to form an acid somewhat weaker and less corrosive than carbonic acid, although it may cause pitting, particularly in the presence of oxygen and/or carbon dioxide. A more significant action of hydrogen sulfide is its effects on a form of hydrogen embrittlement known as sulfide stress cracking (SSC). Hydrogen sulfide gas is also a naturally occurring gas in the geothermal environment. Its percentage in geothermal gas makes up about 1% to 5%.

3.1.4 Anions

Anions such as chlorides, carbonates, and sulfates increase the electrical conductivity of aerated drilling fluids. Since most corrosion processes involve electrochemical reactions, the increased conductivity gives enhanced corrosion rates. Concentrated salt solutions are usually less corrosive than dilute solutions due to decreased oxygen solubility in the relatively concentrated form of salt solution. In this case, with 20% oxygen this lower solubility is not relevant. Chloride is a major anion in the geothermal fluid matrix that is derived naturally from the dissolution of rocks with hot fluids. Carbonates and sulfates are also natural components of geothermal fluids brought about by the reaction of CO_2 or H_2S gases with water.

3.2 Factors Affecting Corrosion Rates

3.2.1 pH

It is a scale measuring hydrogen ion concentration in solution. Since the pH scale is logarithmic, each pH increment of one unit represents a ten-fold change in hydrogen ion concentration. The pH of pure water is 7.0. Values of pH towards 1.0 are increasingly acidic and pH values toward 14.0 are increasingly alkaline. In the presence of dissolved oxygen, the corrosion rate of steel in water is relatively constant between pH 4.5 and 9.5, but it increases rapidly at pH values lower than 4.5. At pH higher than 9.5, corrosion increases slowly then rapidly.

3.2.2 Temperature

Corrosion rates increase with increasing temperature. A rule of thumb is that corrosion rates double for each 10°C temperature rise.

3.2.3 Pressure

Pressure affects corrosion by increasing the solubility of oxygen and other corrosive gases. For example, at 100°F (37.8°C) and 100 psi (0.689 MPa) the solubility of oxygen in fresh water is about 230 ppm. At 100°F (37.8°C) and 500 psi (3.45 MPa) however, the oxygen solubility increases to 1270 ppm.

3.2.4 Velocity

Corrosion rates can increase with higher rates of flow.

3.2.5 Heterogeneity

Localized variations in composition or microstructure may increase corrosion rates. Ringworm corrosion, that is sometimes found near the upset areas of drill pipe or tubing that has not been properly heat treated after upsetting, is an example of corrosion caused by non-uniform grain structure.

3.2.6 High Stresses

Highly stressed areas may corrode faster than areas of lower stress. The drill stem just above drill collars often shows abnormal corrosion damage, partially due to higher stresses and high bending moments.

3.3 Forms of Corrosion Damage

Corrosion can take many forms and may combine with other types of damage (erosion, fatigue, etc.) to cause severe damage or failure. Several forms of corrosion may occur simultaneously, but one type usually predominates. Getting information on the form of corrosion will help in planning the corrective action. The forms of corrosion most often encountered with drill stem material are presented in the succeeding subsections.

3.3.1 Uniform or General Attack

During uniform attack, the material corrodes evenly, usually leaving a coating of corrosion products. The resulting loss in wall thickness can lead to failure from reduction of the material's load carrying capability.

3.3.2 Localized Attack (Pitting)

Corrosion may be localized in small, well-defined areas, causing pits. Their number, depth, and size may vary considerably; and they may be obscured by corrosion products. Pitting is difficult to detect and evaluate, since it may occur under corrosion products, mill scale, and other deposits, in crevices or other stagnant areas, in highly stressed areas, etc. Pits can cause washouts and can serve as points of origin for fatigue cracks. Chlorides, oxygen, carbon dioxide, and hydrogen sulfide, or combinations of these gases, are major contributors to pitting corrosion.

3.3.3 Erosion - Corrosion

Many metals resist corrosion by forming protective oxide films or tightly adherent deposits. If these films or deposits are removed or disturbed by high velocity fluid flow, abrasive suspended solids, excessive turbulence, cavitation, etc., accelerated attack occurs at the fresh metal surface. This combination of erosive wear and corrosion may cause pitting, extensive damage, and failure.

3.3.4 Corrosion Fatigue

Metals subject to cyclic stresses of sufficient magnitude will develop fatigue cracks that may grow until complete failure occurs. The limiting cyclic stress that a metal can sustain for an infinite number of cycles is known as the fatigue limit. In a corrosive environment no fatigue limit exists, since failure will ultimately occur from corrosion, even in the absence of cyclic stress. The cumulative effect of corrosion and cyclic stress (corrosion fatigue) is greater than the sum of the damage from each. Fatigue life will always be less in a corrosive environment, even under mildly corrosive conditions that show little or no visible evidence of corrosion.

3.4 Sulfide Stress Cracking (SSC)

In the presence of hydrogen sulfide, tensile loaded drill stem components may suddenly fail in a brittle manner at a fraction of their normal load carrying capability after performing satisfactorily for extended periods of time. Failure may occur even in the apparent absence of corrosion, but is more likely if active corrosion exists. Embrittlement of steel is caused by the absorption and diffusion of hydrogen at the molecular level and is much more severe when hydrogen sulfide is present. The brittle failure of tensile loaded steel in the presence of hydrogen sulfide is termed sulfide stress cracking (SSC).

3.4.1 Strength of the Steel

The higher the strength (hardness) of the steel, the greater is the susceptibility to SSC. In general, steels having strengths equivalent to hardness up to 22 HRC (Hardness Rockwell C-Scale) maximum are resistant to SSC. If the chemical composition is adjusted to permit the development of a well tempered, predominantly martensitic microstructure by proper quenching and tempering; steels having strengths equivalent to hardness up to 26 HRC maximum are resistant to SSC. When strengths higher than the equivalent to 26 HRC are required, corrective measures must be used. The higher the strength required, the greater the necessity for the corrective measures.

3.4.2 Total Tensile Load (Stress) on the Steel

The higher the total tensile load on the component, the greater is the possibility of failure by SSC. For each strength of steel used, there appears to be a critical or threshold stress below which SSC will not occur; however, the higher the strength, the lower the threshold stress.

3.4.3 Amount of Hydrogen and H_2S Gases

The higher the amount of molecular hydrogen and H_2S present in the environment, the shorter the time before failure by SSC. The amount of atomic hydrogen and H_2S

required to cause SSC are quite small, but corrective measures to control their amounts will minimize the atomic hydrogen absorbed by the steel.

3.4.4 Time

Time is required for molecular hydrogen to be absorbed and diffused in steel to the critical concentration required for crack initiation and propagation to failure. By controlling the factors referred to above, time-to-failure may be sufficiently lengthened to permit the use of marginally susceptible steels for short-duration drilling operations.

3.4.5 Temperature

The severity of SSC is highest at normal atmospheric temperature and decreases as temperature increases. At operating temperature in excess within 57°C, marginally acceptable materials (those having hardness higher than 22 to 26 HRC) have been used successfully in potentially embrittlement-causing environment. The higher the hardness of the material, the higher is the safe operating temperature requirement. Caution must be exercised, since SSC failure may occur when the material returns to normal temperature after it is removed from the hole.

4. CORROSION MANAGEMENT

4.1 The Corrosion Management Framework

The program presented here is based from the NACE International Publication 1D177 (Reaffirmed 1995) entitled "Monitoring Techniques for the Control of Corrosion of Drill Pipe, Casing, and Other Steel Components in Contact with Drilling Fluids". These techniques have been specifically modified to cover aerated drilling techniques. Included in this paper are the methods for monitoring and treatment to reduce the corrosion within the acceptable rate for the drilling downhole tubulars.

Figure 3 outlines the corrosion management framework. The framework is a cycle of continuous improvement process that involves data collection, corrosion testing, implementation, review and evaluation, and lessons learning. At the center of the process is the corrosion management box which collects all the information from all the aspects and stages of the corrosion framework map. After the gathering of relevant information, the protocols are reviewed and if necessary, changed, to further improve the corrosion management strategy.

4.2 Laboratory Testing

Laboratories provide support to field operations by conducting research and testing to simulate field corrosion conditions. One aspect of development is the creation of a corrosion inhibitor package for geothermal aerated drilling that is suited to a client's geothermal fluid drilling condition. It is important to get beforehand the geothermal fluid chemistry and know the degree of gas and salts concentration so that a full understanding and an appropriate corrosion inhibition program is formulated.

4.2.1 Electrochemical Corrosion Testing

This kind of testing is conducted in a controlled environment. It usually uses a synthesized fluid or representative fluid sample to simulate the condition of the geothermal fluid environment. The instrument used is a linear polarization resistance instrument fitted with a probe with standard carbon steel tip having similar metallurgical characteristics of that of the drill stem. The instrument provides a direct measure of the corrosion rate and a qualitative pitting tendency (imbalance). All corrosion tests are conducted in various temperature-controlled conditions. While conducting the electrochemical test at increasing fluid temperature, gas (CO_2 and H_2S) is slowly introduced until saturation is reached.

4.2.2 Weight Loss Testing

This testing uses coupons of similar metallurgy as the electrodes used in the electrochemical corrosion test. The testing is usually done in an oven over a 24-hour period with temperature simulating geothermal reservoir conditions and using synthetic fluids that simulate the geothermal fluids. The weight of the coupon will be determined at the start and at the end of each simulation testing period to accurately determine the total material loss of the coupon during the exposure period.

4.3 Corrosion Control Chemicals for Aerated Drilling

4.3.1 Drilling Corrosion Inhibitor

WFT Corrfoam 1 is a potassium salt of a glycol phosphate ester designed as a corrosion inhibitor for use in a water-based drilling systems. It is an anodic inhibitor for control of general and pitting corrosion from oxygen, hydrogen sulfide, and carbon dioxide. It can be used in a foam or air-mist system without offsetting drilling fluids properties. It can be batched or added continuously during drilling. It does not contain ammonium salts or hydrochloride salts and is biodegradable.

4.3.2 Drilling Corrosion Inhibitor

The chemical WFT C-100 is an amine sulfurized borate blend for use in the control of oxygen, hydrogen sulfide, and carbon dioxide corrosion. It protects drill pipe and other exposed steel equipment that is in contact with drilling mud, polymer fluids or air mist/foam systems. WFT C-100 is miscible in both fresh and brine waters. Among the advantages of this chemical is that it protects drill pipe against H_2S, CO_2, and oxygen corrosion, has a highly polar formula that gives corrosion inhibitor film persistency, is soluble in all concentrations of brine, is effective in the presence of crude oil, and is easy to use and can be fed directly from the shipping drum.

4.3.3 High-Temperature Acid Corrosion Inhibitor

WFT 9368 contains a quinoline quat surfactant, a synergistic blend of acytylenic alcohol replacement, solvents and highly effective dispersion package that enable it to inhibit corrosion in all hydrochloric (HCl) and hydrochloric - hydrofluoric (HCl - HF) acid concentrations. It has a high flash point, making the product non-hazardous and enabling high-temperature performance. It is also compatible with other intensifiers, which increases its application temperature limit further. It can eliminate sulfide scaling and hydrogen embrittlement and disperses easily in acid and water.

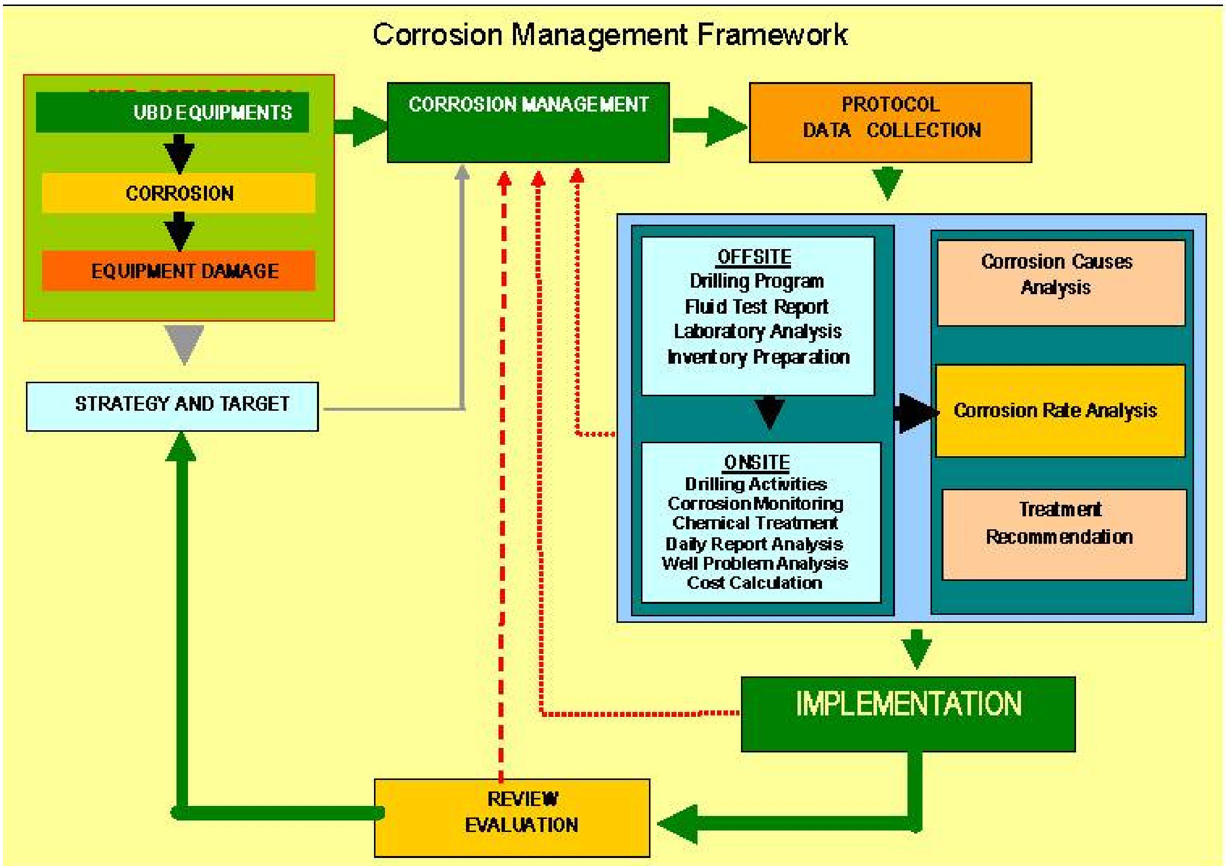

Figure 3. Aerated Drilling Corrosion Management Framework.

4.3.4 Hydrogen Sulfide Scavenger

WFT 9812 is an active aqueous polymeric aminoalcohol solution designed to be effective in drilling fluids systems both as an H_2S converter and a corrosion inhibitor supplement. It has a unique, non-wetting ability that prevents it from interfering with the drilling fluid rheology. This non-wetting characteristic, in a closed mud system, allows it to continue to scavenge even more H_2S than the stoichiometric calculations would indicate. The obvious advantages are: fast, effective H_2S removal, provides corrosion inhibition, will not liberate formaldehyde, non-wetting characteristics, works on both water and gas solutions, stable in both high-temperature fluids and in acid fluids. It controls the H_2S odor through reduction, thereby controlling the health hazards of H_2S.

4.3.5 Triplex Corrosion Control Systems

The versatile Triplex corrosion control system is a job-specific combination of three corrosion inhibitors to provide quick passivation and long-term protection for downhole tubulars and hardware at temperatures up to 260°C (500°F). Triplex systems are used in aerated drilling operations in mild to extremely corrosive environments and are particularly suited to geothermal applications. Triplex systems combine three different inhibition mechanisms to reduce localized corrosion to near zero, even in the presence of oxygen, high chlorides, and acid gases.

The unique three-component Triplex system bonds to metal surfaces within minutes, protecting surfaces from exposure to oxygen, chlorides, or acids for extended periods of time. In geothermal environments, as the drilling fluid transitions from liquid to steam, these systems also function as a neutralizer or condensate corrosion inhibitor, providing continuous protection during the transition.

An anodic inhibitor combines with available oxygen to react with metal surfaces—a process known as passivation. A cationic inhibitor then forms an organic protective film, and a second cationic inhibitor repairs any flaws or imperfections in the organic and passivation layers. Unlike most anodic phosphate inhibitors, the tenacious, protective barrier that forms at temperatures over 149°C (300°F) inhibits further deposition of mineral scales on the metal surfaces.

The unique inhibitive properties of the Triplex system are specifically designed for the following types of corrosion sources: influx of production fluids, high bottomhole temperatures and pressures, acid gases, electrical conductivity of liquids and high oxygen concentrations.

4.4 Chemical Treatment Program

Each chemical treatment program in place is customized based on the information gathered on the chemistry of the drilling environment and on client's requirements. Chemical requirement for corrosion inhibition vary with each well section and depth because of variation of temperature and pressure so a treatment program is formulated for each depth section. The program might be a combination of two or all of the corrosion inhibitor chemicals. However, the concentration and volume requirement of these chemical will still depend on the most accurate information that can be gathered during the testing phase.

4.5 Corrective Measures to Minimize SSC

One or more of the following measures can be used to minimize SSC. Certain conditions may require more specialized treatment.

- Use of appropriate inhibitors and/or oxygen or H_2S scavengers to minimize weight loss corrosion.
- Use degassers and desanders to remove harmful dissolved gases and abrasive material.
- Wash out all aerated drilling residues when finished using the drill string. Cleaning can be done by hydroblasting with fresh water and then coating with chemical inhibitor.

While generally not affecting corrosion rates, the following measures will extend life by lowering the cyclic stress intensity or by increasing the fatigue strength of the material:

- Use thicker walled components.
- Reduce high stresses near connections by minimizing doglegs and by maintaining straight hole conditions as far as it allows.
- Minimize stress concentrations such as slip marks, tong marks, gouges, notches, scratches, etc.
- Use quenched and tempered components.
- After exposure to a sour environment, use care in tripping out of the hole, avoiding sudden shocks and high loads.
- If economically viable, after exposure to a sour environment, remove absorbed hydrogen by aging in open air for several days to several weeks. The removal of hydrogen is hindered by the presence of corrosion products, scale, grease, oil, etc. Cracks that have formed (internally or externally) prior to removing the hydrogen will not be repaired by baking or stress relief operations.
- Limit drill stem testing in sour environments to as brief a period as possible, using operating procedures that will minimize exposure to SSC conditions.

4.6 Monitoring

A comprehensive procedure for all aspects of the corrosion monitoring has been developed. The procedures are based on the standard procedures published by the regulating organization of corrosion engineers and international standards.

4.6.1 Drill Pipe Circular Ring Coupon

Drill pipe corrosion coupons are appropriate devices to monitor corrosion. Drill pipe ring coupons run in the drill string are exposed to actual downhole conditions of fluid chemistry, pressure, temperature and fluid velocity. Procedures for testing using corrosion ring coupons are in place so that accurate data can be obtained.

4.6.2 Oxygen Gas Monitoring

Oxygen gas monitoring is only relevant if a cryogenic fluid is being used. However, if aeration is done with compressed air, the maximum concentration of oxygen gas equal to air composition of ~20% will be used.

4.6.3 Drilling Fluid and Precipitate Analysis

During drilling, periodic analysis of the properties of the drilling fluid is conducted to determine the content of certain chemical parameters used to determine if the corrosion inhibition is working. Iron and chloride are regularly checked by the corrosion engineer to determine if the current chemical treatment program is still working or if there is a need for adjustment. At the same time, the concentration of phosphates and phosphonates will also be analyzed to make sure that the right concentration of inhibitors is present for the drilling fluid condition. Lack or excess of these components in the drilling fluid must be avoided in order to guarantee the success of the corrosion program. In addition, monitoring of pH and water contaminants (total hardness, and total alkalinity) is also conducted so as to give the corrosion engineer the data needed to create a drilling fluid chemistry profile at any stage of drilling.

4.6.4 Erosion Monitoring

Since drilling involves transport of cuttings and sand, erosion problems are likely to be encountered if the flow velocity is allowed to exceed the erosion velocity. In order to avoid potential erosion problems, the production rate of a well should be limited to ensure that the flow velocity is reduced to the recommended maximum of approximately 150 ft/sec.

Wall thickness of all equipment should be checked regularly. Usually a baseline thickness measurement is conducted prior to use of an equipment. Various points on the equipment will be marked on the pipe work and numbered. The wall thickness measurement point should be taken at the point where turbulence is most likely to occur down stream of the pipe.

4.7 Report Writing of Lessons Learned

Throughout each project, lessons are learned and opportunities for improvement are discovered. Documenting lessons learned not only confirms successes (what worked well that should be repeated in future projects) but also identifies shortcomings and discovers the root causes of problems that occurred. This helps to avoid those problems in later project stages or future project engagements. Documenting the lessons learned is part of the continuous improvement process.

5. CONCLUSION

Geothermal well drilling using aerated fluids is increasingly the choice of drilling technology for geothermal development in the Asia Pacific region. This technology is being used because of the many cost benefits that it brings. However, these advantages can be negated by a single factor, corrosion. Corrosion plays a major factor in aerated drilling because the chemistry of geothermal fluids and the oxygen content in drilling fluid constitute the perfect recipe for the corrosion process to proceed. Corrosion, however, can be controlled if sufficient knowledge and understanding of the fluids is at hand. Drilling fluids can be engineered by adding chemicals to inhibit and scavenge certain corrosion-forming chemical constituents so that corrosion can be controlled within an acceptable level.

This paper presents a corrosion management program specifically designed for geothermal drilling using aerated fluids. With an array of corrosion inhibition chemicals at hand and an understanding of corrosion engineering in the geothermal drilling environment, corrosion control during aerated drilling in geothermal environments can be simplified and implemented effectively and efficiently.

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