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The Care and Feeding of Biodegradable Lubricants

Lessons Learned in the Real World

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Abstract

As environmental enforcement agencies increase pressures and costs for petroleum lubricant spills, many offshore operators are using or considering environmentally safer products. These types of fluids can protect the users against fines, cleanup costs and downtime, but care must be given in selecting the right product for a specific application.

This paper will review the definitions of environmentally preferable products and strengths and limitations of each type. It will also review the various definitions of "biodegradable" and the maintenance practices required to prolong the life of the fluid and the equipment. Finally, the paper will present the data gathered and observations made by Transocean Inc, and Terresolve Technologies, Ltd during a successful nine-month (6000 hour) field demonstration. This field demonstration was in the central hydraulic system of the Deepwater Nautilus and utilized Terresolve's EnviroLogic 146H vegetable-based hydraulic fluid.

Introduction

There is growing concern regarding the environmental impact and associated costs of lost petroleum based fluids. The National Oceanic and Atmospheric Administration (NOAA) estimates over 700 million gallons of petroleum enter the environment each year, over half of which is through irresponsible and illegal disposal. Industry experts estimate that 70% to 80% of hydraulic fluids leave systems through leaks, spills, line breakage and fitting failure. Petroleum is persistent and toxic. It damages living organisms including plants, animals and marine life for many years. In addition, the Coast Guard, EPA and local governments are increasing the range of responsibility of lubricant releases including significant fines and clean up costs.

In addition to regulatory pressure, Transocean was faced with a major oil company client who was concerned with petroleum hydraulic fluid getting into their environmentally safe drilling mud. Even a small amount of petroleum would contaminate the mud and cause it to be classified as hazardous. In their search for an environmentally safe fluid, Transocean learned that not all environmentally safe fluids or the companies that promote them are the same.

Terresolve Technologies, a world leader in environmentally safe fluid technology has teamed up with Transocean, the leader in deep water drilling, to monitor a field demonstration of biobased hydraulic fluid in an offshore drilling rig. The Deepwater Nautilus completed a 6000-hour field demonstration using Terresolve Technologies' readily biodegradable EnviroLogic 146H hydraulic fluid. The fluid not only protected the Nautilus from the exposure due to leaks and spills but also actually improved the performance of the hydraulic system. Terresolve and Transocean have developed this paper to share their insights and results from these tests.

Release to the environment

According to NOAA, 706 million gallons of petroleum are released into the ocean each year. Over half of that, 363 million gallons, are because of irresponsible maintenance practices and routine leaks and spills.

As demands on lubricant systems increase, the likelihood of accidental release of fluids increases. Increased operating temperatures, pressures and working cycles shorten the life of circuit components. The single best approach to protecting the environment, the equipment and the operation is to prevent leaks and spills through good routine maintenance. A good preventative maintenance program will:

- Increase productivity since equipment is utilized more,
- Better utilize in-shop maintenance since there is less emergency work,
- Improve control of spare part inventory and reduce parts usage,
- Reduce equipment down time,
- Reduce safety hazards,
- Increase equipment life,
- Reduce fines and clean-up costs due to environmental release, and
- Reduce down time related to environmental release.

Oil spills

There are increasing regulatory pressures from the EPA, Coast Guard and other environmental organizations. While small releases will not result in a Resource Conservation and Recovery Act (RCRA) clean up, large spills will. All petroleum hydraulic fluid spills are "reportable events". These events involve a great deal of clean-up cost, administrative procedures and punitive fines that can range from tens of thousands to hundred of thousands of dollars.

While spilling large quantities of biodegradable hydraulic fluid is still considered under RCRA to be a reportable event, agencies are required to evaluate "biobased oils" differently than petroleum-based oils. As awareness of biodegradable fluid increases, state and federal agencies become more lenient regarding fines and clean-up costs. In fact, there are several case studies of equipment releasing several hundred gallons of vegetable-based hydraulic fluid into environmentally sensitive areas with no fines and minimal clean-up expense. In most instances, the operator was able to continue working while clean-up efforts were underway. Since the fluids were biodegradable and non-toxic, there was no long-term negative effect to the ecosystem.

There is a common misperception that the Coast Guard approves oils based on the oil not leaving a sheen. This is not true. The Coast Guard does not approve, recommend or endorse any fluids. Furthermore, the Coast Guard does not approve or recommend any test procedures, but rather,

follows United States statute laws. The oil sheen that is frequently referenced is inferred from the Clean Water Act as defining "any substance that leaves a sheen, emulsification, or discoloration, as a pollutant and be subject to appropriate fines and regulations governing pollutants". The Coast Guard also relies on the guidelines as outlined by equipment manufacturers and highly favors the use of biobased and biodegradable fluids.

Biodegradability

Biodegradation is the process of chemical breakdown or transformation of a material caused by organisms or their enzymes. Figure 1 defines it.

The Aerobic Biodegradation Process

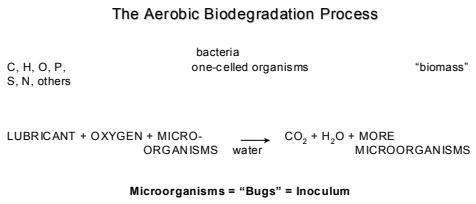

Figure 1. Aerobic Biodegradation

Biodegradation Measurement

There are two commonly used measurements for biodegradation. The first is "primary degradation" which measures reduction of the Carbon and Hydrogen bonds (C-H) in the initial solution; this is the reduction of the amount of the lubricant. The most widely used test that measures this decrease is the CEC-L-33-A-93.

The second measurement of biodegradation is "secondary degradation" or "ultimate degradation". This measures the evolution of CO_2 through the biodegradation. The usual test for this is the OECD 301or the ASTM D4684.

Figure 2, below, shows the process.

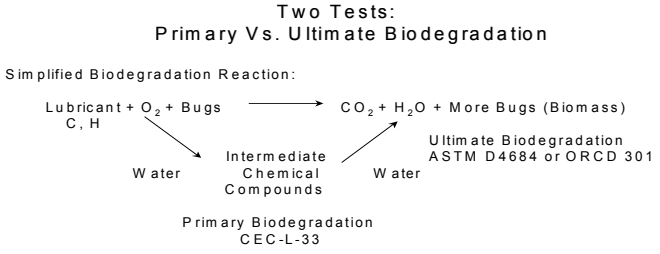

Figure 2. Primary vs. Secondary Biodegradation

Biodegradability Defined

There is no single definition of biodegradability. Throughout the United States and internationally there is a wide range of environmentally preferable definitions. The ASTM 6064 has defined biodegradable as a function of degree of degradation, time, and test methodology. See chart below.

Persistence Designation	Test Method	% Degradation	Days
Pw1	Ultimate	60	28
Pw2	Ultimate	60	84
Pw3	Ultimate	40	84
Pw4	Ultimate	<40	84
PwC	Primary	80	21
Pw4	Primary	<80	21

Table 1. ASTM Biodegradation Classification

Despite these definitions, there are two widely used designations for biodegradability, readily and inherently. Readily biodegradable is defined as degrading 80% within 21 days as measured by the decrease of a test sample. This type of degradation is preferable because in most cases, the fluid will degrade long before environmental damage has occurred. Because of this, they require little in terms of long-term bio-remediation. Vegetable-based lubricants and some synthetic ester-based products exhibit ready biodegradation.

There are several petroleum-based lubricants that claim "inherent biodegradability". Inherent biodegradation is defined as having the propensity to biodegrade, with no indication of timing or degree. These types of products can persist in the environment for years, continuing to cause substantial damage. They require long-term remediation due to the environmental persistence. Typically, these products are petroleum-based, like conventional lubricants. The chart below illustrates the difference in degradation timing of a readily biodegradable product compared to an inherently biodegradable product.

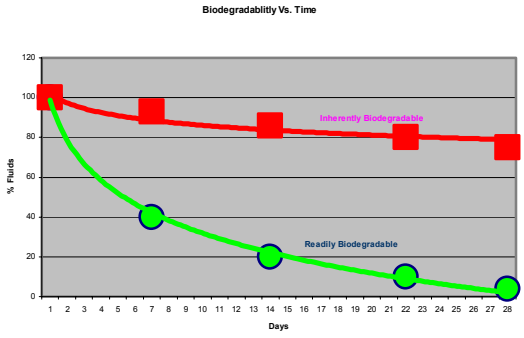

Chart 1. Readily Biodegradation

Looking at Chart 1 it is easy to see the difference between a readily biodegradable product and an inherently biodegradable one. The EPA and Coast Guard utilize this differentiation when evaluating an oil release.

Eco-toxicity

Another measurement to determine environmental effect of a lubricant is "eco-toxicity". Historically, tests for eco-toxicity have concentrated on the aquatic environment with a number of standard test procedures. Most typically, the tests are for "acute toxicity". This is a measurement of the concentration required to kill various organisms over a short period of time ranging 24-96 hours. Depending on the tests and its end points, the toxicity of a fluid is described by a loading rate that has a 50% effect (EL50) or causes 50% mortality (LL50) after the stated time. That is, at what concentration of fluid one half of the sample organisms die.

Ecotoxicity in Soil	Ecotoxicity in Water	Loading Rate wppm ll50
Ts1	Tw1	>1000
Ts2	Tw2	1000-100
Ts3	Tw3	100-10
Ts4	Tw4	<10

Table 2. ASTM Ecotoxicty Classification

Performance of Biofluids

There are a wide variety of performance levels among biodegradable products. When an environmentally preferable product is required outside the common temperatures range, a biodegradable synthetic is usually required. While offering biodegradation, these products can operate in temperatures in excess of 400° F and still offer long fluid life. As would be expected, these products are significantly more expensive.

Care must be taken in choosing the appropriate product for the specific application. Responsible Environmentally Preferable Product (EPP) suppliers can clearly indicate their definition of "environmentally preferable". The Federal Trade Commission has been very specific in their requirements for environmental claims and state "look for claims that give some substance to the claim, the additional information that explains why the product is environmentally friendly". Many "would be" EPP suppliers use misleading environmental claims such as "inherently biodegradable" or "food grade". Suppliers should be able to support performance claims with testing data. These data can include standard industry tests (ASTM), field-testing, and equipment manufacturer tests. Unless an EPP supplier specializes in environmentally preferable products, they are probably not expert in the field.

Product Demonstration

When Transocean first wanted to utilize an environmentally safe hydraulic fluid, they learned that not all environmentally safe fluids or the companies that promote them are the same. It seemed like every oil company has some type of "environmentally safe" oil. One must read the fine print to understand what they were really selling".

Since there is no standard for environmentally preferable fluids, many different types of products claim to be environmentally safe. For the most part they fall into three major classes of products:

1. Inherently Biodegradable products are those that will break down "some day" and the time to do so is usually measured in years. The environmentally safe aspect is that they are made from either food grade oil or highly refined petroleum base fluids and contain

no heavy metals in the additives. While not truly biodegradable, they can have reduced toxicity.

2. USDA H1 "food grade" lubricants that are designated for use in food processing plants. They are designed for light duty applications where the fluid does not come in contact with food. Food grade oils are typically impractical for severe marine applications. In addition, they are toxic; in fact an entire batch of food must be discarded in the event of contact with the lubricant. Finally, they are petroleum-based and therefore environmentally persistent (inherently biodegradable or non-biodegradable) meaning they will be toxic to marine life for long periods of time.
3. Readily biodegradable products such as vegetable based break down into safe, environmentally compatible components (CO_2 and H_2O) by over 90% in 28 days or less. They are also non-toxic, so they don't kill marine life. They typically are designed for low operating temperatures (less that 220°F).
4. Synthetic products usually offer enhanced performance as compared to vegetable or petroleum products. Some can be readily biodegradable and non-toxic and can withstand operating temperatures over 400°F.

History

While readily biodegradable products have a long history of successful performance in a wide range of applications, they are relatively new to the marine industry. As such, Terresolve and Transocean wanted ensure that the oil properties were sufficient for the severe duty in an offshore drilling rig.

Historically vegetable based fluids have not exhibited sufficient performance for offshore applications. There were several reasons for this.

1) Fluid formulations

Traditionally, a lubricant is compounded from base oil and a variety of performance chemistries. Early pioneers in the vegetable-based lubricant market used the same chemistry that was used for petroleum lubricants in vegetable base-oils. It was a great idea, but it didn't work. The characteristics of vegetable oils are vastly different than those of petroleum oils. Vegetable oils had to be formulated for their individual strengths and limitations. Today, there are several vegetable-based products on the market. They offer good performance and a fair price. While all vegetable-based lubricants have temperature limitations, there are some that are better than others. One should check with their lubricant supplier to determine their maximum and minimum operating temperatures. While most vegetable-based lubricants have a maximum operating temperature of 140° F, there are some that offer protection as high a 220° F. Similarly, most vegetable-based lubricants offer good performance to 30° F, yet there are some that flow below -30° F.

2) Fluid Choice

Even the highest performing biobased fluids have operating limitations in terms of temperature and life expectancy. Using a biobased fluid in an application over 220°F (and as low as 160°F for some fluids) will cause premature and possibly catastrophic equipment failure. There are numerable cases in which using a vegetable based fluid in the wrong application was a major contributor to the failure. In extreme, high temperature, environmentally sensitive applications readily biodegradable synthetic fluids should be utilized.

3) Fluid Care

Traditional biobased fluids offer unique performance characteristics however they require special care to maximize their useful life. While water is the enemy of all lubricants, most biobased fluids are more susceptible to hydrolytic breakdown, the result of which can be acid formation. These acids can attack seals, increase wear and accelerate fluid aging. Proper filtering will prolong the useful life of these fluids.

With these performance characteristics in mind, Terresolve and Transocean proceeded with their field demonstration in November 2002. The Central Hydraulic System (CHS) of the Deepwater Nautilus was chosen for its wide range of applications. It powers over 40 different pieces of equipment from most major manufacturers including Varco, Weatherford, Schlumberger, National Oil Well, Ingersol Rand and others. It is a 3000-psi system, powered by 5 hydraulic power units from Hannon and Rexroth axial piston variable stroke pumps.

Interestingly, when this project began, most U.S. based manufacturers had little or no experience with readily biodegradable fluid, while most European manufacturers were well aware of them. The US manufacturers had evaluated white oil "inherently" biodegradable fluids and found, for the most part, white oils did not offer sufficient performance. They have since evaluated the Terresolve biodegradable products and either approved them for use or are in the process of evaluating them.

To maintain proper cleanliness, a 40-liter per minute (12 gallon per minute) bypass kidney filter was installed. A 3-micron absolute, 200 beta ratio, water-absorbing cartridge was used. This system maintained fluid cleanliness to and ISO 16/15 level and maintained water content below 0.03%.

While Terresolve EnviroLogic 146H is compatible with petroleum fluids, to ensure proper results, a through drain and flush was performed. Over a 36-hour period, the Nautilus' petroleum based hydraulic fluid was drained and the system was flushed 3 times with Terresolve's EnviroLogic 146H oil. Typically, a environmentally compatible flushing fluid would be utilized, however, in this case, utilizing the EnviroLogic 146H was logistically simpler. After each flush, each component of the system was operated briefly to ensure complete flushing. Despite this effort, there was a fairly high residual petroleum level as measured by elemental analysis (137 ppm Zn). The system was then refilled with fresh ER 146H and put back in service.

In-service oil samples were taken on a weekly basis and analyzed at independent labs by both Terresolve and Transocean. Due to some repeatability issues for the independent lab, a third lab was utilized for "round-robin" testing.

The data is as follows:

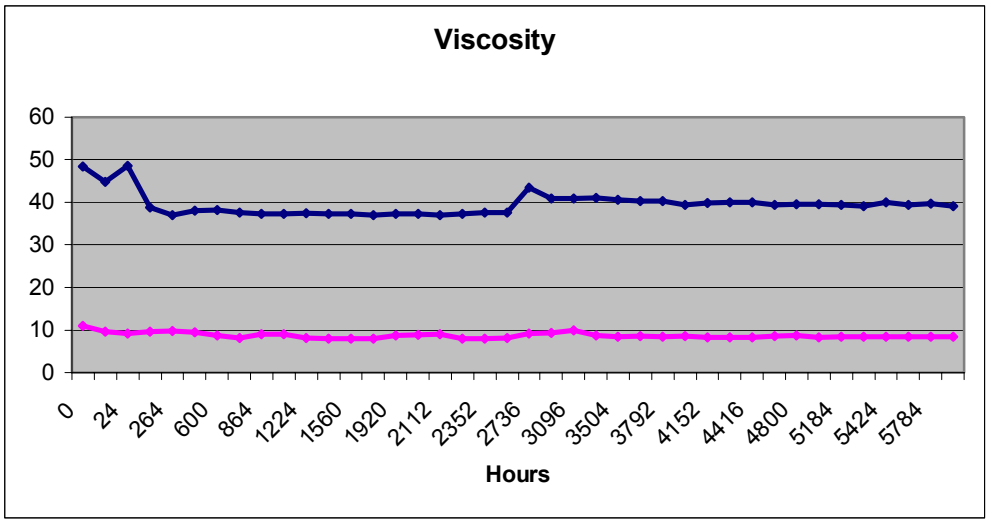

Chart 2. Viscosity

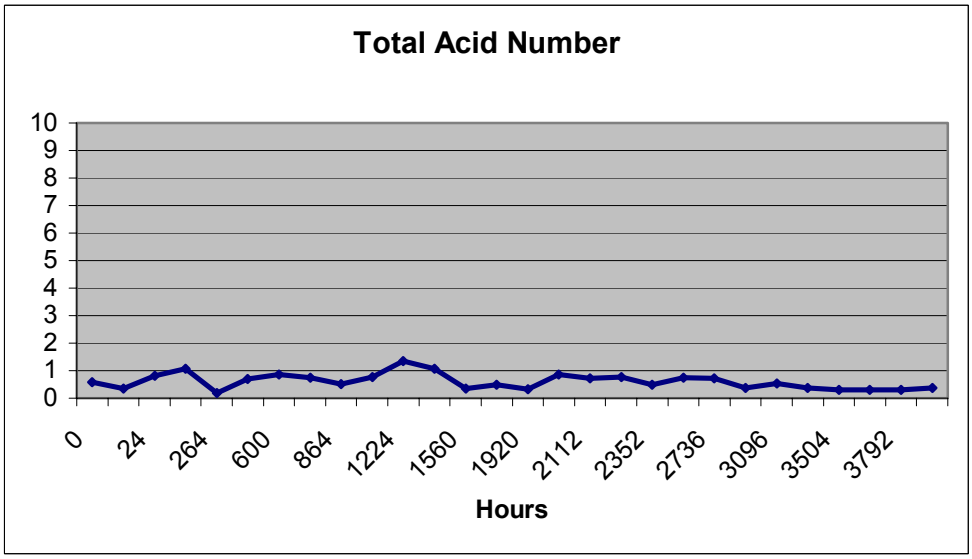

Chart 3. Total Acid Number (TAN)

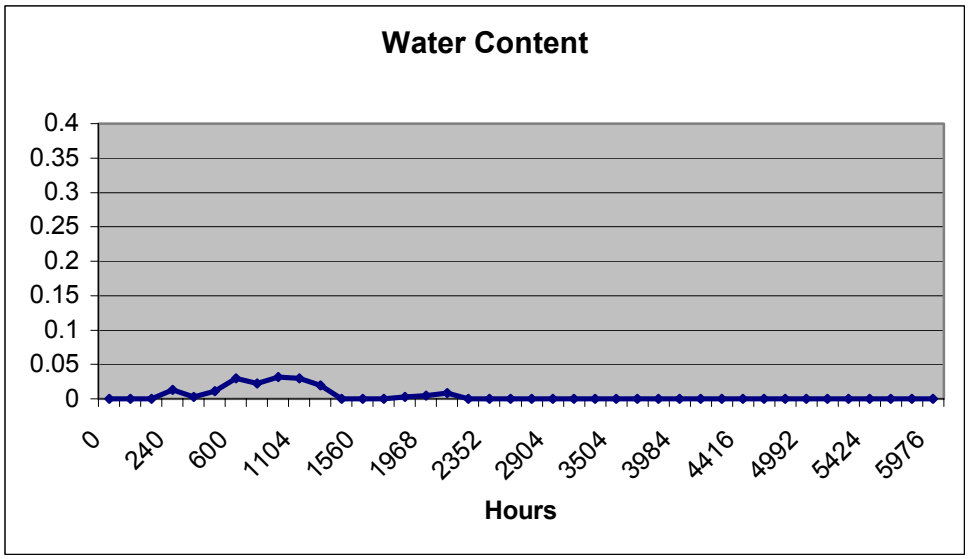

Chart 4. Water Content

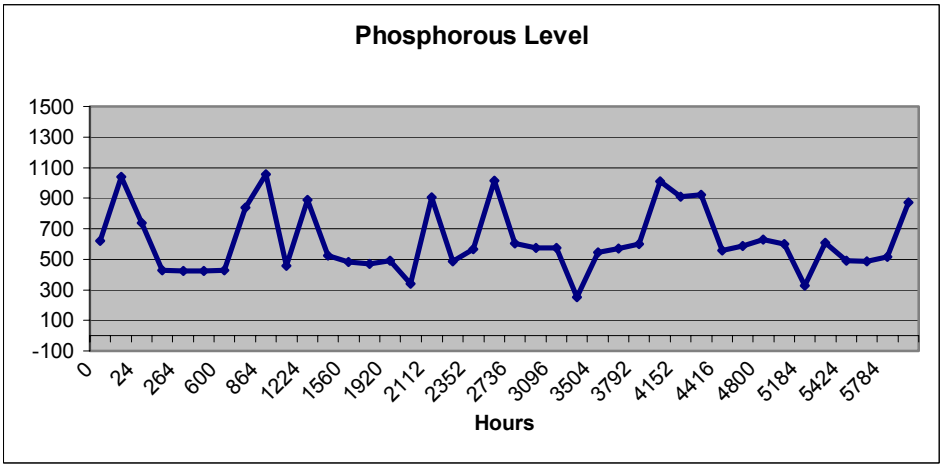

Chart 5. Phosphorous Level

Observations

Throughout the entire demonstration and to this date, the performance of Terresolve's EnviroLogic 146H has been excellent. The biofluid actually improved over-all performance, decreasing operating temperatures and increasing overall system responsiveness. This is typical because the lubricating qualities of a vegetable oil are better than those of petroleum thereby reducing friction and wear. It should also be noted that the biofluids, which have a much higher Viscosity Index than petroleum, maintained a superior high temperature profile.

Over time, the harsh working environment actually sheered the fluid viscosity at 40°C down about 10 viscosity units, dropping an ISO 46 hydraulic fluid "out of grade". While the viscosity loss did not to have any adverse effect on performance, a change of 10% or more can be a negative indicator. Since all the other major characteristics maintained their appropriate levels and the high degree of viscometric flexibility of the hydraulic system, there was no concern

about the performance of the fluid. In addition, this viscosity at 100°C, which is closer to the operating temperature of the system, stayed constant. The formulation, however, was modified to improve the sheer stability and the fluid stayed in specification for the remainder of the trial. All the other parameters remained in specification and the fluid continues to perform well.

Even taking the higher cost of using EnviroLogic 146H, the Nautilus has saved money. The maintenance staff has reported a reduction in the servo-valve sticking, which saved in man-hours, equipment and downtime.

While every effort is made to prevent hydraulic fluid from escaping, there was an incident where there was a release. The Nautilus took appropriate action, preventing further spillage, attempting to reclaim as much oil as possible and reporting the spill to the MMS and the Coast Guard. When the authorities learned it was a readily biodegradable product, they required no further action and no fines were levied.

Additionally, using a readily biodegradable hydraulic fluid allows the Nautilus to work in environmentally protected areas and potentially gain jobs that they could not with petroleum based fluids on board.

Conclusions

The true proof of performance is the field. Any fluid supplier should support their customers with routine oil monitoring and interpretation of the results. Since biodegradable products behave differently than conventional petroleum products, one should not count exclusively on the conventional oil analyst's interpretation test labs results.

It is important to partner with a biofluid supplier, with enough field and technical experience to support an oil-monitoring program and to be willing and able to support product changes.

Many factors should be considered when choosing a biodegradable fluid. The key considerations to be evaluated prior to selecting any fluid include:
Temperature
Pressure
Seals and elastomers
Water intervention
Fluid life
Spill potential
Client choice

Readily biodegradable lubricants can save time, money and protect the environment, however, they must be properly maintained. Since the key to long fluid life and top tier performance is keeping the fluid clean and dry, proper filtration is essential.

Transocean had to do their homework to determine that using a readily biodegradable hydraulic fluid was the "right thing to do". It's the right thing for their clients, the right thing for the environment and right thing for Transocean.

About the Authors

Fred Sullivan is the Mechanical Superintendent for Gulf of Mexico/North American Region for Transocean. He has over 20 years of field marine engineering experience both in Military and commercial equipment. Mr. Sullivan is considered an expert in deep-sea drill rig maintenance and the application of on-board biolubes.

Transocean excels at constructing oil and natural gas wells in the deep waters and harsh environments. They provide rigs for all types of petroleum companies in offshore drilling markets that include the U.S. Gulf of Mexico and eastern Canada, Brazil, the U.K. and Norwegian sectors of the North Sea, West Africa, Asia, including Australia, the Middle East, India and the Mediterranean.

Mark Miller is the Head of Sales and Chief Executive Officer of Terresolve Technologies. Mr. Miller has a B.S. in Chemical Engineering from Tufts University and an M.B.A. from Manhattan College. He has engineered, sold and marketed lubricants and lubricant additives for over 20 years.

Terresolve Technologies, a Cleveland-based company, is dedicated to providing non-toxic, biodegradable lubricating products that deliver exceptional performance. For more information about Terresolve, field test results and all of its environmentally friendly products, visit their web site at www.terresolve.com or call (800) 661-3558.