Palm Oil Derived Esters – An Environmentally Safe Drilling Fluid

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ABSTRACT

The rising world energy demand has led to exploration for oil and gas in increasingly difficult environments. Exploration is now extending into sensitive regions, in particular, offshore fields. Drilling in deep water in increasingly deviated and extended wells and borehole instability in challenging geological formations are some of the obstacles encountered.

*Oil-based drilling fluids are widely used in drilling, especially in highly technical wells. This is because oil-based drilling mud systems perform much better than water-based muds in bore hole stabilization and providing lubricity thereby give faster rates of penetration. However, they are a cause for environmental concern and with the potential long-term liability for damage caused by mud spills and problems in disposal of the oil-contaminated drill cuttings, changes are afoot. The industry has been replacing highly aromatic oils (*e.g*. diesel) with low aromatic mineral oils as well as synthetic oils. However, as environmental legislation and controls become more stringent, even the newer and less polluting mineral and synthetic oils in vogue now may be adjudged unsuitable because of their non-biodegradability. Indeed, today, in many parts of the world, including countries like the USA, United Kingdom, Holland, Norway, Nigeria and Australia, the use of diesel and mineral oil-based drilling fluids in offshore operations is already either severely restricted or banned because of their toxicity, persistency and bio-accumulation.*

In direct response to the need for a high performance and environmentally safe alternative to petroleum-based materials, common vegetable and fish oils have been tested. *However, none of them as yet offers the necessary chemical stability nor rheological properties required. Many individual results were compared during the initial testing period. Notwithstanding this, after considerable research and extensive testing, a high performance and biodegradable vegetable-based ester has been*

produced from palm kernel oil. This ester has been produced in Malaysia since 1995 and has found widespread acceptance and applications in offshore regions where pressure from the environmental authorities has been mounting. This biodegradable ester is an alternative to petroleum-based muds. This is because petroleum muds are costly and troublesome to process for recovering and transporting the drill cuttings to the shore for treatment and disposal. The used vegetable-based esters, in contrast, can be safely discharged into the ocean without harming the eco-system.

Malaysia is becoming more conscious of the need to exercise greater care in protecting its environment. Sensing the need for better control over marine pollution, the Department of Environment proposed in 1999 an amendment to the Environmental Quality (Scheduled Wastes) Regulations 1989 to include drilling mud or residues containing hazardous compounds *(Part I, item 35) in the list of scheduled wastes. However, incorporating it is still an ongoing and arduous process. The petroleum industry has generally been slow to respond simply because there is no regulatory requirement to do so. Although environmental friendly ester-based carrier fluids are available since the early 1990s, the additional cost is deemed unnecessary. However, the waste we leave on our seabeds will stay around for a long time and continue to impact us well into the future. Therefore, we must act immediately in order to prevent a public outcry later for our lack of serious attention and responsible action. Good practice and common sense should dictate [see USA Environmental Protection Agency (EPA)] the use of best available technology at reasonable cost. The additional cost to use such systems represents less than 2% of the total well cost. It also makes perfect sense to champion the use of renewable and environmentally friendly palm derived products in Southeast Asia since Malaysia is the world's largest producer of palm oil.*

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INTRODUCTION

Among others, shale- and clay-rich geological formations remain a constant challenge in drilling due to their instability and water sensitiveness. Various drilling fluids have been applied to meet this issue. Drilling fluids since the late 1960s are based on diesel and/or mineral oil. These oil-based muds (OBM) are invert emulsions with the oily phase forming the outer phase, encapsulating an inner, brine phase stabilized by emulsifiers and other conditioning additives. Oil-based mud systems perform much better than water-based muds in hole stabilization and allow faster penetration rates. Additionally, one of the important features of OBM is its high lubricity. Lubricity is of great importance when drilling extended and deviated wells, more and more common in offshore exploration. Ester muds have generally better lubricating properties than other non aqueous fluids.

ECOLOGICAL IMPACT ON THE ENVIRONMENT

A major drawback of OBMs is their poor biodegradability in aerobic conditions. Most importantly, they degrade even more slowly in anaerobic conditions. Anaerobic conditions are typical on the seafloor and thus in the pile of drill cuttings dumped overboard from the drilling platform. A typical well may generate between 1000 and 1500 t of cuttings. With an average oil retention of 15%, around 150 - 225 t of oil from the drilling fluid is discharged into the sea for each well drilled (In the Gulf of Siam, one rig can drill up to 40-50 wells per year.). A large area around the drilling site may thus be affected (*Figure 1*). It is the disposal of the cuttings that very early on raised concern over the ecological impact on marine life and, subsequently, on the marine food chain (*Figure 2*).

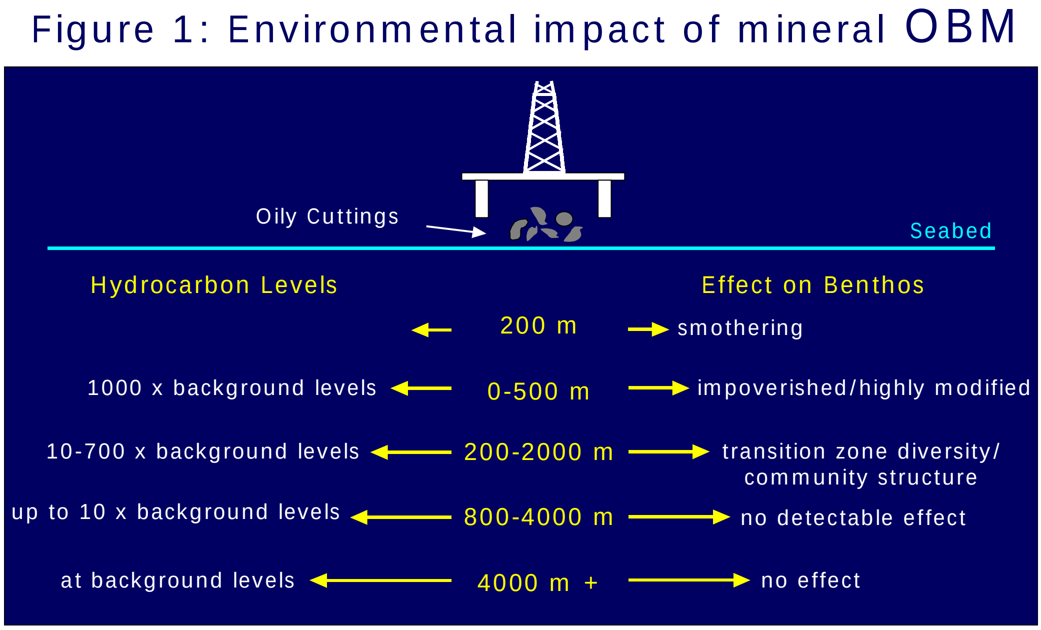

Figure 1. Environmental impact of mineral oil-based mud (OBM).

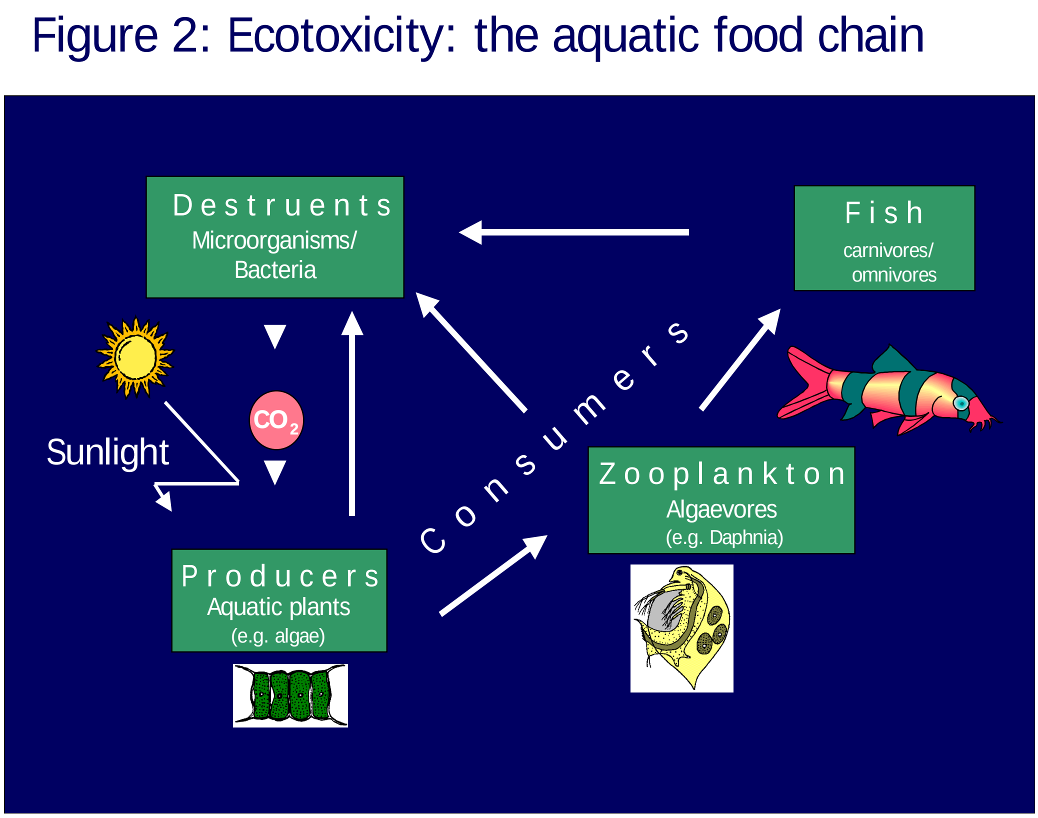

Figure 2. Ecotoxicity: the aquatic food chain.

In summary, mineral oils and most petrochemical synthetic fluids can pollute the marine environment by dumping of the cutting piles overboard and accidental spillage because of:

- low biodegradability, in particular, in anaerobic conditions;
- high toxicity from the presence of aromatic compounds;
- tainting of marine life, affecting its eating qualities; and
- severely impact on the seafloor sediments and food chain.

The Challenge

The industry therefore needed to find a fluid that satisfies both the environmental and technical criteria by:

- showing excellent technical performance: it would have to behave like a traditional OBM with all the technical advantages;
- obtaining regulatory approval; and
- being cost-effective.

The Concept

This study made use of the *green* chemistry concept. Initially, several vegetable oils (peanut, rapeseed, soyabeen oil) and fish oil were screened. However, all of them (tri-glycerides) were found too viscous, and, worst, hydrolyzed at elevated temperatures, as would be encountered during drilling. The hydrolysis, due to their poor tolerance of alkalinity and poor high temperature stability, finally made the derivatives of palm oil and palm kernel oil more suitable substitutes. Splitting the triglycerides into monomeric fatty acids and subsequently transforming them to esters proved to be extremely promising.

WHAT MAKES PALM OIL/PALM KERNEL OIL DERIVED VEGETABLE ESTER FLUIDS SO UNIQUE?

As already outlined, the unique ecotoxicological properties of esters have dramatically reduced the impact of drilling fluids on the marine environment. Consistently, vegetable ester drilling fluids have passed all the presently exercised test protocols. Both aerobically and anaerobically esters are readily degradable. This is due to their natural long, unbranched and even numbered C-chains that bacteria can digest easily, even under difficult circumstances. The balanced C-chain composition is obviously benign to marine species as high tolerances are registered for esters in contrast to the synthetic (petrochemical) base fluids. The esters contain no aromatics or any other toxic hydrocarbon derivatives.

Seafloor surveys in the North Sea, Gulf of Mexico, offshore Australia and Brunei and ongoing toxicity testing with various marine species have confirmed the esters' environmentally benign properties. In the past, the accumulation of cuttings with mineral oil-based muds has caused hydrocarbon levels 10-700 times higher than that of the natural background (*Figure 1*). Such detrimental effects to the benthic fauna are not observed with ester fluids - all seabed surveys have documented short-term recoveries after the ester cutting disposal.

Beside the ecotoxicological advantages, the technical performance also highly favours the ester-based fluids. Drilling with ester fluids results in exceptionally well gauged bores. Esters strongly protect the geological formation, preventing the swelling of reactive clay and shale formations. Their excellent lubrication adds to these advantages, providing support in deviated and extended reach operations. The polar ester group and balanced vegetable C-chains are the main factors conferring these properties. But, their high stability against hydrolysis is an additional factor.

Human Health Aspects

As part of responsible worker care, safety has also to be considered. It is well known that esters pose a much smaller risk to human health than mineral oils or related substances.

Fish Taint

Taint means the adverse effect of a substance on the smell or taste of a food making it unsuitable for human consumption. Thus, the tainting potential is an important parameter in the assessment of substances likely to be exposed to the marine environment. Fish studies in the North Sea confirm that esters have minimal impact on the food quality of commercially exploited fishes. This aspect is not to be overlooked in evaluating the impact of substances to be dumped in the marine environment.

Synthetic Fluids

Since their introduction in 1990 in Norwegian waters, vegetable esters have surpassed all expectations. Although the chemical and drilling industry has produced alternatives to esters (mostly based on synthetic petrochemicals), all of which have reasonably good technical performance, their environmental behaviour varies. Esters have thus consistently outperformed them by:

- showing excellent ecotoxicological properties, in particular, high anaerobic biodegradability and low toxicity (*Figures 3* to *5*);
- posing a much smaller risk to human health (no inhalation toxicity!);
- having been used for over 10 years without any epidemiological issues (The same cannot be said, *e.g.*, internal olefins and mineral oils which have caused skin irritation and inhalation problems.); and
- not tainting marine life, not accumulating and not having any negative effects on algal photosynthesis.

Figure 3: Anaerobic biodegradation of esters

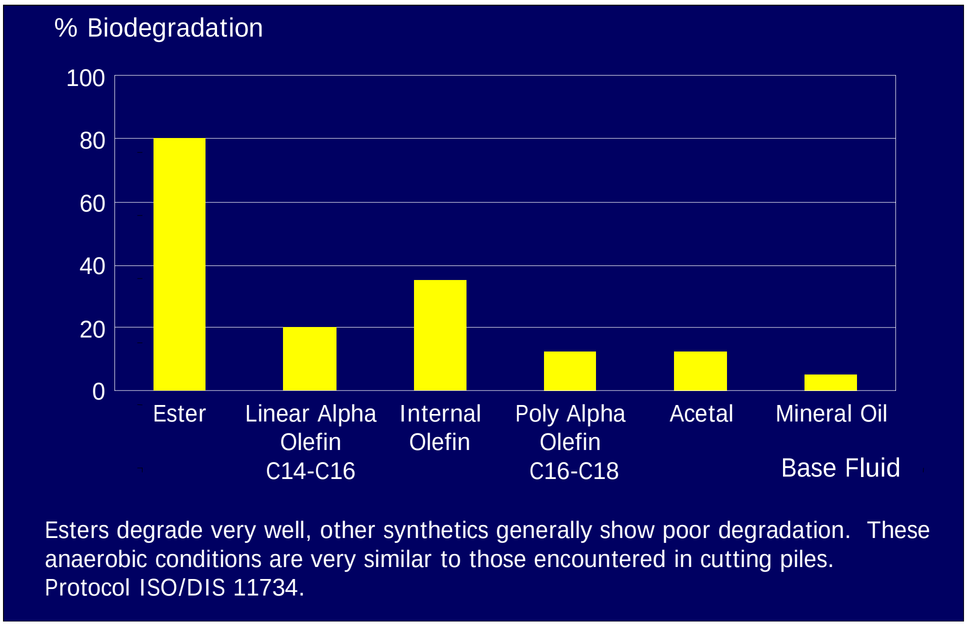

Figure 3. Anaerobic biodegradation of esters.

Figure 4: Solid phase biodegradation test results

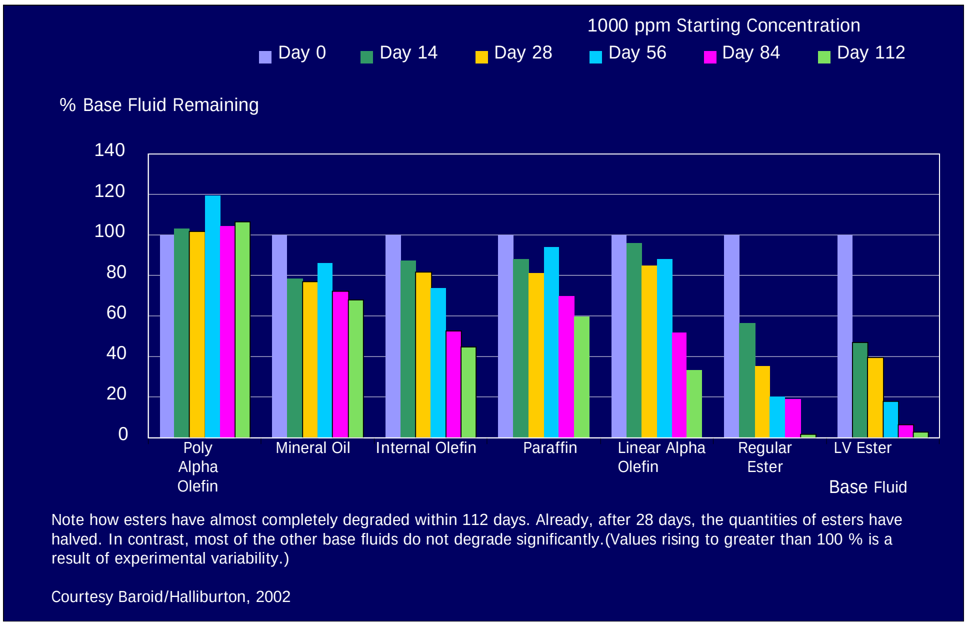

Figure 4. Solid phase biodegradation test results.

Figure 5: Toxicity of base fluids

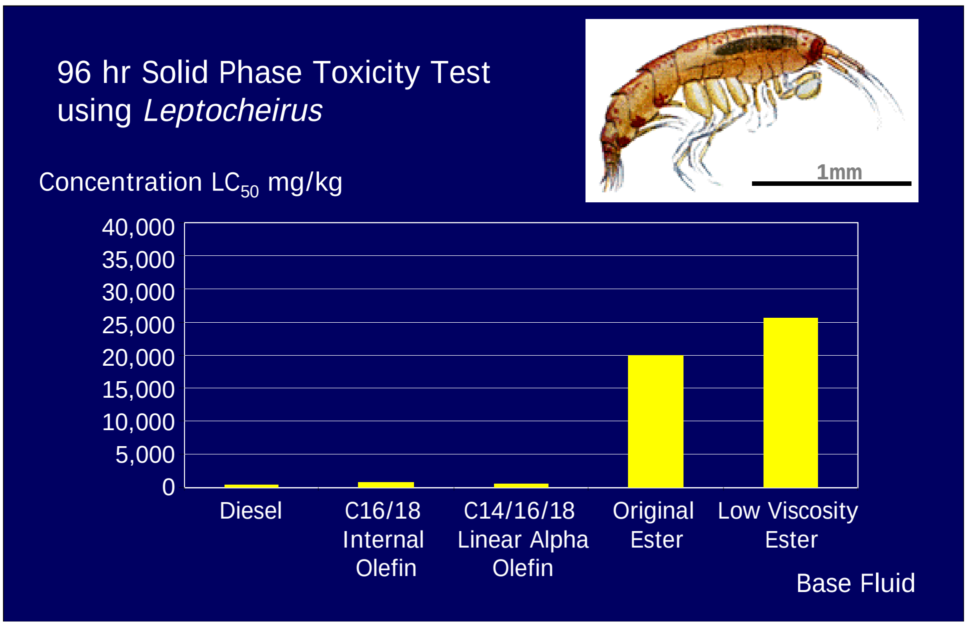

Figure 5. Toxicity of base fluids.

THE REGULATORY EQUATION / PHILOSOPHY OF SUSTAINABILITY

From the beginning of our research, it was a firm intention to work with governmental institutions formulating new rulings based on sustainable energy concepts. This approach helps the oil and gas industry to improve its public image and oil companies enhance their corporate image meeting the needs for sustainability, thus avoiding long-term liabilities for the marine environment.

The idea of using renewable resources for exploration of fossil energy (*Figure 6*) has increasingly impressed all participants. This *green* strategy decisively reduces contamination of the environment by not using non-natural hydrocarbons, thus minimizing or avoiding long lasting contamination and future liabilities from, in particular, polluted and noxious wastes on the seafloor.

Figure 6: Petrofree ester fluids – "The Concept"

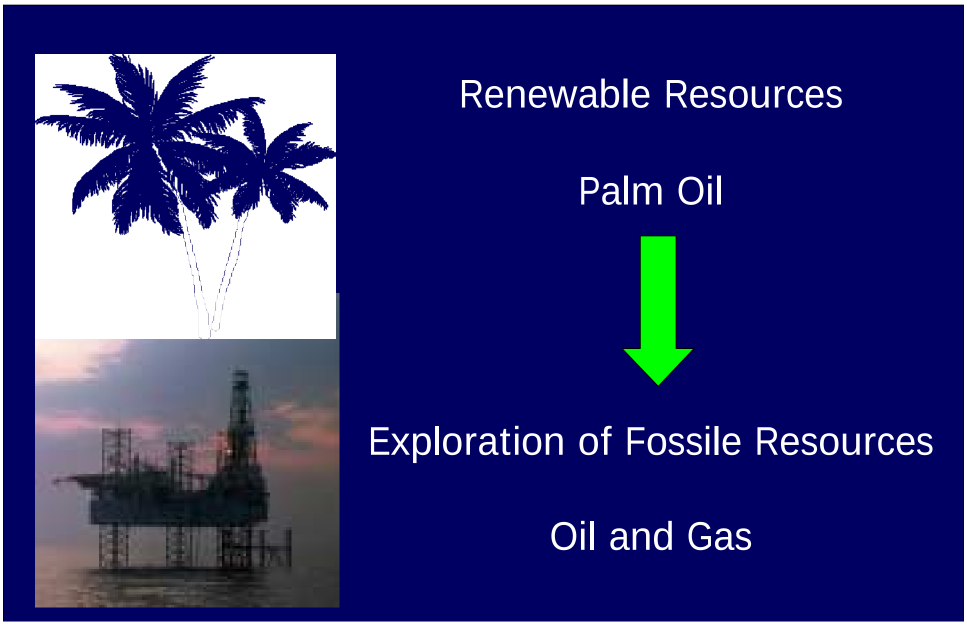

Figure 6. Petrofree ester fluids – the concept.

Where Do We Stand Today?

Today, numerous government agencies are imposing increasingly stringent environmental compliance on the use and discharge of drilling fluids, in particular, in offshore environments.

In the Gulf of Mexico, the United States Environmental Protection Agency (US-EPA) has raised the bar. Strict standards are set for compliant fluids, and are being continuously reviewed and adjusted. The US-EPA's quest to reduce negative offshore impacts on the marine ecosystem from discharge of the fluids is the objective of the National Pollutant Discharge Elimination System (NPDES). Ester-based fluids meet the highest of the EPA standards, satisfying the 275 days biodegradation test and Leptocheirus Test (US-EPA 1999). *Leptocheirus plumulosus*, a tiny crustacean, plays an important role in marine toxicity tests for discharge compliance as it is very sensitive to contamination in marine sediments.

Figure 7: Toxicity testing (Europe and US)

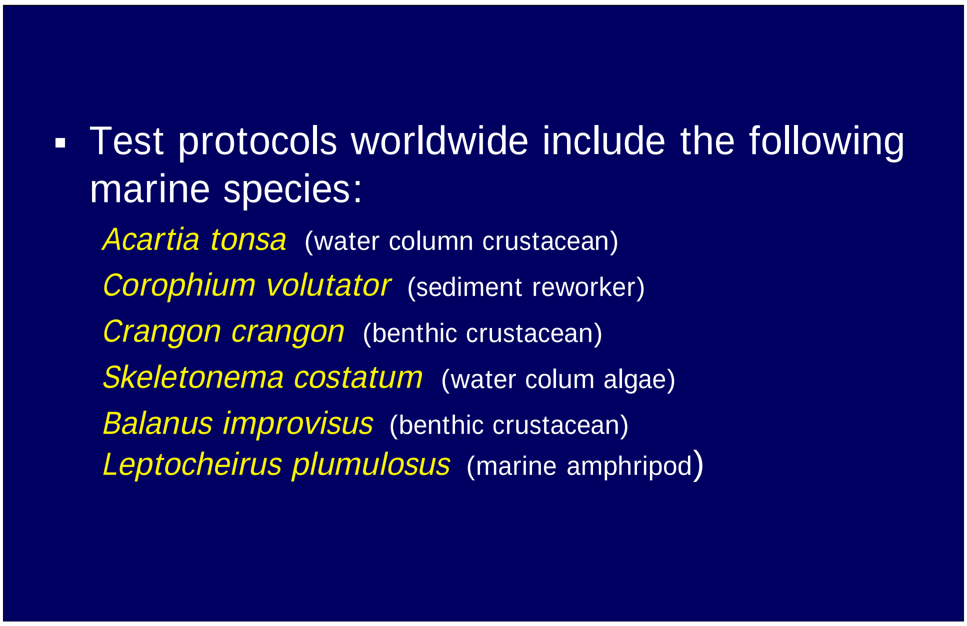

Figure 7. Toxicity testing (Europe and US).

Worldwide, similar protocols to those used by the US-EPA are being implemented based on toxicity of various marine species (*Figure 7*). As a result, many fluids derived from petroleum are no longer acceptable. In contrast to the US-EPA ruling, in operations in the North Sea, regulated by the Oslo Paris Commission (OSPAR), cuttings are to be shipped onshore. However, this so-called zero-discharge strategy still requires ultimate disposal of the cuttings, and certainly still has an environmental impact due to the increasing difficulty in finding terrestrial waste disposal sites. It is also important to consider that comparing shipping-to-shore with dumping the ester fluid cuttings into the sea, substantial financial savings can be made over the onshore treatment and disposal costs, fuel (for the transport and treatment) and reduction in air emissions.

The US-EPA, as part of its rulemaking decisions, undertook not only extensive potential environmental impact assessments but also studied the cost, resources, occupational hazards and chemical exposure of the alternatives with offshore discharge, shipping to shore and treatment of the cuttings and re-injection of the wastes into the sea bed. In their study, the government examined in particular the impacts of:

- drilling discharges on the sea floor;
- other impacts caused by shipping the drill cuttings (from non-ester-based fluids) ashore; and
- the cost for shipping, onshore transfers and final disposal of the cuttings on land.

In a resume, the EPA's extensive holistic environmental impact assessment recommended sea disposal of synthetic fluid (esters and certain olefinic fluids) cuttings in favour of shipping contaminated (non-ester based fluids) drill cuttings to the shore. In comparing seabed disposal of ester fluids with shipping the fluid cuttings to shore, the Agency found the following:

- financial savings of over USD 7 million;
- a saving of onshore disposal or re-injection of 80 741 t of wastes;
- fuel savings equivalent to 27 057 barrels of oil; and
- air emissions reduced by 384 t.

The above were obtained from collecting average data in the Gulf of Mexico from a one year's period. Most other countries with offshore drilling are now introducing new regulations to protect their marine environment. In West Africa and Brazil, in particular, but also in Vietnam, discharges of fluids and cuttings are coming under increased scrutiny, following the lead of the US-EPA and OSPAR in the North Sea.

Authorities will increasingly monitor the implementation of their guidelines. Phase out schedules for non-complying fluids have to be strictly observed by the operators as a condition in their permits to drill. In many cases, the individual operator's standards are even more stringent to minimize the environmental impact of their work and to earn kudos as good global citizens.

Commercial Issues

The cost of ester fluids is higher than that of mineral oil or synthetic petroleum-based drilling fluids. This higher cost, as shown in *Figure 8*, reflects the expense of producing. The esters from renewable resources (for example, palm kernel oil) as opposed to merely refining mineral oil pumped from the ground. The higher cost per barrel of ester is off-set by technically superior properties, in particular by an increased rate of penetration, less drilling problems and reduced liabilities on spillage or lower disposal cost, and of course, because of the superior environmental properties as discussed earlier. Yet, taking all related costs (including waste disposal of cuttings, shipping to shore or depositing in land storage) into account, ester carrier fluids offer a more economical solution. In regards to future liabilities, vegetable-based ester fluids are the least expensive technology in the long run.

Figure 8: Base fluid relative costs

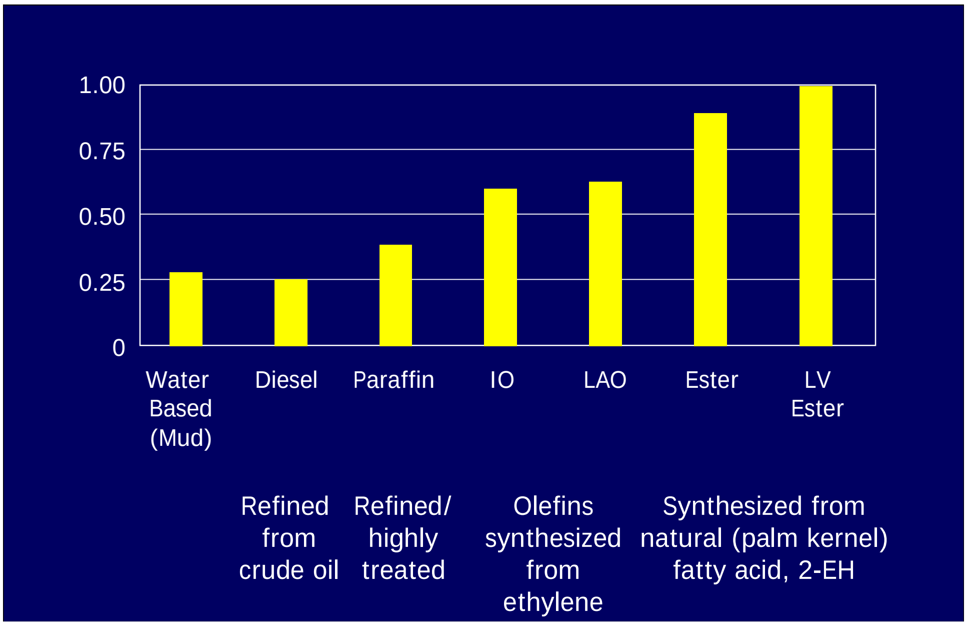

Figure 8. Base fluid relative costs.

What's Next?

In the meantime, new, low viscosity esters and new ester-based drilling fluids have been developed. Continual improvements in process technology and increasingly strict regulatory rulings are enhancing the use of esters in drilling fluids worldwide. Also in the meantime, certain blends with vegetable esters offer additional opportunities to satisfy present needs in several offshore regions.

THE MALAYSIAN EQUATION

For a long time now, esters produced in Malaysia have been used worldwide (Brunei, Australia, Gulf of Mexico, North Sea and West Africa). It is somewhat ironic that this local product has found success without the country but not within it. Malaysia is the world's largest producer of palm oil, and an important centre for oil and gas development and exploration with a major indigenous oil company. Esters offer a unique opportunity to champion the use of home grown, renewable, palm derived products in the country. This will benefit the local economy in generating work in their production and contribute to a sustainable environment.

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