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STUDY TITLE: A Literature Review of Environmental Impacts of Synthetic Based Drilling Fluids

REPORT TITLE: Environmental Impacts of Synthetic Based Drilling Fluids

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KEY WORDS: synthetic based drilling fluid; water based drilling fluid; oil based drilling fluid; drilling mud; drill cuttings; linear alpha olefin; poly alpha olefin; internal olefin; linear alkyl benzene; ether; ester; acetal; Gulf of Mexico; North Sea; Australia; outer continental slope; benthic; toxicity; bioaccumulation; biodegradation; anaerobic; anoxia; hypoxia; ecological recovery; ecological risk assessment.

BACKGROUND: Drilling fluids are required for drilling oil and gas wells. During drilling, drilling fluid is circulated down the hollow drill pipe, through the bit and up the annulus between the drill pipe and the borehole. The fluid carries drill cuttings (crushed rock produced by the drill bit) to the surface. The drilling fluid is processed on the platform to remove the cuttings and recycled back down the well. The separated cuttings are in most cases, discharged to the ocean. The discharged drill cuttings contain 5 to 15% adhering drilling fluids.

There are two major types of drilling fluids, water based fluids (WBFs) and nonaqueous base fluids (NABFs). WBFs, used in most offshore drilling operations in U.S. waters, consist of fresh or salt water, barite, clay, caustic soda, lignite, lignosulfonates, and/or water-soluble polymers. NABFs, are emulsions. A base fluid consisting of a liquid hydrocarbon or other water insoluble organic chemical forms the continuous external phase while calcium chloride brine forms the discontinuous internal phase. NABFs also contain barite, clays, emulsifiers, water, calcium chloride, lignite, and lime. The two most important types of NABFs are oil based fluids (OBFs), in which the base fluid is diesel fuel or a petroleum-based mineral oil, and synthetic based fluids (SBFs), in which the base fluid is a well characterized synthetic organic chemical. SBF base fluids include linear-α-olefins, poly-α-olefins, internal olefins, linear alkyl benzenes, ethers, esters, or acetals. The SBF base fluids used most frequently in U.S. waters are linear-α-olefins and internal olefins.

Although WBFs are used for drilling most wells in offshore waters of the U.S., use of SBFs is increasing. SBFs have several technical advantages over WBFs, particularly when drilling in very deep water or when drilling a highly deviated well. OBFs have many of the same technical advantages as SBFs, but, because of their adverse environmental impacts, OBFs and OBF cuttings are not permitted for offshore disposal in U.S. waters. WBFs and WBF cuttings are currently permitted for disposal in Federal waters. SBF cuttings, but not SBFs are currently permitted for offshore disposal in the Gulf of Mexico.

OBJECTIVES: 1) To review and summarize the available information in the scientific literature about the composition, environmental fates, and environmental effects of SBFs in the marine environment; (2) to incorporate the available information into a screening-level ecological risk assessment for discharge of SBF cuttings to deep offshore waters of the Gulf of Mexico; and (3) to produce an annotated bibliography of publications concerning the environmental fates and effects of SBFs.

DESCRIPTION: A computer-based literature search was performed for all available published documents dealing with SBFs and SBF base fluids and additives. Technical contacts within the oil and gas and drilling mud industries of the United States, North Sea countries, and Australia were contacted for unpublished reports and information about marine environmental fates and effects of SBFs and SBF cuttings. All the potentially relevant reports and publications were accessed and reviewed. An annotated bibliography of SBF publications was prepared. All the relevant information was synthesized and interpreted in a technical review and in the form of an ecological risk assessment for SBF discharges to deep offshore waters of the Gulf of Mexico.

SIGNIFICANT CONCLUSIONS: The SBF base fluids used most frequently for drilling in the Gulf of Mexico are linear-α-olefins (LAO) and internal olefins (IO). Bulk SBFs are not permitted for discharge to waters of the Gulf of Mexico, but SBF cuttings are. Discharged SBF cuttings usually contain 5 to15% adhering SBF. The SBF cuttings form clumps in the receiving waters and quickly settle to the bottom following discharge to the ocean. SBF base fluids are biodegradable. Esters degrade most rapidly. LAO and IO biodegrade at moderate rates under aerobic and anaerobic conditions, but poly-α-olefins and acetals do not biodegrade at a rate significantly greater than that of mineral oils in OBF. Biodegradation often causes depletion of oxygen in sediments. SBFs and SBF base fluids have a low toxicity to water column and sediment-dwelling marine organisms. However, high concentrations of SBF in sediments produce adverse effects in benthic communities. The usual response is the loss or decrease in abundance of several species of benthic fauna and an increase in the abundance of a few opportunistic species, leading to an overall decrease in species diversity. This effect probably is caused by organic enrichment of the sediments with biodegradable SBF base fluid, leading to sediment hypoxia. Direct burial may also contribute to effects of SBF cuttings in benthic communities, particularly in deep continental slope waters. Recovery of the benthic community occurs slowly as SBFs are biodegraded or advected from the site by sediment transport. Recovery may require three to five years. Adverse effects of SBF cuttings discharges have not been observed in the water column and are not expected because of the low toxicity of SBFs and the rapid settling of cuttings to the bottom.

STUDY RESULTS: Cuttings containing 5 to 15 percent adhering SBF are discharged to the ocean during drilling with SBFs. During drilling of each of 21 wells in the UK Sector of the North Sea in the late 1990s, 150 to 3000 metric tons of cuttings containing 11 to 300 tons of SBF were discharged to the ocean. SBF cuttings tend to clump together in large particles that settle rapidly to the sea floor. Because of the rapid settling, SBF cuttings discharges do not increase water column turbidity and drilling fluid ingredients do not reach concentrations in the water column high enough to cause toxicity to water column organisms. The cuttings settle in a very heterogeneous pattern on the bottom near the platform, the direction of deposition depending on water column currents. Several field studies have shown that the highest concentrations of SBF cuttings usually are located in sediments within about 100 m of the platform. However, some SBF cuttings may be deposited out to 1 to 2 km from the discharge point. SBF base fluid concentrations as high as 200,000 mg/kg dry wt have been observed in sediments. Concentrations in sediments usually are less than 10,000 mg/kg at distances greater than 200 m from the discharge. SBF base fluid concentrations in sediments usually decrease with time due to resuspension, bed transport, mixing, and biodegradation.

Sediment dwelling bacteria and fungi are able to use SBF base fluids as a source of nutrition, releasing simple non-toxic metabolic degradation products. Biodegradability of SBF base fluids under different conditions in sediments varies widely. Esters are most biodegradable; poly-α-olefins degrade slowly. Biodegradation of SBF base fluids in sediments results in depletion of oxygen concentrations in the sediments. Oxygen depletion slows biodegradation and adversely affects resident benthic fauna.

SBF base fluids have a low bioavailability and toxicity to water column and sediment dwelling marine organisms. Their toxicity is much less than that of OBF base oils. The toxicity of SBFs is comparable to that of WBFs.

Several field studies have been performed to monitor the biological effects of SBF cuttings discharges on the benthic environment. The studies show that where SBF base fluids accumulate to high concentrations in sediments, adverse effects in benthic communities are evident. The usual pattern of response to SBFs in sediments is a decrease in the number of taxa of marine animals in the sediments, accompanied by little change or even an increase in the number of individuals present. This change results in a decrease in species diversity. The change in benthic community structure is considered an organic enrichment effect. Microbial degradation of SBF in sediments results in oxygen depletion and hypoxia or anoxia. Sensitive species are eliminated and are replaced by tolerant, opportunistic species. Population size of the opportunists may increase to a high biomass as the fauna use the elevated microbial production as food. Recovery of affected benthic substrates occurs when SBF concentrations decline to levels that are low enough that the sediments can become re-oxygenated.

It is probable that within three to five years of cessation of SBF cuttings discharges, concentrations of SBF base fluids in sediments will have fallen to low enough levels and oxygen concentrations will have increased enough throughout the previously affected area that complete recovery will be possible. The rate of deep-water benthic ecosystem recovery will depend on the rate of recruitment and recolonization by the benthic fauna characteristic of the area. Because some species of deep-water benthic animals reproduce and grow slowly, complete recovery may require many years. However, ecological succession toward recovery is likely to begin shortly after completion of cuttings discharges and will be well advanced within three to five years when SBF base fluids have degraded to low concentrations.

STUDY PRODUCTS: Neff, J.M., S. McKelvie, and R.C. Ayers, Jr. 2000. Environmental Impacts of Synthetic Based Drilling Fluids. A final report for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-064. Contract No. 15240. 132 pp.

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