Effects of Oil and Chemically Dispersed Oil in the Environment

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INTRODUCTION

Consider this scenario – an oil tanker has been involved in an accident near mangroves and a large salt marsh. Some of the tanker's cargo has been released in the accident. One member from the team of decision-makers is assigned the responsibility of recommending countermeasure options. While dispersants are one option, he is concerned about their possible effect on resources in the area, including all resident plants and animals. Many papers are available which provide information on the different effects of chemically dispersed oil on biological resources. However, applying the findings from numerous scientific experiments to a real-world emergency is not easy. What this person wants is a concise course that in layman's terms explains the general effects of oil and chemically dispersed oil on various biological resources. Such a course would have made preparing for, and now dealing with, dispersant use issues less time consuming, while making the information more comprehensible. This course was designed to fill that planning need. Ideally, it should be read along with other reference material as part of pre-spill planning activities, not just during a response emergency.

PURPOSE OF THE COURSE

This course has been developed as a reference document for oil spill response decision-makers, to provide an accurate summary of exposure and effects of oil and chemically dispersed oil in the marine environment. During both pre-spill planning and actual response, decision- makers are faced with many questions concerning exposure and effects. For instance:

- What will the oil do to a particular biological resource, both to individuals and the entire population?
- Is dispersant alone likely to cause adverse effects?
- Will adding chemical dispersants change the way oil affects plants and animals?
- Would it be better to expose one resource to the oil so that another resource could be protected?

These are the types of questions addressed in this course.

Part One of the course provides a general, background discussion on concepts necessary for understanding the potential sources of oil and dispersed oil contamination that can cause adverse effects. This information provides the foundation for understanding oil chemistry, toxicity, and exposure. **Part Two** focuses on the effects of undispersed oil and **Part Three** discusses how chemically dispersing oil changes expo- sure and effects to marine animals and plants. Resources are discussed in groups, according to their distribution in the environment and their likelihood of exposure to oil and chemically dispersed oil (i.e., surface- dwelling, water column, bottom-dwelling, and intertidal). **Part Four** provides information on the tradeoffs of various decisions and information on conducting an ecological risk assessment.

This course also identifies and explains specific terms associated with oil that may be used by technical experts during planning or response operations. The first time a new technical term is used within this book- let, it will appear in an ALL-CAPS format; this signifies that a more detailed explanation or definition is present in the right or left margin near where the word(s) is first used within the main text.

PART I: SOURCES OF CONTAMINATION AND INJURY

The type of oil spilled is a key variable in determining its impact on a biological resource. The composition of crude oil is different from re- fined products, and both compositions can vary greatly. For instance, one crude oil may have many components that evaporate quickly into the atmosphere, whereas, another crude oil may be composed of many heavy components that can persist in the environment for a long time. General oil properties are reviewed below. A more detailed discussion on oil chemistry can be found in the first course in this series, "Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It? An Information Course for Decision-Makers."

Purpose of Part I, Section I

To review oil composition and properties.

***Hydrocarbons** are chemical compounds composed solely of carbon and hydrogen atoms. In crude oils, hydrocar- bons are the most abundant compounds–up to 85 percent of the overall mixture (Gilfillan, 1993).*

SECTION I: WHAT IS OIL?

HYDROCARBONS are the most abundant organic compounds in crude oil (NRC, 1989; Gilfillan, 1993). There are essentially three groups of hydrocarbon components in every crude oil type:

1. Lightweight components (low molecular weight)
    - contain 1 to 10 carbon atoms (C1 to C10);
    - evaporate and dissolve more readily than medium or heavy-weight components, and also leave fewer residual weathering compounds (often called residue) than medium or heavy- weight components;
    - are thought to be more BIOAVAILABLE to animals (readily absorbed by an organism) than medium or heavyweight components; and
    - are potentially flammable and readily inhaled, so, are of concern for human health and safety.

    Examples: Benzene, Toluene, Ethyl-benzene, Xylene, ALKANES (see the first course in this series for more information).

    Because lightweight components are biologically available to organisms and can be readily inhaled, their potential TOXICITY to animals and humans is of concern.

2. Medium-weight components (medium molecular weight)
    - contain 11 to 22 carbon atoms (C11 to C22);
    - evaporate or dissolve more slowly, over several days, and may leave behind some residual weathering compounds which can appear as a coating or film;
    - are sometimes regarded as more toxic than the lightweight components; and
    - are not as bioavailable as lower-weight components, resulting in lower chemical toxicity to animals.

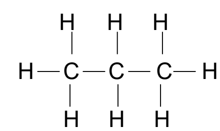
    Example: POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) (see the first course in this series for more information).

3. Heavyweight components (high molecular weight)
    - contain 23 or more carbon atoms (≥C23);
    - undergo little to no evaporation or dissolution;
    - can cause long-term affects via smothering or coating by residual weathering compounds. These residuals may remain in the water column and sediments indefinitely (Helton, 1996); and
    - are not very bioavailable, resulting in lower chemical toxicity to animals when compared to light or medium-weight components.

    Example: Asphaltenes (see the first course in this series for more information).

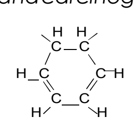
*To be **Bioavailable** is to be in a form that is conducive to uptake by organisms. Bioavailability is the tendency of a substance (in this case, individual oil components) to be taken up by a biological organism (Rand and Petrocelli, 1985).*

***Alkanes** are petroleum hydrocarbon compounds, also called normal paraffins and isoparaffins. Alkanes are characterized by branched or un- branched chains of carbon at- oms with attached hydrogen atoms and contain only single carbon-carbon bonds (no double or triple bonds between carbon atoms).*



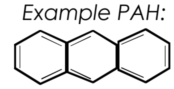
***Toxicity** represents the degree of danger a substance poses to animal and plant life. The words "toxic" and "poisonous" have, essentially, the same meaning. Therefore, it can be said that something with high toxicity is highly poisonous, and vice versa.*

***Polycyclic Aromatic Hydrocarbons (PAHs)** are a class of hydrocarbons characterized by multiple rings with six carbon atoms each. PAHs are considered to be the most acutely toxic components of crude oil, and are associated with chronic and carcinogenic effects.*



Six-carbon Ring

Example PAH:



Anthracene

Persistence *refers to an oil's or refined product's tendency to remain in the environment for a long period of time following a discharge. Persistent oils are those crude and refined oil products that may not be completely removed from an affected environment as a result of weathering processes or cleanup operations. When reading persistence measurements, higher numbers mean greater persistence.*

Non-persistent *oils and products will be rapidly and completely removed from the affected environments through natural weathering processes. They are largely composed of light-weight components. Only short-term effects are expected from non-persistent oils.*

Pour point *is the temperature above which an oil begins to follow*

Crude oils are composed of various combinations of compounds in each of the three component categories. When comparing crude oils, the concentration of the larger molecular-weight compounds (medium and heavyweight) relative to the number of lightweight components within the oil affects PERSISTENCE. Oils with greater concentrations of medium and heavyweight components will typically have greater persistence. Because oils with greater persistence remain in the environment longer, they lengthen the period of time during which organisms are at risk of exposure. Oils composed primarily of the lightweight components are usually considered NON-PERSISTENT.

For purposes of illustration, Table 1 lists some of the differences in common petroleum products. For more information on this topic, a full discussion of the properties of different oil types can be found in the first course, "Fate of Spilled Oil in Marine Waters: Where Does It Go? What Does It Do? How Do Dispersants Affect It: An Information Course for Decision-Makers."

Table 1. Comparison of oil properties for several commonly used refined oil products.

Oil Type	Components	Relative persistence*	POUR POINT (average)	Boiling Point Range
Gasoline	Mostly lightweight (<10 C atoms)	1	NA (<0° F)	104-302° F
Fuel oil #2 (diesel)	Light- and medium-weight (10 to 20 C atoms)	8	0° F	93-365° F
Fuel oil #6 (bunker)	Mostly heavy-weight (25 to 50 C atoms)	400	60° F	615-826° F

* Relative persistence values were calculated by Markarian *et al.* (1993), and are based on the persistence of the product in the environment, divided by the persistence the least persistent oil product (gasoline), which has a persistence value of 1.

The effects of oil depend on the chemical composition of the oil itself. To be harmful, oil components must be bioavailable to the organisms. Some components which are considered harmful (i.e., alkanes in the C1 to C10 range) have a high volatility. This means that, unless the concentration of oil is very high, they will usually evaporate before becoming bioavailable to organisms in the water column. Other oil components are also considered harmful, but their molecules are very large, making them less soluble in water. Because these components are less soluble, they are also less biologically available to organisms in the water column. The two classes of oil components thought to be the most bioavailable, and, thus, most dangerous for water column organisms, include the alkanes in the C12 to C24 range and the two and three-ring polycyclic aromatic hydrocarbons (PAHs) (NRC, 1985; 1989; Gilfillan, 1993; Neff and Sauer, 1995). Potentially hazardous levels of bioavailable oil components such as these usually exist in the water column for only a short period of time after a spill. According to Neff and Sauer (1995), "potentially toxic concentrations of (dissolved) petroleum hydrocarbons, if they are attained at all, probably persist in the water column for only a few days or weeks." This time period is considered to be even shorter by other researchers.

Purpose of Part I, Section II

To review the basic composition and properties of dispersants.

Surfactants *are naturally occurring and chemically manufactured molecules often referred to as surface active agents or "detergents." Surfactant molecules contain both water-seeking (hydrophilic) and oil-seeking (oleophilic, or hydrophobic) portions that orient themselves at the oil-water interface so that the oil-seeking portion of the molecule at- taches to the oil and the water-seeking portion of the molecule faces outward into the surrounding water.*

Solvents *are chemical com-pounds that are included in dispersants to assist the surfactants in penetrating the oil.*

Section II: What is a Dispersant?

Chemical dispersants are mixtures that contain "surface-active" chemicals (SURFACTANTS) and SOLVENTS. The surfactants actually cause the oil to "disperse" into tiny droplets that remain suspended in the water column. As the saying goes, oil and water do not mix...without surfactants. In simple terms, surfactant molecules have one end that sticks to oil and another end that sticks to water. This means that the surfactant will work to lightly attach water and oil molecules together, allowing the oil to mix in with the water as small droplets. More information about the action and chemical composition of dispersants can be found in the second paper in this series "A Decision-Maker's Guide to Dispersants."

Part II: Toxicity and Exposure

Purpose of Part II, Section I

To define toxicity and explain how it is typically measured.

Exposure *is contact of an organism with a chemical, physical, or biological agent (e.g., oil). Exposure increases with the amount of time an agent is available for absorption at the exchange boundaries of the organism (e.g., skin, lungs, digestive tract).*
Technically, exposure to a toxin equals dose plus concentration. The dose is the actual quantity of an agent an organ- ism is in physical contact with and the concentration is the amount of the toxin in a given volume of that agent.

Section I: Toxicity
What is Toxicity?

Rand and Petrocelli (1985) define toxicity as the "inherent potential or capacity of a material [in this case oil or dispersed oil] to cause adverse effects in a living organism." Adverse effects are responses outside the "normal" range for healthy organisms and can include behavioral, re-productive, or physiological changes, such as slowed movements,