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Effects of Oil and Chemically Dispersed Oil in the Environment

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Module 1: Sources of Contamination and Injury

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the chemical composition of crude oil and differentiate between lightweight, medium-weight, and heavyweight hydrocarbon groups.
- **Evaluate** how oil properties such as volatility, solubility, and carbon count dictate environmental persistence and bioavailability.
- **Select** appropriate response strategies based on the interaction between surfactants and solvents within chemical dispersants.

Executive Summary: The impact of an oil spill is primarily determined by its chemical composition, specifically the ratio of lightweight to heavyweight hydrocarbons. While lightweight components pose the highest acute toxicity risk due to their bioavailability, heavyweight components lead to long-term environmental persistence and physical injury through smothering.

Section I: What is Oil?

Hydrocarbons are the primary organic compounds in crude oil, often comprising up to 85% of the overall mixture. The specific type of oil spilled is a critical variable in determining its impact on biological resources.

Hydrocarbon Classification by Molecular Weight

Crude oils contain three main groups of hydrocarbon components defined by their carbon (C) atom count:

- **Lightweight Components (C1 to C10):**
 - These evaporate and dissolve more readily than heavier components, leaving behind less residual "weathering" residue.
 - They are highly **bioavailable**—readily absorbed by organisms—and are potentially flammable, making them a primary concern for human health and safety.
 - Examples include Benzene, Toluene, and **Alkanes**.



- **Medium-Weight Components (C11 to C22):**
 - These evaporate or dissolve more slowly, typically over several days, and may leave residual films or coatings.
 - They possess lower bioavailability than lightweight components but are sometimes regarded as having higher inherent toxicity.
 - Examples include **Polycyclic Aromatic Hydrocarbons (PAHs)**.
- **Heavyweight Components (\geq C23):**
 - These undergo virtually no evaporation or dissolution and can persist in water columns and sediments indefinitely.
 - They cause long-term injury via physical smothering or coating rather than chemical toxicity.
 - Examples include Asphaltenes.

Key Engineering Properties

- **Bioavailability:** The tendency of individual oil components to be taken up by a biological organism.
- **Toxicity:** Represents the degree of danger a substance poses to life; synonymous with being "poisonous".
- **Persistence:** The tendency of oil to remain in the environment. High concentrations of heavyweight components increase persistence, whereas lightweight components are considered **non-persistent** as they are rapidly removed through natural weathering.
- **Pour Point:** The temperature above which an oil begins to flow. If the water temperature is below this point, the oil becomes too stiff for effective chemical dispersion.


Comparative Oil Properties

The concentration of different molecular-weight compounds dictates the persistence of refined products.

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 heavyweight (25 to 50 C atoms)	400	60° F	615-826° F

* Relative persistence values are based on the product's persistence divided by that of gasoline.


 **Design Tip:** To be harmful, oil components must be bioavailable. While lightweight alkanes (C1-C10) are toxic, they often evaporate before they can become bioavailable unless oil concentrations are extremely high.

Section II: What is a Dispersant?

Chemical dispersants are mixtures of **surfactants** and **solvents** designed to accelerate the natural process of oil breaking into tiny droplets that remain suspended in the water column.

Functional Components

- **Surfactants:** Molecules with a water-seeking (hydrophilic) end and an oil-seeking (oleophilic) end. They orient themselves at the oil-water interface to attach water and oil molecules together.
- **Solvents:** Chemical compounds included in the mixture to help surfactants penetrate the oil and reduce the viscosity of both the dispersant and the oil.

 **Safety Constraint:** Dispersant use represents a deliberate introduction of chemicals into the water and increases hydrocarbon concentrations in the water column. This trade-off must be weighed carefully, as dispersed oil may increase short-term risk to water column resources while protecting sensitive shorelines like mangroves or salt marshes.



Checkpoint Quiz

1. Which hydrocarbon group is primarily associated with long-term injury via smothering rather than acute chemical toxicity?

- a) Lightweight components (C1-C10)
- b) Medium-weight components (C11-C22)
- c) Heavyweight components (\geq C23)
- d) Alkanes

Answer: (c). Heavyweight components undergo little evaporation or dissolution and cause long-term effects by coating or smothering organisms.

2. Based on Table 1, which refined product is 400 times more persistent than gasoline?

- a) Fuel oil #2
- b) Diesel
- c) Fuel oil #6 (bunker)
- d) Benzene

Answer: (c). Table 1 lists Fuel oil #6 as having a relative persistence of 400 compared to gasoline's value of 1.

3. How do surfactants facilitate the dispersion of oil into the water column?

- a) By increasing the viscosity of the oil to prevent it from spreading.
- b) By reacting with sunlight to neutralize toxic oil components.
- c) By using dual-ended molecules to attach oil to water as small droplets.
- d) By causing the oil to evaporate faster than natural weathering.

Answer: (c). Surfactants contain water-seeking and oil-seeking ends that allow the oil and water to mix as small, suspended droplets.



Module 2: Part II - Toxicity and Exposure

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the biological and environmental factors that control the transport, transformation, and fate of oil toxins.
- **Evaluate** toxicity data using LC50 and EC50 endpoints to categorize the relative danger of substances.
- **Differentiate** between nominal concentrations and the water-accommodated fraction (WAF) when interpreting oil toxicity results.
- **Analyze** the environmental variables, such as tide stage and shoreline type, that dictate the level of exposure.
- **Identify** the difference between acute and chronic exposure durations and their typical biological outcomes.
- **Evaluate** how dispersant application shifts exposure risks between different marine resource groups.

Executive Summary: Toxicity is the inherent capacity of a substance to cause adverse biological effects. In marine environments, these effects are a function of chemical concentration and exposure duration, though measuring oil toxicity is complicated by the fact that oil is a complex mixture rather than a single compound. On the other hand, exposure is the contact between an organism and a chemical agent, determined by kind, duration, frequency, and concentration. Dispersant use changes the exposure profile by shifting oil from the surface to the water column.

Section I: Toxicity

Understanding Toxicity and Its Measurements

Toxicity represents the degree of danger a substance poses to life. Adverse effects include responses outside the "normal" range, such as slowed movements, reduced fertility, or mortality.

Control Factors in Aquatic Environments

- **Chemical Properties:** Solubility and vapor pressure.
- **Ecosystem Properties:** Salinity, temperature, and water depth.
- **Input Rate:** The source and rate of the chemical entering the environment.