

IN-SITU BURNING

A DECISION-MAKER'S GUIDE TO IN-SITU BURNING

REGULATORY ANALYSIS AND SCIENTIFIC AFFAIRS
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Regulatory Analysis and Scientific Affairs

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Regulatory and Scientific Affairs Department

API PUBLICATION 4740

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TABLE OF CONTENTS

Photograph Credits	ii
Foreword	iii
Overview	viii
 Section I. Introduction	 1
Purpose of This Booklet.....	1
 Section II. Oil Chemistry Review	 4
What is Oil?	4
Behavior and Weathering Effects	5
How Does Burning Change the Oil?	8
 Section III. <i>In-situ</i> Burning	 9
What is It?	9
Ignition Sources	9
How is <i>In-situ</i> Burning Conducted?	10
On Water	10
Oil Thickness Requirements	10
Equipment Requirements	11
Operational Guidelines	11
Health and Safety	12
On Land	12
Oil Thickness Requirements	13
Equipment Requirements	13
Operational Guidelines	13
Health and Safety	14
Why You Use <i>In-situ</i> Burning?	14
How Does Weathering of Oil Affect Potential ISB Issues?	15
 Section IV. When to Consider <i>In-situ</i> Burning	 16
When to Consider <i>In-situ</i> Burning on Water	16
What are the Optimal Site Conditions For Considering Use Of <i>In-situ</i> Burning on Water?	18
When to Consider <i>In-situ</i> Burning on Land	20
What Are The Optimal Site Conditions For Considering Use Of <i>In-situ</i> Burning On Land?	21
Additional Considerations	23
Impacts to Plants from the High Temperatures Present During <i>In-situ</i> Burning	23

Burning in High Organic Soils	24
Potential Effects of the Fire on Overhead or Adjacent Structures.....	24
Public Notification and Air Quality Approvals	25
Section V. Operational Issues for <i>In-Situ</i> Burning.....	25
Equipment and Experience Needed for Conducting <i>In-situ</i> Burning.....	25
On Water	26
On Land.....	26
Pre-burn Planning	27
Monitoring.....	29
Pre-burn Monitoring.....	29
Monitoring during the Burn.....	30
SMART	30
Immediate Post-burn Monitoring.....	31
Post-burn Data Gathering	32
Required Authority	33
Section VI. <i>In-situ</i> Burning Health and Safety Concerns	33
OSHA Requirements for ISB Personnel	33
ISB Safety Plans	35
Section VII. <i>In-situ</i> Burning Case Histories and Lessons Learned.....	36
Case Studies of <i>In-situ</i> Burning on Land.....	37
Case Study No. 1 — Refugio County, Texas	37
Case Study No. 2 — Brunswick Naval Air Station, Brunswick, Maine.....	38
Case Study No. 3 — Chiltipin Creek, Texas.....	39
Case Study No. 4 — Mosquito Bay, Louisiana.....	40
Case Studies of <i>In-situ</i> Burning on Water	41
Case Study No. 5—Exxon Valdez Test Burn, Prince William Sound, Alaska.....	42
Case Study No. 6 – Newfoundland Offshore Burn Experiment, Newfoundland, Canada	42
Lessons Learned from Prescribed Burning	43
Lessons Learned from ISB on Land	44
Future Efforts.....	45
On Land	45
On Water	46
List of Acronyms	48
Generic ISB Checklist for Oil Spill Response	50
References Cited & Further Reading.....	54
List of Contacts for Additional Information	58

TABLE OF CONTENTS, CONT.

Acknowledgements.....	59
-----------------------	----

LIST OF FIGURES

Figure 1. Crude Oil Composition	4
Figure 2. Generic Fractional Distillation in the Crude Oil Refining Process.	6
Figure 3. Oil combustion by-products.	8
Figure 4. An example of a hand-held igniter. [Image from FOSS Environmental at www.fossenv.com]	9
Figure 5. A Helitorch.	9
Figure 6. Typical minimum oil slick thickness range (2 – 5 mm) required for ignition.	10
a. Steel construction boom.....	11
b. Fire-resistant fabric boom	11
c. Water cooling system boom.....	11
Figure 7. Oil collection on water.....	11
Figure 8. Burn residue recovery on water and on land.....	12
Figure 9. Example of firebreaks	13
Figure 10. Oil in Ice Interactions.....	17
Figure 11. <i>In-situ</i> Burn Pre-approval Status for the Coastal States of the U.S.	34
Figure 12. Example of PM-10 inhalation	35
Figure 13. Refugio County, TX burn.....	37
Figure 14. Refugio County, TX after the burn.....	37
Figure 15. Oil/residue re-maining after the burn, Refugio County, TX.	37
Figure 16. Brunswick Naval Air Station burn	38
Figure 17. The site of the Brunswick Naval Air Station Burn, 4 to 5 months later.	38
Figure 18. The Mosquito Bay, LA burn	39
Figure 19. Chiltipin Creek 2 years after the initial burn.....	39
Figure 20. The Exxon Valdez Test burn. (Figure not available.).....	40
Figure 21. The Mosquito Bay, LA burn, 13 months later.....	41
Figure 22. Images from the NOBE experimental offshore burn.....	43

LIST OF TABLES

Table 1. Equipment that might be needed for <i>in-situ</i> burning operations on land and on water.	25
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OVERVIEW

- The American Petroleum Institute (API) commissioned the preparation of two booklets to help bridge the gaps in the understanding of *in-situ* burning (ISB) use, effectiveness, and effects.
- This booklet (second of two) focuses on the operational ISB considerations and issues associated with *in-situ* burning both on land and on water.
- This series was developed as a training tool or planning tool for *in-situ* burning. It is NOT an operations manual.
- Crude oil is a complex mixture of thousands of different compounds, composed primarily of carbon, hydrogen, sulfur, nitrogen, and oxygen. Hydrocarbons (composed solely of carbon and hydrogen atoms in various combinations) are the most abundant compounds found in crude oils.
- *In-situ* burning involves controlled burning of oil that has spilled from a vessel or a facility, including pipelines.
- For an *in-situ* burn on water to ignite and sustain, the spilled oil must be approximately $\frac{1}{10}$ of an inch or 2–3 millimeters in thickness—so containment in some form is necessary to limit spreading.
- On water, spilled oil is contained within a boom or naturally, such as in ice, and ignited using an ignition source. On land, the oil may need to be contained by physical means (such as dikes), but the spilled oil will collect in natural depressions or low-lying areas where it can be contained and ignited.
- When conducted properly, *in-situ* burning significantly reduces the amount of spilled oil (on the water or on land surface), thereby, preventing that oil from remaining in the environment or moving and affecting other resources and habitats.
- *In-situ* burning offers a practical method to remove large quantities of oil from the land or water surface very quickly, however there are many limiting factors that should be taken into account before a burn is conducted. Physical limitations such as wind speed, wave height, thickness of the oil, oil type, how weathered the oil is, and how emulsified the oil is can limit the feasibility of ISB. Other factors to consider are human exposure to smoke, monitoring requirements, accessibility to the impacted site, and recovery of burned/unburned product and residue.
- As oil weathers, it loses its more volatile components. Emulsification may also occur when water mixes with the oil. Either of these processes make it more difficult to ignite the oil as well as sustain the burn. Optimal oil conditions for burning are less than 30% loss by evaporation and less than 25% water content.

- Equipment needed to conduct *in-situ* burning may consist of:
 - Ignition systems – Helitorch component system, gelled fuel, hand held igniter
 - Fire Booms – fabric booms, metal booms, air bubble and water spray systems, and other boom concepts
 - Firefighting/control equipment
- A burn plan will be required. This plan should address human health and safety issues, burn methods, monitoring plans, termination conditions, and post-burn cleanup and restoration. Attempts should be made to remove all remaining burn residue from the environment.
- Monitoring an *in-situ* burn is essential for success and learning more about its effectiveness and effects. Monitoring can include air quality measures as well as maintaining a constant watch on the fire and smoke plume, condition of the boom, and the speed and positions of the towing vessels, if in open water.
- In the United States, the Special Monitoring of Applied Response Technologies (SMART) was developed to provide monitoring guidance for the collection and reporting of real-time information on *in-situ* burning and dispersant use. SMART allows responders to effectively determine potential human health exposures during a burn so that impacts to the public are minimized or eliminated. SMART allows decision-makers to determine when to stop a burn to ensure limited population impacts. SMART is not intended to determine worker health and safety exposure limits.
- In the United States, before an *in-situ* burn can take place (on land or on water), approval must be received from the appropriate state and federal agencies. The approval process varies from state to state or region to region. In some areas of the United States, regional planning efforts have developed pre-approval zones for *in-situ* burning.
- Human health concerns (for both responders and the public) are addressed in monitoring plans. Responders are equipped with protective clothing and masks, as needed. The primary concern for public safety is that of air quality.
- The smoke from a burn contains particles that have been found to be harmful to humans. The smoke plume reaching receptor populations should not exceed the average federal and/or state air quality standards in public areas; otherwise the burn should not be allowed or should be terminated.
- Also included in the booklet are case studies from various locations with different environments, oil types, and situations. Lessons learned have been developed from these responses, which highlight advantages and disadvantages of *in-situ* burning.

Section I. Introduction

You are in the midst of a large oil spill and it's your first month on the job. Approximately 20,000 gallons of a medium-weight crude oil has been discharged into the environment. Earlier you were asked by the *Unified Command* (UC) to identify options to remove this oil that will also minimize the potential impacts to the environment (see boxes on pages 2 and 3). Based on the circumstances, you recommended that burning the oil in place, *in-situ* burning (ISB), would provide the greatest value in terms of removing the threat of liquid oil to resources at risk in and on the ground and water.

Now, the On-scene Coordinator (OSC) needs additional information. You have been asked to provide more information on *in-situ* burning including the operational issues and concerns associated with conducting an ISB, worker and public health issues, and monitoring. Your research will help the OSC verify the appropriateness of this removal method for the incident-specific spill conditions and determine if the requirements for an *in-situ* burn are achievable within the recommended window of opportunity.

As always, the OSC wants the information as soon as possible. You have had basic oil spill response training, and you have heard of ISB, but this is the first time you have been involved in an ISB response. During your training, you remember that there were several guidance documents that have been developed to assist responders in understanding the concept of ISB.

Purpose of This Booklet

This scenario is fictitious but the circumstances are possible. ISB is a response option that has been used less frequently than countermeasures like booms and skimmers or contaminated soil removal. Consequently, familiarity with the pros and cons of this option is limited. There are ISB "experts" in the United States and internationally, but the intentional practice of this response tool remains relatively limited for both on water and on land situations.

This booklet is the second in series that was developed as a reference document for oil spill response decision-makers. It provides the reader with a comprehensive, concise, yet clear summary of the operational requirements and limitations for ISB, and allows decision-makers to better understand the function of *in-situ* burning and the tradeoffs facing decision-makers in using



An *In-situ* Burn.

Unified Command (UC) is responsible for all aspects of the response, including developing incident objectives and managing all incident operations (*refer to information box on Page 3 for more information*).

Actual UC makeup for a specific incident will be determined on a case-by-case basis taking into account:

1. specifics of the incident;
2. determinations outlined in existing response plans; or
3. decisions reached during the initial meeting of the UC.

The makeup of the UC may change as an incident progresses, in order to account for changes in the situation. The UC is a team effort, but to be effective, the number of personnel should be kept as small as possible.

this technology when responding to an oil spill on land or on water.

The first booklet, “The Fate of Burned Oil” (API Publication No. 4735), was prepared to provide an accurate summary of the fate and effects of burned oil on water and on land, as well as in the air.

Throughout both booklets, the first time a new technical term is used, 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.

For More Information...

The American Petroleum Institute commissioned the development of the booklet, “Fate of Spilled Oil in Marine Waters: Where Does it Go? What Does It Do? How Do Dispersants Affect it? An Information Booklet for Decision-makers” (API Publ. 4691).

This booklet provides a more detailed summary on oil chemistry and is recommended reading. This booklet is available from API Publications at www.api.org.

A Team Effort...

The Incident Command System, Unified Command, Incident Commanders, On-scene Coordinators, and Responsible Parties

During a response to an oil spill, in many cases there are several federal agencies as well as state and local agencies from the affected area that become involved with the response efforts. The **Incident Command System (ICS)** is a response tool that has been almost universally adopted by state and federal agencies as the method of rapidly organizing a coordinated response to an incident, such as an oil spill. If all agencies involved in the incident are using the same categories to address critical needs to manage their agency, the cooperative effort of all the agencies will increase dramatically.

The **Unified Command** structure is a necessary tool within the ICS for managing multi-jurisdictional responses to oil spills or hazardous substance releases. When planned for and practiced, ICS/UC is viewed as the most effective response management system to address discharges or releases. The ICS/UC is an integrated and flexible structure that emphasizes cooperation and coordination in local, state, and federal responses to complex multi-jurisdictional, multi-agency incidents.

Within the ICS/UC, there is a requirement for a single individual, or **Incident Commander (IC)** to be the final decision-maker for the efforts of the response. The UC is a structure that brings together the “Incident Commanders” of all major organizations involved (federal, state, local, and **Responsible Party** groups) in the incident in order to coordinate an effective response while at the same time carrying out their own jurisdictional responsibilities. These “Incident Commanders” are typically referred to as **On-scene Coordinators (OSC)**—those individuals who have the pre-designated legal authority to make decisions for their agency during an incident, including the access and disbursement of funds to address their agency’s response needs. There may be Federal On-scene Coordinators (FOSCs) from EPA and the U.S. Coast Guard; the affected State(s)’ On-scene Coordinators (SOSCs); and Local OSCs representing their local jurisdictions. The UC links the organizations responding to the incident and provides a forum for these entities to make consensus decisions. Under the UC, the various jurisdictions and/or agencies and non-government responders may blend together throughout the operation to create an integrated response team.

The UC is responsible for overall management of the incident. The UC directs incident activities, including development and implementation of overall objectives and strategies, and approves ordering and releasing of resources. Members of the UC work together to develop a common set of incident objectives and strategies, share information, maximize the use of available resources, and enhance the efficiency of the individual response organizations.

Unified Command speaks to the issue that all of the major players in an incident need to get together to share information, resources, and responsibility for the smooth delivery of effective service. But, as in all events, there can only be one boss, one “shot caller,” directing the focus of the group, and setting the group’s goals. This whole system of “who’s in command” and Unified Command only works if all agencies are aware of each other’s primary needs.

For more information on ICS and the Unified Command, access the National Response Team’s “Incident Command System/Unified Command Technical Assistance Document,” available from:

[http://nrt.org/production/nrt/home.nsf/resources/Publications1/\\$File/ICS_UC_Technical_Assistance_Document.pdf](http://nrt.org/production/nrt/home.nsf/resources/Publications1/$File/ICS_UC_Technical_Assistance_Document.pdf).

Section II. Oil Chemistry Review

What is Oil?

Hydrocarbons are defined as chemical compounds composed solely of carbon and hydrogen that come in various lengths and structures.

Trace Metals in oil consist primarily of Nickel, Iron, Vanadium, Copper, and Arsenic.

Asphaltenes and **Waxes** are components in the oil that are considered relatively inert and resistant to most weathering processes.

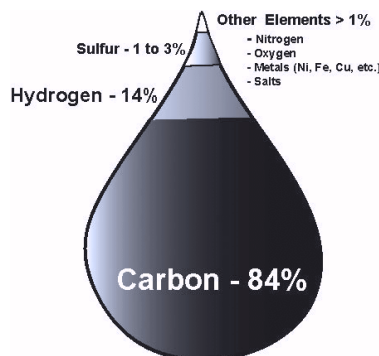


Figure 1. Crude Oil Composition

Oil is not one “thing;” it is a complex and highly variable mixture of compounds. Even oil extracted from the same well may change in component mixtures over time (Lewis and Aurand, 1997). Crude oil, the unprocessed oil that is recovered from the ground, is composed primarily of **HYDROCARBONS**, and to a smaller extent compounds containing **TRACE METALS** (Figure 1). Hydrocarbons (including **ASPHALTENES** and **WAXES**) are the most abundant compounds in crude oils (NRC, 2003). In general, there are three groups of hydrocarbons in every oil:

- Light-weight components (low molecular weight)
 - contain 1 – 10 carbon atoms in each molecule (C1 to C10);
 - are simple in molecular structure;
 - evaporate and dissolve rapidly (hours) and leave little or no residue ;
 - many of these components (e.g., benzene) are thought to be readily absorbed by animals through the skin or through inhalation; and
 - are potentially flammable and readily inhaled by people, and so are of concern for human health and safety.
- Medium-weight components (medium molecular weight)
 - are composed of 11 – 22 carbon atoms (C11 – C22);
 - are more complex molecules than light-weight;
 - evaporate or dissolve more slowly, over several days, with some residue remaining;
 - are sometimes regarded as a greater concern than the light-weight components since they persist in the environment longer and therefore present a longer term risk of exposure (NRC, 2003); and
 - are not as bioavailable as lower-weight components, so are less likely to affect animals.
- Heavy-weight components (high molecular weight)
 - made up of 23 or more carbon atoms ($\geq C23$);
 - undergo little to no evaporation or dissolution; and

- can cause chronic (long-term) effects via smothering or coating, or as residue in the water column and sediments (NRC, or 2003).

Crude oils are composed of various combinations of the three hydrocarbon categories. When comparing crude oils, the relative concentration of the larger molecular compounds within the oil affects **PERSISTENCE**; oils with greater concentrations of medium- and heavy-weight components will typically result in increased persistence. Oils composed primarily of the lightweight components are usually considered **NON-PERSISTENT**.

REFINED PRODUCTS are typically composed of a narrow range of processed components, usually containing the lighter-weight components (e.g., gasoline, condensates, and diesel-like products). Low **API GRAVITY** oil products are primarily composed of heavy-weight components sometimes mixed with a blending agent (No. 2 fuel oil is a common blending agent) in the development of these heavy refined oils. (See Figure 2 on next page for more information on the oil refinery process.) There are also several naturally occurring crude oils that are considered low API gravity oil products (NRC, 1999).

Behavior and Weathering Effects

When oil is spilled at sea or on land, it is subject to different transport and weathering processes (more information on weathering of oil is available from Scholz et al., 1999; NRC, 2003). Of the eight major weathering and behavior processes, the following can directly influence slick ignition and burning:

Advection: Advection or drifting only occurs for spills on water.

It is the process of surface slicks being transported away from the site of a spill by water currents. Advection is usually a combination of residual current movement and wind-induced surface movements. Other causes of movement may occur from tidal currents, river outflows, and longshore currents. The advection process influences the location of slicks and thus determines whether the oil can be burned from a safe distance from the spill source or from land where people, property or other resources can be at risk. Advection can move the oil away from land, sensitive resources, or population centers; it can also move the oil toward these resources of concern.

Persistence is a means of defining how crude and refined oil products may remain in the environment. Persistent oils may not be completely removed from an affected environment as a result of weathering processes or clean-up operations.

An oil that is considered **Non-persistent** is a refined product that will be completely removed from affected environments through natural weathering processes. They are largely composed of light-weight components. Examples include gasoline, No. 2 fuel oil and diesel.

Refined Products include petrochemical products developed in various refinery processes, like gasoline, diesel, bunker fuel oils, etc. For more information on the refinery process, see the next page.

API Gravity (°API) is a scale for measuring fluid specific gravities based on an inverse relationship with specific gravity (SG). This scale was primarily developed to expand the scale for specific gravity so that larger values are used. An oil with a low specific gravity (e.g., gasoline; SG = 0.73) will have a high API gravity (API = 62).

API gravity = $(141.5/SG \text{ at } 60^{\circ}\text{F}) - 131.5$

More on Refining Oils...

Crude oils contain hundreds of different types of hydrocarbons and other components mixed together. Crude oil composition can vary widely from well to well in the same region. There are often noticeable differences between crude oils that are recovered at different times from within the same well.

In the refining process, oils are separated into various hydrocarbon components, also known as fractions or cuts, based on the number of carbon atoms in each molecule. By heating the crude oil and letting it vaporize, the distillation process (also known as fractional distillation) allows the collection and retrieval of the different hydrocarbon molecules based on their vaporization temperatures.

Newer distillation techniques (catalytic cracking) allow a refinery to process the crude oils into the various fractions, but it also allows the breaking of longer chains into shorter ones. This technique allows a refinery to produce a specific product (e.g., gasoline versus diesel fuel), based on demand for the product. The oil remaining after distillation is called the residual or residuum.

Refineries must treat the fractions that they produce to remove impurities. Then, using the various fractions collected, they often combine the processed and unprocessed crude oils to create the desired product. For example, the combination of residual oils and diesel fuel are often used to create Number 6 fuel oil for power plants or bunker fuels.

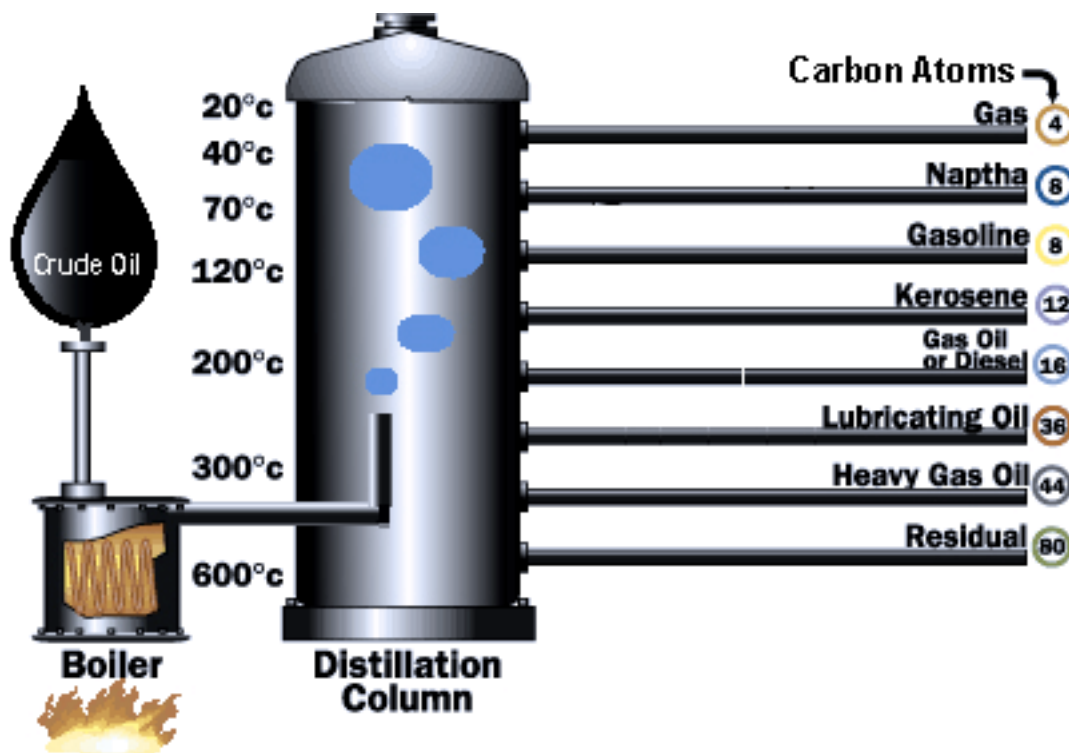


Figure 2. Generic Fractional Distillation in the Crude Oil Refining Process.

Spreading: Spreading is a key process for *in-situ* burning on land and on water because the thickness of an oil slick is determined by the spreading rate of the oil spill. The ignitability and burnability of an oil spill is strongly dependent on the thickness of the slick. Another element influencing the spreading factor on water is the SPECIFIC GRAVITY of the spilled oil. The oil's specific gravity will determine where in the water column the oil will float. If the oil does not float, it is not a candidate for *in-situ* burning.

Evaporation: Evaporation is one of the most important processes that affect the properties and behavior of any spilled oil. Highly evaporated oils are difficult to ignite and burn because the remaining heavier weight components don't readily sustain burning. Therefore, it is important to understand evaporation rates for various oil types and how evaporation affects the properties of the oil remaining on the surface.

Emulsification: When crude oils and heavy refined oils are spilled at sea, they often form water-in-oil emulsions, which occur in the presence of mixing energy usually from wave action. During emulsification, water is incorporated into the oil in the form of microscopic droplets. When water content of a slick reaches 50% – 85% (depending on oil type), ignition and burning become very difficult, if not impossible, without the use of special additives.

Natural Dispersion and Dissolution: Dispersion and dissolution are physical processes that move the oil and the more soluble lower molecular weight hydrocarbons from the slick into the water-column. For *in-situ* burning, dispersion and dissolution effects will remove oil from the slick into the water column that could otherwise be burned. Under moderate to high turbulence or wave action, "temporary dispersion" may occur. This is where relatively large oil droplets may break from the slick causing them to be temporarily submerged and when they resurface, they can be outside the burn area and may remain unburned in the environment.

Specific Gravity is defined as the ratio of the mass of a given material (e.g., oil) to the mass of freshwater, for the same volume and at the same temperature. Most crude oils and refined products have specific gravity values (SG) between 0.78 and 1.00. If the SG of the oil is less than the SG for the receiving water (fresh-water = 1.0 at 4°C; seawater = 1.03 at 4°C), it will float on the water surface.



Figure 3. Oil Combustion By-products.

Particulate Matter (PM-10) is the general term used for a mixture of solid and liquid droplets found in the air. PM-10 refers to small, coarse (10 microns in diameter or smaller) particulate matter that is potentially harmful if inhaled because it may become lodged in the lungs.

How Does Burning Change the Oil?

Burning the oil *in-situ* allows for the rapid removal of liquid oil, that has been collected and contained, from the ground and water surface. An ISB converts the liquid oil into its primary gaseous combustion products—water and carbon dioxide, plus a smaller percentage of other unburned or residual byproducts, including soot and gases (NRT, 1992). ISB does not completely remove spilled oil from the environment; the burned oil is primarily converted to airborne residues (gases and large quantities of black smoke or soot) and burn residue (incomplete combustion by-products) (see Figure 3). The airborne residues have the potential to negatively impact natural resources by introducing toxic components through inhalation or direct contact with the various combustion by-products. For more information, refer to Section VI within this volume.

During an ISB, the effect of the combustion plume on downwind human populations and natural resources is a significant concern. One of the key issues associated with ISB effects is the presence of **PARTICULATE MATTER**, and particularly the small particles less than 10 microns in diameter that are referred to as “PM-10.” The particulate matter in the smoke is composed primarily of elemental carbon. Particles smaller than 10 microns are easily inhaled and drawn deeply into the lungs where they can lodge and cause damage.

Carbon dioxide is the primary gaseous by-product from an ISB. Additional gaseous by-products include carbon monoxide, nitrogen oxides, sulfur oxides, and volatile organic compounds. Human exposures (acute and chronic) to each of these gases (CO, NO_x, SO₂, and VOCs) are regulated by the USEPA’s National Ambient Air Quality Standards (NAAQS) and the Occupational Safety and Health Administration (OSHA). OSHA requires that the levels of exposure must be monitored when humans can be exposed to these chemicals via inhalation or direct dermal contact (like during an *in-situ* burn).

Section III. *In-situ* Burning

What is It?

In-situ means “in place.” *In-situ* burning refers to the controlled burning of oil spilled from a vessel, facility, pipeline, or tank truck close to where the spill occurred (ASTM, 2003a). For spills on open water, responders usually have to collect and contain the oil using fire-resistant booms, because the oil has to be a minimum thickness to be ignited and sustain burning. In ice-infested waters, the ice can act as a natural boom, keeping the oil thick enough to burn. *In-situ* burning can also refer to burning of oil inside a vessel before it discharges.

In-situ burning of spills on land occurs more often than on water because the oil doesn’t emulsify, submerge, or spread into thin sheens as quickly, and the oil is usually more accessible. Most of the time, *in-situ* burning on land is conducted shortly after a spill is discovered, when the oil is still thick.

Ignition Sources

A fire can be started with a range of ignition sources, from a simple match to more sophisticated equipment (see Figure 4 and 5). The ignition source is used to provide enough heat for a long enough period so that some of the oil vaporizes and the vapors ignite. Heavy oils require longer heating time and a hotter flame to ignite, compared to lighter oils. A key goal during an on-water burn is to ignite as much of the oil surface as possible, so that the oil is heated enough to form vapors and sustain the burn.

Specialized ignition sources include the “Helitorch,” an incendiary device that hangs from a helicopter and drops a burning napalm-like substance (**GELLED GASOLINE**) onto the area to be burned (Figure 5). The Helitorch requires a highly trained flight crew to operate the equipment effectively. The gelled gasoline is loaded into a 55-gallon tank on the Helitorch. The fuel is pumped through a nozzle and ignited with propane jets. The falling stream of burning fuel separates into individual globules that burn for 4 – 6 minutes, igniting the oil or other combustible material. Its success rate is high, and it has ignited crude oil in winds up to 16 knots (30 km/hr). Helitorches are commercially available, being first developed for fire-fighting and forestry management. They are safe because they allow ignition from a distance, thus keeping people removed from the open fire.

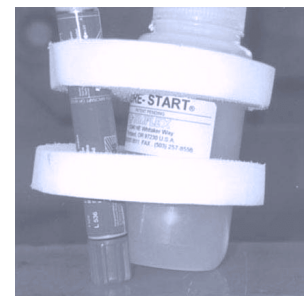


Figure 4. An Example of a Hand-held Igniter. [Image from FOSS Environmental at www.fossenv.com.]

Gelled Gasoline is a gasoline/diesel mixture formed by adding a chemical thickener to gasoline. Thickeners include aluminum soaps, wax, tallow, etc.

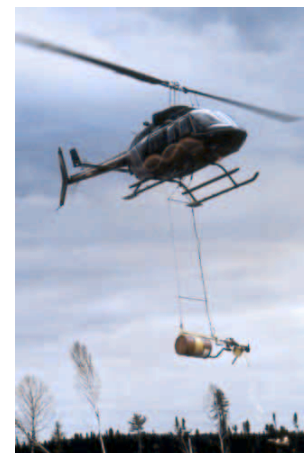


Figure 5. A Helitorch.