FATE OF BURNED OIL
IN-SITU BURNING

Things You **Should Know**

Combustion of oil yields predominantly CO2 and water vapor which are released to the atmosphere along with small quantities of particulates and other gases (~10%).

Particulate concentrations in a plume are greatest at the burn site and decline with increasing distance from the burn site, primarily through dilution, dispersion, fallout, and precipitation.

Burn residue from incompletely combusted oil has much less acute toxicity compared to the original oil as the lighter, more toxic components are destroyed by burning.

Chemical properties of ISB residue typically consist of resins, less volatile aromatics and other high molecular weight hydrocarbons.

Overview

In-situ burning (ISB) is a response technique that removes spilled oil from a land, snow, ice, or water surface by igniting and burning the oil. ASTM International (2014) defines controlled in-situ burning as “burning when the combustion can be started and stopped by human intervention.” The combustion by-products (primarily carbon dioxide and water but also particulates, gases, and other minor components) are released to the atmosphere, with the possibility of some unburned oil or incompletely burned oil residue remaining at the conclusion of a burn.

One of the greatest benefits from ISB is that a burn can rapidly reduce the volume of spilled oil and minimize or eliminate the need to collect, store, transport, and dispose of recovered oil and oily wastes. Decision-makers from federal, state and local agencies or other stakeholders must consider the benefits and risks of conducting a burn versus using other response options, since all options have potential environmental and human health risks. ISB also has the potential to significantly reduce the duration of cleanup operations. In certain instances, ISB might provide the only means of quickly and safely eliminating large amounts of oil.

Spilled oil begins to burn when an ignition source heats oil to a temperature that produces hydrocarbon vapors above the slick in sufficient quantities to support combustion. Once a fire is ignited, hot air rising above the fire draws air in from the sides which helps to concentrate the vapors. Particulate concentrations in a plume are greatest at the burn site and decline with increasing distance from the burn site, primarily through dilution, dispersion, fallout, and precipitation. The fate of oil remaining after ISB varies by the degree of combustion, type of original oil and habitat of the spill location.

This fact sheet summarizes in more detail the physical and chemical fate of burned oil in the environment.

Fact Sheet Series

- Introduction to It-Situ Burning
- **Fate of Burning Oil**
- ISB Human and Environmental Effects
- Assessing ISB Benefits and Risks
- ISB Approval in the U.S.
- ISB Operations

Introduction

A primary goal of oil spill response is to minimize the environmental impacts from the spill by recovering or reducing the quantity of oil in the environment. ISB offers the potential to remove large quantities of oil from water, land, snow and ice through combustion, which converts the spilled oil into its primary combustion by-products – water and carbon dioxide. A small percentage of other unburned or residual by-products – such as soot (carbon particulates), gases, and burn residues – remain due to incomplete combustion. The fate of oil remaining after ISB varies by the degree of combustion, type of original oil and habitat of the spill location.

What Happens to Burned Oil?

Spilled oil begins to burn when an ignition source heats oil to a temperature that produces hydrocarbon vapors above the slick in sufficient quantities to support combustion. Once a fire is ignited, hot air rising above the fire draws air in from the sides which helps to concentrate the vapors. For burns on water, this airflow also draws surrounding oil toward a fire. Most heat from a fire rises, but a small portion goes into the oil to produce more vapors for combustion (**Figure 1**). This self-sustaining process continues until the remaining liquid oil can no longer produce sufficient vapors to sustain combustion. ISB emissions are combustion by-products (particulates, gases, water, etc.) released to the atmosphere and ISB residues and unburned oil are products that often remain at the conclusion of a burn.

FIGURE 2 Typical Combustion by-products from burning crude oil. (modified from Ross 1996)

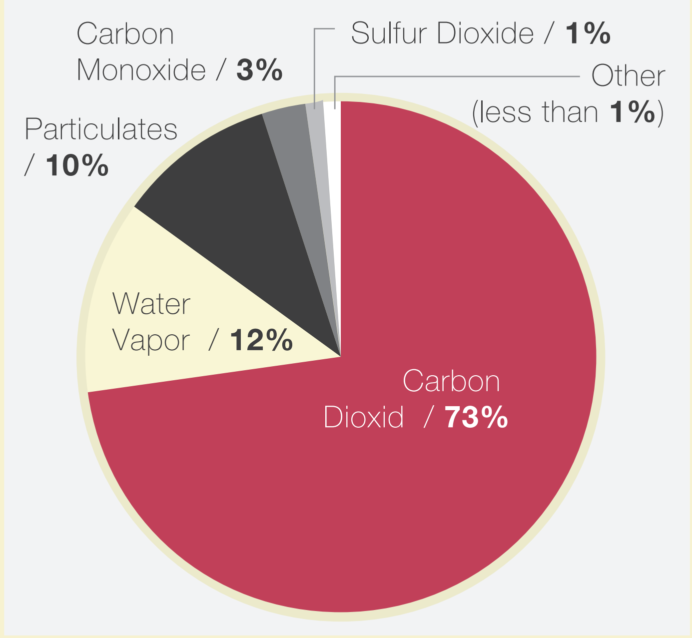
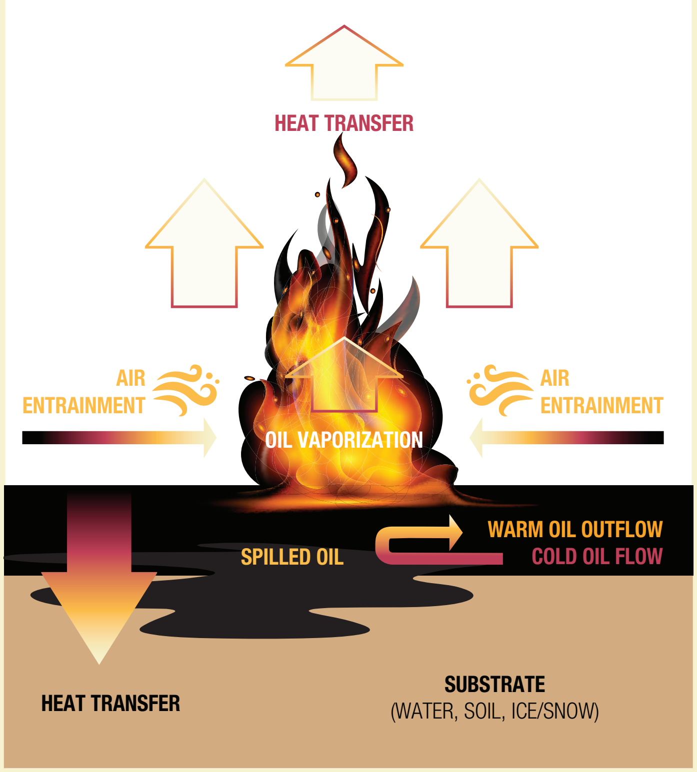


FIGURE 1. Key oil and heat transfer processes during ISB. (Source: adapted from Fritt-Rasmussen, 2010)



ISB Emissions

Combustion of oil in the open environment does not result in the total destruction of the hydrocarbons. Although most oil is converted to carbon dioxide and water vapor, inadequate natural mixing of oxygen from air into hydrocarbon vapors yields incomplete combustion. **Figure 2** shows a typical distribution of by-products from crude oil burns.

When not enough air is drawn into the fire for complete combustion, a black plume of smoke is produced consisting of carbon particulates (black soot) and gases. A white plume of water vapor and/or steam may also appear.

The amount of particulates from burning oil is estimated to vary from two percent to 20 percent of volume of oil burned (Buist 2013). The particulates then rise with the heat of combustion to form a plume in the atmosphere. Burns conducted on land can consume vegetation, so the plume may also incorporate different particulates from that combustion. **Figure 3**, **Figure 4** and **Figure 5** show smoke plumes from on-water and inland burns.

Generally, smoke plumes rise quickly with hot gases and remain aloft for long distances downwind before the plume dissipates thus minimizing human and wildlife exposures. The largest and heaviest particles will, however, precipitate from a plume first. Rugged terrain (e.g., hills and mountains) and weather (wind, inversions, and precipitation) can greatly influence plume behavior. Plumes that drift into mountainous areas can result in particulates at or near ground levels in those locations. Atmospheric inversions can restrict plume rise, causing it to spread at a lower altitude.

During a spill event, responders consider the location of the spill, the terrain and current weather patterns in relation to human and wildlife population centers when deciding whether to use ISB as a response tool. For more information on the factors considered when deciding whether to use ISB during a spill, please refer to **ISB Fact Sheet 4 – Assessing ISB Benefits and Risks.**

Particulate concentrations in a plume are greatest at the burn site and decline with increasing distance from the burn site, primarily through dilution, dispersion, fallout, and precipitation. Particulate concentrations in a smoke plume are not easy to predict because they are a function of many factors including soot yield, fire size, burn efficiency, distance downwind from the burn, terrain features, and atmospheric conditions (e.g., wind speed) (Buist, 2013).

In addition to carbon dioxide, water vapors and particulates, the dark ISB smoke plumes are comprised of gases at low concentration levels. These gases include carbon monoxide, sulfur and nitrogen oxides, and volatile organic compounds (VOCs).

All crude oil contains VOCs, such as benzene, toluene, ethylbenzene, and xylene, which are organic (carbon-based) chemicals with high vapor pressure. VOCs evaporate into the air, giving crude oil its distinctive odor. VOCs that have not already evaporated from the oil tend to be destroyed during ISB.

Polycyclic aromatic hydrocarbons (PAHs) are a natural component of petroleum oils and often assumed to be present in the smoke plumes along with the perceived health risk due to their carcinogenic potential. However, the PAH concentrations in ISB plumes are low with the majority being adsorbed onto the particulates. PAHs are not typically considered an acute inhalation hazard to humans (ATSDR, 1996) and have been identified by a variety of sources as a minor human health hazard associated with ISB (Barnea, 1995). Additional information on PAHs is provided on page 5.

FIGURE 3. Smoke plume from ISB at the Deepwater Horizon response. (Source: NOAA 2010).

FIGURE 4. Smoke plume from a burn of crude oil in an inland marsh area. (USCG 2013).

FIGURE 5. Plume observation from a peat bog in-situ burn (EPA 2002)

Another possible combustion ISB by-product is dioxin, which is a persistent chemical in the environment. However, measurements during test burns and the Deepwater Horizon incident found only background levels, which indicate that dioxins are not produced by burning oil (Fingas, 2012).

ISB Residue and Unburned Oil

Since no burn is 100 percent efficient, residue and unburned oil may remain after a burn. However, they will likely be a fraction of the original amount of spilled oil. The remaining residue and unburned oil contain elevated concentrations of heavier compounds as they are generally depleted of the more volatile components.

Physical properties of ISB residue depends on the burn efficiency and oil type and can range from thick, sticky liquids to semi-solid tar-like or brittle substances. Efficient burns of heavier oils generate brittle, solid residues (like peanut brittle), while medium oils result in semi-solid residues (like cold roofing tar). The residue from lights oils are thick liquids or taffy-like substances (Buist, 2013).

Chemical properties of ISB residue from an efficient burn typically consists of resins, less volatile aromatics and other high molecular weight hydrocarbons. A common perception is that ISB residue is highly toxic but the more volatile and typically most toxic compounds are lost through evaporation and burning. The heavier constituents that may be considered toxic, such as PAHs, that are not destroyed in the burn may remain in the residue at higher concentrations due to much smaller volume of oil residue but are typically still relatively low. Additional information on PAHs is provided in the next section.

On water, if the thickness of the oil slick reaches one to two millimeters, then the burn will generally self-extinguish leaving the remaining unburned oil floating on the surface. The residue of the burned oil can either sink or float depending on the density of the original oil. There is a correlation between medium and light oils producing floating residues and heavy oils producing sinking residues (SL Ross, 2002). Liquid residues and unburned oil from ISB on the water surface can be recovered using mechanical skimmers or sorbents. If the unburned oil can be concentrated again into a 2-3 mm thickness, then this unburned oil could be re-ignited (API, 2015a and 2015b).

FIGURE 6. Burn residue immediately after an inland ISB (NOAA 2014).

FIGURE 4. Burn residue clean-up after an in-situ burn in a peat bog (EPA 2002).

Inland, ISB can occur in a wide range of habitats, such as wetlands, forests and grasslands, with varying types of vegetation, soil and ground surface contours. As with marine spills, the fire will self-extinguish when the oil has insufficient thickness to sustain burning although for land spills this is generally negligible since there is no underlying water to cool the oil. ISBs on land may, however, result in some oil penetrating into the soil before it can be burned. Recovery of ISB residues and unburned oil on land can be done manually or with mechanical equipment, and recovery of residues from inland lakes and marshes can be done using nets or manual tools.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a group of compounds with carbon ring structures that naturally occur in organic deposits, such as coal and crude oil and are persistent in the environment. Elevated PAH concentrations can pose a risk to human health and the environment. This topic is addressed in **ISB Fact Sheet 3 – ISB Human Health and Environmental Effects.**

PAHs are characterized by low vapor pressures and relatively low flammability (compared to other oil compounds). PAHs do not generally dissolve in water; however, solubility in water does increase as the size (i.e., number of aromatic rings) of the PAH compounds decreases. An example of a smaller PAH with two aromatic rings is naphthalene. Larger, multiple ring PAHs, such as benzo[a]pyrene, are produced by incomplete combustion; however, the concentrations of these larger PAHs are low.

PAHs can be present in air as vapors or are adhered to surfaces, such as particulates (ATSDR, 1995). After ISB, low levels of PAHs can be found in unburned oil, burn residue, smoke particulates and gases (ASTM, 2014) but are typically below levels of concern for human health. Overall, more PAHs are nearly or completely destroyed by burning oil than are created (Fingas, 1999).

Figure Sources

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Figure 4 – USCG (2013). Smoke plume from a burn of crude oil in an inland marsh area – photo. Retrieved from: https://usresponserestoration.wordpress.com/tag/in-situ-burning/

Figure 5 – EPA. 2002. A Crude Oil In-Situ Burn in a Peat Bog – Photo. Retrieved from: https://archive.epa.gov/emergencies/content/fss/web/pdf/leppala_04.pdf

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