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ORIGIN, FATE AND EFFECTS OF OIL POLLUTION IN THE MARINE ENVIRONMENT

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INTRODUCTION

Petroleum hydrocarbons enter the marine environment by a number of different routes as a result of both human activities and natural processes. In addition, biogenic hydrocarbons are present in quantities larger than those derived from petroleum. The ultimate fate of these oils is to be broken down into their most basic components, mainly water and carbon dioxide. The rate of degradation is, however, dependent on many factors, not least the physical characteristics of the oil. This paper also describes the main effects of spilled oil in particular.

SOURCES OF PETROLEUM HYDROCARBONS IN THE MARINE ENVIRONMENT

Estimates of global inputs of petroleum hydrocarbons in the marine environment were considered by the National Academy of Science (1981). The findings are summarized in the following table, expressed as million metric tonnes of oil introduced per annum:

	Input Rate, Million Metric Tons/Year	
Source	Best Estimate	Probable Range
NATURAL SOURCES		
Marine Seeps	0.2	0.02 - 2.0
Sediment Erosion	0.05	0.005- 0.5
OFFSHORE PRODUCTION	0.05	0.04 - 0.07
TRANSPORTATION		
Tanker Operations	0.7	0.4 - 1.5
Drydocking	0.03	0.02 - 0.05
Marine Terminals	0.02	0.01 - 0.03
Bilge and Fuel Oils	0.3	0.2 - 0.6
Tanker Accidents	0.4	0.3 - 0.4
Non-Tanker Accidents	0.02	0.02 - 0.04
ATMOSPHERE	[0.3]*	0.05 - 0.5

* A value of 0.3 was used for the atmospheric inputs in the calculations, although the atmospheric panel did not wish to give a best estimate for this input.

Source	Input Rate, Million Metric Tons/Year Best Estimate	 Probable Range
MUNICIPAL AND INDUSTRIAL WASTES AND RUNOFF		
Refineries	0.2	0.1 - 0.6
Municipal Wastes	0.7	0. - 1.5
Non-Refining Industrial Wastes	0.2	0.1 - 0.3
Urban Runoff	0.03	0.01 - 0.2
River Runoff	0.1	0.01 - 0.5
Ocean Dumping	0.02	0.005- 0.02
TOTAL	3.3	1.3 - 8.8

The transportation losses relate mainly to tanker operations and can be traced back to cargo residues remaining on board referred to as clingage. The amount of clingage depends particularly on the wax content and viscosity of the previous cargo, but typically amounts to about .4% of the cargo carrying capacity, i.e. 800 tonnes on a 200,000 DWT crude carrier. During ballasting and tank cleaning operations half of this quantity can be lost overboard unless precautions are taken to retain oily slops on board. Recent developments such as segregated ballast tank (SBT) arrangements, crude oil washing (COW) systems with associated inert gas systems (IGS), together with established 'load-on-top' (LOT), have contributed to reducing operational pollution from tankers. Also included in transportation losses are marine terminal spills occurring mainly in connection with loading and discharging, as well as discharges of machinery space bilge and fuel oil sludges amounting to 320,000 tonnes annually, which are generated by all ships. Although the quantities of waste oil discharged from ships can be controlled through strict management, provision of adequate shore reception facilities for slops and dirty ballast water and machinery space oily wastes and residues is an integral part of any such programme.

Accidental spills from ships involve tankers in particular, which contribute 390,000 tonnes annually. Collisions and groundings account for 83% of major spills (over 700 tonnes) and principally occur in port approaches or congested shipping routes close to coastlines. The pollution risk from non-tankers is attributable to fuel oil which on large vessels can be carried in quantities of up to 5,000 tonnes. A review of world oil spills by cause/operation conducted by ITOPF indicates that the majority occur during routine operations but these are relatively small in volume.

Offshore oil exploration and production activities have experienced several major pollution incidents such as Ekofisk (Norway), Hasbah VI (Kuwait Action Plan Region), Ixtoc I (Mexico), Funiwah 5 (Nigeria) and the recent Nawruz incident, as well as a much larger number of small spills from routine operations such as oil transfer, formation water discharges and drill mud processing. Roughly three quarters of the spill volume from offshore platforms is attributed to accidents. The risk of well blowouts is less during production than the exploration phase, but the resulting oil spills are likely to be greater.

Terrestrial oil inputs are represented by discharges of process water from coastal refineries and other industries, waste oils particularly from coastal communities carried to sea in sewage, through storm drains and by rivers. By comparison, atmospheric inputs of petroleum hydrocarbons are less significant, but the extent of fall-out is difficult to estimate accurately on a global scale. Again, the main portion of marine pollution from the atmosphere can be linked to road vehicles emitting exhaust fumes.

Natural oil seeps and erosion products are also difficult to quantify and show a very patchy distribution. Seeps tend to be associated with regions of tectonic activity in oceanic margins whereas erosion of exposed oil-rich sediments will take place at terrestrial locations and usually form part of the river runoff.

CHARACTERISTICS OF SPILLED OIL

The most dramatic changes in oil characteristics occur when oil is spilled on the sea surface and subsequently undergoes various physical and chemical changes. By comparison, effluent discharges and river runoff are predominantly composed of water with a small percentage of oil in dissolved or dispersed form. The appearance of such oil is rarely more conspicuous than a thin oily sheen covering the water surface.

The most obvious characteristic of oil spilled on the sea surface is its tendency to spread horizontally under the combined forces of gravity, viscosity and surface tension. As a rule, gravity dominates initially, influenced by the viscosity of the oil. After a few hours the oil thickness will be much reduced and surface tension succeeds gravity as the main spreading force. Typically, oil spilled on water will form a thin lens with the inner portion thicker than the edges. A few crude oils and heavy fuel oils are exceptionally viscous and tend not to spread much but remain in rounded patches. Most crude oils spread to a thickness of approximately 0.3mm within 12 hours. In the absence of other influences, spreading continues until the oil has virtually formed a monomolecular layer no more than 0.5 micrometres thick. This is visible on the sea surface only as a faint silver sheen. Once spreading has progressed to the formation of rainbow-coloured or silvery sheens, the natural dissipation of the oil is rapid.

At the same time as oil is spreading and moving over the sea surface, a series of natural processes occur causing physical and chemical changes of the oil, known collectively as weathering; this includes evaporation, dissolution, oxidation, emulsification and microbial degradation.

Evaporation

The most significant process is evaporation and within a few hours of a spill the more volatile fractions of an oil are lost to the atmosphere at a rate determined by wind speed, temperature and the type of oil. Rough seas increase the rate of evaporation since they encourage the loss of oil from the crests of waves as aerosols and sprays. High wind velocities and temperatures also increase evaporation rates.

The residue remaining on the sea has a higher density and viscosity than the original oil. Most crude oil spills lose up to 40% of their volume in the first 24 hours, whereas heavy fuel oil containing few volatile compounds, will show little evaporation even after several days. Light refined products such as gasoline, kerosene and diesel oil will evaporate almost completely in a matter of hours, creating a fire hazard in confined areas such as ports and harbours.

Dissolution

Losses from dissolution are relatively low since most petroleum hydrocarbons have a low solubility in sea water. The most soluble components of oil also tend to be the most volatile with the result that evaporation loss offsets dissolution. Unlike evaporation, this is a long term process which continues throughout the duration of the weathering process.

Biodegradation

Biodegradation of oil by marine bacteria, fungi and yeasts contribute significantly to the transformation of oil into oxidised products. The rate of degradation is dependent on temperature, nutrient and oxygen availability and the type of oil. Because bacteria are active at the oil/water interface, the rate of degradation is enhanced by thin sheens or by the formation of dispersed oil droplets with a large combined surface area. Temperature, nutrient supply and oil composition also affect the rate; lighter components are degraded faster than high molecular weight ones and higher temperatures increase the biological activity. Under optimum conditions in regions similar to the Kuwait Action Plan (KAP) Sea Area, bacteria can oxidise up to 2 grams of oil per square metre per day.

Emulsification

Dispersion, or the formation of oil in water emulsions is another important mechanism affecting the natural fate of spilled oil particularly in turbulent waters. Under moderate sea conditions, thin oil sheens disperse rapidly into microscopic droplets which are then available for other weathering processes such as solution and biodegradation.

Some crude oils and heavy fuel oils are prone to form water in oil emulsions or "mousses" which often increase the persistence of the oil and retard clean-up operations. The tendency for mousse generation is greatest for oils of low viscosity under the action of moderate waves. In the KAP Region Sea Area mousses tend to break up under the high temperatures and sunlight into free water and oil, but its weathering at sea is extensive; highly persistent tar balls can be formed which are solid rather than fluid. Many of the countries in this Region have experienced problems with tar ball deposition on beaches but much of this pollution can be attributed to illegal discharges of dirty ballast or machinery space residues. Such discharges can only be reduced by provision of adequate reception facilities, which is currently under study by the Regional Organization for the Protection of the Marine Environment (ROPME) and an effective aerial surveillance and enforcement programme to detect and prosecute vessels which discharge illegally. Oman has recently initiated such a programme and from all reports this has acted as an effective deterrent against illegal discharges from vessels transiting their coastal zone.

Oxidation

The chemical combination of hydrocarbons with oxygen is called oxidation. This reaction occurs at the surface and will occur more rapidly when the oil is spread into a thin film. Ultra-violet radiation from sunlight also accelerates oxidation and under ideal conditions can result in weathering of as much as one per cent of the spilled oil per day.

Sedimentation

Several oil spills such as the Amoco Cadiz, Ixtoc I and Nawruz have featured oil sinking either to a midwater position or to the seabed. Probably the most common cause is the incorporation of sediment in weathered oil. Sinking is also possible when a marked decrease in the density of surface waters is encountered, for instance in estuarine areas. The physical properties of oil have already been discussed by the previous speaker.

Oil on the sea surface moves under the influence of winds and currents. The mechanism whereby surface movement is induced by wind stress is imperfectly known but it has been found empirically that floating oil will move roughly downwind at a rate of about 3% of the wind speed. In the presence of surface currents, an additional movement of the oil proportional to the current strength will be superimposed on any wind-driven motion. Close to land, the strength and direction of any tidal currents must be considered when predicting oil movement, whereas further out to sea the contribution is less significant in view of the cyclic nature of tidal movement.

EFFECTS OF OIL POLLUTION

The effects of oil pollution fall into two broad categories:

1 damage to marine life, particularly through the toxic, noxious or tainting properties of oil; and

2 fouling of amenity facilities and man-made installations caused by physical coating of oil.

Many of the effects of oil pollution can be recognized in terms of economic loss. On this basis it is evident that commercial fisheries, coastal wetland exploitation, tourism and coastal industrial installations represent primary resources of interest. Not all resources are equally sensitive to oil pollution and the sensitivity may vary at different times of the year. In addition, undesirable damage can be caused to marine parks and other designated areas of environmental importance and to unexploited resources which may be vital to coastline protection or ecological balance. Examples of such resources include mangrove forests and coral reefs. It should be recognized that a full appreciation of possible oil pollution damage can only be gained by considering such effects against a background of other pressures exerted on the resources in question. For example, the absence of mangrove forests on some coasts is a result of commercial exploitation rather than pollution.

Environmental damage such as extinction of populations or destruction of habitats is viewed as undesirable, yet it is notoriously difficult to evaluate the damage in either economic or ecological terms.

A most important function of mangroves from an economic viewpoint is in providing rich feeding grounds for young species of commercially important fish and shellfish. Oil pollution damage of these nursery grounds would most likely be related to toxicity - of freshly spilled oil in particular. In the shallow waters typical of mangrove swanps, toxic concentrations of hydrocarbons could build up sufficiently to affect the young states which are generally more sensitive to such damage than the adults. Localized damage to mangrove trees has been observed in the past following oil spill contamination. Physical oil coating can cause defoliation and death of individual trees. The full significance of such localized effects for a large stand of mangrove trees is, however, unknown. In common with most coastal wetlands, mangrove forests are sensitive to the physical disruption of their habitat caused by effects to remove polluting oil. Once the complex root systems have been penetrated by oil there remains no practical remedy for clean-up other than allowing natural degradation to take its course.

Live coral is nearly always submerged even during l[illegible]tides and the probability for physical coating by oil from a spill is [illegible]fore slight. Any damage is more likely to be caused by either dispersed oil dropl[illegible] the water-soluble fraction of spilled oil. For this reason the use of chemical dispersants could be harmful to coral reef organisms in areas of poor water exchange by increasing the concentration of hydrocarbons in the sub-surface water layers. In contrast to chronic pollution, for instance in the vicinity of a refinery outfall or a marine terminal, experimental research recently conducted by ARAMCO has indicated that single oil pollution incidents are unlikely to cause notable damage to coral reefs if there is surface movement of the oil under the influence of wind and currents.

The effect of oil spills on deep sea and nearshore fish stocks is generally regarded to be slight on account of the high fecundity of fish coupled with their natural tendency to avoid contaminated waters. However, due to sampling problems it remains difficult to detect pollution effects against a background of highly variable natural mortality. In terms of economic loss the most significant effect is often the damage to fishing gear by oil contamination. The tainting of fish catches can sometimes be significant, leading to marketing problems if consumers lose confidence in the quality of fish products.

In contrast to the environmental damage caused by toxicity of oil, it is mainly its physical properties that are detrimental to recreation, tourism and coastal industries. Recreational activities and tourism are affected directly in the event of bathing beaches becoming covered by polluting oil and oiling of pleasure boats in marinas etc. In addition, more subtle effects such as reduced tourist numbers or hotel bookings are sometimes attributed to oil spills, particularly if media coverage of an incident has been extensive. However, effects of even the largest oil spills on the amenity use of shorelines are usually short-lived and any disruptions beyond a single season are rarely attributable to impaired amenities.

In this Region power stations and desalination plant water intakes are of particular concern and many governments have taken measures to protect these intakes by such measures as booms, netting and bubble barriers. Similarly, oil industry installations also draw sea water mainly for cooling purposes.

Although the intakes are usually situated at a sufficient depth to avoid direct suction of floating oil, the possibility of suspended oil droplets reaching the intakes is recognized as undesirable. The use of dispersant chemicals in the vicinity of these intakes should be avoided because on initial application oil can be dispersed to a depth of up to 10 metres.

In the confines of major ports, the explosion or fire risk posed by freshly spilled oil can necessitate disruption of welding and other construction work in docks which may involve sparks or naked flames. In addition, ship movements may be disrupted whilst clean-up activities, involving for instance oil booms, are in progress. In some ports where frequent small spills occur from routine operations, the background levels of oil pollution may be high but tolerable for most activities. Spills on a larger scale may cause unacceptable contamination of port structures, ship building and repair yards.

Traditional coastal industries which could be affected by shore pollution include sea salt production from salt pans located at the high tide level. In rough weather contamination of the salt pans could result from oily sea spray. Measures must also be taken to prevent ingress of oil into the sea water intakes for the salt pans.

LITERATURE

Exxon Background Series. 1978. Fate and effects of oil in the sea. EBS 12/78, 11pp.

Ferguson-Wood, E.J. & R.E. Johannes (EDS.). 1975. Tropical Marine Pollution. Elsevier Oceanography Series No.12, 192pp.

IMO. 1981. Petroleum in the marine environment. 23pp.

IMO. 1982. IMO/UNEP Guidelines on Oil Spill Dispersant Application and Environmental Considerations.

The Royal Society. 1980. The effects of oil pollution: some research needs. ISBN 0 85403 156 1, 103pp.

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