Water Research 135 (2018) 262–277

Contents lists available at ScienceDirect

Water Research

journal homepage: www.elsevier.com/locate/watres

# A review of bio-based materials for oil spill treatment

Bhairavi Doshi [a,*], Mika Sillanpää [a,b], Simo Kalliola [a]

[a] Laboratory of Green Chemistry, Lappeenranta University of Technology, Sammonkatu 12, Mikkeli, 50130, Finland
[b] Department of Civil and Environmental Engineering, Florida International University, Miami, FL, 33174, USA

ARTICLE INFO

*Article history:*
Available online 15 February 2018

*Keywords:*
Oil spill
Sorbent
Particle
Surfactant
Aerogel
Gelator
Separator

ABSTRACT

Being cost-effective, synthetic materials were initially used abundantly for the removal of oil. Gradually, however, awareness of the use of dispersants like Corexit, which makes water resources more toxic than oil, has changed the scenario for the treatment of spilled oil. The removal of spilled oil from water resources is still a very topical issue. An eco-friendly and sustainable approach towards the environment has introduced many low-cost, non-toxic and biodegradable materials along with different biomasses to make micro-to nano-sized materials, membranes, sponges/aerogel, etc. for the removal and recovery of oil from water resources. Additionally, the reusability of these materials after the recovery of oils has added one more step towards sustainability. This review comprises the work conducted by various researchers in the field of the removal and recovery of spilled oils using various biomasses and polymers, either in the form of sorbents or separators.



**Contents**



## 1. Introduction

Currently, the challenge is to clean water resources, which are being polluted by oil either in the form of routine shipping, run-offs from industry, dumping, or oil spills (NOAA, 2017a). An oil spill is the accidental or intentional discharge of petroleum hydrocarbons into the environment, especially the marine ecosystem. An oil spill on water can be transported by wind and current, and the distributed oil either evaporates or forms a surface slick, disperses in water, or submerges and accumulates in the sediments (Reddy et al., 2002; Liu et al., 2012). Additionally, temperature, salinity, and waves also increase oil transportation and weathering rates.

* Corresponding author.
*E-mail address:* Bhairavi.doshi@lut.fi (B. Doshi).

https://doi.org/10.1016/j.watres.2018.02.034

Moreover, oil spill from tankers such as Exxon Valdex in 1987 (11 million gallons) (Carson et al., 2003) and Deep Horizon in 2010 (4.9 million barrels) (Brody et al., 2010) were marked as the greatest disasters for the marine environment. Since most oils float on the water surface, seabirds and marine animals are mainly affected (Barron, 2012), and other creatures and terrestrial animals are harmed if the oil comes ashore (Brody et al., 2010). Such spilled oils also affect humans through inhalation, skin and eye irritation. Many researchers have reviewed the aspects and impacts of these spills on the ecosystem over time (Jernelöv, 2010; Henkel et al., 2012; Chang et al., 2014) and developed various methods and chemicals for oil spill response (Michel et al., 1992; ITOPF, 2014a). However, the spill intensity and location determine the clean-up technology that needs to be applied.

Oil spill treatment methods can be classified as physical/mechanical, chemical, or biological (EPA, 2017). Physical/mechanical methods include booms that are stationary floating devices to prevent the movement of the oil slick. Using high-temperature booms enables the burning of the oil in-situ (Evans et al., 2001; Fingas, 2011; IOGP, 2016). Skimmers are stationary or mobile devices, that were used to remove floating and/or emulsified oil from the water surface (Michel et al., 1992). Hydrophobic meshes that repel water but allow oil to pass through can be utilized in skimmers for enhanced oil recovery. Chemical methods include dispersants (IPIECA, 2001; ITOPF, 2014b; Graham et al., 2016) sprayed on the oil spill to break it up into small droplets (NOAA, 2017b). In addition, sorbent materials may be used in small-scale oil spills. Biological methods include the addition of microbes and/or nutrients and/or oxygen to stimulate bacterial growth and the resultant biodegradation of the spilled oil (Azubuike et al., 2016). However, physiochemical methods have limitations in terms of crude oil clean-up, so recently biological methods have held sway (Das and Preethy, 2011; Dave and Ghaly, 2011). However, the selection of sorbent materials is dependent on the nature of the spilled oil (Teas et al., 2001).

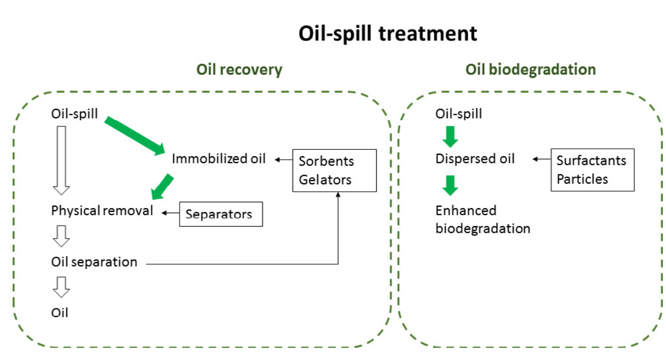
The rate at which oil can be treated in open waters depends on the treatment method. Dispersants applied from aircrafts are the fastest, followed by skimming and in-situ burning (Graham et al., 2016). In addition, environmental conditions affect the performance of the treatment methods, such as wind, currents, waves, oil viscosity, and sensitivity to debris. The costs of different oil spill treatment methods from the least to most expensive are as follows: in-situ burning, dispersants, mechanical recovery, and manual cleanup. Despite cost efficiency, in-situ burning generates many particulates and carbon dioxide in the environment (Mullin and Champ, 2003). Choosing the oil spill treatment method becomes an optimization task by minimizing both the environmental impact and cost of operation. Local jurisdiction also affects costs, due to possible fines based on the amount of spilled oil, which limits the oil spill. However, some treatment methods leave the oil in the environment, so it may still cause damage to the ecosystem. It was therefore suggested to impose fines based only on the amount of oil left in the environment. In other words, recovering the spilled oil would decrease the amount of the fine. This kind of jurisdiction could make recovery methods more economically viable, depending on the scale of the fine and the oil spill scenario (Prendergast and Gschwend, 2014).

Most of the materials reviewed in this paper aim to either recover spilled oil or enhance the biodegradation of the oil. The best solution in the case of an oil spill depends on numerous factors, and the optimal solution from environmental and economic points of view might be a combination of several different methods. Therefore, instead of classifying oil spill treatment methods based on technical aspects, solution-based classification of oil recovery or oil biodegradation is proposed. In the case of an oil spill, either the oil must be left in the environment for biodegradation or it can be recovered from the environment, and to achieve this there are different technical methods and materials. Scheme 1 shows this classification.

Existing dispersants/chemical herders are chemically stable, but non-biodegradable so remain longer in the marine environment. There is therefore a growing demand for green, facile and eco-friendly, low-cost sorbents from biopolymers for the treatment of oil spills and chemical leaks. In past few years, advanced materials such as aerogels, foam membranes, inorganic meshes, and surface-modified fabrics have been used extensively for the separation of oil-water mixtures. Meanwhile, the increasing population rate has increased the rate of food consumption, resulting in massive amounts of bio-waste globally. For this reason, the wise way is to use such easily biodegradable bio-waste or biomass to produce low-cost sorbents with higher oil sorption capacity that are simple to scale up for the cleanup of an oil spill, rather than hazardous chemicals. This review addresses the potential and environmentally-friendly bio-based materials in the form of sorbents, particles, gelators, surfactants and separators for oil spill treatment. These kinds of bio-based materials have recently been the subject of increasing interest in oil spill treatment applications, and reviews have been published on specific materials or methods (Sabir, 2015; Ifelebuegu and Johnson, 2017). The different materials and methods for oil spill treatment are suitable for different kind of conditions. For sustainable and effective oil spill treatment, bio-based materials must be studied extensively, since one material is unlikely to be suitable in all possible oil spill scenarios. Additionally, local legislation has also affected the economic view of the materials, and method design must be considered. Legislation is subject to changes due to increased environmental awareness, which has a direct impact on oil spill treatment methods, so the utilization of bio-based materials in different kind of oil spill treatment methods and materials must be extensively studied and researched, in response to different kinds of oil spill scenarios and possible future legislation. This review highlights a wide range of different bio-based oil spill treatment materials and methods along with their strengths and weaknesses.

## 2. Statistical trend of sorbents used in oil spill response

The statistical trends based on the Scopus database of various sorbents studied extensively in the past ten years are given below (Fig. 1). This implies that more research is being conducted using these materials as oil sorbents. Statistical data shows a continual increment in the use of nanoparticles and aerogel for oil spill treatment in the past few years.




**Scheme 1.** Oil spill treatment methods based on the oil recovery or oil dispersion.