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Oil Spills and Sustainable Cleanup Approach

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ABSTRACT

The need for extensive study o improving and developing viable natural absorbents in recent years is increasing due to the enormous negative environmental impact of oil spill to the surroundings and the inhabitants. This paper reviews the negative effect of oil spill in the past, how oil spills affects plants and animals, different adopted control and cleanup techniques which include mechanical devices and the use of sorbent materials, it also emphasized on the necessity for the development of available materials in diverse parts of the World especially in the tropical region. Therefore proposes eco-friendly materials such as raffia palm fibres, palm fruit wastes, kenaf as promising oil absorbent materials.

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INTRODUCTION

Oil spills seemed to be the highest sea and river pollution. Generally, oil is accidentally discharged during extraction, distribution, storage, and usage. The British Petroleum (BP) explosion on 20th April, 2010 in the Gulf of Mexico covered 790km of shoreline within 36 months, which resulted to several casualty's (Welch and Joyner,2013; Polson,2011).The discharges of 260,000 barrels by Exxon Valdez in the gulf of Alaska, 24,000 barrels spills in River Monongahela due to storage tank rupture, oil tanker failure in the Strait of Malacca, the 978 Amoco Cadiz super tanker accident; Arabian Gulf incidence in 1991as a result from the release of huge barrels of oil in the operation Desert Storm (Kapoor andRawat,1994), the Prestige oil tanker incident that resulted to 12000 tonnes of oil spilled in Galicia, Spanish coastlines in 2002, are but a few case's oil spill accident in the previous years. It can be stated in recent years that the trend has changed greatly. About 22 oil spills incidence along the Norwegian coastline alone in the last two decades has been reported (wwf.no/dette).

Oil spill has a great negative influence on the ecosystem by putting the marine lives at high risk. However, the extent of risk is dependent on the type and volume of the oil in addition to other abiotic factors such as the sensitivity limit of the marine habitat. Oil spill on river or sea envelopes the water surface and consequently, shields the diffusion of sunlight that enhances photosynthesis. Aquatic lives rely mainly on Phytoplankton and seaweed for existence. Majority of crude oil discharge occurred in the water ways. About 5millions tons of unrefined oil products are transported per annum averagely across the ocean globally (Anisuddin *et al*., 2005, Fominyen, 2010). Oil consists of wide range of organic (hydrocarbon) based constituents which might be crude oil, refined, edible and non-edible oil. However, crude oil may contain other elements such as sulphur, hydrogen sulphide and oxygen (Wang and Fingas, 2003).

Oil spill effects have attracted several researchers from different disciplines involving petroleum engineering, biology, environment engineering, marine engineering, chemical engineering, materials engineering (Espeda and Johannessen, 2000; Stephanie, 1994; Mario, 2000; Vendrell, 1993; Price, 1991; Fingas and Fieldhouse, 1994; Fingas, 1995). However, sustainable oil clean up approach is still a huge and challenging task due to high cost and environmental impact of the current practices. The traditional techniques that have been used over time include; the use of chemical dispersants, containment (oil booms), mechanical recovery (skimmers and separators) and bioremediation. The strategies and efforts for cleanup activities depend upon various factors such as water temperature, nearness to shoreline, spill volume, oil type and density, waves, weather, currents and response speed (Graham, 2010). These factors create limitations, which possess challenges in recent years. The need for eco- friendly and cost effective natural sorbents cannot be overemphasized in recent times. Diverse agricultural products such as peat, leaves and wood products have been

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employed. Cotton, straws, kenaf, corn cob, wood fibre, milkweed floss, peat moss, kapok fibre was reported (Choi and Cloud, 1992; Scharzberg, 1971).

These materials for absorbents need to fulfil several criteria before they can be considered to be viable oil spill clean-up absorbents. The material should be hydrophobic and oleophilic, possess high rate of uptake and retention, and be able to release absorbed oil (John, 2001). The hydrophobicity and oleophilicity enhance oil absorption capacity with little or no water uptake. The high uptake capacity facilitates large amount of oil pick up relative to the weight of material. The high rate of uptake shows that the material absorbs the oil quickly. The retention over time confirms that oil does not leak from the material after absorption. On the other hand, it is also essential to cheaply and easily remove absorbed or adsorbed oil from the material; otherwise, it becomes cumbersome and inefficient in the long run. Preferably, the material should be reusable and biodegradable (McLeod and McLeod, 1974).

Table 1: Oil spill history (www.marine group).

Year	Country	Incident	Quantity (tonnes)
1967	UNITED KINGDOM.	Torrey Canyon ran aground off Cornwall spilling	125,352
1970	SWEDEN	collision involving Othello in Tralhavet Bay.	59,743
1972	OMAN	collision of Brazilian tanker Horta Barbosa with the South Korean tanker Sea Star.	114, 576
1976	USA	Argo Merchant ran aground off Nantucket	24,961
1978	FRANCE	Amoco Cadiz ran aground near Portsall	218, 240
1979	MEXICO	Gulf of Mexico.	454,667
1979	TRINIDAD & TOBAGO	a collision off Tobago between the Atlantic Empress and the Aegean Captain	300,080
1983	SOUTH AFRICA	Spanish tanker Castillo de Bellver Fire	245,520
1989	USA	Exxon Valdez hit rocks in Prince William Sound	32, 736
1990	USA	The tanker, American Trader	974
1991	KUWAIT	final phase of the Iraqi attack of Kuwait.	7,557,935
1992	INDONESIA	Nagasaki Spirit collided with container Ocean Blessing in the Malacca Straits spilling some 1993	12,000
1993	SINGAPORE / INDONESIA / MALAYSIA	Singapore-registered tanker Maersk Navigator collided with the empty tanker Sanko Honour in the Andaman Sea	272,800
1995	UNITED ARAB EMIRATES	Panamanian-flagged supertanker Seki	15,900
1996	AUSTRALIA	Iron Baron, ran aground on a reef	500
1998	NIGERIA	ruptured pipeline to one of Mobil's terminals	5,456
1999	FRANCE	registered tanker Erika breaks up in stormy seas	15,000
2000	BRAZIL	leaked from a refinery	31,491
2000	MALAYSIA	A sunken Chinese cargo ship at Tanjung Po anchorage point at the Sarawak River mouth	5,000
2003	PAKISTAN	An oil tanker has broken up off Pakistan's Arabian Sea port, Karachi	10,000
2004	CANADA	occurred at the Terra Nova offshore oil platform	1,386
2005	USA	Murphy oil refinery spill	2,660
2006	LEBANON	Jiyeh power station oil spill	20,000
2007	NORWAY	Statfjord oil spill	4000
2008	USA	New Orleans oil spill	8,800
2009	AUSTRALIA	Montara oil spill	4,000
2010	NIGERIA	Exxon Mobil oil spill	3,246
2011	CANADA	Little Buffalo oil spill	3,800
2012	USA	Arthur Kill storage tank oil spill	1,090
2013	USA	Magnolia refinery spill	680
2013	THAILAND	Rayong oil spill	43

2. Adverse effect of oil spill:

Marine oil spills pose a great and severe threat to our coastal environment as shown in Fig. 1. The contaminants (oil) are often discharged into the water bodies as a result of accidental discharge. For example, demolition of oil storage tanks and sometime from oil rig drilling, war, natural occurrence and vandalized pipelines which, consequently, cause harm to the ecosystem.

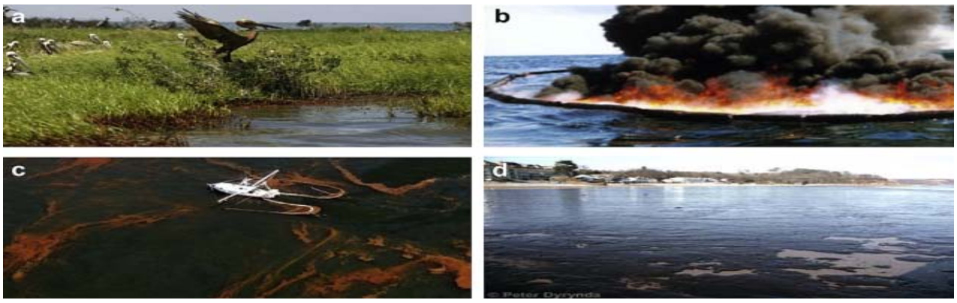

Fig. 1: Oil spill effect (Salbu, 2009).

Estimated figures of 25,000 birds died in the 1967 Torrey Canyon incidence, more than 3450 sea birds were reported killed including other aquatic animals in the Amoco Cadiz oil spill. However, there was no recorded evidence of adult fish killed (Simpson, 1968), open sea oil spill does not always have significant toxic effect on adult fish. The Buzzard Bay incidence in Massachusetts in 1968 resulted to the killing of large numbers of fish; in this case, the oil was light with high toxicity and was spilt into shallow turbulent water (Baker *et al*., 1980). The British Petroleum Gulf of Mexico's incidence claimed estimated lives of 997 birds, 400 sea turtles and 47 Mammals (Polson; Kapoor and Rawat, 1994). Furthermore, oil spill may result to oxidative effect that affected biomolecules, drastic reduction of sea plants, because any negative effects on photosynthetic organisms [Bott *et al*.; O' Brian and Dixon, 1976), will influence the population of others, which will consequently, affect other species in the ecosystem (Salbu, 2009; Varela *et al*., 2006; Stekoll and Deysher, 2000).However, this effect is dependent on the toxicity, the volume of oil discharged and species tolerant. Residue of oil spill over a long period of time hinders the possible recovery of the ecosystem (Peterson *et al*., 2003). The negative impact of oil spill is not peculiar to aquatic lives alone but also affects the soil if discharged on land and the coastline. This drastically renders the soil unfertile which will result to shortage of agricultural produce supply. Table 2 shows a comparison of the number of dead sea birds due to Exxon Valdez and Braer oil spills.

Table 2: The effects of the Exxon Valdez and Braer oil spills on seabirds (Kingston, 2002).

Species	Shetland spill	Alaskan spill
Loons	14	395
Sea ducks	167	1440
Grebes	0	462
Heron	3	1
Mergansers	1	121
Geese	0	9
Kittiwakes	133	1225
Gulls	74	696
Cormorants	864	836
Shear waters	0	3399
Murres	220	20562
Other auks	29	2174
Bald eagles	0	125
Fulmars	31	870
Other birds	0	3152

3. Factors limiting oil spill mitigation:

Oil spill clean-up is a rigorous exercise due to several factors that influence its control. Some of these factors are discussed briefly as follows:

Salinity:

Salinity of ocean is 1g of salt per 1kg of water. The influence of salinity on oil clean-up has been studied. Increase in salinity increases water density and thus reduce the interfacial tension. The decrease in surface tension, therefore, enhances oil recovery from the water (Mazindouh and Omar, 2003) as shown in Table 3 and Fig.2.

Table 3: The effect of salinity on density and surface tension (Mazindouh and Omar, 2003).

Simulated Seawater ($kgNaCl/m^3$)	Density (kg/m^3)	Interfacial Surface Tension (mN/m)
0.0	996	48.0
10.0	998	45.0
20.0	1010	27.2
30.0	1020	25.5

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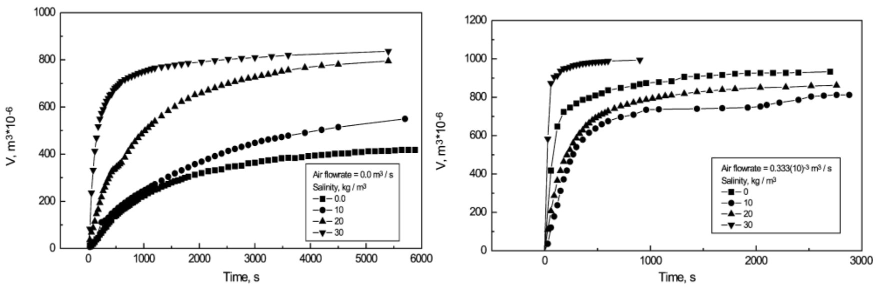

a. b.

Fig. 2: The rate of oil spill clean up using vaccum technique (Mazindouh and Omar, 2003):
a- Effect of salinity on oil spill clean-up for still water;
b- Effect of salinity on oil spill clean-up for circulated water.

3.1 Temperature:

Temperature is an essential factor to consider in oil spill clean-up because of its variation from a region to region and seasons. High temperature enhances evaporation of lighter part of oil because, increase in temperature reduces oil viscosity; however, the nature of the oil also plays a significant role [Kuclick *et al*., 2001). At a low temperature, the solubility of oil in water is relatively lowered. The heavier fraction on the water surface tends to hinder combustion and the effectiveness of surfactant (Satish *et al*., 2003).

3.2 Wave height:

Sea conditions affect's oil clean-up enormously, when the weather is rough, the water surface is agitated. This churning hinders the effectiveness of containment using a boom. This is because during this period, some of the oil escapes from the confinement (Koda, 2013).

3.3 Surfactants:

These are chemical additives that lower the interfacial surface tension between oil and water. It is used as dispersant for oil spill clean-up. Thus, the oil droplets are reduced to smaller droplets, which become denser and consequently, sink to the sea bed (Graham, 2010).

4. Oil spill confinement and clean-up measures:

In the past, containment and recovery measures have been utilized for oil spill mitigation. The conventional techniques include: containment and mechanical recovery; burning; bioremediation; chemical dispersant and the use of absorbent. The recovery techniques are dependent on various factors such as weather conditions, sea condition, oil type and environmental considerations, which could necessitate the combinations of these measures for clean-up. These techniques are briefly outlined as follows:

4.1 Oil booms:

Booms are structured normally used to confine oil spill from spreading before using skimmers and separators for oil recovery. Booms have been used extensively in the past during the oil spill incident. This method is eco-friendly [Castro *et al*., 2010). However, weather conditions possess an adverse effect on efficiency. Skimmers are mechanical devices for recovering oil from the surface of rivers, lakes, canals, harbours or open sea. Skimmers can be grouped under five categories (Wardley, 1983) as;

Group A: Skimmers who depend on the adhesion of oil to a solid medium that revolves in a vertical plane with part of the bottom half of the medium (metal discs or other materials) below the water surface.

Group B: Skimmers who rely on the attachment of oil on a continuous belt pulled between the oil-water interfaces. The adhered oil can then be scraped from the belt otherwise squeezed if the belt is an absorbent material.

Group C: Skimmers function by incorporating centrifugal devices that create a vortex to raise the viscosity of the oil to a point from which it can be trapped and pumped out.

Group D: This group involves devices which separate oil from water through a weir. The weir ranges from a few centimetres to about ten metres in length.

Group E: This group function by combining one or more devices mentioned above.

4.2 In-situ burning:

This method involves burning slick of oil on the water surface. This technique was first implemented and recorded in northern Canada in 1958 and have been used extensively in some of the Scandinavian countries. It is generally subject to the approval of government agencies because of the flammability of hydrocarbon products (crude oil, gasoline and kerosene). Fresh crude oil on the water surface will burn when ignited, though; this depends on the percentage of volatility content. Oil on the water surface with thickness less than about 2.5 millimetres cannot be burnt successfully (Wardley, 1983).

4.3 Dispersants:

These are chemical compositions made from surfactants and other additives that help to reduce the interfacial surface tension between oil and water. For effectiveness, dispersants need to be sprayed uniformly with reasonable concentration (Marine board, 1989). The following basic criteria are essential for effective dispersal of oil to take place chemically (Butler, 1989): (i) Dispersant must be deposited on the oil slick, (ii) Dispersant must diffuse to the oil/water interface or mix with the oil, (iii) It must have an optimum concentration that will initiate a maximum decrease in water-oil surface tension and (iv) It must be able to disperse the oil into droplets. The uses of dispersants are restricted or regulated because of their toxic nature (EPA, 2013; Bly *et al*.,2007). More so, it is recommended that its application should be in the deep sea with vigorous agitation (Ladd and Smith, 1970). This tends to reduce the negative impact on the sea bed.

4.4 Absorbent:

Oil is removed by sorbent materials in two modes or mechanisms. These are: (i) adsorption and (ii) absorption. Adsorption involves the adherence of the oil to the sorbent material. The removal of oil is dependent on the viscosity of the oil. The more viscous the oil, the thicker the layer that will adhere to a given material. On the other hand, absorption relies on capillary attraction; oil fills the pores within the material and migrates upward (uptake) into the material due to capillary force. The rate of penetration (P) is directly proportional to the radius of the capillaries (r) and inversely proportional to the viscosity of the oil.

$$P = \propto d/2\mu \quad (1)$$

$$P = Kd/2\mu \quad (2)$$

Where P = rate of penetration of oil, K = surface boundary, d = diameter of capillaries, μ = viscosity.

However, Darcy’s law shows flow rate phenomenon in porous materials as given in [Decamps, 2003, Zhong *et al*., 2002).

$$u = -\ k/\mu\nabla P \quad (3)$$

where u is the average velocity; K, the permeability of the porous materials, μ viscosity and ∇P, the pressure gradient.

Sorbents are materials with high affinities for oil and repellent for water. They can be classified as; inorganic minerals, synthetic, organic and organic (agricultural) products. Sorbents are cheap, efficient, environmentally friendly and easy to deploy. However, efficiency is dependent on sorption capacity, density, wettability, retention rate and recyclability (Sun *et al*., 2003; Lehr, 1971). Examples of sorbents are; inorganic minerals (organoclay, activated carbon, zeolites, and graphite), polymeric materials (rubber tires, plastics), synthetic organic products e.g. open cell polyurethane, and agricultural products (cotton, straws, corn cobs, coconut shells, kenaf, kapok fibres, rice husk, and silkworm cocoon (Johnson, *et al*., 1973; Smith, 1983; Anthony, 1994; Tsai *et al*., 2001).

Different types of sorbent's materials have been studied in previous years as discussed below:

4.4.1 Synthetic materials:

The most widely and satisfactory sorbent materials are synthetic polymeric materials. The properties of these materials can be varied by altering their micro-pores. Foams of polyurethane, urea formaldehyde, polyethylene, nylon, polyester materials have been used. Most of the synthetic sorbents can absorb as much as 60 to 100 times their weight. For instance, it has been reported that open-cell polyurethane foams can absorb oil 100 times their weight (Jarre *et al*., 1979). Some of these synthetic materials tend to absorb more water in preference to oil due to their large pores. However, polyethylene fibre roving are highly hydrophobic (Wardley,1983). Tire powder efficiency for oil cleanup has been studied (Lin *et al*., 2008), the studied revealed that tire is oleophilic and can withstand 100 times cycles without losing its sorption potency. Polyethylene and polypropylene plastic waste powder and sheets as oil sorbents have been reported [Dia *et al*.,], PE powder and sheet were effective in heavy oil uptake than light oil. However, PP powder only showed considerably oil sorption in heavy oil. Despite good hydrophobic and oleophilic nature of these materials, their non-biodegradable nature is a great disadvantage (Decamps, 2003).

4.4.2 Inorganic materials:

These are small size-granules, generally used to sink spilled oil on the water surface. These include organic ash, glass wool, vermiculite, clay, sand, perlite, activated carbon, etc. One of the more successful inorganic manufactured materials used in the past, though expensive was ekoperl. This material is in form of fine granule, therefore, can absorb light oil much more than oil with high viscosity. Organoclay has been reported to have high sorption and retention quality and can be equally used to synergize activated carbon in order to improve the efficiency of activated carbon (Carmody *et al*., 2007; Alther, 2001; Beall, 2003).

4.4.3 Natural organic materials:

Natural or agricultural products are widely distributed and largely used in most parts of the world for oil spill cleanup. The materials include, hay, straw, sawdust, reeds, peat, bagasses, gorse, dried palm fronds, etc. Most of these materials are oleophilic because of their waxy nature, they become light weight when dried, which improves their buoyancy in water, and usually oil is trapped in the mat of criss-cross strands or fibre rather than absorption by capillary force. Straw has been the most widely and probably the most efficient of all these materials. Straw fibres can float on the water surface for a very long period of time to collect oil adequately. It has been reported that straw sorption capacity is higher than commercial synthetic organic material from propylene (Choi, 1996). Similarly, kapok, rice husk, banana trunk fibre, acetylation of raw cotton, cotton grass fibre, has been reported to be efficient as oil sorbent (Lim and Huang, 2007; Abdullah and Rahmah, 2010; Kumagi *et al*, 2007; Sathasivam, 2010; Adebajo *et al*., 2006, Sun *et al*., 2004).

5. The future study guidelines:

Agricultural products have been proven to be effective as oil spill sorbent from the reviewed literature. However, for sorbent to be highly efficient, it must meet the conditions itemized below and above all, their availability and environmental friendliness are essential. This paper proposes some guidelines for further studies of palm fruit's fibre, palm kernel shell and raffia palm fibre. These products are easily available in Malaysia and some other tropical countries. The use of date palm activated carbon as sorbent has been studied [36]. However, little studies on raffia palm fibre, activated carbon from palm kernel shell and fibre as sorbent for oil spill clean-up has been reported to the best of my knowledge. Fibres from raffia palm and palm fruit fibres are promising environmentally friendly sorbent for oil spill clean-up. More so, addition of acetic anhydride by way of chemical modification can further enhance their efficiencies.

The following characteristics must be considered when choosing sorbent materials for oil cleanup:

i. Availability (the sorbent materials should be readily available and accessible)
ii. Eco-friendly (the materials should be bio-degradable or cheaply recyclable)
iii. Cost (cost of acquisition, processing, recovery, etc., should be relatively cheap)
iv. Ease of application (their application should not be cumbersome)
v. Oil retention (good quality to retain recovered oil without deformation)
vi. Rate of adsorption or absorption (should be able to adsorb oil to fibre surface, especially heavy oil and large pores for absorption of light oil).
vii. Re-usability (the ability to be used many times, i.e. cycle and still able to retain sorbent capacity is desirable).

6. Conclusions:

The study reviewed the adverse effect of oil spill and control measures. From the review, it is evident that oil spill is detrimental to the environment; therefore, the need for cost-effective and environmental friendly sorbents for oil spill clean-up is imperative. Straw and Kapok have more sorbent capacity than commercial polypropylene. However, these materials are not readily available to every part of the world. Therefore, the use of palm fruit fibres, raffia palm fibres, palm fruit wastes, kenaf as natural sorbent has been proposed for oil spill clean-up in the tropical region, especially, because of their boundless abundance. Moreso, chemical modification of these materials will further enhance their performance as oil absorbents.

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