Treatment of petroleum-contaminated water resources: modern techniques

Pogharnitskaya O.V.[1,2], Konovalov V.V.[1,3] , Dmitrieva N.V. [4], Belozerova D.S.[1], Strelnikova A.B. [1]

[1] National Research Tomsk Polytechnic University, 30 Lenina Ave., Tomsk, 634050, Russia
[4] Novosibirsk State University, 2 Pirogova Str., Novosibirsk, 630090, Russia

E-mail: [2]pov@tpu.ru, [3]sltan@ngs.ru

Abstract. The article deals with the issue of petroleum-contaminated water resources. The authors have analyzed the dynamics of oil spills, including the world's largest ones, and claimed the issue to be global. The modern methods of mitigating oil spill effects have been studied, as well as the modern techniques of water resource treatment. The particular attention is paid to peat sorbent production, which is considered a promising trend of petroleum-contaminated water treatment.
Key words: water resources, oil, petroleum contamination, peat, water resources treatment

Introduction

Over the past decades, negative environmental impact attributed to oil spills has substantially increased. The major damage has been caused to water resources.

In practice, oil spills and leaks inevitably occur at different stages of recovery, processing, and transportation, with oil pipeline accidents being particularly dangerous. Therefore, it is quite difficult to develop the whole range of preventive measures to reduce the environmental impact.

Having penetrated into the ground, oil results in complicated processes, which makes the treatment of petroleum contaminated soil and water a challenging task. Currently, water resource contamination caused by oil spills is a topical issue on both national and global scale.

Another urgent question to be solved today is water resource treatment, which involves wastes recovery and recycling. It is also important to choose the optimal methods to mitigate the negative environmental impact.

Materials and methods

Today, different economic sectors search for the methods to liquidate oil spill under various plausible scenarios.

Laboratory experiments, land survey, and practical experience made it possible to describe oil properties and develop methods of oil spill liquidation. The research was mainly focused on the moderate climate regions, however, the Arctic scenarios, which imply low temperatures and presence of sea ice, were investigated as well.

According to the data by the Division of Mineral Resource Management, the USA, there were 858 fires and explosions on offshore platforms over the period of 2001–2010, which means approximately one accident per four days. Annually more than 1.5 billion tons of oil, which accounts for about 40% of all recovered oil, is transported by tankers. This figure is significantly higher than that of oil recovery in offshore fields, the latter being within the range of 30–34% over the past years. In accordance with statistics, the amount of oil spilled during transportation is 23-26 times as high as that during offshore recovery [1].

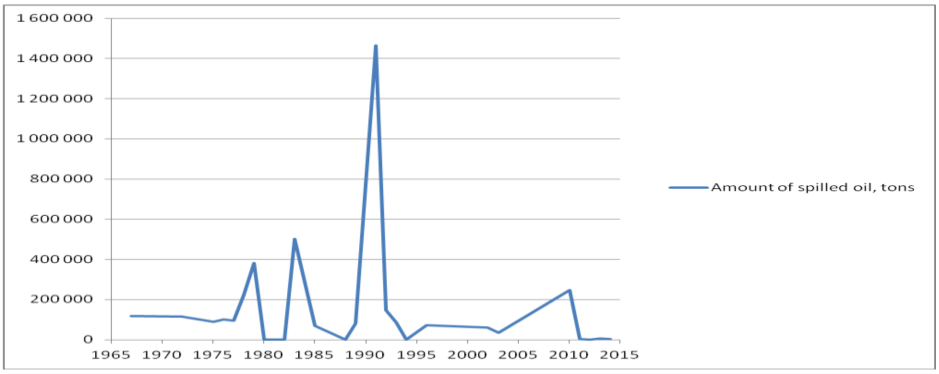

Fig. 1. Amount of oil released due to the largest oil spills

Figure 1 illustrates the data on oil released in the result of the largest oil spills, without reference to minor ones. Statistical data on offshore oil spills indicate that the share of major oil spills (more than 700 thous. tons) is relatively small and has decreased over the studied period. Most accidents occurred before 2000: 1970s – 245 spills (54%), 1980s – 94 spills (21%), 1990s – 77 (17%), 2000s – 35 (8%) [2].

Table 1 shows figures on the largest oil spills (the data are based on the materials published by the International Tanker Owners Pollution Federation (ITOPF) and elaborated by the authors of the present article).

Table 1. World's largest oil spills

Tanker / Platform	Year	Location	Responsible party	Amount of spilled oil, tons	Damage caused
The Gulf War oil spill	1991	The Persian Gulf	Iraq	1 091 405	$540 million
Ixtoc I oil spill, Mexico's semi-submersible drilling rig Sedco 135-F	1980	The Gulf of Mexico, about 100 km northwest of Ciudad del Carmen	Mexican state-owned petroleum company PEMEX	467 000	$42 million
Tanker Atlantic Empress	1979	Tobago, West India	South Gulf Shipping Co. Ltd., Greece	287 000	not available
Oil spill on the Colva river, the pipeline Kharyaga-Usinsk	1994	The Republic of Komi	AO Komineft, Russia	264 000	not available
Tanker ABT Summer	1991	700 nautical miles off the Angolan coast	Liberia	260 000	not available

Platform Deepwater Horizon, Macondo field, BP	2010	The Gulf of Mexico	British Petroleum, Great Britain	245 566	More than $40 billion
Tanker Castillo de Bellver	1983	Saldanha Bay, South Africa	Empresa Nacional Elcano De La Marina Mercante Madrid	252 000	not available
Platform Nowruz	1983	The Persian Gulf	Iran	250 000	not available
Tanker Amoco Cadiz	1978	5 km (3.1 mi) from the coast of Brittany, France	Amoco Corporation	223 000	$85.2 million
Tanker Odyssey	1988	700 nautical miles off the coast of Nova Scotia, Canada	Polembros Shipping Ltd. Great Britain	132 000	not available
Supertanker Torrey Canyon	1967	The Isles of Scilly, Great Britain	Barracuda Tanker Corporation, British Petroleum, Great Britain	119 000	not available
Supertanker Sea Star	1972	The Gulf of Oman	South Korea	115 000	not available
Tanker MT Haven	1991	Genoa, Italy	Cyprus	114 000	not available
Tanker Irenes Serenade	1980	Navarino Bay, Greece	Greece	100 000	not available
Supertanker Urquiola	1976	La Coruna, Spain	Bilbao, Spain	100 000	not available
Tanker Hawaiian Patriot	1977	300 miles off Honolulu, Hawaii	Liberia	95 000	not available
Tanker Independenta	1979	The Bosphorus, Turkey	Romania	95 000	not available
Tanker Jakob Maersk	1975	Porto, Portugal	Denmark	88 000	not available
Tanker MV Braer	1993	The Shetland Islands, Great Britain	Braer Corporation, Canadian Ultramar Ltd	85 000	not available
Khark 5	1989	120 nautical miles off Morocco	Iran	80 000	not available
Tanker Sea Empress	1996	Milford Haven waterway, Great Britain	Oriental Ocean Shipping, Spain	72 000	not available
Tanker Katina P	1992	Maputo Bay, Mozambique	Malta	72 000	not available
Tanker Nova	1985	Kharg Island, Iran	Iran	70 000	not available
Tanker Prestige	2002	The Spanish coast	Mare Shipping Inc., Liberia	60 000	€4 billion

Tanker Exxon Valdez	1989	Prince William Sound, Alaska, the USA	Exxon Corporation	37 000	$ 3.5 billion
Tanker Tasman Spirit	2003	Near the city of Karachi, Pakistan	Spain	35 000	not available

As shown in the table above, there were numerous offshore oil spills over the past 50 years, which had negative impacts on the marine ecosystem.

For instance, the Exxon Valdez oil spill, which occurred in Prince William Sound in 1989, caused great damage to the particularly sensitive ecosystems of Alaska. This is due to the fact that the coastal waters of Alaska are cold and fail to provide habitat for the bacteria capable of hydrocarbon degradation. Warm waters, on the contrary, are rich habitat for the above-mentioned bacteria and oil degradation is regulated by the environment, however, this fact does not permit the parties to waive their responsibilities for the damage caused.

Having integrated the data obtained from various information sources, one can state that the amount of oil that annually enters the world ocean ranges between 5 and 100 million tons, with oil spill accidents accounting for only 12–15% of this volume. The sources of hydrocarbon input to the world ocean are given in table 2 [3].

Table 2. Sources of oil input to the world ocean

Source	million tons per year
Oil transporting and shipping (except for accidental oil spills)	1.83
Accidental oil spills	0.3
Discharges with rivers (including urban municipal sewage)	1.9
Discharges of waste water from coastal industries	0.8
Atmospheric fallout	0.6
Natural seeps	0.6
Offshore production	0.08
Total:	6.11

As for Russia, petroleum transported by sea is mainly export, and the major sources of petroleum input to the marine environment are ship-related:

- discharges of tank-washing residues, oil-contaminated ballast water, and bilge water;
- discharges in the harbors;
- accidental discharges.

An example of accidental discharges is the Russian tanker Nakhodka oil spill: the tanker broke up en route to Kamchatka in 1997, which resulted in contamination of some 200 km of the coastal area. Another Russian oil tanker, the Volgoneft-139, broke apart in Kerch Strait, with 1.2 thous. tons of oil residue released [4].

According to Greenpeace Russia, the Russian Federation, where the oil pipeline stretches for 400 thousand km, is among top countries in terms of the frequency of pipeline accidents. Annually at least 5 million tons of petroleum is released into the environment, which is five times as much as the amount of oil spilled in the Gulf of Mexico in 2010 [5].

Petroleum contaminated water resources are an urgent issue for West Siberia, since many companies involved in oil recovery, transportation, and processing are located in this region. Having entered the water, the oil forms a thing film on the surface. This film prevents oxygen ingress into the water, which has a negative impact on fish and plants [6].

More often than not, oil spills on soil lead to groundwater contamination [7].

Due to the above-mentioned reasons, there should be enhanced techniques for the treatment of petroleum contaminated water and soil. This question is particularly topical under the circumstances of intense petroleum production and necessitates new approaches.

Contaminated soil is usually recovered via technological and biological methods. Technical methods are as follows: mulching, raking and removal of the contaminated layer, burning out. However, it takes a long time for the ecosystem to recover, about 10-25 years and even more.

Biological methods are more promising and include various agricultural engineering techniques, such as liming, use of sorbents and fertilizers [8].

It is supposed that natural and synthetic sorbents, such as peat, polymers, sand, and containment booms are only auxiliary means, which prevent oil spread. Peat sorbents are also widely used today and tend to be more efficient than many organic sorbents, including those exported from other countries.

Siberian Research Institute of Agriculture and Peat of Russian Academy of Agricultural Sciences, Tomsk, received a patent on removal of petroleum from water surface. One gram of peat is enough to adsorb from 8–11 to 15 grams of oil. Peat sorbent developed at the research institute to liquidate oil spill effects, i.e. hydrocarbon contaminants and oil slick. The sorbent is produced from the upper peat with low decomposition rate (5–10%), which is modified to obtain hydrophobic properties. The sorbent porosity and sorption capacity are significantly higher than those of hydrocarbons.

The peat sorbent has many advantages in comparison with other sorbents, such as activated carbon, straw and bulrush chaff, buchwheat, which are characterized by lower capacity for oil (0.5–2.7 grams of oil per a gram of sorbent) and hydrophilicity causing release of trapped oil and preventing sorbents from floating.

In addition, synthetic sorbents fail to decompose under natural conditions and should be recycled, unlike peat sorbent, which is environmentally friendly. Moreover, synthetic sorbents absorb both oil and water, but peat absorbs only oil spill from the surface.

The issue of water deposits removal is especially topical for oil producing regions as there are many oil leaks caused by pipeline failures. When in water, hydrocarbons have a negative impact on fish, shell fish, etc.

The scientists from the Institute of Biology, Tomsk State University, in cooperation with NTO Priborservis have developed a technique which allows lifting up oil from the bottom. The technique is based on flotation effect: the place where petroleum is accumulated get under pneumo-mechanic impact, which makes oil "stick" to the contact of two phases, air and water, and rises to the surface. The method has already been efficiently implemented in the Republic of Komi, where it helped to raise 157 tons of oil from the bottom of Lake Schuchye [9].

Conclusion

Russia is rich in peat as the significant share of global peat reserves is located within the territory of the country, and particularly in West Siberia. Tomsk Oblast is ranked second in terms of peat reserves (first is Tyumen Oblast). The estimated peat reserves account for 30 881 412 thous. tons, which makes up 18 % of all national reserves. More and more people and organizations get interested in using peat, however, peat recovery in Tomsk Oblast is at its initial stage since there is no appropriate infrastructure, regulations are inapplicable to monitor peat recovery, reserves are poorly estimated, there is no actual data on peat bogs, etc.

To overcome these challenges, there should be innovations implemented in the industry. It is necessary to consider in detail the questions as follows: peat fields exploration and development, environmental assessment of peat bogs, the rate of fire hazard, innovative products which can be obtained from peat, the efficiency of peat in agriculture and treatment of petroleum-contaminated resources, etc.

Oil spills inevitably lead to negative environmental and economic effects, which causes biological misbalance of water resources. To cope with the consequences, it is important to adequately response to the oil spills, implementing modern techniques and technologies, following world's best practices contingency management, for instance, in case of fire [10–12].

References

[1] Bogoyavlensky V I 2014 Oil and gas exploration in the Arctic and the World' ocean: emergency response (in Russian) *Arctic: Environment and Economy* **4 (16)** 48
[2] Oil Tanker Spill Statistics 2015 (London, United Kingdom: ITOPF) 4
[3] Vladimirov V A 2014 Oil spills: causes, scales, effects (in Russian) *Civil safety strategy: issues and research* **1** 217
[4] Supreme Commercial Court took jurisdiction over revision of an award on 507 billion rubles for oil spill in the Kerch Strait 2013 (in Russian) [Electronic resource] URL: *http://portnews.ru/news/156514/* reference date 19.09.15
[5] Accidents comparable to The Gulf of Mexico oil spill tale place in Russia several times a year 2012 (in Russian) [Electronic resource] URL: *http://news2.ru/story/348542/* reference date 15.09.15
[6] Savichev O G, Tokarenko O G, Pasechnik E.Yu, Nalivaiko N.G., Ivanova EA., Nadeina L.V. 2015 Microbiological composition of river waters in the Ob' basin (West Siberia) and its connection with hydrochemical indices *IOP Conf. Series: Earth and Environmental Science 27 80292-8*
[7] Brakorenko N N, T.V. Korotchenko 2016 Impact of petroleum products on soil composition and physical-chemical properties *IOP Conf. Series: Earth and Environmental Science 33 012028*
[8] Kablov V F, Ioschenko Yu P 2004 Oil spills and the issue of oil removal *Fundamental Research* **6** 64–65
[9] The technique developed at the Institue of Biology, TSU, allows lifting up oil from water resource bottoms and saving… 2015 (in Russian) [Electronic resource] URL: http://www.tsu.ru/news/vernut_ozero_k_zhizni/?sphrase_id=13110 reference date 19.09.15
[10] Vazim A A, Romanyuk V B, Akhmadeev K N, Matveenko I A 2015 Associated petroleum gas utilization in Tomsk Oblast: energy efficiency and tax advantages *IOP Conf. Series: Earth and Environmental Science* **27** 012078
[11] Tsibulnikova M R, Kupriyanova O S, Strelnikova A B 2015 Economic assessment of environmental impact in the course of oil field development and production *IOP Conf. Series: Earth and Environmental Science* **27** 012076
[12] Matyugina E G, Glyzina T S, Kolbysheva Yu V, Vusovich O V 2016 Compensation for oil pollution damage *IOP Conf. Series: Earth and Environmental Science* **27** 012070