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A system of containment to prevent oil spills from sunken tankers

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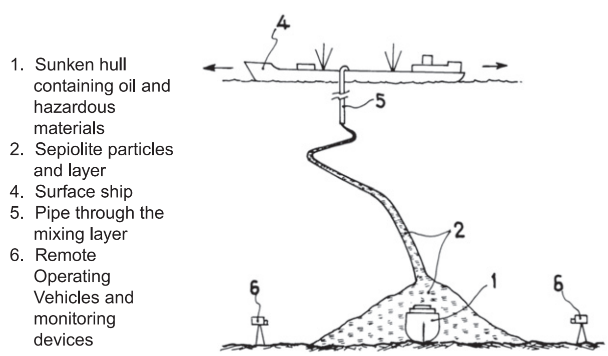
HIGHLIGHTS

- Oil extraction from sunken tankers is not able to extract the totality of oil.
- A sepiolite-based physical barrier can be created to bury the wreckage.
- It is inexpensive, widely available, stable in seawater and highly absorbing.
- The layer may be deposited by a tube passing through the mixed layer.
- Wrecks containing fuels and hazardous materials could be stably confined.

GRAPHICAL ABSTRACT



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ABSTRACT

Worldwide tank spills represent 10% of the average annual input of oil in the sea. When such spills arise from wrecks at depth, neutralisation of environmental impacts is difficult to achieve. Extracting oil from sunken tankers is expensive, and, unfortunately, all of the oil cannot be extracted, as the Prestige case demonstrates. We propose an environmentally appropriate, cost-effective and proactive method to stop the long-term problem of leaks from sunken tankers similar to the Prestige. This method confines the wreck with a "sediment" capping of sepiolite mineral that emulates a natural sediment. A set of experiments and simulations shows that sepiolite has the characteristics necessary to accomplish the confinement of any current or future sunken tanker with minimal environmental perturbation.

1. Introduction

Worldwide tank spills represent about 10% of the average annual input of oil in the sea (Rothwell and Stephens, 2016). From 1967 to 2015, there have been at least twenty major wrecks where cargo

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consisting of 11,000 to 287,000 tons of oil have been lost (ITOPF, 2016). In thirteen of these wrecks, the ship sunk with a fraction of the cargo. CEDRE (2003) reviewed the measures that were implemented to neutralize these wrecks in order to mitigate or avoid future leaking. Table 1, based on CEDRE (2003), Ganten (1985), and IOPC (1989), summarizes these measures. In some cases, no attempt has been made for neutralising the situation. In others, pumping, controlled release, reflotation and rigid confinement have been attempted with limited success.

Abandonment of the wreck and its oil cargo has been frequently the choice when the wreck depth involved costs perceived as high, there were no sensitive areas in the vicinity and/or sunken cargo was limited (CEDRE, 2003). An example was the Nakhodka, sunk in 1997, 140 km off the Japanese coast and at a depth of 2500 m. This wreck, however, continued leaking medium fuel oil for decades (CEDRE, 2002).

If some action is decided, then pumping is the more utilized measure. In the case of the Tanio tanker (Ganten, 1985), the French government decided to remove the threat of further oil pollution and examined various possibilities, including the burial of the wreck under a concrete dome, and the pumping of the cargo oil from the wreck. Finally, the latter option was implemented.

Pumping usually leaves 10 to 40% of the sunken liquid cargo in the wreck. These percentages include residual products of high viscosity that adhered to the cistern walls and were trapped in the corners. Included as well were products that escaped from cargo cisterns through cracks invisible to external observation and that have been redistributed in other closed volumes of the wreck (CEDRE, 2003). The extraction efficiency is higher when the oil has low viscosity and/or when hot water or some fluidizing agent is employed, as in the Erika case. This wreck was located at a depth of 120 m, and the extraction was almost complete, although it took almost two months to implement a main pumping in the two parts of the wreck, and a final fine pumping to recover 11,280 t of heavy fuel oil.

In the Pallas wreck, a cement sarcophagus was used to confine the residual oil (4 t) that remained in the wreck after pumping. In this case, the extraction was also exceptionally efficient because, after the pumping, the last fluid oil residuals were skimmed and the remaining bituminous oil sludge was collected by a dredge. These operations were facilitated because the shipwreck was shallow.

Extraction operations become increasingly difficult depending on the depth of the wreck. Refloating of the vessel may simplify these operations, it is difficult to implement, however, if the wreck is too deep or is structurally weak. There is the additional risk of a massive release of the cargo if the hull is damaged during the process.

Another procedure is controlled release. The hull of the ship is pierced by divers using explosives or by cutting, which allows the hydrocarbons to float to the surface where they are collected by pumping. This method is recommended when the cargo is limited, the shipwreck is shallow, and the hydrodynamic situation is simple.

Michel et al. (2005) reviewed the historical wrecks where oil recovery was implemented and concluded that their cost depended on the complexity of the recovery. They grouped the wreck situations in the following four classes: (i) shallow depth (<20 m), low oil viscosity, protected water body and local mobilization of personnel and equipment: 1.2–3.7 million US dollars (USD); (ii) moderate depth (20–50 m), moderate oil viscosity, weather and sea restrictions and regional mobilization: 2.5–6.2 million USD; (iii) deep depth (50–250 m), high oil viscosity, poor wreck condition, open water, weather limitations and lengthy mobilization of personnel and equipment: 6.2–25 million USD or more; (iv) extreme depth (>250 m), high oil viscosity, poor wreck condition, open water, weather limitations and lengthy mobilization of personnel and equipment: 25–124 million USD or more. The costs have been translated into 2017 USD with a U.S. inflation calculator.

In the case of the Prestige (Algaigés et al., 2006), the extraction by floating bags, made by the Repsol company in the summer of 2004, removed, officially, 90% of the oil content (Faro de Vigo, 2004). The inventory of the residues obtained at the beaches and in previous simulations (CEDRE, 2002; Marcos et al., 2004), however, shows that up to 32% of total oil content might remain in the tanks (Marcos et al., 2004; Bosch, 2006). This partial oil extraction is consistent with data provided from past oil extractions (CEDRE, 2002, 2003) and may be due to the high content of asphaltenes and resins in the transported oil. In the case of the Prestige, which was split into two parts and is resting at a depth of 3500 and 3800 m deep, respectively, the cost of extraction was €100 million. The total cost of the catastrophe was €770 million (Loureiro et al., 2006).

Even without intervention, the environmental impact of the Prestige and other wrecks will decline due to natural settling, that is, sediments will cover the wreck and prevent further environmental damage (NEA, 1988). Sediment is a natural physico-chemical barrier that prevents the migration of contaminants (Himmelheber, 2009). In addition, a 10 cm-thick marine sediment layer would be anoxic at its base and would inhibit rusting (Archer et al., 2002; Rutgers and Loff, 1990). Unfortunately, the sedimentation rate in the deep ocean, which is a combination of turbidite deposition and settling from the ocean surface, is only on the order of 1 to 10 cm per 1000 years (Haupt and Stattegger, 1999) at the wreck's location. In other words, the wreckage would rust through before sufficient burial with natural sediment would occur and provide an effective barrier.

Taking this natural process as a model, a physical barrier can be created with sedimentary material to bury the wreckage. It must be strong enough, however, to withstand the maximum differential pressure that is forcing the remaining oil out of the tanks. The pressure of the water column is high, but it is unable to produce any differential pressure on

Table 1
Analysis of past tanker wrecks and decisions taken to avoid future leaking[a].

Date	Wreck	Wreck location	Sunken cargo (t)	Depth (m)	Decision	Fuel extraction (tons)	Cost (Million $)
1977	Böhlen	France	9800	110	Pump-out	2500	78
1980	Tanio	France	5000–8000	90	Pump-out	6500	42–100
1988	Kasuga-Maru	Japan	1100	270	Do nothing	0	–
1991	Vistabella	Antilles	2000	600	Do nothing	0	–
1995	Cleveco	USA	4542	21	Pump-out	1287	3.18
1996	Irwing-Whale	Canada	3100	67	Refloating	3100	34.7
1996	Sea-Venture	France	45	45	Controlled release	–	0.09
1996	Stonia	Stonia	418	70	Pump-out	258	3.96
1997	Nadhodka	Japan	2480	2500	Do nothing	0	–
1998	Pallas	Germany	448	A few meters	Pumping + sarcophagus	444	10 + ?
1998	Yuil n° 1	South-Corea	1400	70	Pump-out	665	7.13
2000	Erika	France	11,300	120	Pump-out	11,280	87.65
2002	Prestige	Spain	14,000–37,000	3500–3800	Passive pumping	11,700	100

[a] Adapted from CEDRE (2003), Ganten (1985), IOPC (1989), http://www.itopf.com/in-action/case-studies/case-study/erika-west-of-france-1999/ and http://pallas36.blogspot.com.es/2008/06/22-wadden-sea-newsletter-1999-1.html.