Heavy oil recovery at sea. Evolution since the *Erika* and *Prestige* spills.

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Abstract
Debriefings and technical analysis of the operations carried out during the Erika and Prestige spills pointed out interesting lessons about the efficiency, limitations and also potential improvements of techniques and means deployed to recover very heavy oil (VHO) at sea. Before and between these spills, other spill cases as well as the analysis of the traffic evolution encouraged the improvement of response techniques and means adapted to VHO. Therefore, efforts have been devoted to improve preparedness and response capacity in the field of recovery at sea that are better suited to VHO spills and severe weather conditions, at least in Europe both by EMSA and by countries feeling much concerned by the risk of VHO spills.
Most of these efforts have addressed the chartering or purchasing of oil spill recovery vessels (OSRVs) fitted with equipment suited to VHO spills, in terms of recovery, storage and transfer of very viscous products, as well as of oil detection. They mainly made use of pre-existing techniques and means, which efficiency has been proven during actual spills. In parallel, efforts devoted worldwide to the research and development of new techniques and means have been very limited in this field, due probably to a lack of funding but also to a lack of proposals. Some efforts have been devoted to the testing and improvement of existing means and techniques, including e.g. annular water injection, mechanical feeder skimmers and trawl nets. Thanks to all these efforts, the capacity to recover VHO spills has been significantly improved since the Erika spill, at least in Europe, but there is still much room for improvement, and R&D should still be encouraged in this particular field.

Introduction

Debriefings and technical analysis of the operations carried out in Europe during the *Erika* (1999) and *Prestige* (2002) spills pointed out interesting lessons about the efficiency, limitations and also potential improvements of techniques and means deployed to recover very heavy oil (VHO) at sea. The experience of the *Erika* spill put pressure on the response equipment manufacturers to develop better technology to respond to these types of spill. Some two years later, the *Prestige* experience reinforced those needs. Before and between these spills, other spills in Europe and in other parts of the world, e.g. the *Nakhodka* spill in Japan (1997) and the *New Carissa* in the USA (1999), as well as the analysis of the traffic trends encouraged the improvement of response techniques and means adapted to VHO. Therefore, efforts have been devoted to improve preparedness and response capacity in the field of recovery at sea, that are better suited to VHO spills and severe weather conditions, in Europe both by the *European Maritime Safety Agency* (EMSA) and by countries feeling much concerned by the risk of VHO spills, and in other parts of the world, notably in Japan and North America.
More recent spills including the *T/V Athos I* spill in the Delaware River (USA, November 2004) and the *T/B DBL-152* (Gulf of Mexico, November 2005) confirmed that response capabilities for VHO still needed improvements, both for poorly floating VHO and for sunken VHO.

The Lebanon spill, in summer 2006, has shown that the same oil can accumulate in very thick slicks in harbours, marinas and coves, and, due to its mixing with large amounts of debris, be very difficult to recover by using conventional skimmers, even those more specifically designed to cope with debris.

Before that, testing and R&D projects related to the recovery of heavy, viscous oils have taken place in various countries, notably in connection with the appearance of new risks, like those resulting in some countries from the importation of *Orimulsion*, or also from the production of new crude oils, like e.g. the very paraffinnic Norne crude in Norway.

On the other hand, a number of arguments speak for greater at-sea recovery efforts for heavy oils relative to light refined or crude oils, including the higher persistence of heavy oils as well as the greater chances of encountering skimmable quantities of oil with heavy oils.

Among the recommendations adopted by the *IMO Third R&D Forum on High Density Oil Spill Response* (Brest, France, March 2002), some addressed the containment and recovery of floating high density oil, notably asking to IMO, governments and industry *inter alia*:

- to improve international co-operation in developing and testing operational VHO collection and pumping systems;
- to consider sharing facilities and to facilitate joint field trials of complete recovery systems;
- to develop equipment testing parameters, to accelerate R&D collaboration.

Seven years later, we can wonder about the results of these recommendations and the progress generally made in the field of the containment and recovery of VHO spills.

Detection of poorly floating VHO

One of the problems encountered with VHO spills, maybe the first, is that slicks of heavy oil will float beneath the water surface and may be difficult to locate, the more as the sea is rough. Experiences in the *Erika* and *Prestige* spills showed that survey of VHO spills in severe weather conditions presents problems for observers, and consequently for the guidance of response vessels.

Some R&D projects have addressed this problem and, more generally, the problem of guiding response vessels without mobilizing aircrafts or helicopters. Projects have been conducted notably in Denmark and Norway, involving the use of response ships radars. In France the *Rapace* project, funded by the National research agency (*ANR*), has allowed the design of a flying drone which could be linked to Vessels of Opportunity (VOs) and provide them with a view of the area surrounding the ship. Tests were carried out at sea on experimental spills in Norway by NOFO on a ship-based radar system and in France by *Cedre* and Ceppol (French Navy) on different systems including the *Rapace* one.

The capabilities of certain active sensors such as laser fluorosensors were also tested for the subsurface detection of oil, notably in Canada (*Environment Canada* and *Canadian Coast Guard*) and Japan (*National Maritime Research Institute*).

Chartering of OSRVs suitable for VHO spills

The *Erika* spill, in December 1999 off the French Atlantic coastline, confirmed both the feasibility and merits of oil recovery at sea. Actually, despite extremely adverse weather and sea conditions, that allowed operations to take place for only three days in a period of three weeks, and despite the very heavy fuel oil viscosity that rendered pumping operations particularly difficult, over 1,100 tons of oil were recovered, which is a remarkable result considering the duration and cost of cleanup of the shorelines subsequently impacted by the rest of the cargo. Such an achievement was the outcome of excellent co-operation on the part of countries that pooled their resources as provided for by regional agreements which had already been activated to deal with the *Sea Empress* spill. Not even two years later, regional co-operation in the Baltic Sea permitted to achieve even better results with the offshore recovery of more than one third of the 2,700 tons of heavy fuel oil spilt by the *Baltic Carrier* tanker in 2001. More recently, during the response to the pollution of the *Prestige* in Spain, and with more than 20,000 tons of recovered emulsion, which means around 25 % of the spill, the European fleet of OSRVs was even more successful in terms of volume of VHO recovered, and, once again, despite numerous breaks due to adverse weather and sea conditions. This good score achieved by dedicated vessels was even doubled by the involvement of numerous VOs fitted with less sophisticated devices, like trawl nets, hand nets, wire net shovels, which proved well suited to the situation.

Following these spills, most efforts for the improvement of spilled oil recovery at sea, at least in Europe, have addressed the chartering or purchasing of OSRVs fitted with equipment suited for VHFO spills, in terms of recovery, storage and transfer of very viscous products, and also in terms of oil detection. They mainly used pre-existing techniques and means, which efficiency has been proven during actual spills.

OSRVs can be specifically designed for use in oil spills, can be permanently converted for use, or can be temporarily converted for use. Few countries have set up real naval means for oil recovery at sea (including containment, skimming, and storage). The solution most often adopted is that of multipurpose or multiple function vessels. Such vessels can easily be converted for oil spill in the event they are needed.

Following major VHO spills, some pre-existing OSRVs have been modified in order to improve their efficiency on VHO spills. For example, considering difficulties encountered when responding to the *Erika* spill first and later to the *Prestige* spill, the French OSRVs *Alcyon* and *Ailette* were equipped with sweeping arms, in addition to their *Transrec* weir skimmers and *Hiwax* skimming heads. And, as a second step of improvement, a bigger supply type OSRV, the *Argonaute*, was contracted, with a storage capacity of 1500 m^3, by the French Navy. Due to its experiences with the *Erika* spill, the German OSRV *Neuwerk* was adapted by installing a special pump (*Foilex* TDS 250) for the admission of highly viscous oils into the sumps of its sweeping arms, as well as a hot water high pressure device in front of the drainage well of the sweeping arms and a hot water tank heating system in the four oil storage tanks of the ship.

In Spain, because of the shortage of antipollution vessels in the country in the aftermath of the *Erika* and *Prestige* spills, the national government passed the National Rescue Plan 2006-2009 that contemplated the construction of four multipurpose rescue and antipollution vessels, which had been launched there since 2005. Some extra capacities were brought by the autonomous government of Galicia, which bought two vessels of smaller size. One of these vessels, *Miguel de Cervantes*, is based in Algesiras, near the Gibraltar Strait. Other ones (*Luz de Mar, Don Inda, Sebastian de Ocampo, Irmans Garcia de Nodal*) are deployed in Galicia and on the Mediterranean coastline, thus improving the response capacity in this area.

Germany also launched a new unit, *Arkona*, based on its Baltic coastline. A new multipurpose vessel fitted with a large storage capacity has been planned to reinforce the oil spill response capacity in Finland. Sweden has built two large capacity OSRVs of supply type, to be launched in 2008. In addition, eight vessels of its fleet were planned to be replaced by new units, from December 2005.
In the field of OSRVs, a major initiative was taken by Europe through the involvement of EMSA in oil spill response capacity with a significant budget dedicated to contracting private companies to increase the European fleet of OSRVs. Specifications issued for these contracts have taken into account lessons from the *Erika* and *Prestige* spills, and notably addressed the capacity of recovering VHO in rough seas.

Despite a large storage capacity, equal to or greater than that of the dredges, only few nations have adopted coastal tankers as OSRVs. Coastal tankers are not easily available due to their economic function and require a longer preparation time since they must be unloaded and their tanks must be gas-freed. Furthermore their manoeuvrability is generally limited, particularly when sailing at low speed as requested for oil spill containment and recovery.
However, in the framework of EMSA's calls for tender aiming at increasing the fleet of oil recovery vessels in Europe, coastal tankers have been selected for different areas: two small tankers based in Malta for operating in the Mediterranean sea, a fleet of coastal tankers associated with two stockpiles of *Lamor* equipment for operating in the Baltic sea, and another fleet operating in the Irish channel.
A new solution was also proposed to EMSA following its 2005 call for tender, which was accepted for the North Atlantic area and which was making use of a cable ship. As it is the case for the *Ile de Bréhat* based in Brest (France), such ships may offer even larger storage capacities, by adapting part of their cable storage tanks, and can be quite rapidly mobilized as they are generally on standby for cable repair and maintenance operations. However this contract ended up after three years due to an increase of activity for cable ships.

Improved use of vessels of opportunity (VOs)

Regarding the involvement of VOs in oil spill response operations, the use of fishing boats in Alaska is both planned in contingency plans and regularly tested by exercises. But on the contrary of what has been done in France since 1978, no specific devices have been developed for this purpose in the USA.
In the case of the *Prestige* spill, the good score achieved by dedicated vessels was even doubled by the involvement of numerous VOs fitted with low-technology devices, such as trawl nets, hand nets, wire net shovels, which proved well suited for the situation. But apart from the improvement of trawlnets and some research on drones for guiding a fleet of such vessels, few improvements have been made since. Some R&D projects, addressing both the technical means suitable for VOs and the management of fleets of VOs, have been proposed but they did not get funded.

R&D projects of OSRVs suitable for VHO spills

In parallel to investments in OSRVs, efforts devoted worldwide to the research and development of new techniques and means have been very limited, except maybe in

the field of the guidance of such vessels by using sensors, probably as a result of lack of funding as well as of a lack of proposals.
In France, a few days after the *Erika* spill, the Ministry of Industry issued a call for proposal in order to improve at sea response to such spills. Four proposals for the design of OSRVs got funded. Less than three years later, following the *Prestige* spill, a second phase for the two most promising of them was submitted to the European Commission, in reply to a call for proposal on the same subject. Only one got funded, the *Oil Sea Harvester* (OSH) catamaran-type OSRV. The project ended in 2008, after numerous technical studies and tests performed in various test tanks. It concluded to the capacity of the OSH design to achieve the objectives of (i) sailing fast to a spill, (ii) recovering oil, including VHOs, in very rough seas, and (iii) of storing onboard enough recovered oil to be autonomous for more than 2 or 3 days of efficient work. The only limitation lies in the forecasted cost of the vessel and the lack of obvious other activities which could make such an investment acceptable. On the other hand, the project permitted *inter alia* the design and test of a brush-type recovery equipment which could be fitted on other supports.

Design of new skimmers and pumps adapted to VHO spills

In the past or more recently, many European countries have devoted efforts, quite often after a major spill in national waters, to dispose of stockpiles of at sea response equipment (including booms, skimmers, pumps and storage) readily available in case of a spill in their waters. For this purpose, most -if not all- countries rely on already existing technologies, and there is almost not any national initiative in Europe or worldwide to conduct or even favour research projects aiming at improvements in this field. There are very few on-going research projects, benefiting either from national or regional funds or from funds from the oil industry, and the market is too limited to encourage manufacturers to fund significant research.

For the last ten years, Japan has been one of the rare countries where new designs were developed and tested in terms of skimming and pumping systems for VHO spills, as a consequence of the *Nakhodka* oil spill (1997). A steam jet suction device was designed and tested by the *Port and Airport Research Institute* (PARI). Tests have shown that it is basically suitable to recover and transfer VHO thanks to its large suction power and very rapid heating. Another system was developed to be operated by crane barges; its testing with HFO and emulsion in a large test tank showed an efficiency significantly higher than that of a conventional grab-bucket, but still modest. It can be reminded that crane grabs have already been the solution in some cases when most of the dedicated skimmers failed on heavy oil, notably when the oil is severely debris laden. But they will only work in calm conditions and their recovery rate is relatively low and decreases with the increasing adhesiveness of the oil. The *Baltic Carrier* (Denmark, 2001) and the *Natuna Sea* (Singapore, 2000) spills are quite recent examples of their use.
Some efforts have been made in the past (e.g. after the *Tanio* spill in France) and recently to develop or adapt pumps able to cope with highly viscous products. Archimedean screw pumps are often used and have been added to several skimmers that had experienced problems at pumping highly viscous products during actual spills. Peristaltic and lobe pumps are also effective in pumping viscous products and are becoming more widely used. However few research has been conducted to develop more specific pumps fully adapted to the needs of oil spill

control, probably due to the fact that most pump manufacturers do not perceive the market as significant.

Tests and improvement of techniques and means

A number of heavy oil recovery tests have taken place over the past ten years, notably in North America, in Japan and in Europe. Tests in North America involved organizations such as: *US Coast Guard* (USCG) and *Canadian Coast Guard* (CCG), *Science Applications International Corporation* (*SAIC*) Canada and *Environment Canada,* as well as *Ohmsett*. Tests in Europe and Japan have been conducted either in the facilities of few manufacturers, or in those of research institutes like *SFT* (*Norwegian Pollution Control Authority*) and SINTEF in Norway, *Cedre* in France, PARI and the *National Maritime Research Institute* (NMRI) in Japan, etc.

Pumps

Improvements have taken place worldwide since 2000 on a series of pumps known as positive displacement Archimedes' screw pumps commonly used for oil spill response. The most known pumps of this type used for oil spill response include *Desmi* DOP series, *Foilex* TDS series, *Lamor* GT-A series and *Pharos Marine* GT series. Research has progressed in improving their abilities to handle extremely viscous oils.
Tests have been carried out on behalf of the CCG and Environment Canada. They were primarily focused on pumps which are commonly used by the CCG and Oil Spill Response Organizations (OSROs) in Canada.
Tests have also taken place in Denmark, in *Desmi*'s test facility, in France, in *Cedre*'s facility, and in Finland, in *Lamor*'s facility, in connection with annular water injection assessment.

Annular water injection

Annular water injection, a technology which actually forces water into the flow of a pumping system to form a lubricating "sleeve" that greatly decreases resistance to flow, was first adapted from oil industry technologies and tested for oil spill response application in France in the eighties by *Cedre* and IFP (French Petroleum Institute).
Research since 2000 has led to dramatic advances primarily in the pumping of heavy oils through the adaptation of steam/water injection systems on the inlet of pumps and annular water injection systems on the discharge end of pumps. After the *New Carissa* spill, annular water injection has been investigated to increase performance capabilities of pumps that are in the USCG inventory. In Canada, this technology was first tested in 2000, involving the adaptation of an annular water injection flange to a GT 185 skimmer operating as a transfer pump and using two test oils: bitumen and bunker C. The water content was high but the test run demonstrated the potential of the technology to improve pumping capabilities (*SAIC Canada*, 2001). Some successes had also been demonstrated later by injecting water (steam/hot water) in the inlet hopper of the skimmer to assist in the internal lubrication of the pump. Similar improvements with inlet and discharge water injection systems were concurrently being made in Denmark to the *Desmi* DOP-250 pump (Drieu et al., 2003).
After the *New Carissa* spill in Oregon (USA), where heavy oil had to be removed from the stranded vessel, the USCG, along with the CCG, began the JVOPS (Joint

Viscous Oil Pumping) programme to determine better ways of handling such viscous materials. The trials were conducted in two phases and the final element was completed in 2004.The *Joint Viscous Oil and Pump Test and Workshop #6* provided a platform to test transfer capabilities of pumps over distances up to 460 m through 150 mm diameter hoses using heavy oils with viscosity in the 200,000 and 500,000 cSt ranges. Water injection allowed pumps to reach flowrates close to the nominal rates of the pumps for water alone.
Before that, these flow enhancing techniques were already incorporated in actual operations. In 2002 they were used in the unloading of VHO from the sunken World War II vessel *Luckenbach* off the coast of California.

Mechanical feeder skimmers

A mechanical feeder skimmer lifts or drags the oil out of the water and feeds it into a collection tank or a pump inlet. Feeding devices such as e.g. belts, brushes or drums are able to drag the oil out of the water, based on combinations of adhering, grabbing, trapping, and squeezing. Prior to 2000 a number of mechanical feeder skimmers have been tested for the recovery of high to extreme viscosity oil, notably of bitumen, in relation to the special properties of spilled *Orimulsion*. Various tank tests were carried out since 1999 in Denmark by *FlemingCo* and in Canada by *SAIC*. They demonstrated the capacity of different types of mechanical feeder skimmers to recover extremely viscous bitumen, including the Swedish *KLK 602* and *Unisep* skimmers, the Canadian *Environment Recovery Equipment* (ERE) *Oriliminator* and CCG *Axiom HOBS* skimmers, the Danish *Desmi* belt skimmer, the Finish *LAMOR/LORI* brush belt skimmer.

Additional advances have been made through the use of belt and brush adapters on weir skimmers commonly used by some responders, including e.g. the US and Canadian Coast Guards. Recent testing has demonstrated improvements in recovery efficiencies which more than doubled the quantity of fluid being recovered while simultaneously reducing water up-take.

Tests have been conducted in the *Norwegian Pollution Control Authority*'s test basin, in Horten (Norway), in connection with a workshop of the Working group of the Copenhagen agreement, on three skimmers (*Lamor* brush skimmer, *Ro-Clean Desmi Terminator* belt skimmer, and *KLK 402* twin drum skimmer).

Tests were also carried out at *Cedre*'s facility, notably in connection with the European OSH project, but also at the request of the French Ministry of transport (Cetmef) asking for a comparison of some small feeder skimmers.

Trawl nets

Oil trawls have been first designed, tested and used 30 years ago for the recovery of oil agglomerated by raw sorbents, notably in France (*Seinip*) and Japan. Quite similar equipment were designed also in Denmark (*Scantrawl*) and in the UK (*Jackson* trawl).The limitations connected with raw sorbent application in open sea conducted to quite an abandon of this technique for more than 15 years. But it resurfaced with the research of solutions first to recover *Orimulsion* bitumen, and then to assist in the inshore response to the *Erika* spill. Tests and actual uses then have confirmed that oil trawls can recover floating tar balls, slicks of solid or extremely viscous oil, oil contaminated debris and floating bitumen. But they have also shown difficulties in the handling and emptying of full recovery socks, and in the cleaning of the confining part

of the trawl itself, which have encouraged opting for a disposable trawl concept, or at least disposable/detachable trawl bags.
During the *Prestige* spill, due to logistic problems, Spanish fishermen discarded the use of trawling nets. They preferred operating the landing nets used for anchovy fisheries, in combination with a winch, a solution close to a technique already developed twenty years before in France.
In France, among the project funded just after the *Erika* spill, one aimed at improving the technique developed twenty years before. This *ECREPOL* project finally favoured the development of a new trawlnet, named *Thomsea*, which has been improved since and acquired by several authorities.

Floating booms and containment systems

Very few research projects and tests have been carried out in the last ten years on the improvement of techniques and means for containing floating oil, and quite none specifically focusing on VHO spills. Some work has been conducted, aiming to develop deep skirted booms for containment of *Orimulsion* that may be appropriate for heavy viscous oils. More recently, tests were conducted in Canada to assess the impact of different netting skirts on the containment abilities of booms under specific flow conditions.
Some projects, however, have addressed the problem of boom limitations in rough seas or in strong currents, which were two major problems encountered during both the *Erika* and *Prestige* spills. The *Simbar* and *BAR3D* projects conducted in France aim at optimizing boom design and deployment, thanks to numerical coupled hydraulic-structural analysis models. A similar project in Switzerland has been applied to a new containment concept.
In Japan, following the *Nakhodka* spill, several ideas were compared and evaluated through oil tank tests; a new type of oil boom system, fitted with a trap boom and a bottom net, was designed and tested.

Dedicated storage tanks

Towable floating rubber tanks have been developed to store recovered oil but these floating tanks often lack capacity and therefore a second transfer to a larger tank is often rapidly necessary. Closed tanks can generally be towed at higher speed, can be stronger and more reliable, but they are more difficult to empty especially if the pollutant is extremely viscous. A solution to the problem consists in using tanks with a removable top, which resemble large inflatable boats. They are much easier to empty but, conversely, cannot be towed at high speed.
Following the improvements brought to these kinds of devices for 30 years, many tanks have been available in both national and private stockpiles for many years. Still, they have been scarcely used in actual spills, probably due to the perceived risk of polluting a clean area (harbour) in case of rupture when towed to a land based discharge.
Such flexible tanks have been used as a first step for the unloading of the *Prestige* wreck, but after a rupture while entering the support vessel, it was decided to replace them by metallic tanks.

Test facilities

It is important to pre-select booms and skimmers according to the location and to dispose of different types of equipment to adapt various situations. However, even if

standards have been developed and are used for the classification and evaluation of equipment, there are only very few facilities worldwide in which spill response equipment can be tested in realistic conditions enabling to compare e.g. various skimmers or booms in similar conditions. The best known is the *OHMSETT* in the USA which was created about 30 years ago and whose activity quite stopped in the mid eighties due to a lack of funding for expensive tests. It started again after the *Exxon Valdez* spill thanks to tests and research funding both from the public sector and from the oil companies and it is now correctly booked both for testing and training activities. After the *Nakhodka* spill the *Port and Airport Research Institute* (PARI) of Japan built a *Simulation Tank for Oil Recovery in Marine Situations* (STORMS) which seems to encounter difficulties to get funds for carrying out tests. In Europe, both Norway (SFT and Sintef) and France (*Cedre*) have dedicated facilities which can be used for the testing of skimmers, but only few tests have been conducted during the last decade.
There are also few tests that have evaluated pumps for spill control purpose. In fact most information on newer pumps comes from reports of their use in actual spill situations and most often only from verbal reports of spill responders or pumps providers. Only few manufacturers or research centres (SAIC, *Cedre*,…) have a dedicated installation for conducting such tests and a standard protocol for these tests which allows comparison between pumps.

Conclusions

Thanks to all these efforts conducted along the past ten years, the capacity to recover VHO spills has significantly improved since the *Erika* spill, at least in Europe, but there is still much room for improvement and R&D shall still be encouraged in this particular field. In this respect, many of the recommendations adopted in 2002 by the *3rd IMO R&D forum* are still waiting for application.

In the coming years, some additional progress can be expected both from the very few recent or ongoing research projects and from ongoing investments. Other significant improvements could come from a better use of vessels of opportunity, notably fishing vessels, provided that funds are allocated to research projects dedicated to developing adapted equipment for the recovery (and storage) of various types of pollutants from such vessels and to improve the organisation and operational guidance of such fleets. These improvements should not focus on VHO spills only, which is the type of spill the world has mainly been facing recently, but should also address other types of spill which already occurred (e.g. spill of lighter crude oil) or could occur in the future in connection with the trends in the maritime traffic (e.g. more and more chemicals), even if it is feared that, in the near future, major VHO spills are likely to occur more and more, notably in European waters as a result of an increase of Russian exports (offshore northern Norway, in the Baltic Sea and in the Black Sea).

Actual or experimental spills could also improve our knowledge of the actual efficiency and limitations of existing or newly developed spill response equipment. But progress will depend on the number, type and size of spills which will occur in European waters (and worldwide) in the coming years, because the souvenir of a spill lasts less and less, which could mean a faster decrease of funding both for research and investments if no new spill happen and show a new improvement in the control of spills offshore and inshore.

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