Dealing with spilled oils that sink or are submerged at sea.

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Abstract

Almost all spills of crude oil and refined oil products float on the sea surface. However, some refined oil products are dense enough to sink in full salinity seawater and a greater number will sink in brackish or freshwater. In some circumstances a spilled oil that is less dense than seawater can be submerged below the sea surface for a large proportion of the time. Spilled oils that are not on the sea surface obviously present a series of challenges for responders:

- Which oils might sink if spilled at sea or in coastal waters?
- What are the processes that can cause spilled oils to sink or be submerged below the sea surface for a proportion of the time?
- Can spilled oil sinking or submerging be incorporated into existing oil spill models to indicate when these processes are likely to occur?
- How can sunken or submerged oils be detected and located?
- What methods would be effective in responding to spills of oil that sink or submerge?

The UK Maritime and Coastguard Agency (MCA) with support from the International Tanker Owners Pollution Federation (ITOPF) instigated a multi-partner project to answer these questions.

A review of the current knowledge and past incidents was conducted to identify the key processes that could lead to spilled oil sinking to the seabed, or being submerged by wave action. This review concluded that only ‘slurry oils’ from catalytic cracking (also known by several alternative names) have densities greater than that of seawater, but these oils can be used as blend components in other oil products, such as Heavy Fuel Oil. Spilled oil in the open sea will be submerged by wave action if (a) it is too viscous to be naturally dispersed, (b) has sufficient cohesion to remain as ‘lumps’ in rough seas, and (c) has a density that is relatively close to that of seawater. The likelihood of submergence by waves is proportional to these properties and the prevailing sea state. Spilled oils in coastal waters or estuaries can sink if they drift into areas with high sediment loads, but a more usual sequence of

events is the oil stranding on a sandy or sediment shoreline, being re-mobilised by tidal action and subsequently sinking in nearshore waters.

Methods to describe these processes for incorporation into oil spill fate and behaviour models were devised. Submerged oils drift only under the influence of the currents near the surface with a much reduced contribution fro the effects of the wind.

Identifying which oils may sink and where - is only part of the process of dealing with them. Where oil may have sunk its potential impact must firstly be evaluated, where this is significant, and taking account of NEBA, recovery may be required. Sunken oil may remain mobile on the sea bed and detection and fixing of sunken oil has historically proven problematic. A variety of novel methods have been tried and combinations of sonar and optical sensors may develop into usable systems in the future.

Recovery, like detection, is problematic and the recovery of large quantities of water sediment and oil which will not separate with gravity alone must be expected and planned for.

Due to the potential mobility of sunken oils detection and recovery need to be closely coupled or ideally combined in a single operation. In shallow waters divers can be operationally successful. In deeper waters ROV's which combine detection equipment and recovery devices may be more efficient.

The fate of sunken and submerged oils, modelling, detection and recovery all require further study and development before they can be relied upon to deal with the problem effectively.

Introduction

In January 2007, the UK Maritime and Coastguard Agency (MCA) published a report of the findings of a very heavy fuel oil (VHFO) risk assessment (BMT Cordah, 2007). The project aimed to identify the quantities and routings of VHFO's as bunkers and cargoes through the UK pollution control zone (UKPCZ). A key finding of the work was a significant increase in VHFO traffic. The transport of VHFO cargoes through the UKPCZ almost doubled from approximately 26 million tonnes in 1998 to approximately 50 million tonnes in 2003. This arose from increases in imports and exports to EU countries and particularly the Netherlands. More significantly, and contributing to imports and exports from the Netherlands, was a rise in Residual Fuel Oil (RFO, a type of VHFO) exports through the Baltic Sea from Russia, which increased from 12.5 million tonnes in 1998 to 27.5 million tonnes in 2003. The trend was expected to continue as exports from Russia increased.

Very heavy fuel oils may have a density close to that of seawater and be vulnerable to submergence or sinking. Oil became submerged for periods following the RFO spills from *Erika* and *Prestige* (ASMA, 2007, Lewis, A. 2003, Michel, J, 2006, Kaperick, J.A. 1995) and the increased transport of such oils through UK waters prompted the MCA to commission a further study to investigate the behaviour of, and response techniques available for, sunken and submerged oils.

The key objectives of the second study were:

- To identify key parameters and their comparative significance in causing oil to sink or submerge.
- To identify algorithms to realistically model the cause and behaviour of submerged and sunken oils in seawater.
- To develop a methodology to incorporate such algorithms into existing modelling capability.
- To determine appropriate and realistic oil recovery techniques for submerged and sunken oils.

The study was jointly funded by the MCA and the International Tanker Owners Pollution Federation (ITOPF) and was conducted by BMT Cordah Limited, Alun Lewis and Oil Spill Response Limited. The final report was delivered in February 2009.

This paper presents a summary of the findings. The full report will be available later in 2009 from the MCA website (www.mcga.gov.uk).

Processes

Following a review of spill incidents where oil had sunk or submerged, and of previous work in this area, five main processes were identified which can lead to non-floating oil:

1. The spilled oil density is greater than seawater and the oil sinks to the seabed.
2. The spilled oil density is close to seawater and wave action causes it to become submerged for periods of time.
3. The floating oil enters a region with high suspended sediment concentrations, mixes with sediment causing its density to increase and it sinks or submerges.
4. Floating oil is stranded, picks up sediment and is remobilised at which point it sinks close to the shore.
5. Oil burns and the residue sinks.

In each case, literature reviews and other studies were conducted to identify how the processes could be modelled to provide early identification of the risk of non-floating oil in future spill response.

Density greater than seawater

There are only a few oils with a density greater than full salinity seawater. These are highly cracked oils known as slurry oil or carbon black feedstock. These have been observed to sink in rivers and the sea on spilling (Lewis, A. 2003, Fingas, M, 1988, Kaperick, J.A. 1995). Freshwater has a lower density than seawater and there have been more incidents of oil sinking in freshwater than at sea.

Density close to seawater

Where spilled oil has a density close to that of seawater, it can be pushed below the sea surface for long periods of time by wave action. There are several oil products and some crude oils that have a density close to seawater. Emulsification and weathering of some oil types can also result in the weathered oil density becoming close to seawater. There have been several incidents where submergence by wave action has been observed (ASMA, 2007, Brown, H. et.al. 1997).

SL Ross conducted tank tests and developed a model to predict when such oil would become submerged (SL Ross, 1987). This showed that the key characteristics for oil submergence were:

- The oil must have a density close to but less than water.
- The oil must be viscous enough to break into fragments of sufficient size to become over-washed.
- There must be sufficient wave energy to push the fragments below the water.

The SL Ross model predicts both the periods when oil will become submerged, the proportion of oil submerged and to what depth it will be submerged.

Mixing with sediment in water column

Several incidents have occurred where oil is believed to have sunk following interaction with sediment in shallow water. This process is dependent on the oil density, sediment density and particle size, sediment concentration in the water column and wave energy. (Gundlach, E.R. 1987, Brown, H. et.al.1997, Cheng, N-S et.al. 2000)

Various laboratory studies have been conducted to better understand sediment-oil interactions. Kirstein and Clary (1989) developed a model that can predict when oil will sink into the water column and to the seabed following sediment-oil interaction. The model requires significant site specific data and would not be easily applicable to a more generic model (e.g. to cover the entire UK). More practical results are available from experiments conducted by Payne et al. (1987) which provide 'rules of thumb' regarding suspended sediment concentrations that can lead to sinking of oil:

- At suspended particulate matter (SPM) concentrations less than 10 mg/l, little sinking of oil is expected.
- At SPMs between 10 and 100 mg/l, significant sorption of sediment by oil can be expected (and sinking of oil) if sufficient mixing occurs.
- At SPMs greater than 100 mg/l, massive sinking of oil may be possible.

Oil sinks following stranding

A large number of incidents have occurred where oil has been observed to strand, remobilise and sink (Gundlach, E.R. 1987 Brown, H et.al.1997, Cheng, N-S et.al. 2000). It is not a phenomenon that occurs with all stranded oils and requires:

- Suitably high density and high viscosity, 'sticky' oils. Lower viscosity oils tend to penetrate sediments, they cannot easily pick up sediment and are not as available on the surface for remobilisation. Light oils may not sufficiently penetrate sediment to allow them to incorporate it on refloating.

- Suitable shoreline substrate – sand or coarse material that allows some penetration of oil.
- A suitable period of time for oil to incorporate sediment, or mixing in the surf zone prior to stranding.

Several studies on interaction between stranded oil and sediment have been conducted, and models have been developed. However, these have focussed on the volume of oil that can be retained by a shoreline rather than the amount of sediment incorporated by oil prior to refloating (Gundlach, E.R 1987, Brown, H et.al. 1997, Cheng, N-S et.al. 2000, Coastal Response Research Center, 2007). As with oil-sediment mixing in the water column, the models require a lot of site specific data and are not suitable for generic application.

Oil burns

Sinking of the residue of burning oil has been observed in a few incidents. Calculation of the density and properties of the residue involved a large number of variables. Whilst it might be possible to model such processes in individual incidents, the range of possible scenarios is substantial, it would therefore be difficult to create a generic model of the processes.

Modelling tool methodology

In the second phase of the project, a methodology was proposed for a tool to predict when oil would sink or submerge, and allow the oil to be subsequently tracked. The proposed tool was designed for UK-wide application by the MCA, with UK input data sources identified, but it could be applied in other areas with different data. In designing the tool, several factors were considered:

- The emphasis was on producing a tool that would be of practical benefit, rather than a complex mathematical model which would have limited use during a spill.
- Many of the models and algorithms reviewed had not been validated in real events. Whilst some of these models could be usefully applied in the method, caution must be applied when assessing their results.
- Some of the algorithms reviewed required significant incident and site specific data that it would not be practical to gather prior to a spill. Whilst some 'rules of thumb' could be taken from results of these models, it was not practical to include them in a generic response tool.
- It was noted from the literature review that there had been several spills where oil had probably become submerged but its disappearance had been attributed to natural dispersion or other factors. One of the most important functions of the methodology was considered to be to make responders aware that oil might become submerged and that further response may still be necessary.
- The tool was designed to allow it to be added to existing oil spill models.

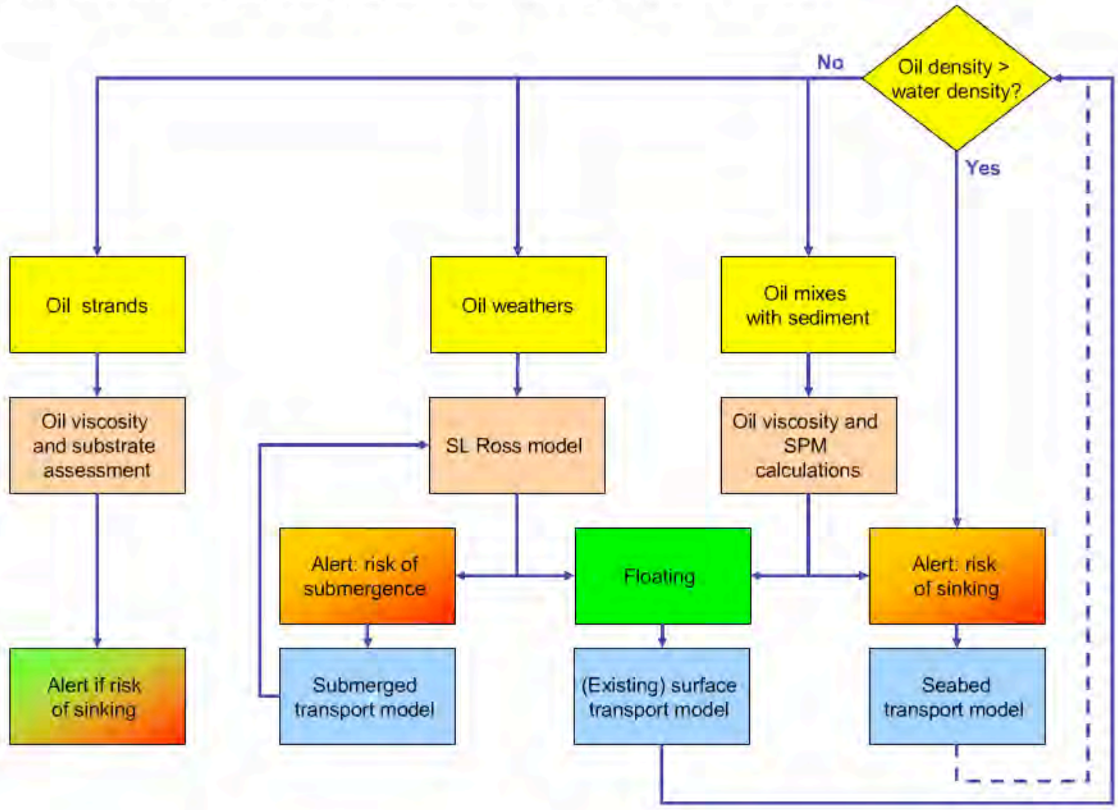
Decision support tools

In any modelling based tool, there is a level of uncertainty that arises from assumptions and estimations within the algorithms. When applying these to events such as oil spills at sea, this is compounded by uncertainty in the prevailing properties of the oil and environmental conditions. The proposed tool included three decision-supporting outputs to provide additional guidance and allow for such uncertainty:

- A 'traffic light' output indicates whether there is a High probability (Red), Medium probability (Amber) or Low probability (Green) of oil submerging.
- Text-based guidance will provide responders with more details of what the model is predicting, its likelihood of occurrence and the features that on-scene personnel should be asked to look out for.
- Spill trajectory and dispersion graphical outputs should display both surface and sub-surface spills in parallel, so that responders are made aware that oil may have submerged even if this is not necessarily clear on-scene.

Methodology

The flow diagram for the proposed methodology is shown below



General approach to modelling oil sinking or submerging. Traffic light – Red, Amber, Green shaded boxes indicate probability of submergence or sinking.

Due to its complexity, the method does not consider burning oil. The method for assessing the other four processes is as follows:

- Where oil density is greater than water, it should be assumed to sink to the seabed, where seabed transport models should be applied. Should the oil move into an area with greater seawater densities, the oil may rise again.

- Where oil density becomes close to that of the on scene water, the SL Ross model (SL Ross, 1987) should be applied. Outputs from this model will be used to give a probability of oil submergence (generating a red, amber or green traffic light alert with associated text-based advice). Where oil becomes submerged its subsurface transport should be modelled and the SL Ross model applied at each time step, such that oil may rise again to the surface if conditions change.
- In regions where oil could mix with sediment in the water column, the simple ‘rule of thumb’ derived from the work by Payne et al (1987, described above) should be applied. Below 10 mg/l SPM, a ‘green alert’ will be output (oil floats), where SPM is between 10 and 100 mg/l an ‘amber alert’ will be given (medium probability of sinking), and where SPM is greater than 100 mg/l a ‘red alert’ will be output (high probability of sinking). Given the difficulties of calculating further sediment uptake once oil has sunk, and also of calculating generic near shore transport, it was not considered meaningful to model seabed transport for that scenario.
- Where oil could strand, remobilise and then sink, there was a significant lack of data on which to base algorithms. Therefore, a simple rule of thumb was proposed based on practical experience of the project staff: if the oil has a viscosity greater than 20,000 cP and strands on a sand or shingle shoreline, responders will be alerted that the oil has a high probability (‘red alert’) of sinking if it remobilises. However, this is clearly an area for further studies.

The tool proposed in the methodology would require a number of data sets to be included beyond those included in typical surface oil spill models:

- 3D current data will be required for subsurface transport.
- Seawater density maps (or model outputs) will be required.
- Maps or model outputs of SPM concentration for UK waters will be required.

Increasingly, forecasts of these metocean parameters are becoming available for use in tools such as this, through projects such as the European Union-funded MyOcean project (www.myocean.eu.org) (personal communication, 2008).

Monitoring, detection and recovery

The final part of the study reviewed existing and novel techniques used to monitor, detect and recover sunken and submerged oils.

A range of different techniques have been applied to the detection and monitoring of sunken oils, including visual techniques, use of sorbents and sonar. However, the study concluded that whilst there had been limited success using these techniques in some incidents, none had thus far proven very effective. Two developmental systems are being assessed by the US Coastguard, based upon sonar and fluorosensor systems which may show future promise (Smedley, J.B. et.al. 1991), (ASMA, 2007).

A general limitation of detection systems is that even if they can identify areas affected by sunken or submerged oil, the oil may have moved by the time containment or recovery equipment can be deployed. Development of effective mathematical tracking models could provide better support in this area.

Conventional booms can effectively contain overwashed oil and trawl nets (or modified nets) have been used to collect submerged oils (Brown, H etal 1987, Sommerville, M. et.al.1997, Weems, L.H. 1997.). Seabed containment techniques have had less success (Western Canada Spill Services. 2008). Again, all containment techniques are limited by the ability to detect where the oil is and deploy containment systems rapidly.

Where stranded oil could sink on refloating, rapid beach cleaning can prevent this. Rapid seabed cleaning can be achieved using dredging techniques but this also recovers a lot of sediment and water, and has potential to damage benthic ecosystems to a greater degree than the original oiling. More selective cleaning can be achieved using divers or ROVs/mini submarines fitted with recovery equipment. These have additional benefits of allowing detection and recovery simultaneously but recovery will be slower than dredging (Michel, J, 2006, Moller, T.H. 1992, NOAA 1992, Usher. D. 2006, Weems, L.H et.al. 1997).

Conclusions and Recommendations

The study has provided a comprehensive overview of the processes that can lead to oil sinking or submerging. It has developed a practical method for modelling these processes during response and has reviewed existing and novel approaches to detection, containment and recovery of such oils. However, it has highlighted that there are many areas in which our knowledge could be improved to provide more effective response to non-floating oils in future.

The report contained 8 recommendations, which have been placed in order of priority.

1. Further studies should be conducted to better understand how stranded oil can pick up sediment and sink on refloating.
2. Practical tests should be conducted that allow generic models to be developed that can consider the effect of oil mixing with sediment in the water column.
3. Further work should be conducted to validate the SL Ross model (SL Ross, 1987) against real incidents (past or future).
4. If near-shore movement of sunken oil is a concern, consideration to development of a generic model for near-shore sunken oil transport should be given.
5. Recovery techniques have potential to cause more damage than the original oiling and consideration should be given to conducting a Net Environment Benefit Analysis prior to these operations (and to have benthic specialists available during the response).
6. A ‘watching brief’ should be kept on detection technologies under test and development by the USCG, Marine Pollution Control Inc. and others mentioned in the project main report.

7. Training of response personnel should be given to increase awareness of the potential for oil to submerge or sink and the situation in which this may occur.
8. The MCA should consider adding procedures for sunken and submerged oil spill response to the National Contingency Plan.
9. Consideration should be given to the formation of a team of experts to better assess and record the effectiveness of monitoring, detection, containment and recovery strategies at future sunken and submerged spills.

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