CLEANMAG: The Magnetic Clean Up Solution for Marine Oil Spills and its Environmental and Financial impact

George Nicolaides

Piraeus University of Applied Science, Department of Mechanical Engineering
Thivon 250, AEGALEO, 12244, GREECE

ENVIRONMENTAL MAGNETIC TECHNOLOGIES S.A, Lesbos GREECE

CLEANMAG RD CONGO SARL, Kinshasa, RDC
It is well known that as far there is a persistent dependency of the world energy on oil, always the planet would have to suffer from the side effects of this dependency, such as the waterborne oil spills [1-10].

Although the traditional technologies have not proved to be fully functional and efficient in the cleanup operation, little attention has been paid to new alternative techniques which have been proved to do a much better job in the field, while at the same time are fully environmentally friendly. In this paper the new magnetic technology CLEANMAG for the cleanup of waterborne oil spills is presented and a comparison with the traditional methods is attempted.
Conventional technologies used today for oil spill cleanup are mainly the following ones:

- containment of the spilled oil using booms
- direct pumping of the bulk quantities of oil
- skimming technology
- in situ burning
- use of various sorbents, solidifiers
- bioremediation
- use of chemical dispersants
The performance of the above technologies depend on many parameters such as:

- the quantity of oil spilled,
- the viscosity of oil,
- the weather conditions,
- geographical parameters,
- time of intervention
- availability of the response means.
Aim of this presentation

- In this work we present the deficiency and shortcomings of the above technologies—techniques used for waterborne oil spill cleanup and a direct comparison would be attempted with the new oil spill cleanup technology CLEANMAG, which is based on the magnetic separation method, where a magnetic sorbent material is being used.
IDENTIFYING THE PROBLEM.

Problems that might arise depending on the means being used:

- for containment, booms are excellent in good weather, but they are totally useless in sea waves with a height more than a meter.
- skimming technology is almost 100% efficient in good weather, but skimmer vessels or skimmer systems can’t perform well in the presence of waves or rough sea conditions.
- Common sorbent materials or solidifiers (using absorption or adsorption or chemical binding) are excellent in soaking substantial oil quantities in relation to their weight, but they are of limited use (mainly manual) since there is a great difficulty to collect them back from the open sea.
The in situ burning method is good only for taking out the lighter hydrocarbons (which they would be evaporated anyway in the long run) but with the shortcoming of creating high air pollution with the production of substantial quantity of smoke and leaving behind the heavier oil residues which due to their higher density they partially sink (submerge below the surface of the water) i.e. the excess of using in situ burning might have been the main cause of the submerged oil plumes found after the recent oil spill in the Gulf of Mexico.
For bioremediation there are many controversial reports for its effectiveness due its slow process. However it should not be used on oil on the sea surface because any such materials added will be diluted and lost in the slick. Bioremediation might be though a good but slow method for oil on land pollution.
At last, the chemical dispersants, where chemical compounds by modifying the surface tension at the molecular level of oil help to the dispersion of it into the water column, leaving practically the water surface free of oil.

The worst consequence of the use of chemical dispersants (no matter how more or less toxicity exhibit) is that the oil is never recovered but simply is dispersed in the marine environment affecting at micro level, the sea bed, plankton and benthos and possibly the whole food chain. In this situation the synergistic effect between the toxicity of oil and the chemical dispersants might be proved lethal to the marine ecosystem.
According to the above all, one can conclude that upon an oil spill accident first the oil containment measures should be taken as soon as possible and then to try to recover the oil immediately when the oil is still in its liquid phase with the most environmental friendly way.

In order this to be achieved will have to use first the booms and subsequently the skimmer technology or make use of sorbent materials.
Unfortunately though, until today was not possible to use the second one, since as has been mentioned before, common sorbent materials would be very difficult to collect from open sea.

However, recently a new technology has been emerged which is based on the use of a magnetic sorbent material (cleanmag) which is being collected by magnetic skimmer conveyor system installed on vessels.

This new technology which is named CLEANMAG has been proved efficient (clean oil from the water down to 10 ppb content) and is the most environment friendly, applicable technology existing today.
CLEANMAG TECHNOLOGY

CLEANMAG technology (cleaning magnetically)[11-16] for the cleanup of waterborne oil spills [11-14], is based on the magnetic separation method of two immiscible liquid phases (the one being of water and the other of oil), by using the recently developed and patented oleophilic, magnetic and oil sorbing material “CleanMag”.

The magnetic separation method in this particular case can be described as follows.

An oleophilic, porous, oil sorbing material which is also magnetic, and exhibits an apparent density lower than that of water (named “CleanMag”), is dispersed in granular form over the area of the spill. The spilled oil is instantaneously sorbed into the material pores by capillary action and subsequently, it is collected from vessels equipped with magnetic means of collection, such as the magnetic drum conveyor belt system.
Functional principle of CLEANMAG

Figure 1: a) Lab demo Oil Spill in a glass container  
       b) After dispersion of the material on the spill
Figure 2: The spill, together with the material, was stirred to simulate bad weather. The aggregates formed are apparent, while the oil has been sorbed by the material. At picture (e) the pollution is removed using a powerful Nd-Fe-B magnet.
CONVEYOR SYSTEM for collection of the material

*Figure 4: Collection of the “CleanMag” material by a “magnetic drum” conveyor belt system. The powerful magnets of the type Nd-Fe-B are placed at the inner surface of the lower drum with an alternate polarity and a radial direction of the magnetization.*
Mini vessel for shallow waters cleanup operation

Figure 5: Tests of the mini Cleanmag antipollution boat as a scaled model useful in shallow water clean up operation.
The CLEANMAG Magnetic Skimmer vessel
CLEANMAG vessel characteristics

- Length: 18.5 meters, width: 4.5 meters, 2 Volvo engines, 220 BHP each one.
- Maximum speed of 11 knots, cruising speed of 7-8 knots and an operational speed of 2-3 knots (up to 7 Beaufort travelling).
- Full navigational-communication equipment (region A2).
- Sludge capacity of 12 m³. CLEANMAG capacity of 10 m³. Storage tank capacity of 10 m³.
- A conveyor belt is operated both by an independent Diesel engine and by an electric motor.
- Operation crew: 2 members (Captain, 1 general duty member).
- It is equipped with 4 cabins - beds, a kitchen box, a WC.
- It is also equipped with a CLEANMAG pneumatic ejection system.
- Full life saving devices such as 15 lifejackets, 1 barrel raft for 10 people.
- Electronic devices for communication via a) VHF (2) and a portable one and b) satellite - GMDSS.
- Electronic navigation through a GPS - plotter system.
- Weather warning receiver (NAVTEX).
- Automatic SOS emitter when in danger or accident (EPIRB).
- Radar system with a 10 mile range.
- Magnetic conveyor belt system capable of collecting up to 20 tons/h of oil.
- Pneumatic system for the dispersion of cleanmag material.
Collection of cleanmag material in windy situation

Figure 8: Experiment of CleanMag collection with the antipollution vessel at Elefsis bay, with high winds
Figure 9: Pictures of the real oil spill experiment on May 15th 2003, at the premises of the MMA of Aspropyrgos. In the upper left picture the experiment preparation is presented, in the upper right one is the deposition of crude oil into the sea, and in the one below, is the cleaning up procedure. The residual oil left into the sea at the experimental site after the clean-up was of the order of 8 ppb!
Advantages of cleanmag technology

- Easy application of the material by naval or aerial means.
- Reduction of the typical clean-up time by 30%.
- The material forms “aggregates” due to its magnetization that delay the expansion of the oil spill because of their volume and low mobility in water, giving enough time to the clean-up operation.
- The material is practically unsinkable even under bad weather conditions.
- The oil does not emulsify with wave motion nor sinks to the seabed.
- In case that the material comes ashore, it does not pollute the environment, since on the one hand the oil is held inside the pores of CleanMag by capillary action and does not percolate through the soil, and on the other hand it can be easily collected with magnetic conveyors pulled by tractors on the shore (thus also preventing coastal pollution).
- Since the oil stays in the pores of the material, it prevents oiling of sea birds and animals.
- It is cost efficient, since one kilogram of material sorbs from 6 to 9 kilograms of oil, depending on oil viscosity.
- In some cases, there can be virtually 100% oil spill clean-up (limited only by the amount of the material available and the number of “CLEANMAG” vessels being used).
- The material is non-toxic to the environment.
- The material can be recycled.
Physical properties of cleanmag material

- **sorption character**: oleophilic-hydrophobic
- **sorption time**: upon contact
- **apparent density**: 0.2 - 0.8 g/cc
- **shape**: porous granules
- **granule size**: 2 - 10 mm
- **residual magnetization**: 0 - 40 emu/g
- **maximum sorption ratio (by weight)**: 1: 6-9 (depending on oil viscosity)
- **toxicity**: non toxic
- **recycling**: Yes
BAT (Best Available Techniques) according to the performance based on the main criteria: time of intervention, type of oil and sea conditions. (Work by G. Guidi et all (2008)) [17-18].

<table>
<thead>
<tr>
<th>Table 1: Main criteria</th>
<th>BAT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CRITERIA</strong></td>
<td>Booms</td>
</tr>
<tr>
<td>Time of intervention</td>
<td>Prompt</td>
</tr>
<tr>
<td></td>
<td>Next</td>
</tr>
<tr>
<td>Typology of spilled oil</td>
<td>Light</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Heavy</td>
</tr>
<tr>
<td>Conditions at sea</td>
<td>Calm</td>
</tr>
<tr>
<td></td>
<td>Choppy</td>
</tr>
<tr>
<td></td>
<td>Icy</td>
</tr>
</tbody>
</table>

According to this table, CLEANMAG is the only technology performing well even in “choppy” seas.
CLEANMAG technology could also be used for the protection of shore line. Below is indicated in a diagram the way this application works (by RAM Europe ltd, Greece).
RAM EUROPE ltd has manufactured the vehicle for shore line protection using CLEANMAG technology

Machine for cleanmag collection from shore line operation
Other cleanmag products and applications

- Besides of the main product which is the cleanmag material (in magnetic form), it is also produced cleanmag material in a non magnetic form. The non magnetic cleanmag due to its light weight presents an adsorption capacity up to 1: 15-22 ratio. This means that 1 kg of material could adsorb from 15 kg up to 22 kg of oil, depending on the type of oil. This material suits for the manufacturing of sorbing booms of various diameters and of length up to 5 meters. At the ends of each boom there are placed strong magnets which are capable of interconnecting themselves and thus creating booms of preferred or even of unlimited length. These particular booms they have relatively a very short adsorbing time which depends on the viscosity of the oil.

- Furthermore, the non magnetic cleanmag is used for the manufacturing of oil spill kits for ships, and these kits it is planed to be certified officially. The same material can be used also for low pressure filtration systems for oil-water separation.
RECYCLING

- Real recycling of the material could be made by using an addition of about 20% of diesel so the viscosity of the contained oil would be lowered and mechanical separation of the oil from the material would be possible. The remaining material then is dried in ambient conditions and after can be used again. However this procedure would require a very high investment, provided that the available pulp for recycling is substantially large.

- The most environment friendly procedure for handling the cleanmag pulp it would be first the extraction of oil by compression. The remaining solid material could be incinerated in power plants or cement industry furnaces. This incineration takes place at temperatures higher than 800 C, (i.e. in cement kilns ) where there are not produced any hazardous compounds neither the ozone layer is at risk, since there is no production of fluorocarbons. Incineration tests of cleanmag compound alone, has given a calorific value of 0.5 the value of pure coal.

- In another approach of handling the solid waste could be the mixing of it with asphalt products for road pavement, while the incineration of the whole pulp from the beginning, for energy production, should not be excluded.
MAJOR OIL POLLUTION ACCIDENTS AND BENEFIT IF CLEANMAG TECHNOLOGY WAS USED INSTEAD

In this section is presented a theoretical approach made by Chr. Glavopoulos[19], in his report for the evaluation on the commercial value of the CLEANMAG patent, in order to estimate the environmental and financial impact of the proposed technology in case it was applied in accidents in large scale.

BASIC ASSUMPTIONS:
- Suggested Price of Cleanmag material to be 15 USD/Kg
- Adsorbing ratio 1:4.3 (medium performance, 1kg of cleanmag absorbs 4.3 kg of oil)
- A 25% of the material cost is added as labor cost.

Also it is considered that by using CLEANMAG technology one minimizes the side damages (preserving the environment, saving sea birds, preserving the coast line, fisheries e.t.c.) which they might bear a substantially large cost for compensations.

The data that Glavopoulos used were published by E.D. Etkins[20] since 1998, while for more recent accidents he used data published in the web.
## Major Oil Pollution Accidents and Benefit if CleanMag Technology Was Used Instead

### Oil Pollution in Greece and Comparative Cost Using CleanMag Technology

<table>
<thead>
<tr>
<th>Boat name</th>
<th>Year of the accident</th>
<th>Location</th>
<th>Oil quantity (tons)</th>
<th>Clean up Cost (USD)</th>
<th>Cost of using CleanMag*</th>
<th>Benefit per case (minimizing cost/damages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILIAD</td>
<td>9-10-1983</td>
<td>PYLOS</td>
<td>252</td>
<td>cleanup: 1,235,160 USD fisheries: 4,200,390 USD other: 12,948,030 USD</td>
<td>60t = 900,000 Eur Work= 225,000 Eur</td>
<td>All the other site damages 15,000,000 USD</td>
</tr>
<tr>
<td>LA GUARDIA</td>
<td>1-10-1994</td>
<td>ASPROPYRGOS</td>
<td>401</td>
<td>cleanup: 2,263,800 USD other: 2,500,000 USD</td>
<td>90t = 1,450,000 Eur Work = 350,000 Eur</td>
<td>2,000,000 USD</td>
</tr>
<tr>
<td>KRIKI SEA</td>
<td>9-8-1996</td>
<td>Ag. THEODOROI</td>
<td>299</td>
<td>cleanup: 6,776,983 USD other: 500,000 USD</td>
<td>70t = 1,050,000 Eur Work = 260,000 Eur</td>
<td>4,500,000 USD</td>
</tr>
<tr>
<td>MARCO POLO</td>
<td>31-8-1996</td>
<td>PIRAEUS</td>
<td>1-2</td>
<td>cleanup: 110,993 USD</td>
<td>0.5t = 7,500 Eur Work = 2,000 Eur</td>
<td>90,000 USD</td>
</tr>
</tbody>
</table>
## The accident of SEA EMPRESS -1996

<table>
<thead>
<tr>
<th>Ship name</th>
<th>Year of accident</th>
<th>Location</th>
<th>Quantity of oil spilled (tons)</th>
<th>Cleanup cost + damages (USD)</th>
<th>Cost of using CleanMag*</th>
<th>Benefit per case (minimizing cost or damages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Empress</td>
<td>15-2-1996</td>
<td>Mill Bay, UK</td>
<td>72.000 crude 361 fuel heavy</td>
<td>cleanup:30.375.614 USD</td>
<td>damages: 241.200.390 USD</td>
<td>1200t = 18.000.000 Eur labor = 4.500.000 Eur</td>
</tr>
</tbody>
</table>

From the above data, 6.8% of the quantity is 4896 tons / 4,3 = 1138 tons ~ 1200 tons of CleanMag (taking into account the worst performance ratio for CleanMag, such as 1: 4,3).

### Side damages
- Local companies: $86.000.000
- Fisheries: $21.760.000
- Environmental damages: $97.800.000
- Tourism losses: $4.862.782

Of course the site damages by using CLEANMAG technology (if not eliminated at all) could be minimized at least to about 50%, meaning a lesser amount of 100.000.000 $.

In a later publication 1999 (www.itopf.com/_assets/spilcost.pdf, pg 4) the above cleanup cost has been estimated to 60.000.000 $.
ACCIDENT M/V ERIKA (12/12/1999- FRENCH COAST of BRETAGNE)

Oil quantity: 20,000 tons (fuel oil)
Damages: 192,000,000 € (http://en.wikipedia.org/wiki/MV_Erika)
A study from the ITOPF (International Tanker Owners Pollution Federation) raises the above cost of ERIKA at 310,000,000 $ (http://www.itopf.com/fileadmin/data/Documents/Papers/costs03.PDF)

<table>
<thead>
<tr>
<th>Category of Claims</th>
<th>Number of claims</th>
<th>Rejected claims</th>
<th>Number of paid claims</th>
<th>amounts (€)</th>
<th>Cleanup cost using 'CleanMag'</th>
<th>Benefit per case (minimizing cost /or damages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fisheries</td>
<td>1,007</td>
<td>89</td>
<td>846</td>
<td>7,763,339</td>
<td></td>
<td>6,000,000</td>
</tr>
<tr>
<td>Fish cultures</td>
<td>534</td>
<td>116</td>
<td>373</td>
<td>892,502</td>
<td></td>
<td>500,000</td>
</tr>
<tr>
<td>Fishing boats</td>
<td>319</td>
<td>30</td>
<td>282</td>
<td>1,099,551</td>
<td></td>
<td>1,000,000</td>
</tr>
<tr>
<td>Fish processing</td>
<td>51</td>
<td>7</td>
<td>44</td>
<td>977,631</td>
<td></td>
<td></td>
</tr>
<tr>
<td>tourism</td>
<td>3,696</td>
<td>457</td>
<td>3,211</td>
<td>76,113,602</td>
<td></td>
<td>35,000,000</td>
</tr>
<tr>
<td>Property damages</td>
<td>711</td>
<td>250</td>
<td>460</td>
<td>2,556,905</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cleanup</td>
<td>150</td>
<td>12</td>
<td>128</td>
<td>31,907,991</td>
<td>18,500,000</td>
<td>13,500,000</td>
</tr>
<tr>
<td>others</td>
<td>663</td>
<td>55</td>
<td>595</td>
<td>8,387,521</td>
<td></td>
<td>3,000,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>7,131</td>
<td>1,016</td>
<td>5,939</td>
<td>129,699,042</td>
<td></td>
<td>59,000,000</td>
</tr>
</tbody>
</table>
An indication of the extraordinary cost of this accident is the fact that in an article from the International Oil Spill Pollution Compensation Fund (IOPC) says that «less than 3% of the spilled oil was collected due to the weather conditions»


Here, we can say almost with certainty, that if CLEANMAG technology would have been applied in the case of the ERIKA accident, requiring to have the same result (meaning 3% collection of spilled oil), we would have to collect 3% of 20,000 tons = 600 tons of oil would require 100 tons of material cleanmag. With a price of 15 €/kg, the cost would have been: 15,000,000 € (material) + 25% labor + means = 18,500,000 € (CLEANMAG) compared with the 31,907,991 € spent cost only for the cleanup.

The site damages would have been minimized at least by 30% - 50%.
ACCIDENT of PRESTIGE (Spain 2002)

The Prestige accident occurred near the Atlantic coast of Spain (Galicia) in 2002, polluting the sea with 76000 tons of oil, and has been characterized as one of the worst oil pollution accident in the shipping industry until today. It has been estimated that **only the cleanup cost of the Galician coast reached the 2.5 Billion € !**  
(http://en.wikipedia.org/wiki/Prestige_oil_spill) while the total cost reached the amount of 12 Billion € !!! (http://virtualfunzone.com/11-most-expensive-catastrophes-in-history.html),  
(http://www.blindloop.com/index.php/2011/05/5-most-expensive-accidents-in-the-history)

**Benefit from using the CLEANMAG technology instead:** In such a case it is easy to assume that CLEANMAG technology by increasing the performance by a 10 % would might have saved in costs an amount of the order of **1.2 Billion €**
BP Oil Spill (DEEPWATER HORIZON Gulf of Mexico)  
(April 2010,)

BP oil Spill in MEXICO (8 Bn $)  

In reference to the for mentioned extremely large oil spill accidents like the Prestige (2002) and the BP Oil Spill (2010), we would like to emphasize that it is obvious that in the case of application of CLEANMAG technology even partially, **the financial savings in the cleanup costs would have sum up perhaps to some Billions of USD.**
CONCLUSION

By evaluating the above results and advantages of CLEANMAG, it is obvious that the new technology, which has been tested and demonstrated on a large scale and in real conditions and has performed successfully, these results might suggest that CleanMag technology might be one of the leading technologies in the battle against the waterborne oil spills for the near future.
NOTE: The CLEANMAG technology has been approved officially by the State of Greece and EPA has declared that CLEANMAG technology due to its functional principle and material used does not need to be on the national schedule (USA), giving therefore the permission to be used freely in the marine environment.

(*) web: www.cleanmag.gr

ACKNOWLEDGEMENT: The pilot tests and demonstration of CLEANMAG technology had been financially supported (1999-2004) by
- The EU program LIFE99 ENV/GR/567
- The PUAS (ex Technological Education Institute (TEI) of Piraeus)
REFERENCES


