INTRODUCTION

Rapid economic growth has caused a significant increase in the demand of fossil fuels, that are mainly transported by ships. Waterborne oil spills are considered to be a major environmental and financial problem causing a growing concern due to the increasing contamination of the marine environment. Oil slicks are usually caused by operational discharges of ships and industries, by accidental tankers' collisions and grounding, and by offshore oil drilling activities and storage facilities. They contribute greatly to the pollution of the sea and sometimes they are responsible for ecological disasters associated with huge economical losses. Especially, coastal areas are subject to the hazardous effects of oil spills due to contamination of the coastal waters and the shoreline, and the subsequent long-term damage of the aquatic environment for fishery and wildlife, the destruction of shore based economical activities, as e.g., fouling of harbour facilities and vessels in port.

A sad -and relatively recent- event is the ecological catastrophe related with the shipwreck of the tanker Prestige, which sank 130 miles off the Galician coast of Spain in November 2002. More than 1000 beaches across NW Spain, France and Portugal have been polluted and the local fishing industry has been devastated, see Fig.1. Today, the mean annual marine pollution from oil products around the globe is estimated at 1.2-1.5 million tons. Even if policies favoring green energy based on non-fossil fuel prevail in the future, oil product demands are not expected to decrease in the next decade. In this connection, oil spill pollution and oil contamination of the seas and coastal areas will continue to represent potentially hazard factors.

The successful application of oil-spill combating techniques in the sea is a formidable task with interweaving complex operational and technical procedures taking place in a narrow time window. Preparedness to respond rapidly and successfully to such accidents has led governmental agencies to develop oil spill contingency plans, as e.g. U.S.C.G. in the US (http://www.uscg.mil), MCA in the UK, (http://www.mcga.gov.uk), AMSA in Australia, (http://www.amsa.gov.au), etc. An essential part of such planning is the ability to apply efficient cleanup techniques, which in turn requires, among others, modeling and simulation of oil spill propagation and dispersion and application of suitable cleanup technologies.

Despite enormous amount of money spent for the application of oil-spill cleaning methods to the protection of the marine environment, cleanup technologies developed so far have not been proved to be quite efficient. Especially for Greece, a coastal and island country, having more than 14000 km of coastline (representing approximately the one-fifth of the European Union coastline), geographically located at the area of major sea routes, the need for development of improved and efficient techniques of rapid oil spill combat is crucial.

1 INTRODUCTION

ABSTRACT: Sea pollution by oil-spills is a huge environmental and economical problem, especially in regions with increased ship traffic. Despite considerable research, current oil-slick anti-pollution technologies have not been proved to be totally efficient. One technique is based on the method of magnetic separation, using an oleophilic, porous, magnetic material having density lower than the water. This material, after sprayed in granular form over the oil spill, absorbs the oil which subsequently can be collected from vessels equipped with appropriate magnetic means. A prototype, single-hull vessel, equipped with magnetic collection system has been designed, constructed and successfully tested. However, it is shown that a twin hull (catamaran-type) provides optimal solution, especially concerning the operability of the ship in the open sea and in the nearshore/coastal environment. The present analysis has been supported by new models for offshore-to-nearshore wave propagation and the hydrodynamic analysis of ships and floating units in variable bathymetry.
In this direction, the present paper aims to propose an optimized and cost effective application of a cleanup technology based on the method of magnetic separation, developed in the framework of a LIFE project (ENV-GR-567); see also Nicolaides et al (1998). By studying various ship hull forms it is shown that a twin (catamaran-type) hull provides an optimal solution, especially concerning the operability of the ship in the open sea and in the nearshore/coastal environment. The present analysis has been supported by wave models for the propagation of wave systems from the open sea to nearby coastal regions, including the effects of variable bottom topography and currents, which is important for the calculation of the effects of wave drift on the dispersion of floating pollutants, the numerical simulation of oil transport and the calculation of oil-spill trajectories, as well as by the application of new models to the hydrodynamic analysis of ships and floating units in variable bathymetry regions.

2 CLEANUP TECHNIQUES

Oil spill transport in marine water is a quite complex process governed by physical, chemical, and biological subprocesses, such as advection, turbulent diffusion, surface spreading, vertical dispersion, evaporation, dissolution, emulsification, hydrolysis, photo-oxidation, biodegradation, particulation, and finally, sea bed and shoreline deposition. The overall process depends on the oil properties, as well as on hydrodynamics, meteorological and environmental conditions, see e.g., Tkalich et al (1999), Korotenko et al (2000), Chao et al (2001). Classical cleanup techniques may be grouped into three separate categories, see, e.g. Tkalich et al (1999): (i) oil recovery from the water surface using mechanical means (boom and skimmer devices), (ii) oil sinking using heavier-than-water materials, and (iii) oil dispersion in the marine water column using chemical dispersants. Only the first technique removes the oil physically from the marine environment, while the other two remove the oil from the sea surface by displacing it to the water column or on the sea bed. Also, the latter methods may cause ecological damage, due to the addition of chemical dispersants to the water.

In this connection, another cleaning technique for use in the maritime environment, proposed by Nicolaides et al (1998a,b), is based on the mechanical collection of the polluting oil, and actually it improves this technique by using a fully recyclable compound. This method is based on the magnetic separation technique together with the exploitation of a new absorbing, oleophilic-hydrophobic, porous and magnetic material, called CLEANMAG® having an apparent density about 0.5-0.7 gr/cm³, which being significantly lower than the water permits this material to float. Moreover, its average grain size of ranging from 2-10mm and the its capacity to absorb oil is between 1:4-1:6 depending on the viscosity of the oil.

The CLEANMAG® material is sprayed in granular form over the oil spill, and absorbs the oil very fast (almost instantly due to its porosity) by forming a floating granular crust, that prevents the oil spill to spread further; see Fig.2. Subsequently, it can be collected from vessels equipped with magnetic collection means, such as electromagnets or magnetic drum conveyor belts, in a relatively small period of time and with a substantial efficiency of oil-recovery from the water surface; see Fig. 3. The laboratory preparation of this material, named after “Cleaning Magnetically”, is achieved by mixing various polymers and/or recycled plastics, magnetic material and surfactants.
(a) After the contact of CLEANMAG® material with the oilslick, the oil is immediately absorbed, forming a granular composition.

(b) Collection of the granular composition and the oil by means of a permanent magnet.

Figure 2. Laboratory exhibition of the application of the CLEANMAG® method.

The collection of the sprayed CLEANMAG® material from the sea surface.

It is a non-toxic, inert, and recyclable copolymer (Nicolaides, 1996, Greek Patent Register: GR1002782/96-OBI), rendering the whole composition an environmental friendly material.

3 DESIGN OF THE CLEANUP SHIP

For the full-scale application of the CLEANMAG® technology a prototype single-hull oil-spill cleanup ship has been designed, built and tested; see Figs. 4, 5. This ship has been appropriately outfitted for the successful application of above technology (see Nicolaides et al 2000, Chatzikonstantis 2001, where a detailed technical description can be found). Despite the successful trials and operation of the prototype cleanup ship, the initially adopted type of vessel does not constitute an optimal solution for the efficient implementation of the proposed cleanup technology.

The main drawbacks of the initial design are:

(i) The limited width of the conveyor belt (in comparison with the ship dimensions) which results in reduced collecting material capacity.

(ii) The fact that the ship must have important trim by bow in order for the fore end of the conveyor belt to come in contact with the floating magnetic material. This results in reduced operability of the ship, especially, in non-calm sea conditions.

After a systematic examination of different hull forms, such as twin- and multi-hull vessels, it has been found that substantial improvement of the design of the cleanup ship can be achieved by means of a catamaran-type vessel. Focusing on the operational capabilities of the vessel under design, important requirements considered are the efficient operation of the mechanical device for the collection of the CLEANMAG® material after sprayed over the oil spill, the adequate range of ship operation, speed of traveling into the accident area, and seaworthiness of the vessel permitting efficient operation in the Greek Seas and nearby coastal areas.

More specifically, by choosing a twin-hull vessel with vertical inner sides for each (symmetric) hull, see Fig.6, an optimal arrangement of the conveyor belt can be succeeded, equipped with side drives and supports for lowering its fore-end into the water surface, with stability during operation in all
weather conditions, and without requiring the vessel to trim. Also, by appropriately selecting the distance of the two hulls the width of the conveyor belt and thus, the capacity of collecting material can be maximized. For the requirements associated with the increased speed of travel (low resistance of ship in calm water) a semi-displacement, hard-chine twin-hull vessel is proposed, permitting a maximum speed higher than the conventional hulls of the order of 20-25 knots. Finally, for the efficient operation of the vessel in real sea states, the overall design procedure has been greatly supported by the development and improvement of mathematical models focusing on:

- the prediction, estimation and forecasting of sea waves and sea currents at offshore and nearshore areas,
- the propagation of floating pollutants (in association with the aforementioned models),
- the prediction of the hydrodynamic responses of ships and floating structures in offshore and nearshore regions,

developed in the framework of Operational Programme for Education and Initial Vocational Training (EPEAEK), that is coordinated by the Greek Ministry of Education and the European Union. In this connection, we review below the methods developed, improved and exploited, aiming to support an optimised design of the cleanup multi-hull ship with good operational capability, especially in nearshore/coastal regions. We mainly focus on the development and optimisation of offshore and nearshore wave models, the prediction and modelling of the wave spectra for the Greek Seas and nearby coastal areas, and models for the transportation and dispersion of floating pollutants offshore and nearshore.

3.1. Wave models
Various linear and nonlinear models (Belibassakis et al 2004, Belibassakis & Athanassoulis 2006, Athanassoulis & Belibassakis 2006) have been developed for offshore to nearshore wave transforma...

3.2. Current effects
Important factors for studying the pollutant transport, especially in nearshore and coastal areas, are the knowledge of the steady currents and of wave-current interaction effects in variable bathymetry regions. Aiming to that, an appropriate numerical model has been developed, (Belibassakis 2005), which is based on a representation of the wave field pressure, leading to a coupled mode system of equations. This model allows for the consistent calculation of the wave transformation from offshore to nearshore areas; see Fig. 8. Also, in this model the effects arising from the inhomogeneous currents and from the variable bottom topography have been taken into account.

3.3 Applications to Greek seas and coastal areas
An important part of the present design project is related to the formulation of scenarios and the application of wave models and pollutant transport models (Korotenko et al 2000, Paladino & Maliska 2000, Reed et al 2004) in real offshore and nearshore marine environments, focusing on particular areas of Greek Seas for which reliable measured data exist. Aiming to this task, during the first pe-
period of the project, a new model for long term wind and wave data has been developed (Stefanakos & Belibassakis, 2005). In addition, exploiting data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) for specific areas in the Mediterranean Sea, useful results for long term wave spectra have been obtained (Stefanakos, 2005). These data have been used, in conjunction with fully 3D, phase-resolving wave transformation models (Gerostathis et al. 2005), to study the short-term spatio-temporal distribution of wave conditions over complex bottom topographies (which is the case of the majority of Greek nearshore and coastal sites), including also the effects of 3D currents (Belibassakis et al., 2007).

4 OPTIMISATION OF CLEANUP SHIP DESIGN

For the investigation of the hull geometry parameters and of other important factors associated with the final form of the cleanup vessel extensive use of available commercial software (AUTOSHIP, MAXSURF, RHINO) has been made.

The geometrical features of the optimum vessel have been obtained after a systematic variation of an initial hull form, using variants corresponding to lengths ranging from 18m to 30m, and searching for a final design with improved hydrodynamic responses for Greek Seas and coastal areas. As concerns the operability of the vessel, the present study has been supported by appropriate models enabling the calculation of the hydrodynamic responses of floating bodies in general bathymetry in 2D and 3D (Belibassakis 2005). An example is presented in Fig. 9, illustrating the effects of bottom slope and curvature variation (that are apparent in nearshore and coastal areas) to the hydrodynamic coefficients and responses of floating bodies of various forms.

As concerns the speed specifications of the new vessel, except of its increased max speed required for fast transit in the location of the oil, the corresponding speed of operation during the collection of the sprayed material from the surface of the water (which depends on the efficiency of the magnetic conveyor) has been decided to remain the same as in the case of the prototype vessel, i.e. of the order of 4-5 knots. The latter provides sweeping capability of about 7 acres per hour of continuous operation.

The design procedure has finally led to the choice of a twin hull vessel with the following characteristics: Overall length 27.47m and projected edge length 25.3m. The main particulars of the twin hull cleanup vessel can be found in Table 1, while the lines plan of the ship is shown in Figure 10. The lines are appropriately chosen for a semi-displacement hull, permitting higher speeds than those expected for a conventional hull, reaching 20-25 knots. The basic details of the chosen lines are: hollow form of the fore body sections, considerable deadrise at the fore part, straighten bow waterlines with narrow angles of entrance, while aft sheer lines have been chosen predominantly straighten or lightly concave (flared) and rising abaft, and transom stern.
Figure 10. Lines plan (body, sheer and half-breadth plans) of a twin hull cleanup vessel for the exploitation of oil-absorbing magnetic material CLEANMAG® technology

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
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<tbody>
<tr>
<td>Length Overall</td>
<td>27.47 m</td>
<td>Hull Spacing</td>
</tr>
<tr>
<td>LWL</td>
<td>24.478 m</td>
<td>4 m</td>
</tr>
<tr>
<td>Beam</td>
<td>10.915 m</td>
<td>Beam</td>
</tr>
<tr>
<td>BWL</td>
<td>9.69 m</td>
<td>2.78 m</td>
</tr>
<tr>
<td>DWL</td>
<td>1.5 m</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>94.08 m³</td>
<td>Volume</td>
</tr>
<tr>
<td>Displacement</td>
<td>96.44 tone</td>
<td>Displacement</td>
</tr>
<tr>
<td>Waterplane area</td>
<td>107.04 m²</td>
<td>Waterplane area</td>
</tr>
<tr>
<td>Wetted Surface</td>
<td>204.92 m²</td>
<td>Wetted Surface</td>
</tr>
<tr>
<td>Prismatic Coefficient</td>
<td>0.661</td>
<td></td>
</tr>
<tr>
<td>LCB</td>
<td>10.115 m</td>
<td></td>
</tr>
<tr>
<td>VCB</td>
<td>0.997 m</td>
<td></td>
</tr>
<tr>
<td>LCF</td>
<td>10.687 m</td>
<td></td>
</tr>
<tr>
<td>Length/Beam</td>
<td>2.455</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Main Particulars of the twin hull cleanup vessel

Also, a skeg has been added at the aft part. For optimal efficiency about the service speed the cross sections have been made round. The design waterline is chosen at 1.5m above keel, which ensures a nominal displacement of about 100 tons. Normal vessel’s condition is without trim. The breadth of each one of the twin hulls is 3.38m and the inner side has been designed to be straight and vertical for efficient operation of the conveyor belt during the collection of the magnetic material. The distance (free space) between the two hulls has been taken to be 4m, maximizing the conveyor belt’s collecting capacity of the used CLEANMAG® material.
The intact stability righting arm diagrams concerning the optimum twin hull vessel have been calculated using Autoship® software. As an example, the righting arm diagram for the design draft \((T=1.5\text{m})\) condition is shown in Fig. 11. From this and similar results concerning ship stability vs. regulation requirements, we obtain that the proposed design offers applicability of the novel CLEANMAG® technology even under harsh sea conditions.

Finally, the resistance and propulsion characteristics of the optimum vessel have been studied using appropriate systematical series. Especially, in Fig. 12 we show resistance of the twin-vessel of Fig. 10 in the design draft \((T=1.5\text{m})\) condition without trim, as obtained from the application of the method based on VWS hard chine catamaran hull series 89, developed by Müller-Graf et al (2002). From this result we obtain that the proposed design is able for very fast transportation (with speeds of the order of 20kn and higher) to the accident area by means of a twin-engine system of the order of 1000 SHP max each.

5 CONCLUSIONS

Despite considerable research, current oil-slick anti-pollution technologies have not been proved to be totally efficient yet. A novel technique is based on the method of magnetic separation using a new material, called CLEANMAG®. The latter is an oleophilic, porous, magnetic material having density lower than the water. This material, after sprayed in granular form over the oil spill, absorbs the oil which subsequently can be collected from vessels equipped with appropriate magnetic means. Significant part of the absorbed oil can then be recovered by further processing in shore facilities.

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REFERENCES


