



SIMULATION OF OIL SPILLS AT THE CASABLANCA PLATFORM (TARRAGONA, SPAIN) UNDER DIFFERENT ENVIRONMENTAL CONDITIONS.

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ABSTRACT

The main objective of this work is the modelization of an oil spill at the Casablanca Platform (Tarragona, Spain) under different environmental conditions and *Simulation Models*. Computerized models used for the simulation of the spill are EUROSPILL, OILMAP, GNOME and ADIOS. Simulation models mentioned above develop a series of *outputs*. First, the most probable trajectory of the spill according to oceanographical and meteorological conditions present during the spill and next hours and the minimum impact time on the coast, if this last arrives to happen. Then, the variation according to the time of the physical and chemical properties of the hydrocarbon mixture. Specifically, the variation of the evaporated fraction of the spilled oil according to time is studied. From the results of the evaporated fraction obtained by the *simulation models*, this fraction is compared with the experimental results obtained by the direct and diffused solar action adjusted, respectively, to a theoretical equation. It is justified because one of the most influent weathering phenomena which affects to a hydrocarbon spill is the evaporation of the volatile fractions, as it modifies as the mixture compo-

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sition as its volume, specially just after the spill or next hours, depending on the kind of mixture, quantity and environmental conditions.

Key words: Oil spill; simulation models; EUROSPILL; OILMAP; hydrocarbons weathering.

INTRODUCTION

Prevention is one of the most important factors for the elaboration of Contingency Plans for hydrocarbon spills, and the importance of this kind of emergency is increasing day by day.

Simulation Models are one of the principal tools, although not the only, which make prevention works in front of a hydrocarbon spill easier.

Spills modelling have got a spectacular advance last years, resulting a great number of commercial computer programmes which allow the simulation of hydrocarbon spills. Generally, these programs have a similar basis and structure.

A series of *input* parameters referred to the spill characteristics and the meteorological conditions during and the hours after the spill, are needed for these programs.

As a result of the spill modelling, a series of *outputs* related to the spill trajectory, the minimum impact time, the impact point and the evaporated, emulsioned and dispersed fraction, just like the remnant quantity of hydrocarbons which will impact to the coast.

METHODS

Simulation models for Hydrocarbon Spills

Simulation Models are computerised systems which allow the estimation of the trajectory and minimum impact time of a hydrocarbon spill depending on environmental conditions by means of algorithms of different complexity. Parallely, a series of results, which are related to the processes of ageing that a hydrocarbon in contact with the environment could suffer, are obtained.

The basic structure of simulation models requires a series of supply parameters of different kind. Firstly, some of the spill parameters required are:

- Date and hour of the spill.
- Geographical coordinates of the spill.
- Type of spill: continuous or discontinuous
- Type of spilt pollutant.
- Quantity of spilt pollutant.

Secondly, environmental parameters:

- Direction and velocity of the currents in the spill area.
- Pattern of winds in the spill area.
- Temperature of the sea and air.



Furthermore, certain models ask for different information about the swell (height and frequency of the waves), presence of ice, water salinity, etc.

On the other hand, simulation models use to incorporate into their system a series of databases referred to the physic chemistry properties of the hydrocarbons, just as Geographic Information Systems (GIS).

Once these supply parameters are inputted, the system generates a series of *outputs* after the simulation as:

- The most probable trajectory of the spill depending on the oceanographic and meteorological conditions of the area.
- Minimum time of impact to the coast, if it occurred.
- Geographic coordinates of the area that is susceptible to be impacted.
- Variation of the quantity of hydrocarbon placed on the coast depending on time.
- Variation of the quantity of evaporated hydrocarbon depending on time.
- Variation of the quantity of hydrocarbon in the water column depending on time.
- Variation of the quantity of hydrocarbon on the sea surface depending on time.
- Variation of the density of the remnant hydrocarbon depending on time.
- Variation of the hydrocarbon viscosity depending on time.
- Variation of the hydrocarbon spill radius depending on time.
- Variation of the hydrocarbon spill thickness depending on time.

As conclusion, simulation models offer important information about the ageing processes of a hydrocarbon mixture in contact to the environment.

Ageing of a hydrocarbons mixture is called to the different processes by the effect of environmental agents as solar radiation, temperature, winds, currents, etc. Consequently, the mixture changes its composition like its physical and chemical properties and the behaviour of the mixture. One of the most important ageing phenomena is the evaporation of the most volatile fractions of the hydrocarbon mixture.

Evaporation is one of the most influent processes during the evolution of the mixture, as for the modifications it produces in the composition as in the volume of the spilt mixture. Evaporation velocity depends on different factors as mixture volatility, which is quite high initially and decreases progressively, temperature and velocity of the air, spill thickness, spill area, turbulence of the sea or the effect of the direct or diffuse radiation.

DEVELOPMENT (APPLICATION AND RESULTS)

Experimental Method

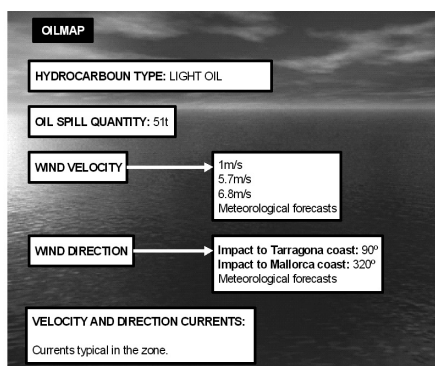
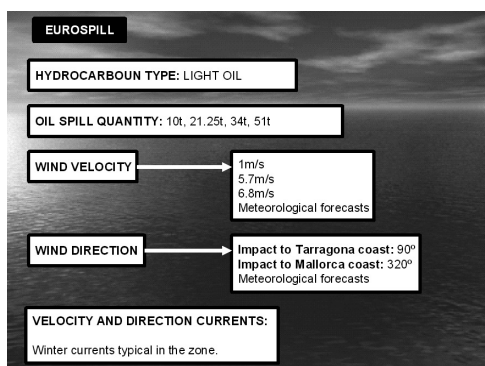
The first objective of this work is doing a series of simulations of crude oil of the Casablanca Platform (Tarragona, Spain), whose geographical coordinates belong to a latitude of 40° 44' N and a longitude of 01° 26' E.

Simulations were done with the EUROSPILL, OILMAP, GNOME and ADIOS models.

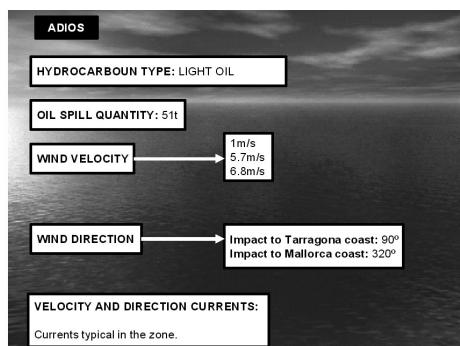
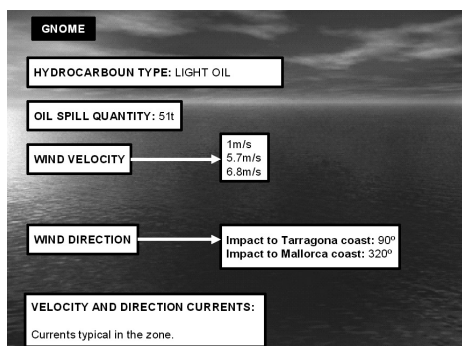
Three hypothesis has been considered:

1. Doing the simulations under meteorological conditions that imply the impact of the hydrocarbons to the Tarragona coast.
2. Doing the simulations under meteorological conditions that imply the impact of the hydrocarbons to the Mallorca coast.
3. Doing the simulations during a period of 54 hours with meteorological data obtained from the Meteorological group of the Universitat de les Illes Balears

Simulations are done with 10 tonnes, 21.25 tonnes, 34 tonnes and 51 tonnes for Arabian Light oil, very similar to the hydrocarbons of the Casablanca Platform. Simulations are done by Oil Spill Slide Rule since in several cases, the only datum obtained in a short period of time is the density of the remnant hydrocarbons mixture.



Figures 1 and 2. General conditions of simulation for the models EUROSPILL and OILMAP.



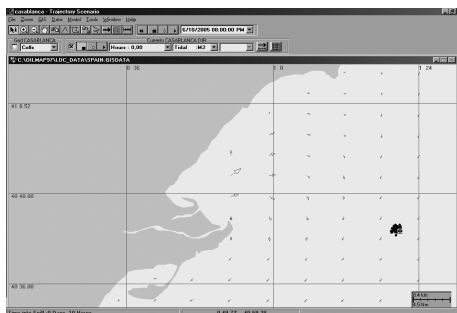
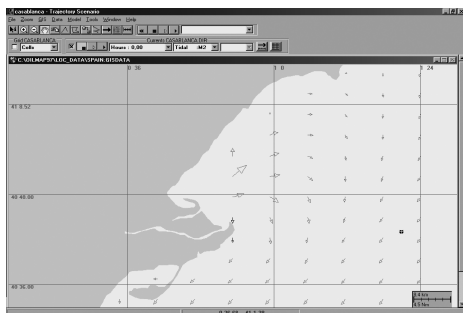
Figures 3 and 4. General conditions of simulation for the models GNOME and ADIOS.



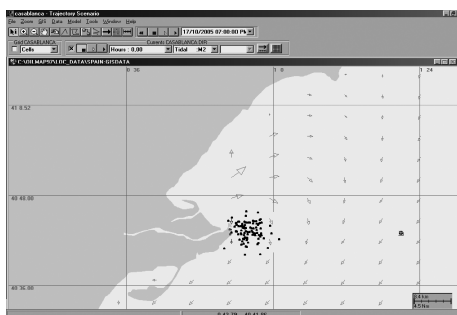
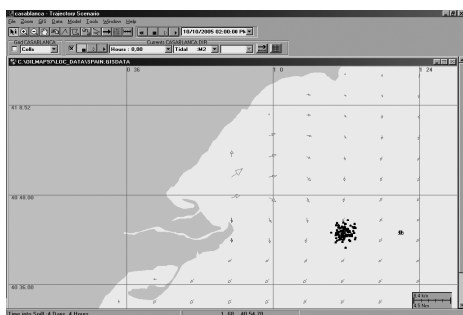
Equally, values obtained from the different simulations were co-related to the equations obtained from the experimental data in environmental conditions under the effect of direct and diffuse solar radiation.

Simulations done with the four programmes mentioned above are shown next in Figures 1, 2, 3 and 4.

Forty four simulations were done with the four models considering the three hypothetical cases explained above. As an example, one of the simulations did with the OILMAP model is shown, considering a spill of 51 tonnes and a wind of 1 m/s E direction (90°) (Figures 5, 6, 7 and 8).



Figures 5 and 6. Initial position of the hydrocarbon spill and after 10 h, respectively.



Figures 7 and 8. Hydrocarbon spill position after 100 h and 283 h, respectively.

As it can be observed, the model shows the most probable trajectory of the spill depending on the oceanographic and meteorological conditions. Consequently, it is possible to know if the spill reached the coast and, in this case, when and where would impact. So that, in the example, the minimum time of impact is 283 h, reaching the coast at a latitude of $40^\circ 43.3' \text{ N}$ and a longitude of $0.5^\circ 56' \text{ E}$.

Paralelly, a series of results belonging to the ageing processes of the spill are obtained, as well as their behaviour on the sea surface. Concretely, the present work is concentrated on the variation of the evaporated fraction of the hydrocarbon mixture depending on the time necessary to do a comparative study among the different models applied and the theoretical equations.

Concerning the theoretical equations considered, evaporation of a light oil has been studied (Bergueiro and Domínguez, 1996) in the environment, spilt over sea water and over sand of different granulometry, under the influence of several meteorological parameters, just as in the laboratory by *tray evaporation*. Studies show that the experimental data obtained from the evaporated fraction depending on time, complied with Equation 1 for a pre-established wind velocities and direct and diffuse radiation.

$$Fm = a \cdot \ln(1 + bt) \quad [1]$$

where:

Fm= evaporated fraction (%).

t= evaporating time (min).

a y b= adjustment parameters

When the Marquardt's logarithm (Marquardt, 1963) is applied, the values of the a and b constants are obtained. Their values are shown in Table 1.

Wind Temperature Interval (°C)	Wind Velocity (m/s)	Direct radiation		Diffuse radiation	
		a	b	a	b
16.8-25.8	1	5.564	0.176	4.156	0.177
16.8-25.8	5.7	6.282	0.155	4.686	0.160
16.8-25.8	6.8	5.896	0.288	4.402	0.229

Table 1. Values of a and b constants depending on the wind velocity and temperature interval.

Comparison of the Evaporated Fraction

Results obtained from the evaporated fraction depending on time were adjusted to a mathematical equation for every one of the studied cases and simulation models used. Subsequently, a comparison among these results and ones from the Equation 1 was done. These comparisons are:

1. Modelling of a spill of 51 t of light oil with a wind velocity of 1 m/s and direction of 90° (Figure 9).

As it can be observed, the best models adjust is by a logarithmic equation like Equation 1, with the exception of the GNO ME model whose adjust is by polynomial equation of second grade.

2. Modelling of a spill of 51 t with light oil and wind velocity of 1 m/s and direction of 320° (Figure 10).

Analogously with the last case, the best adjust of the evaporating results is obtained by a logarithmic equation for all the models with the exception of the GNOME model, whose adjust is a second grade polynomial.

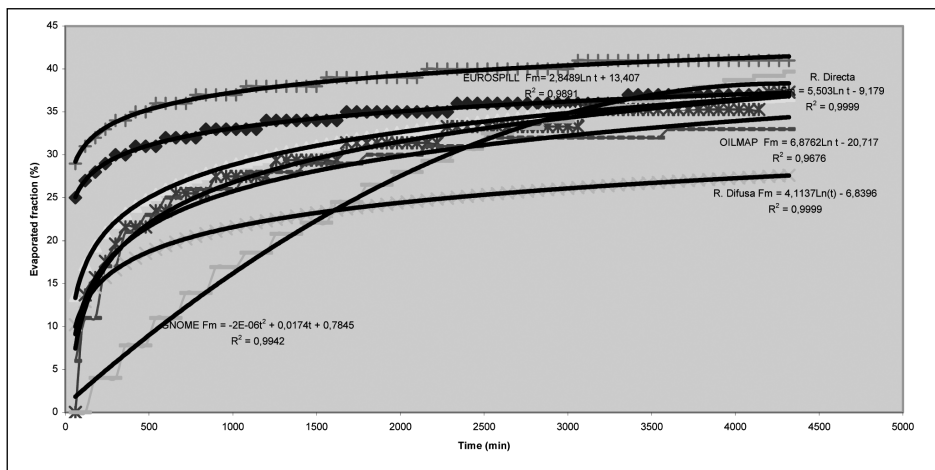


Figure 9. Comparison of the variation of the evaporated fraction depending on time using the different models with a wind velocity of 1 m/s and a direction of 90°.

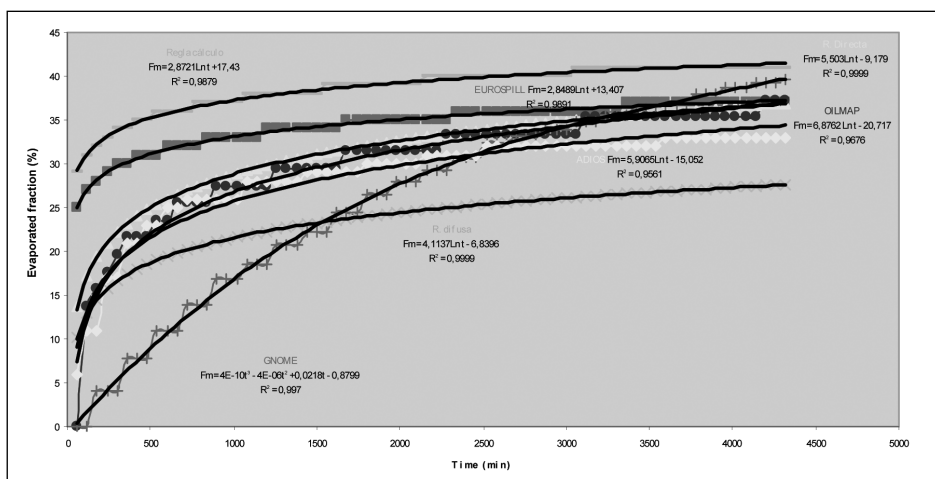


Figure 10. Comparison of the variation of the evaporated fraction depending on time using the different models with a wind velocity of 1 m/s.

3. Modelling of a spill of 51t of light oil with a wind velocity of 5.7 m/s and a direction of 90° (Figure 11).

The results are adjusted to logarithmic equations, with the exception of the EUROSPILL model whose results are adjusted to a polynomial equation of third degree, and the GNOME model which is adjusted to a polynomial equation of second degree.

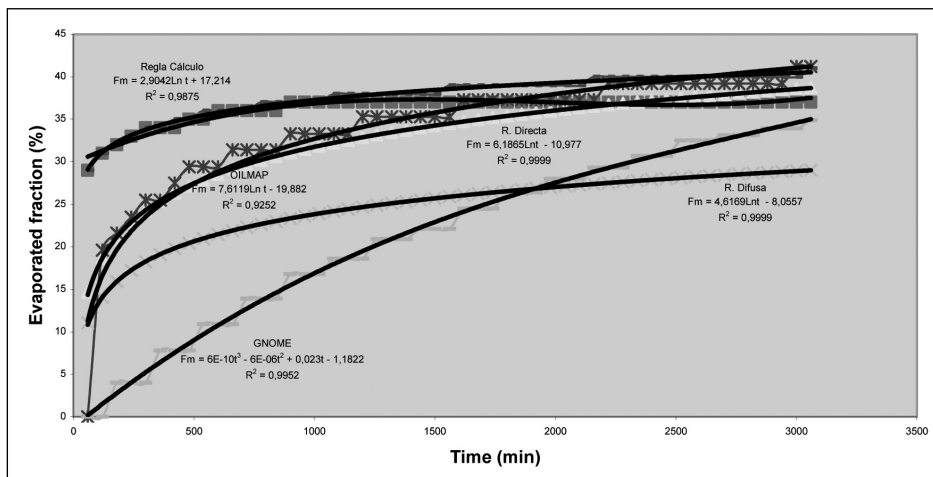


Figure 11. Comparison of the variation of the evaporated fraction depending on time using the different models with a wind velocity of 5.7 m/s.

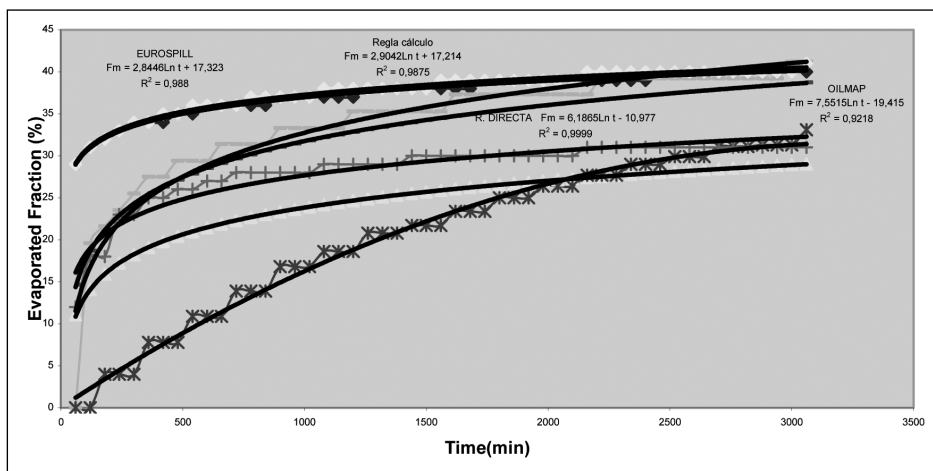


Figure 12. Comparison of the variation of the evaporated fraction depending on time using the different models with a wind velocity of 5.7 m/s.

4. Modelling of a spill of 51t of light oil with a wind velocity of 5.7 m/s and a direction of 320° (Figure 12).

The results are adjusted to logarithmic equations, with the exception of the GNOME model which is adjusted to a polynomial equation of second grade.

5. Modelling of a spill of 51t of light oil with a wind velocity of 6.8 m/s and a direction of 90° (Figure 13).

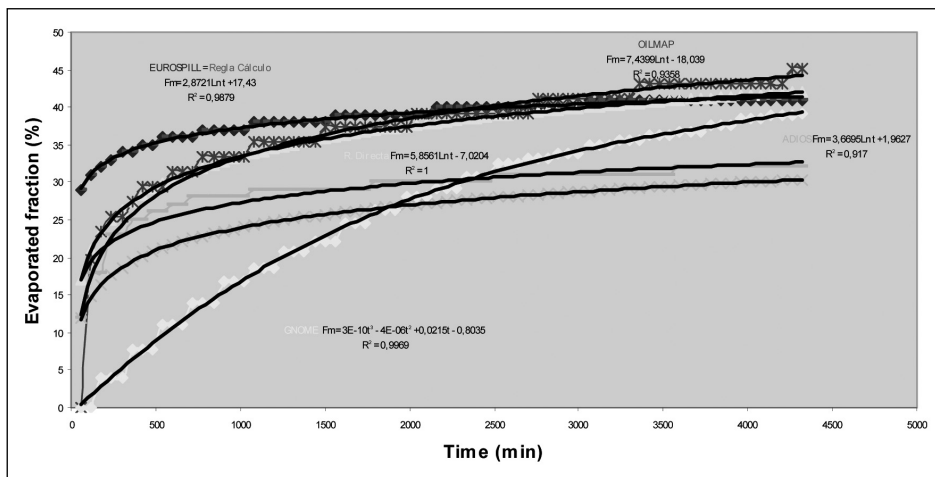


Figure 13. Comparison of the variation of the evaporated fraction depending on time using the different models with a wind velocity of 6.8 m/s.

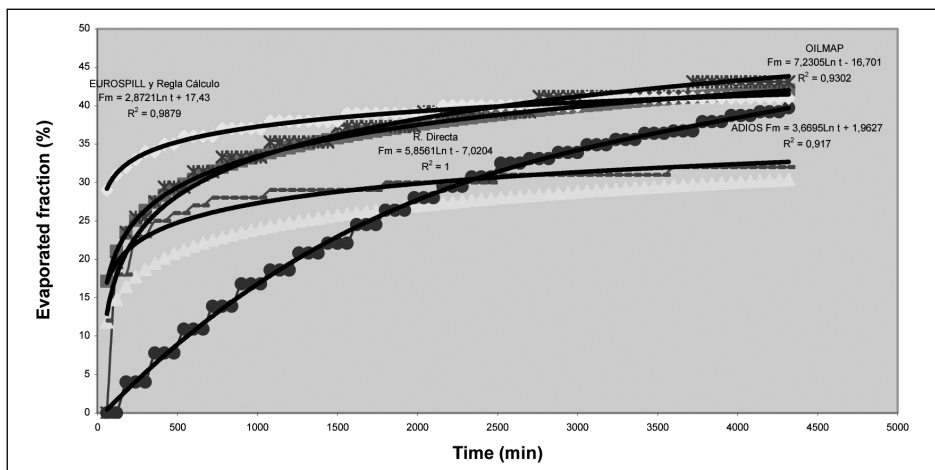


Figure 14. Comparison of the variation of the evaporated fraction depending on time using the different models with a wind velocity of 6.8 m/s.

The results are adjusted to logarithmic equations, with the exception of the GNOME model which is adjusted to a polynomial equation of third grade.

6. Modelling of a spill of 51t of light oil with a wind velocity of 6.8 m/s and a direction of 320° (Figure 14).

The results are adjusted to logarithmic equations, with the exception of the GNOME model which is adjusted to a polynomial equation of third grade.

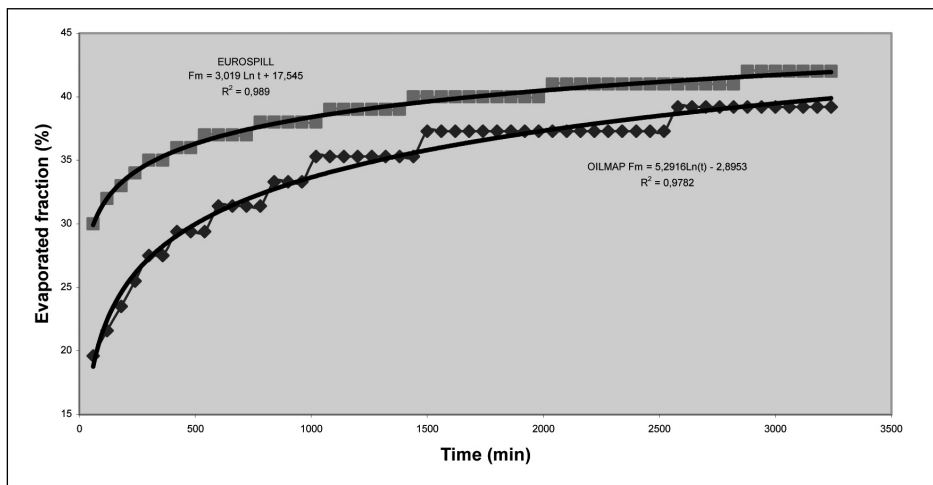


Figure 15. Comparison of the variation of the evaporated fraction depending on time with EUROSPILL and OILMAP models.

7. Modelling of a spill of 51t of light oil with the environmental conditions obtained from the meteorological simulations using the programmes OILMAP and EUROSPILL (Figure 15).

The reason why these two models have been tried is that variable meteorological conditions during the entire process according to the predictions did for the spill area are able to be used.

Both models give good results with the logarithmic equation 1.

Spill Trajectory

From the simulations done with the different models, the probable areas where the spill could impact to the coast were obtained. Simulations with E wind have the impact zone in San Carles de la Ràpita, as Figure 16 and Figures 17 and 18 show.

Simulations with wind direction of 320° , the impact zone is Sa Dragonera (Mallorca) (Figures 19, 20 and 21).

The trajectory followed by the spill, under environmental conditions obtained from meteorological simulations is shown in Figure 22.

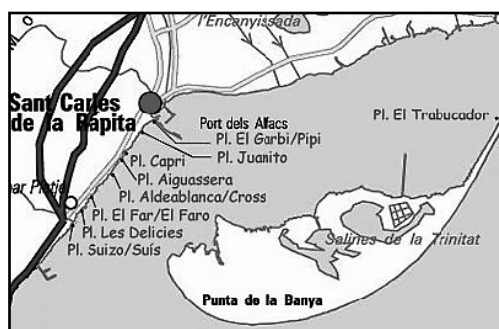
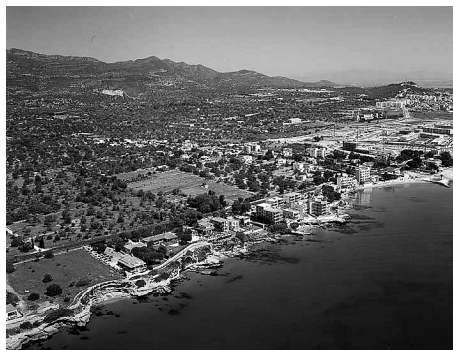


Figure 16. Impact zone of the hydrocarbons at Tarragona.



Figures 17 and 18. Beach Els Eucaliptos, Amposta, Tarragona and Suís, Sant Carles de la Ràpita, Tarragona.

The simulation with the OILMAP model shows that hydrocarbons don't have reached the coast after 54 h. There has been an evaporation of the spilt crude of 39,2% and 31t, with a viscosity of 1849,7 mPa·s, remains on the sea surface.

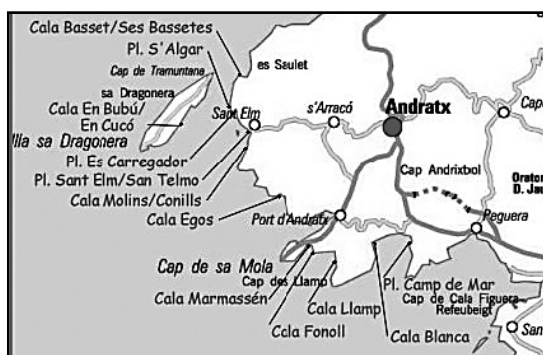
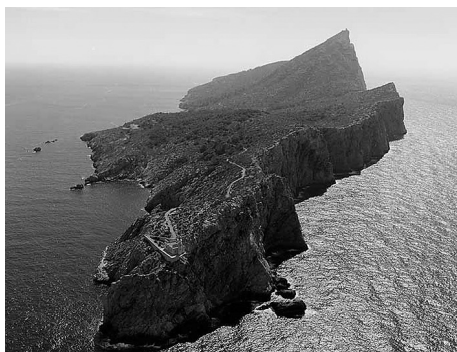


Figure 19. Impact zone of the hydrocarbons in Mallorca Island.



Figures 20 and 21. Sa Dragonera Island, and S'Algar (Andratx).

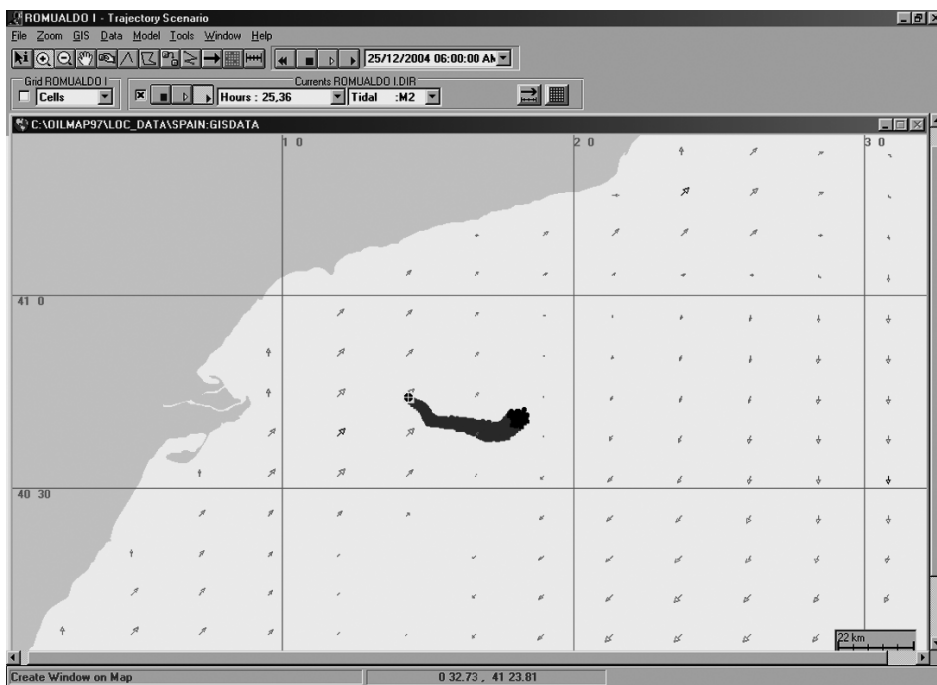


Figure 22. Trajectory followed by the hydrocarbon spill under environmental conditions obtained from the meteorological simulations.

Restoration and Cleaning Costs

Several calculations have been done using the equations suggested by Bergueiro and Moreno (2002). Firstly, the number of workers needed for the cleaning and restoration of Tarragona and Mallorca affected areas have been calculated with a result of 34 days. Next, the number of workers needed resulting 871 for Sant Carles de la Ràpita and 869 for Sa Dragonera.

Finally, the cost of cleaning and restoration has been estimated in about one million and a half euros for both cases.

CONCLUSIONS

1. From the simulations carried out with a spill of 51t under the effect of a E wind, result that hydrocarbons impact to Sant Carles de la Ràpita area after 20 h. During this period of time the 37,00% of the spilt hydrocarbons have been evaporated resting 32,13t on the sea surface, with a density of $0.23 \cdot 10^5$ mPa·s, a flash point of 101,8°C and a water content of 80%.



Equally, 130t of a mixture of hydrocarbons and water have been placed on the coast.

2. From the simulations carried out with a spill of 51t under the effect of a 320° wind, result that hydrocarbons impact to Dragonera Island (Mallorca) after 87h. During this period of time the 42,00% of the spilt hydrocarbons have been evaporated resting 26,01 t on the sea surface, with a density of 1006 kg/m³, a viscosity of 0.40·10⁵ mPa·s, a flash point of 119°C and a water content of 80%. Equally, 85t of a mixture of hydrocarbons and water have been placed on the coast.
3. From the simulations carried out with a spill of 51t under the environmental conditions obtained from meteorological simulations, result that hydrocarbons have not impacted to the coast after 54h. During this period of time the 42,00% of the spilt hydrocarbons have been evaporated resting 29,58t on the sea surface, with a density of 1006 kg/m³, a viscosity of 0.41·10⁵ mPa·s, a flash point of 120°C and a water content of 80%.
4. Plots belonging to the variation of the evaporated fraction versus time, which have been obtained from the different simulation models, have their best adjust as logarithmic equations like $Fm = a \bullet \ln(1 + bt)$. This equation gives good results in the evaporation studies done in the environment and in the laboratory. The values of the evaporated fraction versus time obtained with the GNOME model have their best adjust with polynomial equations of second and third grade.
5. The values of the physical parameters obtained by the different models, show variations during the first tours after the spill, whereas at the end of the evaporation, the agreement of these parameters is quite satisfactory.
6. The number of workers needed, time of intervention and the total cost for the cleaning and restoration of both affected zones by the two spills with the next results:

Sant Carles de la Ràpita area:

Estimated time for cleaning and restoring the coast: 34 days.

Number of workers needed: 871.

Cost of the operation: 1.495.756 €.

Sa Dragonera area:

Estimated time for cleaning and restoring the coast: 34 days.

Number of workers needed: 869.

Cost of the operation: 1.489.143 €



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MODELIZACIÓN DE VERTIDOS DE HIDROCARBUROS EN LA PLATAFORMA CASABLANCA (TARRAGONA, ESPAÑA) BAJO DIFERENTES CONDICIONES MEDIOAMBIENTALES.

RESUMEN

El objetivo principal de este trabajo es el de modelizar un derrame de hidrocarburos en la Plataforma Casablanca (Tarragona, España) bajo diferentes condiciones medioambientales y modelos de simulación. Los modelos informatizados utilizados para la simulación del derrame son EUROSPILL, OILMAP, GNOME y ADIOS. Los anteriores modelos suministran una serie de *outputs*. En primer lugar, la trayectoria más probable del derrame de acuerdo a las condiciones oceanográficas y meteorológicas reinantes durante el derrame y las horas posteriores y el tiempo mínimo de impacto en la costa, si éste último llega a producirse. Además, se obtiene también la variación de las propiedades físicas y químicas de la mezcla de hidrocarburos en función del tiempo transcurrido desde el momento del vertido. Se estudia la variación de la fracción evaporada del hidrocarburo vertido respecto al tiempo. Los resultados de fracción evaporada obtenidos mediante los modelos de simulación se comparan con los resultados experimentales obtenidos bajo la acción de la radiación solar directa y difusa, correlacionados mediante una ecuación teórica. Los estudios de evaporación se justifican debido a que ésta es uno de los fenómenos de envejecimiento más influyentes que afecta a un vertido de hidrocarburos, lo que provoca una modificación del volumen y de la composición de la mezcla remanente.

METODOLOGÍA

Parte experimental

El primer objetivo de este trabajo es el de efectuar una serie de simulaciones de vertidos de crudo de petróleo desde la Plataforma Casablanca (Tarragona, España), cuyas coordenadas geográficas corresponden a una latitud de 40° 44'N y una longitud de 01° 26' E.

Se han considerado tres hipótesis de trabajo:

1. Efectuar las simulaciones bajo unas condiciones meteorológicas que impliquen el impacto de los hidrocarburos en la costa de Tarragona.
2. Efectuar las simulaciones bajo unas condiciones meteorológicas que impliquen el impacto de los hidrocarburos en la costa de Mallorca.



3. Efectuar las simulaciones durante un periodo de 54 horas con datos meteorológicos obtenidos de estimaciones efectuadas por el Grupo de Meteorología de la Universitat de les Illes Balears.

Las simulaciones se efectuaron con 10 t, 21 t, 25 t, 34 t y 51 t para un crudo Arabia Ligero de características muy similares a los hidrocarburos que se obtienen en la Plataforma Casablanca. Se realizaron cuarenta y cuatro simulaciones con los cuatro modelos y considerando los tres casos hipotéticos planteados anteriormente.

El modelo genera la trayectoria más probable del vertido de hidrocarburos según las condiciones oceanográficas y meteorológicas. Consecuentemente, es posible determinar si el vertido alcanzará la costa y, en caso afirmativo, cuándo y dónde impactará.

Costes de limpieza y restauración

Utilizando las ecuaciones propuestas por Bergueiro se ha calculado, en primer lugar, el tiempo necesario para la limpieza y restauración de las zonas de Tarragona y Mallorca afectadas por los vertidos de hidrocarburos, resultando ser de 34 días. Seguidamente se ha estimado el número de personal necesario resultando ser 871 para el caso de Sant Carles de la Ràpita (Tarragona) y 869 para el caso de Sa Dragonera (Mallorca). Finalmente se ha estimado el coste derivado de dicho personal, resultando ser del orden de millón y medio de € en ambos casos.

CONCLUSIONES

De las simulaciones efectuadas con un derrame de 51 t bajo el efecto de un viento Este puro, se obtienen que los hidrocarburos impactan en la zona de Sant Carles de la Ràpita al cabo de 20 h. Durante ese tiempo se ha evaporado un 37% de los hidrocarburos derramados quedando 32,13 t en la superficie del mar, con una densidad de 1005 kg./m³, una viscosidad de 0,25 · 10⁵ mPa.s, un punto de flash de 101,8 °C y un contenido en agua del 80 %. Igualmente se han depositado en la costa 130 t de una mezcla de hidrocarburos y agua.

De las simulaciones efectuadas con un derrame de 51 t bajo el efecto de un viento en dirección 320°, se obtienen que los hidrocarburos impactan en la zona de la isla de Dragonera (Mallorca) al cabo de 87 h. Durante ese tiempo se ha evaporado un 42% de los hidrocarburos derramados quedando 26,01 t en la superficie del mar, con una densidad de 1006 kg./m³, una viscosidad de 0,40 · 10⁵ mPa.s, un punto de flash de 119 °C y un contenido en agua del 80 %. Igualmente se han depositado en la costa 85 t de una mezcla de hidrocarburos y agua.

De las simulaciones efectuadas con derrame de 51 t bajo condiciones ambientales obtenidas a partir de simulaciones meteorológicas, se llega a la conclusión que transcurridas 54 h los hidrocarburos no han impactado en la costa. Durante ese tiempo se ha evaporado un 42% de los hidrocarburos derramados quedando 29,58 t



en la superficie del mar, con una densidad de 1006 kg./m^3 , una viscosidad de $0,41 \cdot 10^5 \text{ mPa.s}$, un punto de flash de 120°C y un contenido en agua del 80%.

Los valores de los parámetros físicos, obtenidos con los diferentes modelos, en las primeras horas del derrame presentan ligeras variaciones entre sí, mientras que en los estadios finales de la evaporación la concordancia de dichos parámetros es bastante satisfactoria.

Se han calculado el número de empleados necesarios, el tiempo de actuación y el coste total de la limpieza y restauración de las dos zonas afectadas por los dos derrames, resultando ser los siguientes. Para la zona de Sant Carles de la Ràpita: tiempo estimado de limpieza y restauración de la costa 34 días, personal necesario 871 y coste derivado del personal 1.495.756 €. Para la zona de Sa Dragonera: tiempo estimado de limpieza y restauración de la costa 34 días, personal necesario 869 y coste derivado del personal 1.489.143 €.

