A Review of Natural Dispersion Models

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Introduction

- This study is an evaluation of existing oil spill natural dispersion models or algorithms
- Natural dispersion algorithms form part of most current oil spill behavior models
- Some of the natural dispersion algorithms have little experimental work behind them[1-8]

The Natural Dispersion Algorithms (Models)

- The Audunson model was developed in response to the Ekofisk Bravo blowout
- The MacKay model was developed as an inclusion into a first comprehensive oil spill behavior model
- The Delvigne model was developed in conjunction with extensive laboratory flume work

Abstract

Natural dispersion occurs when fine droplets of oil are transferred into the water column by wave action or sea turbulence. Depending on oil conditions and the amount of sea energy available, natural dispersion can be insignificant or it can temporarily displace a portion of the oil. Current models predict the amount of oil entering the water column, but do not deal with how long these droplets stay in the water column.

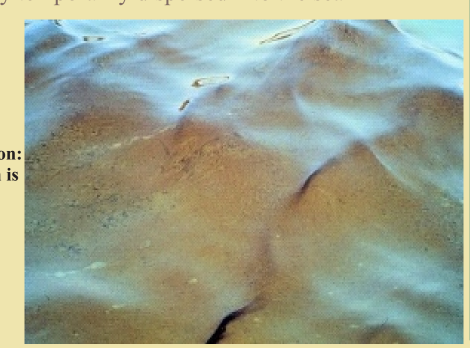
The most commonly-used model is by Delvigne. Delvigne measured the droplets entering the water column using a simplified procedure. These data were then converted to a model to predict the entry of droplets into the water column. Delvigne recommended procedures to calculate the resurfacing of the dispersed droplets but no models have implemented these.The Delvigne model might be adjusted to be more unit consistent.

The other models used include the Audunson and Mackay models. These models are also reviewed. The Audunson model is simple and does not incorporate any inputs other than the wind speed. Further, the Audunson model predicts that most slicks will dissipate within a day or a few days. The Mackay model predicts little natural dispersion. Although the Mackay model incorporates a sea state function to a certain degree.

Several issues have been noted about all natural dispersion models. These are:
1 In all cases natural dispersion models predicted the input of droplets into the water column and despite recommendations did not include re-surfacing.
2 The natural dispersion predicted was measured as a temporary phenomenon - that is the instantaneous input of droplets into the water column. The persistence was not measured.
3 All models over-predict natural dispersion, especially in cases of low sea states.

Model Essentials

- Natural dispersion algorithms should include consideration of sea state (wind), oil viscosity (other properties)
- There exists a sea state or wind threshold for the onset of natural dispersion
- Models should incorporate an algorithm for the resurfacing of oil, oil is only temporarily dispersed into the sea



A chemical dispersion: a natural dispersion is never this intense

Description of the Models

The Mackay Model

The theoretical approach begins with the assumption that (MacKay et al., 1980)[8]:

$$R_D = D(dC/dZ) = C_S K_1 \quad (1)$$

Where RD is the rate of diffusion of particles in $g/m^2.s$,
D is the rate of diffusion (m/s),
dC/dZ is the gradient of diffusion (g/L.m),
Cs is the concentration of small particles in g, and
K1 is the mass transfer coefficient rate (m/s).

After a number of manipulations one gets the expression for the lifetime of a slick (not counting the rise of the droplets):

$$t = x_o^{1.25} \frac{\rho}{1.25 k_3 S} \quad (2)$$

Where: t is the lifetime in seconds (not counting rising),
Xo is the starting slick thickness,
ρ is the oil density,
K3 is a constant, and
S is the sea state.

These equations and further assumptions are combined into the following equation which uses some of the above material:

$$F = K_A (U + 1)^2 \quad (3)$$

Where F = fraction of the sea surface subject to dispersion per second,
U is the wind speed in m/s, and
KA is a constant.

The Audunson Model

Audunson proposed that the rate or coefficient of natural dispersion should change only with wind speed as:[1,2]

$$\lambda_n = \lambda_o \left(\frac{U}{U_o}\right)^2 \quad (4)$$

Where: λn is the coefficient of natural dispersion,
λo is the base coefficient of natural dispersion,
Uo is the wind speed at which λo was estimated, here taken as 8.5 m/s,
U is the wind speed in question.

Substituting the values in the equation, one obtains:

$$\lambda_n = 0.1 \left(\frac{U}{8.5}\right)^2 \quad (5)$$

Where the items are as above and λn would be given as /day.

A Comparison of Dispersion Models

Parameters	Audunson	Delvigne	MacKay
Inputs	Windspeed	Wave Height/energy	slick thickness
		% of breaking waves	sea state
		wind speed	(droplet large or small)
		oil constants	oil density
Typical		droplet size	
Days to 100% for 10 mPa.s Oil	3	65	1400
Days to 100% for 200 mPa.s Oil	3	3800	1800
Treatment of Inputs			
Windspeed	linear	x^2	~~x^2
Oil Properties	not included	~1/viscosity$^{1.5}$	~1/density
Droplet size	not included	chosen spectra	small vs. large
Slick Thickness	not included	not included	thickness$^{1.25}$

The Delvigne Model

The model began with the quasi-empirical equation:[3-5]

$$Q_{(d)} = C_o D^{0.57} d^{0.7} \Delta d\, S_{cov} F_{wc} \quad (6)$$

Where: Q(d) Is the entrained mass rate of droplet sizes in the interval around d per unit surface area and per unit time - given in kg/m^2 s,
D is the energy dissipation of the breaking wave per unit surface area (J/m^2),
Co is a constant for a given oil, a light oil is about 1000 to 1800, a medium oil about 500 to 1000 and a heavier oil <500,
d, Δd is the droplet size and range of droplet size (interval) in m,
Scov is the fraction of the sea covered by oil (0 to 1), and
Fwc is the fraction of sea surface affected by breaking waves per unit time (s^{-1}).

This was developed further by defining portions of the above equation:

$$F_{wc} = c_b (U - U_i) / T_{ww} \quad (7)$$

Where: Fwc is the fraction of sea surface affected by breaking waves per unit time (s^{-1}) as in the equation above
Cb is a constant ~ 0.032 s/m
U is the wind speed (m/s)
Ui is the wind speed at the initiation of breaking waves (~ 5 m/s), and Tw is the wave period (s).

So the equation above can be rewritten as:

$$F_{wc} = 0.032 (U - 5) / T_w \quad (8)$$

Also, the energy dissipation (D) has been proposed as:

$$D = 0.0034 \rho_w g H^2_{rms} \quad (9)$$

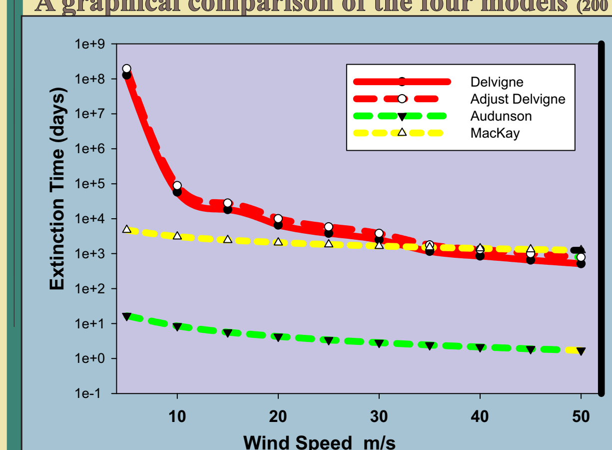
where: D is the energy dissipation of the breaking wave per unit surface area (J/m^2)
ρw is the density of water (kg/m^3) which is 1030 for typical seawater
g is the acceleration due to gravity (m/s^2) which is 9.81
Hrms is the r.m.s. value of the wave height (m).

Substituting both of these into equation (14) we get:

$$Q_{(d)} = C_o (34.4 H^2_{rms})^{0.57} d^{0.7} \Delta d S_{cov} (0.032(U - 5)/T_w) \quad (10)$$

Where: Q(d) Is the entrained mass rate of droplet sizes in the interval around d per unit surface area and per unit time - given in kg/m^2 s,
Co is a constant for a given oil, a light oil is about 1000 to 1800, a medium oil about 500 to 1000 and a heavier oil <500,
Hrms is the r.m.s. value of the wave height (m),
d, Δd is the droplet size and range of droplet size (interval) in m,
Scov is the fraction of the sea covered by oil (0 to 1), and
Tw is the wave period (s).

A graphical comparison of the four models (200 mPa crude*)



* A comparison with other crude oil viscosities shows analogous results - with the Audunson model showing no difference and the Mackay model a modest difference and the Delvigne model responding significantly to the viscosity

Recommended Approach

- Delvigne's equation offers the best model at this time

As only Delvigne's model was based on experiments, it is recommended for further development (see below)

Starting with Delvigne's equation[4,5] (Equation 10 opposite) and making the following adjustments:
a) substitute viscosity in the equation for the constant
b) adjust the initial wind speed to 15 m/s from 5 m/s
c) complete the equation for other parameters as noted by Delvigne. The resulting equation is:

$$F_{(d)} = 6.3\times10^{-4}/\rho^{1.5} \ (34.4 H^2_{rms})^{0.57} \ (0.032 (U - 15) / T_w) \quad (11)$$

Where: F(d) Is the fraction of entrained mass rate of droplet sizes in the interval around from 10 to 30 μm - given in /hour,
ρ is the viscosity of the oil in cSt or mPa.s,
Hrms is the r.m.s. value of the wave height (m),
U is the wind speed in m/s, and
Tw is the wave period, s.

Several conclusions might be made about natural dispersion models.[6,7] These are:
1 In all cases natural dispersion models predicted the input of droplets into the water column. In no case was the resurfacing of the droplets actually modeled.
2 The natural dispersion predicted was measured as a temporary phenomenon - that is the instantaneous input of droplets in the water column. .
3 The Audunson equation over-predicts natural dispersion, especially in cases of low sea states or winds,
4 The Delvigne and Mackay model reach somewhat similar conclusions, however the MacKay model has less inputs and no wind threshold,
5 Many of the constants in all three models appear to be arbitrary , and only in the case of the Delvigne model were there direct correlations to experimental data

References

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Conclusions

- In all models only the input to the sea was modeled- although most models suggested ways that resurfacing should be predicted
- The Audunson model over-predicts dispersion and has no inputs. The MacKay model has limited inputs. Delvigne model based on some experiments
- A proposed modification to the Delvigne is the best recommended solution at this time