Empirical Studies of the Spreading of Oil Spills

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A series of test spills varying in size from 13 to 51 barrels was carried out in the Arabian Gulf using Arabian light and heavy crude oils. The areas of the black oil part of the spill, the sheen and the total slick were measured at various times. Comparison with commonly used spread formulas showed wide discrepancies between predicted and measured results.

1. INTRODUCTION

A series of test spills was carried out in the Fall of 1982 in the Arabian Gulf for the purpose of estimating oil spill size by visual observation. The spills involved 13 barrels of Arabian heavy crude oil and 20 and 51 barrels of Arabian light crude oil. The spills were photographed by a specially equipped aerial survey plane at various times over the duration of the spill, and the subsequent photographs were scanned electronically and computer-analyzed. The resulting area calculations from this analysis were compared with some standard oil spreading formulas.

2. PROCEDURE

All spills were made from tanks fastened to the aft-deck of a 100 ft workboat. The oil was fed by gravity through a pipe 15 ft long with a 3 in. diameter. The end of the pipe was fitted with a funnel held horizontally to the water surface to reduce entrainment of the oil in the water. During the 51 barrel spill, an auxiliary 1.5 in. diameter pipe was also used. Table I summarizes various parameters related to the test spills.

As has been reported for other spills (Jeffery, 1973; NAS, 1975), the oil separated into two major regimes, a thick 'black oil' regime and a thin 'sheen' regime. In some situations a third regime which contained heavy sheen mixed with small spots of black and brown oil was also noticed. This third region was more pronounced when the slick was observed from low altitudes.

As the oil spread, photographs were taken by

TABLE I
Spill parameters

Initial size (barrels)	13.09	19.60	51.07
Oil type	Heavy	Light	Light
Spill date, 1982	5 December	12 December	21 December
Release time	8.59 am	9.20 am	8.25 am
Duration (min)	121[a]	148[a]	329
Wind direction	ESE	NW	NW
Wind speed (knots)	15	14	10
Wave height (ft)	2–3	1–2	1–2
Sea temperature (°F)	70	68	62

[a] Area measurements only for shorter time period.

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a WILD brand camera from the survey plane at altitudes which varied between 2500 ft and 9500 ft depending on spill site and cloud cover. Earlier attempts at using black-and-white film and black-and-white infrared had proved unsuccessful for delineating the slick, therefore color film was used exclusively. The time when each photograph of the slick was taken was recorded automatically.

Seven photographs from the 13 barrel spill, eight photographs from the 20 barrel spill and eight photographs from the 51 barrel spill were scanned at 200 μm resolution on the optronics C-4500 film scanner/rewriter. The resulting digitized pictures were then processed on an HP 1000 microcomputer. Initially, some experimental processing was tried on several of the digitized pictures. This involved maximum machine-processing with minimum operator-input and included automatic classification of the original color regimes in the photographs, as well as ratioed spectrum bands. Due to the effect of glare and ripples on the water surface, and differences in sun angle, automatic classification proved insufficiently accurate. Therefore, the images were contrast-enhanced by expanding the brightness range in critical regions and the thick and thin areas of the slick were outlined manually. The resulting areas were color-coded and measured by the computer.

3. RESULTS

The area of the entire slick, the black part, and the sheen were plotted against time for the three spills. Polynomial regressions of various orders were then computed for the resulting area–time data points and the polynomials with the highest f-ratios, the ratio of regression mean squares to residual mean squares, were selected (see any standard engineering book for details, e.g. Walpole and Meyers, 1972). Table II lists the coefficients of the polynomial and corresponding f-ratios for the various data sets. Figures 1 and 2 show the fit for the black and sheen areas, respectively, for the 51 barrel spill. As in the case with the 13 barrel spill, a quadratic curve is the best fit for the black area versus time, whereas a linear curve is the best fit for the sheen and total slick areas. Presumably this reflects the fact that the thicker part of the slick reaches an equilibrium area quite rapidly, whereas the time to reach

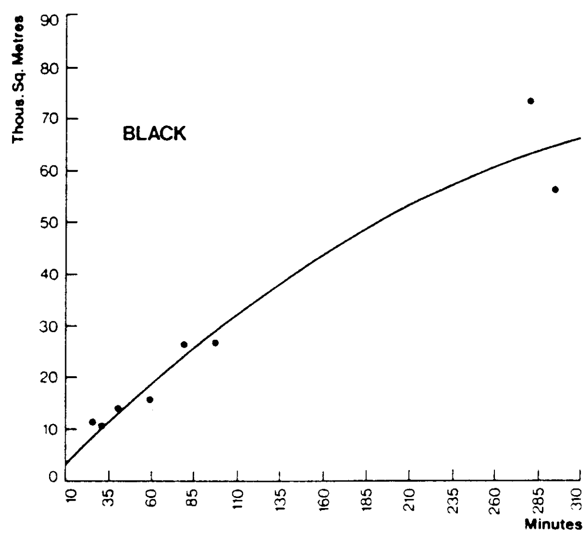

Fig. 1. Plot of black area versus time for the 51 barrel spill.

TABLE II
Area functions for spills

Initial spill volume	*Color regime*	*Best fit polynomial*	*f-ratio*
13	Black	$A = 0.148 + 0.439t - 0.005t^2$	75
	Sheen	$A = -8.32 + 2.27t$	171
20	Black	$A = 0.485 + 0.183t$	63
	Sheen	$A = -0.549 + 0.638t$	82
51	Black	$A = 0.308 + 0.336t - 0.000405t^2$	63
	Sheen	$A = -21.0 + 2.81t$	2545

A = Area in thousands of square meters.
t = Time in minutes from spill release.

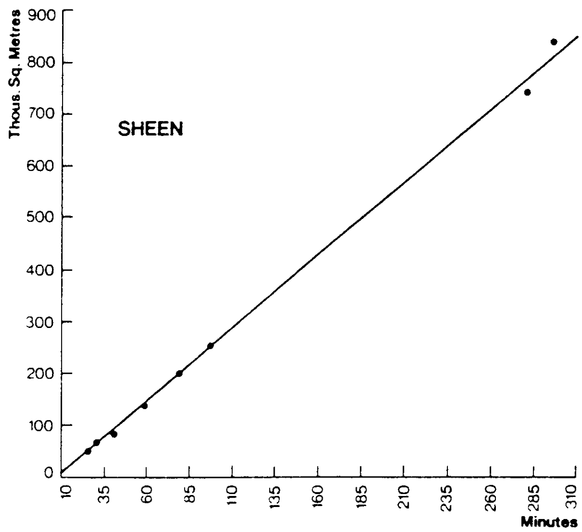

Fig. 2. Plot of the sheen area versus time for the 51 barrel spill.

equilibrium for the sheen area is much longer than the duration of the experimental spills, about 5 h for the longest case. The decrease in the size of the black area as time increases past the vertex of the parabolic curve of the black areas could be explained by assuming that black oil feeds the sheen part, as hypothesized, for example, by Mackay (1980). The 20 barrel spill lasted for such a short time that a linear fit is the best fit, even for the black area. One interesting outcome was the fact that the 20 barrel light crude oil spill actually spread more slowly than the 13 barrel heavy crude oil spill, an anomaly which can perhaps be explained by the fact that the wind and current conditions were different for the two spills.

4. COMPARISON WITH LEADING FORMULAS

The anomaly mentioned in the previous section illustrates the difficulty of constructing a spreading formula applicable in all circumstances. Moreover, leading spread formulas incorrectly treat oil as if it were a single substance with uniform density and thickness rather than looking at the sheen and black oil parts separately. They also often presume a calm sea-state. It is therefore not surprising that when two of the most common spread models, the Blokker model (Blokker, 1964) and the Fay model (Fay, 1971) were compared with actual results, the difference was considerable.

The Blokker model was used in the format and with the constants suggested by Jeffery (1973):

$$R(t) = [R_0^3 + (3\ \kappa t V P_0/\pi P_w)\ (P_w - P_0)]^{1/3} \tag{4.1}$$

Where κ = Blokker's constant (= 216); P_0 = oil density (g cm^{-3}); P_w = water density (g cm^{-3}); t = time (s); R_0 = initial radius of slick (cm); $R(t)$ = radius at time t (cm); and V = volume (cm^3).

The spread plots of predicted versus actual spread area are shown in Figs. 3–5. It is seen that the Blokker model is in reasonably close agreement with the 20 barrel spill, significantly underestimates the 13 barrel spill, and underestimates the 51 barrel spill by sometimes more than a factor of four.

The Fay model divides, spreading into three phases: a gravity-inertial phase, a gravity-viscous phase and a viscous-surface tension phase. Only the first two phases were applicable to the time spans of the experimental spills. The formula for the gravity-inertial phase is:

$$R(t) = 1.14\,[gVt^2\,(P_w - P_0)/P_w]^{1/4} \tag{4.2}$$

Where g is the gravitational acceleration (9.81 m s^{-2}). The formula for the gravity-viscous phase is:

$$R(t) = 1.45\ [(gV^2t^{3/2}/\upsilon^{1/2}_w)(P_W - P_0)/P_0]^{1/6} \tag{4.3}$$

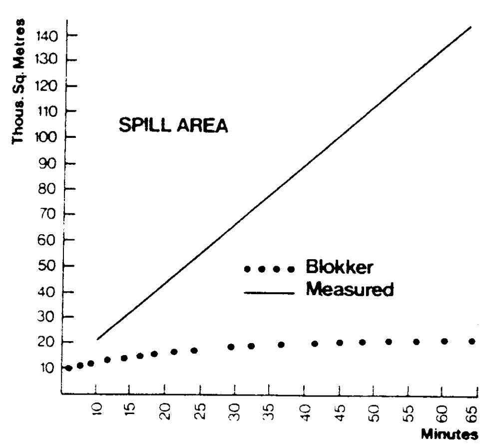

Fig. 3. Plot of measured area of total slick compared with that predicted by the Blokker model for the 13 barrel spill.

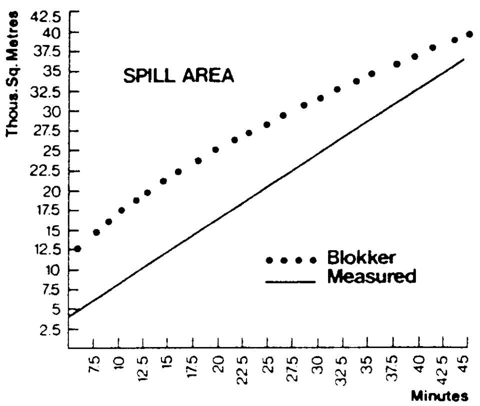

Fig. 4. Plot of measured area of total slick compared with that predicted by the Blokker model for the 20 barrel spill.

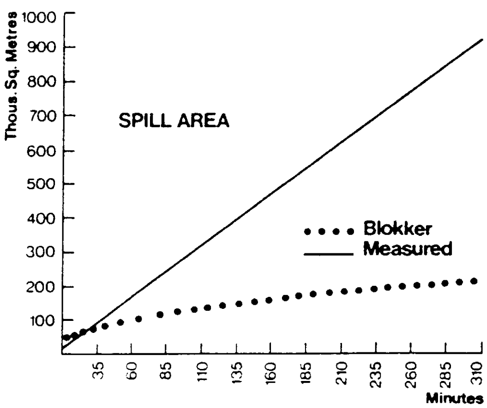

Fig. 5. Plot of measured area of total slick compared with that predicted by the Blokker model for the 51 barrel spill.

Where υ_w is the water viscosity ($\simeq 10^{-4}$ m s^{-1}).

In all comparisons with the actual spills the Fay predictions were even worse than those of the

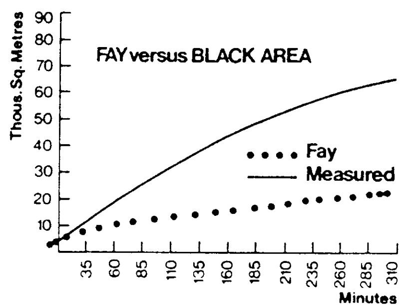

Fig. 6. Plot of black oil area for the 51 barrel spill compared with the Fay model prediction of total slick area.

Blokker model, in the 51 barrel case under-estimating by an order of magnitude. A better fit can be made by matching the Fay prediction for total slick area with the actual area of the black part of the slick (see Fig. 6). Of course, the Fay model, as well as the Blokker model, may have done better when applied to actual-sized spills rather than the small experimental ones used here, although neither would have been capable of explaining the anomaly between the 13 and 20 barrel spills.

5. CONCLUSIONS

The spreading of oil on the open ocean is a complicated process involving several environmental factors which are unique for each individual spill. Formulas based on treating oil as a uniform substance spreading on calm waters will be ill-suited to provide actual predictions of spread rate.

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