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Assessing the Spreading of Nile Blend Crude Oil in the Sudanese Red Sea Coastal Water

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Abstract

Spreading is one of the most important processes of the early stages of oil slick transformation. Four physical forces were considered to develop spreading: gravity, inertia, viscous and surface tension forces. In this study Fay's analytical approach was used to predict the spreading of Sudanese NB in the Red Sea coastal water. These results were verified using experimentally determined data from the measurement of the spread of Sudanese crude oil and kerosene on the surface seawater of the Red Sea. Two different weather conditions (wind and calm weather) were considered. The spread under calm condition was found to be slower than that under wave action. Field data showed that, Fay's theory greatly underestimated slick growth. The spreading rate of kerosene was found to be 1.12 to 4.78 times the spreading rate of NB crude oil. The results of NB was compared with other three crude oils namely Arabic Light crude oil, North Sea crude oil, and Venezuela crude oil using Fay spreading theory. The results showed that spreading rate of Arabic light, North Sea and Nile Blend were almost the same. Venezuela crude oil showed a lower spreading rate.

Keywords: Spreading, Fay equation, Nile Blend crude oil.

Introduction

The surface spreading modeling of the oil slick is one of the most important processes in the early stage of the oil slick transformation, because of the influence of the surface area of the oil slick on weathering processes such as evaporation and dissolution.

Therefore, it is essential to recognize the mechanism of crude oil spreading on the water surface, in order to reduce its environmental impacts by means of adequate contingency plan and containment strategies. The tendency of the oil to spread in the surface of water is the result of balance of four physical forces, gravity, surface tension, inertia and viscous. In terms of these forces, it is expected that gravity and surface tension will increase the spread while inertia and viscous forces retard it**.** Three phases were identified. The beginning phase where only gravity and inertia forces are important. The intermediate phase where the gravity and viscous forces are dominant. The final phase is governed by balance between surface tension and viscous forces. This paper aims to study the extent of spreading of the Sudanese crude oil (NB) on the Red Sea surface water using analytical Fay method and experimental data.

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Materials and Methods

Fay's spreading theory

In the present simulation, Fay's spreading theory (1971) was used, and the results were compared to data collected from the field measurement. The equations corresponding to the Fay spread theory are:

Gravity-Inertia $1.14(\Delta\, gVt^2)^{1/4}$

Gravity-Viscous $0.98(\Delta\, gV^2t^{\,3/2}v^{-12/2})^{1/6}$

Surface Tension-Viscous $1.60\,(\sigma^2t^3\rho_w^{\,-2}v^{-1})^{\,1/4}$

Where:

$\Delta = 1 - \rho_o / \rho_w$

ρ_o and ρ_w: oil and water density

σ: spreading coefficient

v_w: Kinematics viscosity of water

V: Volume of oil

g: gravitational acceleration

t: time

The extent of spreading is affected by wind, wave, and current, but probably more by the physical and chemical nature of oil. The rate at which the oil spreads is also determined by the prevailing conditions such as temperature, tidal streams**.**

The testing procedures were as follow: 250 ml of Sudanese crude oil (Nile Blend) and kerosene spilled,and then allowed to flow freely on the water surface of the Red Sea at strip I (dock yard) near Faculty of Marine Science of Red Sea University, Port Sudan. The diameter of oil spilled was measured against time for each test. The measurements of the diameter were conducted every ten seconds for 60 seconds**.** The tests were conducted under two different weather conditions that was under wave action and in calm weather. A total of four tests were performed.

Results and Disscusion

As expected, after a period of time in which the slick accelerates, the mass center of the slick remains moving with the water velocity. Oil slick usually drifts in the same direction as that of the prevailing wind. The direction of the oil slick, as influenced by the wind, should be taken as that of the wind, (Murry and Murry, 1973). The speed of the wind-driven component of the slick movement is generally considered to be about 3 percent of the wind speed (Wu, 1975). It can be noticed that as the oil spill is spread, the initial perturbation tends to disappear and the slick takes a rounded shape.

It was observed that, on calm water, spilt oil spreads to form a homogeneous circular patch quite quickly. The rate of spreading was3 estimated based on the following assumptions:

1- The oil slick is circular.
2- The oil is homogenous mixture.
3- Only motion relative to the centroid of the oil slick was considered.

Based on these assumptions the balance of gravity, surface tension, viscous and inertial forces for a circular oil slick was applied to the oil spill. The results

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obtained by applying Fay‘ s preading formulae for crude oil (Nile Blend) and kerosene were coupled to experimentally determined values from the measurement of the spread of Sudanese crude oil and kerosene on the surface seawater of the Red Sea. The results are shown in Figures 1 and 2.

Crude oil

Figure 1 shows the comparison of the experimental results to those obtained by applying Fays spreading formulae. The Figure describes the oil slick dimensions as a function of time for a 250 ml spill**.** Tests showed that the diameter of the crude oil slick spread under wave action ranged from 0.98 to 1.42 m at 10 and 60 seconds, respectively. The spread under calm condition was slower than that under wave action. The diameter of the crude oil slick spread in calm condition varied between 0.34 to 0.72 m at 10 and 60 seconds. This can be attributed to the fact that wave action, produces breaking of the oil-water surface tension, thus increasing the spreading in the wave propagation direction.

The results from the oil spreading measurements obtained in this study indicated that, when oil spilled on the water surface, spreading under wave action was larger than that predicted by Fay's spreading theory. This is in agreement with field data obtained by Flores, *et al* (1998). It is important to notice that Fay's theory has been derived under the assumption of calm water; therefore spreading is expected to be larger under the effect of waves, marine currents and/or wind. More reliable models of oil spreading need to be developed. This can be accomplished by performing tests for a large range of oil properties and water conditions. Experimental results indicated that more realistic results were achieved in the gravity-viscous and gravity-inertia phases based on on an assumption that, the weather is calm (water not influenced by wind or tide). Oil spreads was larger for tests done under wave action, so the model was less reliable to reflect the behavior of the crude oil under wave action (Fig. 1). Models that do not consider inertial forces justify this in the fact that the inertial spreading phase is very short, which is actually true as gravity-inertia stage lasts in a very short time.

Kerosene

Tests 3 and 4 were applied to investigate the spreading behavior of kerosene. Results obtained from the field were compared to those calculated from Fay's equations. Experiments showed that the diameter of the kerosene spill spread under wave action ranged from 1.1 to 6.8 m at 10 and 60 seconds. The spreading was slower when tests were applied under calm condition. Kerosene spill reached, under calm conditions, a diameter of 0.41 and 1.22 m in 10 and 60 seconds respectively.

The theory of Fay with was compared experimental data carried out under both calm and wave condition as shown in Figure 2 is presented. The predicted results obtained from Fay equations for determining kerosene diameter ranged from 0.549 to 3.192 m at 10 and 60 seconds respectively. It is observed that, the Fay gravity-viscosity stage was a very good representative to the data carried out under calm condition (Fig. 2).

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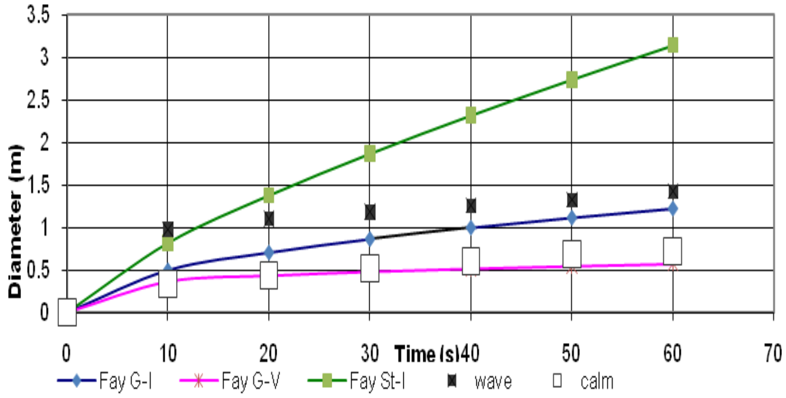

Fig.1. Nile Blend crude oil Vs Fay spreading theory

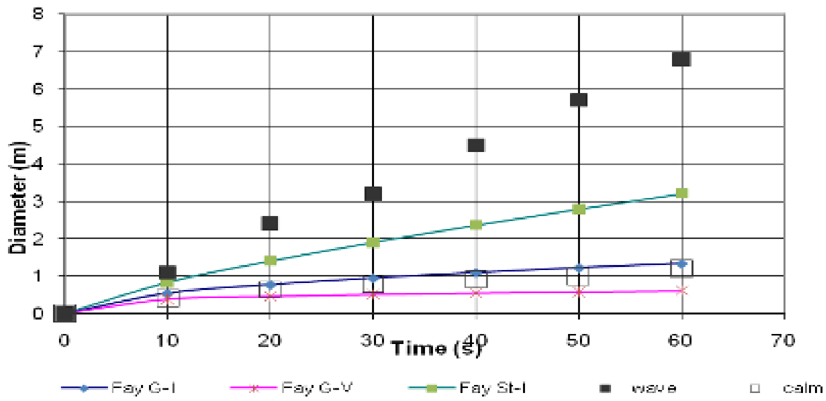

Fig.2. Kerosine experimental results Vs Fay spreading theory

Experimental results from the Gulf Region indicated that more realistic results are achieved in the gravity–viscous phase when wind parameters are considered, based on the assumption that, oil spreads as an ellipse with the major axis in the direction of the wind**.** Actually, this stage is the most important one among other stages, Mackay *et al* (1980) for example started with the Fay Gravity-Viscous and surface tension–viscous formulation to obtain a thick and thin slick equation. Garicia *et al* (1996) have recently proposed a correction to the Mackay spreading theory, by determining expressions for Mackay's constants, which are shown to be variable and depending on oil and water characteristics. If surface tension is neglected that is only first two stages considered (GI, GV), then the model can be applicable up to 10 days after the spill depending on its magnitude.

It was noticed that, towards the end of the test, spreading did not stop as it just entered the surface tension–viscous regime with appearance of fine slick which spreads in a diagonal direction.

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Similar to the previous test, field data showed that Fay's theory greatly underestimated slick growth. This is due to breaking of the oil–water interface tension under wave activity, since there is additional perturbation and stirring than that considered for Fay's surface-tension-viscous regime. Fays results described the spreading of an instantaneous spill in calm waters. For the case of the calm condition, it is very clear that Fays work explained this phenomenon properly.

The spreading of kerosene was found to be larger than that of crude oil. This may give indications that kerosene spreading is easier. The spreading rate of kerosene was found to be 1.12 to 4.78 times the spreading rate of Nile Blend crude oil. The growth rate of the diameter of the oil slick, was found to be slightly affected by the oil viscosity, in fact increasing oil viscosity decreased the growth rate of the oil slick.

A comparison of the spreading of the Sudanese crude oil with other three crude oils namely Arabic Light crude oil, North Sea crude oil, and Venezuela crude oil was carried using Fay spreading theory for the different speeding stages and the results are shown in Fig. 3 to 5.

Spreading at Gravity-Inertia stage showed a steep increase of the spill diameter at the first 10 seconds for all oils followed by a slower gradual increase (Fig. 3). The spreading rate of Arabic Light, North Sea and Nile Blend were almost same attaing a diameter of 0.50 m in 10 seconds and increased to 1.22 m in 60 seconds. Venezuela crude oil showed a lower spreading rate with a diameter of about 0.39 m at 10 seconds and about 0.95 m at 60 seconds (Fig. 3). A similar trend was also observed in Gravity-Viscosity stage, with the only difference being in the spreading rate. The spreading rate in this stage showed a lower rate. The diameter of oil spill of Arabic light crude oil, North Sea, and Nile Blend was 0.37 m at 10 seconds and increased to 0.57 m at 60 seconds. Venezuela crude oil showed a lower spreading rate with a diameter of 0.31m and 0.48 m at 10 seconds and 60 seconds, respectively.

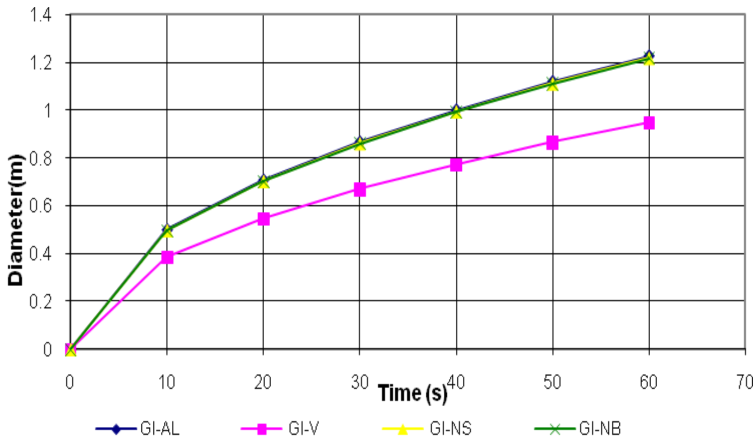

Fig.3. GI spreading stage for different crude oils

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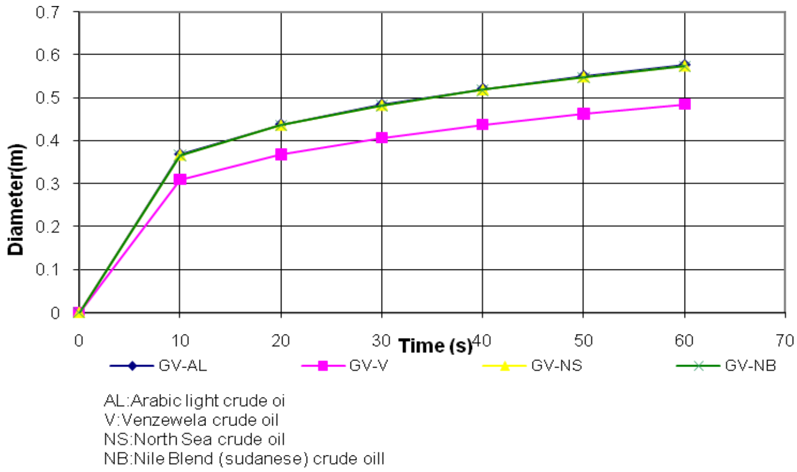

Fig.4. GV spreading stage for different crude oil

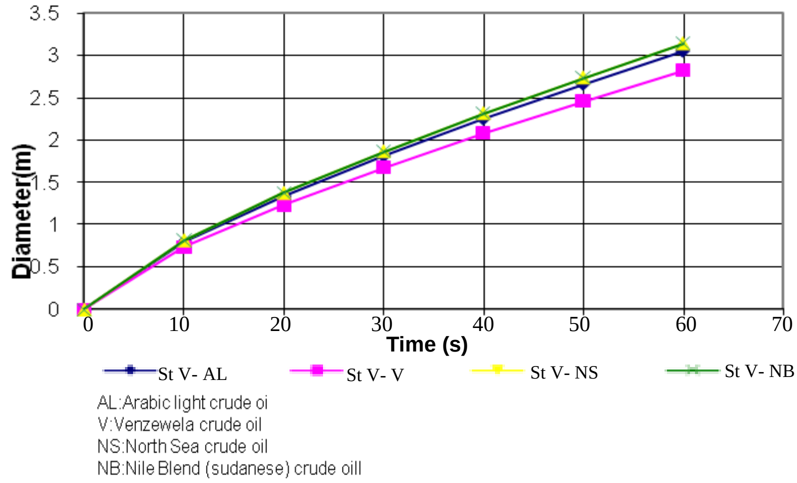

Fig.5. St V spreading stage for different crude oil

A very small difference was noticed in the spreading rate in Surface tension-Viscosity stage, for the Nile Blend (Sudanese crude oil) and North Sea crude oil (Fig. 4). This indicates that these two crude oils have similar chemical properties. The diameters of Nile Blend crude oil spill were 0.818 and 3.136 m at 10 and 60 seconds respectively. Venezuela crude oil showed somewhat lower rate of spreading with diameters of 0.74 and 2.82 m at 10 and 60 seconds, respectively. The diameter of oil spill of Arabic light crude oil under application of Fay theory produced diameters of 0.79 and 3.05 m at 10 and 60 seconds respectively. The comparison of the spreading of these crude oils in surface tension viscosity stage is shown in Fig. 5.

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Conclusions

Spreading of NB was performed. Both experimental measurements and calculation based on Fay's equations were performed. Two conditions of sea surface were considered, calm and under wave action condition. It was found that, Fay equations greatly underestimate slick growth. The spreading of kerosene was found to be larger than that of crude oil .The NB results were compared with other crude oils. Spreading rates of Arabic light, North Sea and Nile Blend crude oils are almost the same. Venezuela crude oil showed a lower spreading rate.

References

Fay, J. A. (1971). Physical processes in the spread of oil on a water surface. In: Proceedings of the Joint conference on prevention and control of oil spills. American Petroleum Institute, pp.463 – 467.

Flores, H., Andreatta, L.G. and Saavedra, I. (1998). Measurements of oil spill spreading in a wave tank using digital image processing, First international conference on oil and hydrocarbon spills, modelling, analysis, and control, WIT press, computational mechanics publication, pp. 164-173.

Garcia, F.R., Mata, L.J. and Flores, H. (1996). A correction to the Mackay oil spreading formulation, in AMOP, pp.2-1627 to 2-1635, Technical Seminar, Vancouver, British, Columbia.

Mackay, D. S., Buist, I., Mascarenhas, R. and Paterson, S. (1980). Oil spill processes and models. Environment Canada, Ottawa, Ontario,

Murry, C. U. and Murry, L.(1973). Adsorption-desorption of some equilibriation of some radionuclides in sediment-freshwater and sediment- seawater system, pp. 105 - 124.

Wu, J. (1975). Wind induced drift currents. *Journal of Fluid Mechan ic*s 68: 49 – 70.

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إنتشار خام النفط السوداني (مزيج النيل) على الساحل السوداني للبحر الأحمر

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مستخلص البحث

تعتبر عملية إنتشار النفط من أهم العمليات خاصة في المراحل الأولية من تحول البقعة النفطية. هدفت هذه الدراسة لمعرفة إنتشار النفط السوداني الخام (مزيج النيل) بإستخدام معادلات Fay مع وضع أربع قوي فيزيائية في الإعتبار شاملة الجاذبية والقصور الذاتي واللزوجة والتوتر السطحي. للتحقق من النتائج، قورنت النتائج المتحصل عليها وفقاً للمعادلة مع بيانات مقاسة من الحقل لإنتشار النفط السوداني الخام والكيروسين علي المياه السطحية للبحر الأحمر. أجريت التجارب في حالتي سكون ونشاط الموج. وجد أن الإنتشار تحت ظروف السكون أقل من ذلكم الذى أُجري تحت تأثير الموج ووجد أيضاً أن إنتشار الكيروسين يساوي 1.12 إلى 4.78 ضعف إنتشار النفط الخام. أظهرت البيانات الحقلية أن نظرية Fay تعطي نتائج أقل من النتائج الحقلية المأخوذة تحت تأثير الموج. قورنت نتائج الإنتشار للنفط السوداني الخام مع أنواع نفط أخرى، شملت النفط العربي الخفيف ونفط بحر الشمال والنفط الفنزويلي بإستخدام معادلة Fay وجد أن معدل إنتشار خام مزيج النيل وبحر الشمال والعربي الخفيف شبه متساوي بينما أظهرالخام الفنزويلي معدل إنتشار أقل.

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