SUST Journal of Engineering and Computer Science (JECS), Vol. 15, No. 2, 2014

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

Masoud Gamiel Ahmed[1], Bashier M. El hassan[2] and K. E.Bashar[3]

[1]Civil Engineering Department, Sudan University of Science and Technology, Sudan
[2]Chemical Engineering Department, University of Khartoum, Sudan
[3]Civil Engineering Department, Omdurman Islamic University, Sudan

Received: 04.11.2013
Accepted: 03.12.2013

***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 Nile Blend 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 underestimates slick growth. The spreading rate of kerosene is 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 show that spreading rate of Arabic light, North Sea and Nile Blend are all most the same. Venezuela crude oil showed a lower spreading rate.

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

المستلخص - تعتبر عملية انتشار النفط من أهم العمليات خاصة في المراحل الأولية من تحول البقعة النفطية. لدراسة انتشار النفط السوداني الخام (مزيج النيل) تم استخدام معادلات Fay مع وضع أربع قوي فيزيائية في الأعتبار وهي الجاذبية، القصور الذاتي و اللزوجة والتوتر السطحي. للتحقق من هذه النتائج تمت مقارنة النتائج المحسوبة من المعادلة مع بيانات مقاسة من الحقل لأنتشارالنفط السوداني الخام والكيروسين علي المياه السطحية للبحر الأحمر. أجريت هذه التجارب في حالتي سكون ونشاط الموج. وجد أن الانتشار للأحوال الساكنة اقل من تلك التي أجريت تحت تأثير الموج ووجد كذلك أن انتشار الكيروسين يساوي 1.12 إلى 4.78 ضعف انتشار النفط الخام. أظهرت البيانات الحقلية أن نظرية Fay تعطي نتائج اقل من النتائج الحقلية في حالة التجارب المأخوذة تحت تأثير الموج. تمت مقارنة نتائج الأنتشار للنفط السوداني الخام مع ثلاثة انواع أخري من النفط الخام وهي النفط العربي الخفيف ونفط بحر الشمال والنفط الفنزويلي باستخدام معادلة Fay ووجد أن معدل الأنتشار لخام مزيج النيل و بحر الشمال و العربي الخفيف شبه متساوي بينما أظهرالخام الفنزويلي معدل انتشار أقل.

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 [1]. Three phases are 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. In the present simulation, Fay's spreading theory [2] is used, and the results are compared to data collected from the field measurement. The equations corresponding to the Fay spread theory are:

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

Gravity-Viscous:

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

Surface Tension-Viscous:

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

where:

$\Delta = 1 - \rho_o / \rho_w$ (4)

ρ_o and ρ_w: oil and water density (kg/m^3)

σ: spreading coefficient

v_w: Kinematics viscosity of water (m^2/s)

V: Volume of oil (m^3)

g: acceleration gravity (m/s^2)

t: time (s)

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

METHODOLOGY

The testing procedures is as follow: 250 ml of the sample and kerosene spilled, then allowing the oil and kerosene to follow freely on the water surface of the Red Sea at strip I (dock yard) near faculty of marine science, Red Sea University, Port Sudan. The diameter of oil spilled is measured against time for each test. The measurements of the diameter were conducted at every ten seconds, in a total time of 60 seconds**.** The tests were conducted under two different weather conditions that is under wave action and in calm weather. A total of four tests were performed.

RESULTS

After a period of time in which the slick accelerates, the mass center of the slick remains moving with the water velocity. An oil slick usually drifts in the same direction as the wind. The direction of the oil slick movement, as influenced by the wind, should be taken as that of the wind [3].

The speed of the wind-driven component of the slick movement is generally considered to be about 3 percent of the wind speed [4]. 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 uninfluenced by wind or tide, spilt oil will spread to form a homogeneous circular patch quite quickly. The rate of spreading is estimated using the following assumptions:

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

Based on these assumptions the balance of gravity, surface tension, viscous and inertial forces for a circular oil slick is applied to the oil spill. The results obtained by applying Fays spreading formulae for crude oil and kerosene are 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 as 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 shows 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 is 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 is larger than that predicted by Fay's spreading theory. This is in agreement with field data obtained by Flores [5]. 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 indicate that more realistic results are achieved in the gravity-viscous and gravity-inertia phases when assumption are made that, the weather is calm that is water uninfluenced by wind or tide. Oil spreads is larger for tests done under wave action, so the model is less reliable to reflect the behavior of the crude oil under wave action (Figure 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 a very short time.

KEROSINE

Tests No. 3 and 4 are applied to study 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 6.8m at 10 and 60seconds. The spreading is slower when tests are applied under calm condition. Kerosene spill reaches an equivalent diameter of 0.41 and 1.22m at 10 and 60seconds respectively under calm condition situation.

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

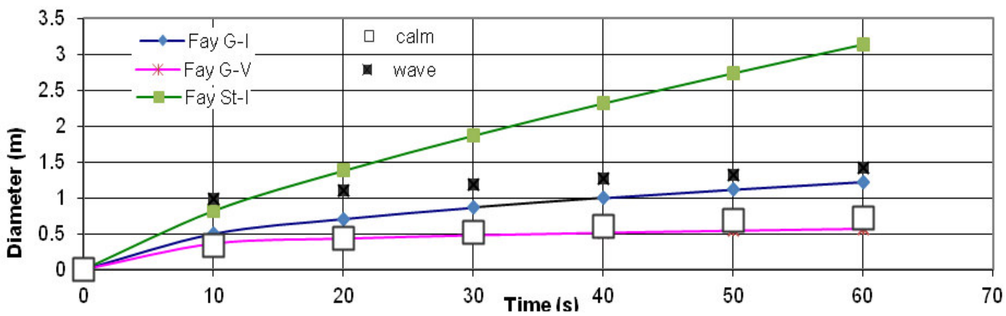

Figure 1: Nile Blend crude oil vs. spreading theory.

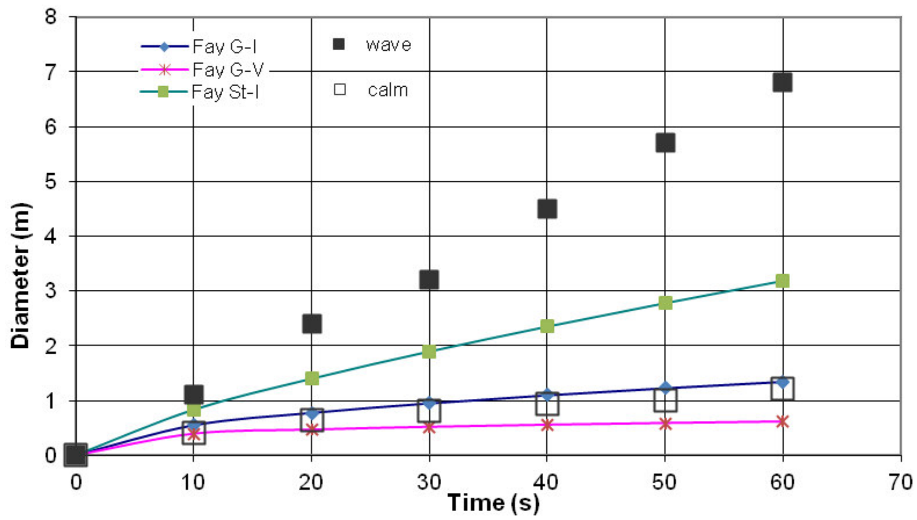

Figure 2: Kerosine experimental results vs. Fay spreading theory

Experimental results from the Gulf Region indicated that more realistic results are achieved in the gravity–viscous phase when wind parameters are considered, when the assumption is made 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 [6] for example starts with the Fay Gravity-Viscous and surface tension–viscous formulation to obtain a thick and thin slick equation. Garicia [7], 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 (Gravity-Inertia, Gravity-Viscosity), 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 does not stop as it just entered the surface tension–viscous regime with appearance of fine slick which spreads in the diagonal direction.

Similar the previous test, Field data show that Fay's theory greatly underestimates 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 describe the spreading of an instantaneous spill in calm waters. For the case of the calm condition, it is very clear that Fays work explains this phenomenon properly.

On comparing the final width of the oil slick spreading with kerosene spreading, the spreading of kerosene is 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.

COMPARISON WITH OTHER CRUDE OILS

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 Figures 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 untill the end of the time of the experiment. The spreading rate of Arabic light, North Sea and Nile Blend are all most the same. The diameter was 0.50 m at 10 seconds and increased to 1.22 m at 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 60seconds (Figure 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 somewhat 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.

The Gravity-Viscosity spreading stage vs. time for these four crude oils is shown in Figure 4. 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, this because they are very similar in their chemical properties and so in spreading coefficient. The diameter of Nile Blend crude oil spill is 0.818 and 3.136m at 10 and 60seconds respectively. Venezuela crude oil showed somewhat lower rate of spreading, the diameters were 0.74 and 2.82m at 10 and 60 seconds respectively. The diameter of oil spill of Arabic light crude oil under application of Fay theory showed diameters of 0.79 and 3.05m at 10 and 60 seconds respectively. The comparison of the spreading of these crude oils in surface tension viscosity stage is shown in Figure 5.

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 is found to be larger than that of crude oil . The NB results were compared with other crude oils. Spreading rate of Arabic light, North Sea and Nile Blend crude oils are all most the same. Venezuela crude oil showed a lower spreading rate.

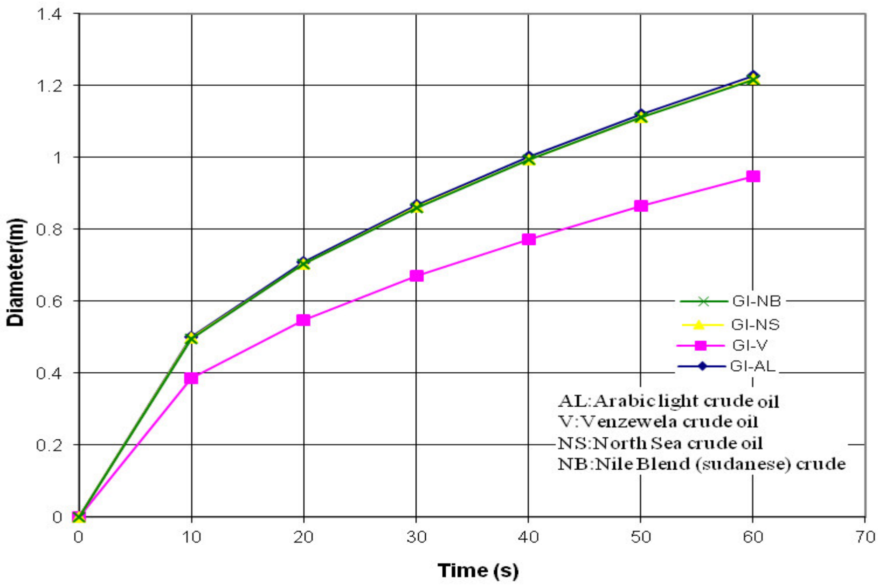

Figure 3: GI spreading stage for different crude oils,

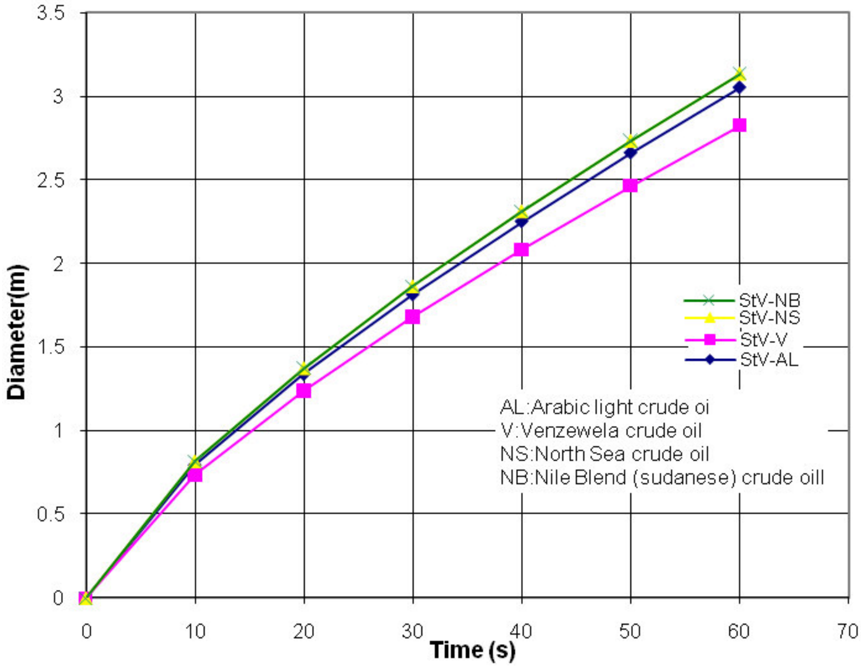

Figure 5: StV spreading stage for different crude oil.

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