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2-Dimensional Spread-Dispersion Rate Predictive Models For Oil Spills In Atlas Cove Jetty Water Environment

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***Abstract:** The search for the development of models to predict the dispersion rate of oil spills fate mitigation is very crucial in addressing the degree of environmental impacts globally. Apapa Lagoon Atlas Cove Jetty is marketers terminal discharge point for upstream products distribution and usually faced the challenges of oil spills contamination. These challenges include lack of proper predictive dispersion rate model to ascertain extent of impacts relative to the characteristic features of the jetty water medium and assessment of the subsurface spread mitigation rate for remedial measures. In order to tackle these challenges, macro-dispersive stochastic and experimental approach are adopted to propose predictive dispersion rate models in two dimensions as a function of hydrodynamic wind velocity, products quantity and associated physical property of product and water medium. Proposed models were simulated using MATLAB (R2007) computational techniques and results obtained demonstrated the dependency of dispersion rate relative to exposure time, quantity spilled, spread extent and hydrodynamic flow regime. Dispersion coefficient was also appraised and found to be correlated well with spill exposure time, water flow characteristics and quantity of product spills. Algorithmic flow chart for the simulation of the proposed predictive models defining various variables is developed in this work.*

***Keywords:** Oil spills, Predictive, Dispersion Rate, Water, Flow Regime*

I. INTRODUCTION

A. STUDY LOCATION

Apapa Atlas Cove Jetty is 14 kilometers long upstream Petroleum product distribution network route that located and bounded on both land and offshore Lagos lagoon coastal waters (figure 1). Due to several ligation challenges resulting from accidental products oil spills discharge into the water, it was necessary to propose predictive dispersion rate model to ascertain the magnitude of impact and extent of subsurface spread to the environment in cognize to the flow regime.

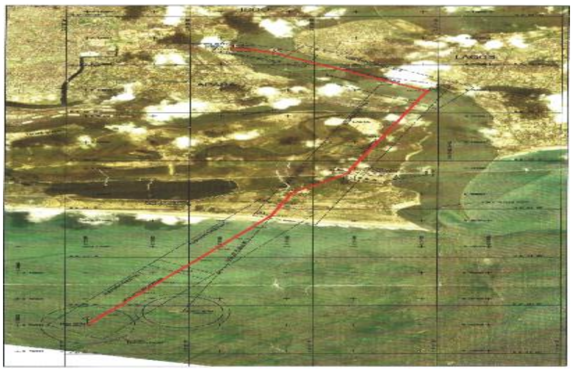


Figure 1.2: Map showing Atlas Cove Jetty 14 Kilometers Pipeline

The designated bearings and distance describing the network route essential for this work in developing stochastic macro-dispersive models of product spills discharged are presented in Table 1

FROM	BEARING	DISTANCE	TO
Pt1	33^{O} 15" 07"	4967.704	Pt2
Pt2	19^{O} 48" 04"	968.248	Pt3
Pt3	48^{O} 13" 27"	1068.716	Pt4
Pt4	20^{O} 31" 07"	3392.204	Pt5
Pt5	302^{O} 37" 36"	2748.736	Pt6
Pt6	286^{O} 07" 51"	637.082	Pt7

Table 1.1: Designated bearings of Distances of the Product Pipeline Network

B. PURPOSE OF THE WORK

Numerous research works have been reported on the development of suitable predictive models to appraise oil spill fate once discharge into water medium (Abowei, 1991). Dispersive spreading is the utmost eminent initial weathering process observed practically once product spills are discharged into environments. The dispersive – spreading phenomena are a function of product spill type (density, viscosity, surface tension, characteristic water medium and off course the soil type. In order to achieve qualitative modeling, the author adopted the following systematic approach as presented below. . The statistical input rate eventually induced researchers and engineers like Abowei et al [ ] who distinguishingly looked at the Engineering and scientific aspects of oil spill fate and trajectory once discharged into the environments.

Oil spilled into the environment undergoes a number of physical and chemical changes collectively known as dispersive weathering processes as presented in figure 1.1

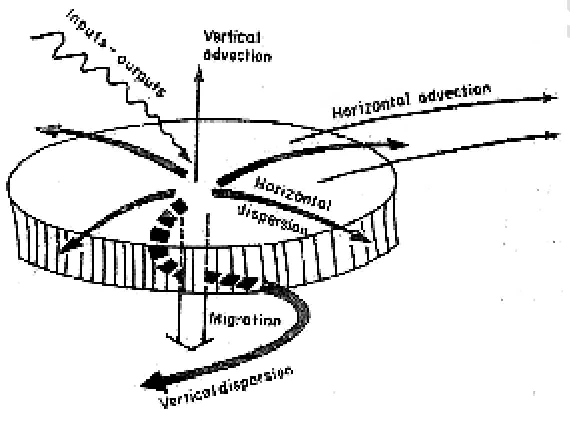


Figure 2: Diagrammatic representation of the relationship between different dispersive processes of spills that requires spill dispersion rate

The consequences of the oil spills discharges into the environment leads to the destruction of aquatic and terrestrial organisms, and including recreational activities of the lithoral communities. Hence it is a justifiable purpose on the aspect of OANDO to model the dispersive weathering processes of oil spills aimed at achieving a control measure for known extent of the dispersion rate in order forestall litigation problems associated with discharge of petroleum products. Therefore the purpose of this work is to develop stochastic macro-dispersive dimensional predictive models with associated coefficients as a function of Lagos lagoon hydrodynamic factors in simulating the fate of oando petroleum products spills into isotropic and anisotropic stagnant water medium.

II. MATERIALS AND METHODS

Fibow adopted a systematic approach aimed at achieving ± 1% tolerance error in all aspect of the modeling. The work entails both experimental and stochastic otherwise called deterministic methods for ergodicity requirements in macro-dispersivity modeling of product spills once discharged into environments. In order to actualize this work, a map-based advection-dispersion modeling was integrated into the developed models for spatial decision support of the control strategy. The entire materials and method adopted by Fibow to achieve the objectives and scope of this study are represented in this section.

A. THEORETICAL FORMULATION

MODELING OIL SPILLS DISPERSIVE – SPREAD IN SUBMARINE PIPELINES

In assessing the environmental impacts of products spill, it is mandatory to develop predictive models for the simulation of dispersive – spread characteristic of oil spills fate. Hence product spill modeling equations are proposed for the simulation of dispersive – spread characteristics in the environments.

a. DISPERSIVE – SPREAD DIMENSION

Figure 2.12 represent a typical products spill submarine pipeline with a case of sudden rupture.

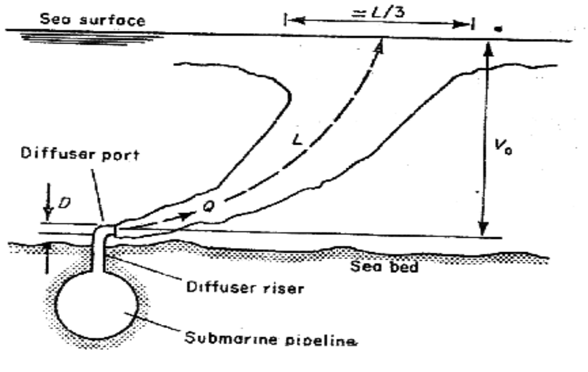


Figure 2.12 Dispersion of spills from a submarine pipeline. Source: Abowei, (1982, 1988, 2007) [ ]

Once a quantity of product spill is discharged from a submarine pipeline, free surface energy occurs between the product spills and the water medium. Admason (1967)[1] represented this energy change as:

$$\partial G = \left(\frac{\partial G}{\partial A}\right)\partial A'_{A'} + \left(\frac{\partial G}{\partial A'_{A'B'}}\right)dA'_{A'B'} + \left(\frac{\partial G}{\partial A'_{B'}}\right)dA'_{B'} \quad \ldots\ldots \ (1)$$

The substrate layers of water A' and products spills B' are dimensionally invoked and have been established by Abowei; 1991 [1] as follows:

$$dA'_B = -dA'_A = dA'_{AB} \quad \ldots\ldots\ldots\ldots\ (2)$$

$$\partial G \big/ \partial A'_{A'} = \sigma_w \quad \ldots\ldots\ldots\ldots\ldots\ (3)$$

$$K_x\left(B'\big/A'\right) = \sigma_w - \sigma_p - \sigma_{wp} \quad \ldots\ldots\ldots\ldots\ (4)$$

$$\sigma_{wp} = \sigma_w + \sigma_p + \varphi\left(\sigma_w \sigma_p\right)^{1/2} \quad \ldots\ldots\ (5)$$

Equation (1) through (5) is simplified resulting into spreading coefficient thus;

$$K_x\left(B'\big/A'\right) = -2\sigma_p - \varphi\left(\sigma_w \sigma_p\right)^{1/2} \quad \ldots\ldots\ (6)$$

Product Spill Monolayer Spreading Rate Modeling Product Monolayer spread rate as a function of physical properties of the product is obtained from the time dependent boundary layer equations for induced natural flow as:

$$\frac{\partial u}{\partial t} + U\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} = \frac{\mu}{\rho}\frac{\partial^2 u}{\partial z^2} \quad \ldots\ldots\ldots\ldots\ (7)$$

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial z} = 0 \quad \ldots\ldots\ldots\ldots\ (8)$$

Equations (8) and (9) are solved by invoking the following dimensional boundary conditions, Abowei; (1991) [2].

$$\frac{\partial h}{\partial t} + U_o\frac{\partial h}{\partial x} = 0 \quad \ldots\ldots\ldots\ldots\ (9)$$

$$K_x\left(B'\big/A'\right)\partial\sigma\big/\partial x + \tau_p = 0 \quad \ldots\ldots\ldots\ldots\ (10)$$

$$\alpha = \frac{\sigma_w - \left(\sigma_p + \sigma_{pw}\right)}{K_x\left(B'\big/A'\right)} \quad \ldots\ldots\ldots\ldots\ (11)$$

Where $\sigma \le \sigma^x \le \tau$

$h = 0, \quad \sigma^x = 1 \qquad at\, x = L$

$h = \infty, \quad \sigma^x \to 0 \qquad at\, x = 0$

$w = 0 \qquad at\, Z = 0$

$u = 0 \qquad at\, Z = \infty$

$$U = U_p\left(\frac{\mu_w}{\rho_w}\right)^{1/2} \quad \frac{\partial u_w}{\partial z} = \left(\frac{\mu_w}{\sigma}\right)^{1/2}\frac{\tau_p}{\mu} \qquad at\, z = 0$$

$$\left(\frac{U_w}{\rho_w}\right)^{1/2}\frac{\partial u}{\partial z} = \left(\frac{\mu_w}{\rho_w}\right)^{1/2}\frac{K_x}{\mu}\frac{d\mu}{dx} \qquad at\, Z = 0 \quad \ldots\ldots\ (14)$$

Solution to equations in (7 – 8) using the boundary conditions in equations (9 – 14) and simultaneously invoking the dimensional analysis $B = \left(\mu_w\big/\rho_w\right)^{1/2}\dfrac{K_x}{\mu_w}$

results in:

$$L = X'\left[\frac{K_x}{\mu_p}\right]^{1/4} t^{3/4} \quad \ldots\ldots\ldots\ldots\ (15)$$

The spreading rate coefficient can also be obtained from adhesion and cohesion forces of spills and water columns. Thus:

$$W_{A'B'} = \sigma_w + \sigma_p - \sigma_{wp} \quad \ldots\ldots\ldots\ldots\ldots\ (16)$$

and

$$W_{B'B'} = 2\sigma_p \quad \ldots\ldots\ldots\ldots\ldots\ (17)$$

Where

$W_{A'B'}$ = Work necessary to separate product spills and water adhesion.

$W_{B'B'}$ = Work necessary to assemble product spill cohesion.

From equation (6) it is true that:

$$K_x\left(B'\big/A'\right) = W_{A'B'} - W_{B'B'} \quad \ldots\ldots\ldots\ (18)$$

Hence equation (5) and (16) results into:

$$W_{A'B'} = \sigma_w + \sigma_p - \left(\sigma_w \sigma_p - \varphi\left(\sigma_w \sigma_p\right)^{1/2}\right) \quad \ldots\ldots\ (19)$$

Equation (19) with further simplification gives:

$$W_{A'B'} = \varphi\left(\sigma_w \sigma_p\right)^{1/2} \quad \ldots\ldots\ldots\ (20)$$

While φ is a constant to be extrapolated.

Adopting the works of (Abowei 1991) [2], the constant φ is evaluated as

$$\varphi = 0.608 - 25.309\sigma_p \quad \ldots\ldots\ldots\ldots\ldots\ (21)$$

Hence, spread coefficient in terms of surface tension is obtained by substituting equation (21) in (6) resulting in:

$$K_x\left(B'\big/A'\right) = \left[0.608 + 25.309\,\sigma_p\right]\left[\sigma_w \sigma_p\right]^{1/2} - 2\sigma_p \quad \ldots.\ (22)$$

In the same vein, in terms of density-viscosity relationship, the modeling equation for coefficient of spread of product spills is the following:

$$K_x\left(B'\big/A'\right) = 1.284 + 0.04978\left(\frac{\mu_p\rho_p}{\mu_w\rho_w}\right)\left[\sigma_w \sigma_p\right]^{1/2} - 2\sigma_p \quad \ldots..\ (23)$$

where

$$\varphi = 1.284 + 0.04978\left(\frac{\mu_p\rho_p}{\mu_w\rho_w}\right) \quad \ldots\ldots\ldots\ (24)$$

Similarly, a predictive model for simulating adhesion force $\left(W_{A'B}\right)$ is obtained by substituting equation (21) into (20) and (24) into (20) for surface tension and density-viscosity relationships respectively:

$$W_{A'B'} = \left[0.608 + 25.309\sigma_p\right]\left[\sigma_w \sigma_p\right]^{1/2} \quad \ldots.\ (25)$$

and

$$W_{A'B'} = \left[1.284 + 0.04978\left(\frac{\mu_p\sigma_p}{\mu_w\rho_w}\right)\right]\left[\sigma_w \sigma_w\right]^{1/2} \quad \ldots.\ (26)$$

b. MODELING OF DISPERSIVE – SPREADING RATE

The results of the experiments were correlated using statistical regression analysis techniques to give a practicable predictive spreading rate model with no perturbation thus:

$$L(\text{Predict}) = \left[11.23 - 1.07\left(\frac{\mu_p}{\mu_w}\right) + 0.333V_p\right]t^{0.87} \quad \ldots.\ (27)$$

Equation (27) was re-modeled as in the works of Abowei (1991) [2] to include the effect of water product spill density, spreading coefficient and volume or quantity discharge to give:

$$L=\left[11.23-1.07\left[\frac{K_x\left(B'/A'\right)\rho_w+2\sigma_p\rho_w-1.204\rho_w\left[\sigma_w\sigma_p\right]^{1/2}}{0.04978\rho_p\left[\sigma_w\sigma_p\right]^{1/2}}\right]t+0.333V_p\right]t^{0.87} \quad \ldots\ldots\ (28)$$

The theoretically developed spreading rate model equation (15) is therefore modified resulting in:

$$L(theo)=\frac{K_x\left(B'/A'\right)}{(0.644)^2\,\mu_p\rho_p\,J_p^3} \quad \ldots\ldots\ldots\ (29)$$

where

$$J_p=0.87\left(11.23-1.07\left(\frac{\mu_p}{\mu_w}\right)+0.333V_p\right) \quad \ldots\ldots\ (30)$$

Similarly, the dispersive – spread model for wind induced environment with known discharge rate of product spill as characteristic of Lagos Lagoon is obtained by adopting multiplier dimensional factor V_j to the models developed with no perturbation as in equation (27) to (30) to give:

$$L=QV_j\left[11.23-1.07\left(\frac{\mu_p}{\mu_w}\right)+0.333\,V_p\right]t^{0.87} \quad ..\ (31)$$

c. *DISPERSIVE – CONCENTRATION MODELS FOR WATER*

ONE DIMENSIONAL APPROACH

The dispersive – concentration distribution of products spill is developed by Abowei (1991) for wind induced flow regimes; (wind perturbation) as follows:

$$C_{\max}(x,y,t)=\frac{M_p}{4\pi\left[Ak_c\,k_y\right]^{1/2}t} \quad \ldots\ldots\ (32)$$

Now c vonsidering $M_p=V_p\,\rho_p$ and $(k_c\,k_y)=Dd_z$

Hence equation (32) results in

$$C_{\max}(x,y,t)=\frac{\rho_p V_p}{\left(4\pi\,ADd_z\right)^{1/2}t} \quad \ldots\ldots\ldots\ (33)$$

Interestingly from the field works of the study, the dispersion coefficient for wind dominated environment results in:

$$Dd_z=0.17k_1'h_2U_2\left[\frac{\mu_p}{2\rho_pU_2b}\right]^{1/10} \quad \ldots\ldots\ (34)$$

where

$U_2 \quad = 2U\sin\phi \quad \ldots\ldots\ldots..\ (35)$

$b \quad \Rightarrow R=\left(y^2+x^2\right)^{1/2} \quad \ldots\ldots\ldots\ (36)$

Combining equations (33) and (34) results in:

…………. (37)

$$C_{\max}(x,y,t)\Rightarrow\frac{\rho_pV_p}{4\pi tA^{1/2}\left[0.17k_1'h_2U_2\left[\frac{\mu_p}{2\rho_pU_2b}\right]^{1/10}\right]^{1/2}}$$

Now invoking equations (35) and (36) in (37) results in:

…… (38)

$$C_{\max}\frac{\rho_pV_p}{4\pi tA^{1/2}\left[0.34k_1'h_2U_1\sin\phi\left[\frac{\mu_p}{4\rho_pU_1\left(x^2+y^2\right)^{1/2}}\right]^{1/10}\right]^{1/2}}$$

where

$$h_2=\left[0.37\left(x^2+y^2\right)\right]/\left(y\left(0.1+x\right)-xy-1\right) \quad \ldots.\ (39)$$

$$k_1\approx1.0 \quad \ldots\ldots\ldots..\ (40)$$

$$\phi=\tan^{-1}\left(y/x\right) \quad \ldots\ldots\ldots\ldots.\ (41)$$

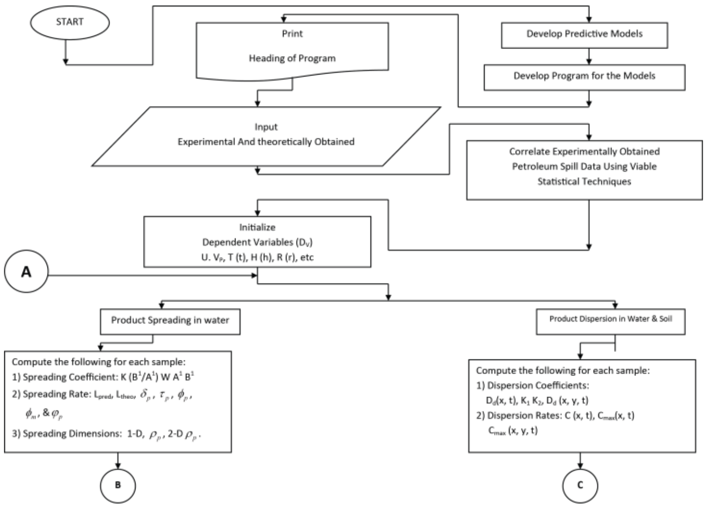
$U=$ Velocity of flow (wind velocity)

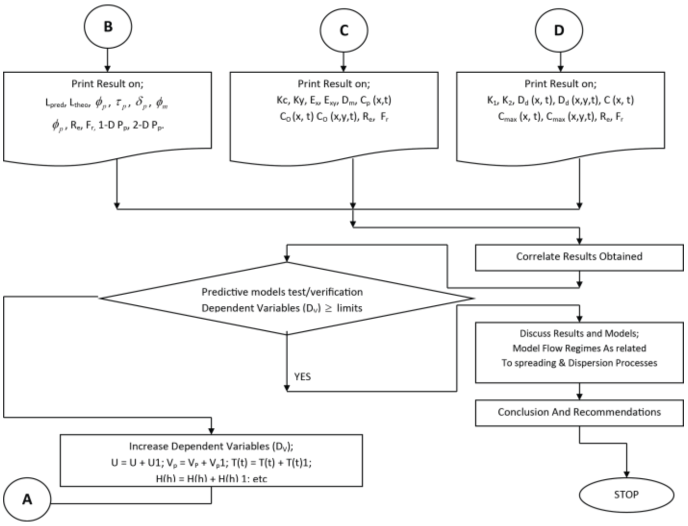
$$=W_R=\left(x^2+y^2\right)^{1/2} \quad \ldots\ldots\ldots\ (42)$$

d. *COMPUTATIONAL MODELING PROCEDURE*

Predictive empirical models were developed from the experimentally obtained data to simulate the dispersive spreading rate of the various products on placid water environment. The lead edge or extent of dispersive – spread (L(x)) was correlated as a function of product sample viscosity ratio (μ_p/μ_w) and the quantity of the product spilled using deterministic least square statistical modeling techniques. The correlated numerical equations were checked by computing the correlation coefficient using product – moment formula for linear correlation coefficient.

The Correlated dispersive – spread rate ($\mu_{\exp}$) model obtained was integrated giving the velocity of dispersive – spread at no perturbation (Uexp). Velocity (Uexp) was substituted into the theoretically developed equations resulting in a generalized predictive model of products spill dispersive – spread as a function of physical properties $\left(\rho_p,\mu_p,\sigma_p\right)$ and quantity (V_P) including dispersive – spread coefficient $\left(K_x\,B'/A'\right)$. Products spill boundary layer $\left(\sigma_p\right)$ shear stress $\left(\tau_p\right)$ and flow regime dimensional characterization models for control mechanism was inculcated into the work.





B. EXPERIMENTAL WORKS

APPARATUS

The following materials/Apparatus were used to obtain the dispersive – spread modeling data.

- ✓ Laboratory open water channel measuring 5.0m length, 0.08m width and 0.14m depth.
- ✓ Silk powder (Moisture free)
- ✓ Oando products (PMS, DPK, AGO)
- ✓ Lagos Lagoon waters
- ✓ Measuring tape mounted on the channel
- ✓ Stopwatch
- ✓ Hydrometer
- ✓ Wilhelmg - type surface tension meter
- ✓ Cannon – Fenske type viscosimeter
- ✓ Thermometer
- ✓ Detergent (Soap)
- ✓ Rags
- ✓ Weir/dam/Funnel
- ✓ Burret/Measuring Cylinders.

EXPERIMENTAL PROCEDURE

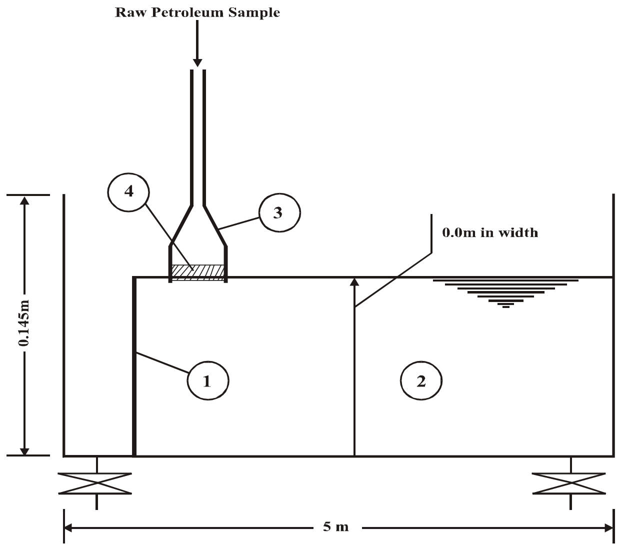
The materials/apparatus were designated and assembled for the study of the dispersive-spreading rate model at no turbulent perturbation on the water surface as shown in figure 2.2(a, b). Health safety and environment issues were addressed prior to the commencement of the work as presented in figure 2.3(a, b).

Figure 2.2a: Setting up the open water Acrylic Channel

Figure 2.2b: Point source spills dispersive-spread rate in water phase PMS

The dam/Funnel containing the predetermined quantity of Oando products sample was gently withdrawn to enable the Oando product spills to spread dispersively over the placid water surface. The dispersive – spread rate of each Oando product samples were determined for each quantity using a stopwatch and measuring tape mounted on the channel meter as shown in figure 2.4 (a – d).

To facilitate recognition of the leading edge of the product spills, a small amount of moisture – free powder was first sprinkled on the water surfaces. The powder sprinkled was infinitesimally small otherwise it will reduce the product spills dispersive – spreading rate. The study was repeated several times in order to ascertain good results. Diagrammatic description of the experimental facility is presented in figure 2.5.



(1) Weir (2) Rectangular Water Channel (3) Funnel (Dam) (4) Raw Nigerian Petroleum Sample

Figure 2.5: Experimental Apparatus and Setup for the Determination of Spreading Rate of Petroleum on Calm Water Surface

The product sample types obtained from Oando is presented in figure 2.6. Typically, physical properties of the products samples obtained from Oando were measured at average temperatures of 29 – 30 – 35^{O}C with the aim of determining their effect on the dispersive – spread rate in the environment as shown in figure 2.7 (a – e).

The surface tension was measured with the aid of a shimadzu ST-1 Wilhelm – type surface tension meter, the viscosities were measured using cannon – fenske Viscosimeter, the density of each product sample was measured using a hydrometer and the quantity/volume per test was determined using measuring cylinders. The physical properties of the product samples obtained from these experiments are presented in table 2.4.

PRODUCT SAMPLE	DENSITY (ρ_p) g/m^3	VISCOSITY (μ_p) (kg/m.hr.)	Surface Tension σ_p (N/m)
PMS	0.744	8.95	0.0276
DPK	0.821	9.88	0.0305
AGO	0.865	10.49	0.0322
SALT WATER (Lagos Lagoon)	1.024	4.12	0.07275
FRESH WATER	0.9943	4.10	0.07270

Table 2.4: Experimentally determined physical properties of product samples & water

III. RESULTS AND DISCUSSIONS

Numerical simulations were made by variable substitution of the Oando products samples (PMS, AGO & DPK) properties as in Tables 1.1 and 1.2 using the developed stochastic and deterministic macro-dispersive models contained in sections 2.2 of this study for both water and soil phases. The aim was to ascertain the stability of the idealized models for prediction of product spills in case of discharge into water and soil environments as typical of Oando Atlas Cove jetty Pipeline project. The results obtained showed authenticity of the models for numerical simulations in case of emergency products spills discharges.

A. DISPERSION RATE IN WATER – STOCHARSTIC

Three multidimensional considerations were focused namely: GIS Map-based advection – dispersion, spread – dispersive modeling at no perturbation and wind induced dominant water phases, and dispersive – concentration predictive modeling with turbulent water phase as characteristic of Lagos lagoon.

a. GIS MAP /TRAJECTORY PROFILES – BASED ADVECTION – DISPASSION RATE MODELING

As shown in figures 2.5(a – c), product spills for the samples were allowed to spill on the Lagoon water surface and standard GIS analyzing functionalities were performed to evaluate the dispersive rate predictive modeling decision support. The results are presented in figure 3 .1(a – d). interestingly the spill flow direction is well represented in Figure 3.1a.

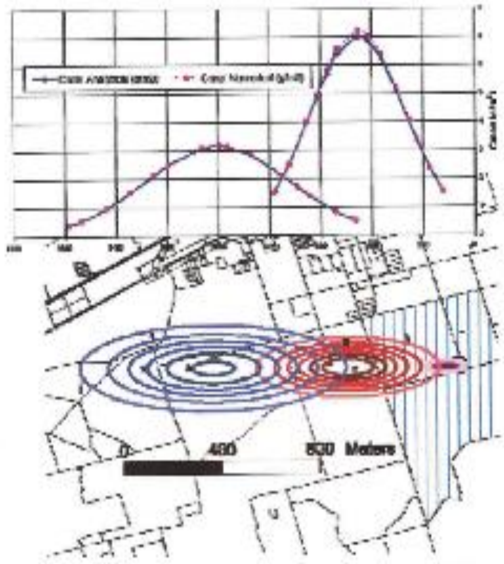


Figure 3.1b: Stochastic trajectory GIS contouring profile of Oando products spill

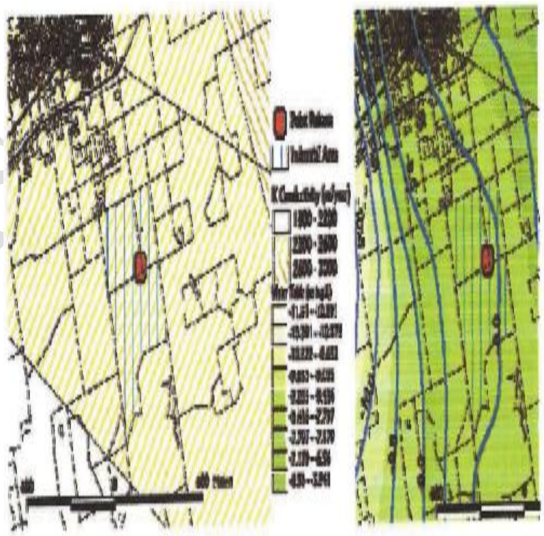


Figure 3.1b: Hydraulic Conductivity (left) and water table (right) maps used for the sample calculation

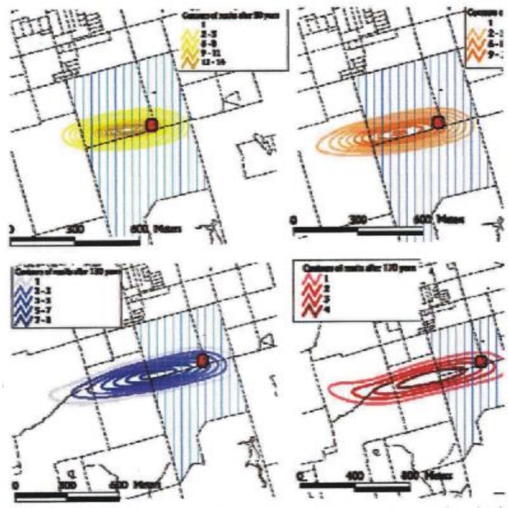


Figure 3.1c: Solution of the sample field calculation contour labels refer to concentration values of models

The results showed limitless convergence stability of spatial discretization in dispersive – concentration distribution as a time frame and distance bearing points functionalities.

Similarly a grid – based GIS platform technique was administered to ascertain surface dispersion for primitive patches plumes formation of the products sample. The results of the grid – based dispersive characteristics are presented in figure 3.2.

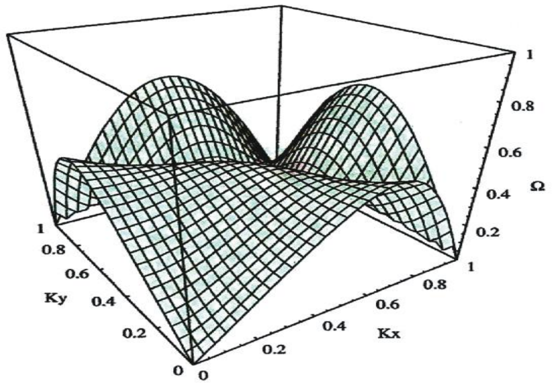


Figure 3.2: Dispersion surface for the primitive equation scheme on grid patch of Oando's product samples – stochastic

The undulating feature of the grid scheme portrays the wave characteristics leading to formation of patches and plumes. Particularly, product spills occur in wave passes of turbulent water environment.

b. SPREAD – DISPERSIVE RATE MODELING

Spread – dispersion rate status is a function of spreading coefficient, adhesion ($WA'B'$) and cohesion ($WB'B'$) forces of product spills - water tension as evidently shown in equations (54) - (56) in this report. Theoretical and experimental results for the PMS, AGO and DPK Oando products species are presented in Table 3.5.

Product Sample	$K_X\, B'/A'$ N/M	$K_X\, B'/A'$ N/M	$W\, A'/B'$ N/M	$W\, A'/B'$ N/M	$WB'B$ N/M	$WB'B$ N/M	Constant Ψ
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	[-]
PMS	0.0032	0.0033	0.0584	0.0585	0.0552	0.0552	1.306
DPM	0.0035	0.0034	0.0650	0.0649	0.0614	0.0615	1.379
AGO	0.0042	0.0044	0.0687	0.0688	0.0645	0.0644	1.422

Table 3.5: Results of Spread – Dispersive Coefficient, Adhesion and cohesion forces

Simulated results obtained from both numerical models and experiments showed that spread – dispersive coefficient depends on products properties notably surface tension and the aquatic medium. Conversely results (Table 3.5) of adhesion and cohesion forces of products spill and Lagos lagoon water depends on the surface tension forces. Adhesion and cohesion forces are the binding or clicking/sticking forces to water medium. In the same vein, the predictive models developed in this report for adhesion, cohesion and spread dispersive coefficients are highly sensitive and significant as both predictive and experiential results are quit compatible with minimum error percentage differential.

Similarly results of spread – dispersive rate obtained from the experimental works at on perturbation for the Oando product samples (PMS, DPK and AGO) are presented in figures 3.3(a-d).

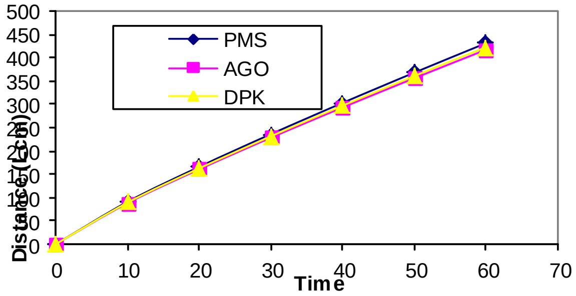


Figure 3.3a: Viscocity Effect of Spread Dispersive Rate for Product Spills in Lagoon Water

The relationship between the extent of spread – dispersive rate of product samples of different volumes and time was determined. Very significant observation deduced from these results was that the spread – dispersive rate increases with increase in the volume/quantity of the product sample at constant physical properties and more remarkable with less viscous samples. Therefore modeling equations for prediction of product samples discharged into lagoon water environment were developed from the experimental results as:

$$\text{PMS: } Lcm = \left[8.906 + 0.333\,V_p\right] t^{0.87} \qquad ..\ (53)$$

$$\text{AGO: } Lcm = \left[8.684 + 0.333 V_p\right] t^{0.87} \qquad \dots\ (54)$$

$$\text{DPK: } Lcm = \left[8.832 + 0.333 V_p\right] t^{0.87} \qquad \dots\ (55)$$

In order to predict the spread – dispersive model for wind induced environment, we invoked the multiplier dimensional factor QV_j to equations (53) – (55) resulting to:

$$\text{PMS: } Lcm = QV_j\left[8.906 + 0.333\,V_p\right] t^{0.87} \qquad (56)$$

$$\text{AGO: } Lcm = QV_j\left[8.684 + 0.333\,V_p\right] t^{0.87} \qquad (57)$$

$$\text{DPK: } Lcm = QV_j\left[8.832 + 0.333\,V_p\right] t^{0.87} \qquad (58)$$

The results obtained from the computations of the developed equations as presented above compared very well with those of the experimental having correlation coefficients of (0.999999) conforming the reasonable degree of accuracy.

c. CONCENTRATION DISPERSIVE RATE MODELING OF PRODUCT SPILLS

The sensitivities of the line source product concentration dispersive rate is found to depend on source geometry, dispersion coefficient, product spill physical properties and the associated water medium characteristics. At this juncture it is worthy to highlight the dependent functionalities of dispersion coefficient as it affects products spill discharges into aquatic water medium. From equations (34) – (42), it was qualitatively established that dispersion coefficient depends on kinematics viscosity $\left(\mu_p / \rho_p\right)$ and the extent of spread – dispersive rate.

For the purpose of the products spill, the following predictive model is eminent for all Oando products: (PMS, DPK and AGO) due to the approximate equal values of the kinematics viscosities as shown in Table 3.6.

Product Type	Density kg/m^3	Viscosity Kg/m.hr.	Kinematics Viscosity μ_p / ρ_p M^2/hr
PMS	744.0	8.95	0.01202
DPK	821.0	9.88	0.012048
AGO	865.0	10.49	0.012129
Lagoon H_2O	1024	4.12	0.004023

Table 3.6: Kinematics viscosity of Oando products PMS, DPK & AGO

Hence equation (34) putting μ_p / ρ_p = 0.12 m^2/hr,

b = constant, K_1 = constant;

Simplifies to:

$$Dd_2 = 0.17 h_2 (U_2)^{11/10} (0.006)^{1/10} \quad \ldots\ldots\ (59)$$

$$Dd_2 = 0.10 h_2\ U_2^{11/10} \quad \ldots\ldots\ldots\ldots\ (60)$$

Substituting equation (35) and (36) into equation (60) gives the dispersion coefficient rate as a function of the longitudinal and transverse direction as well as product properties including water characteristics as:

$$Dd_2 = 0.20\left(x^2 + y^2\right)^{1/2} (Sin\phi)^{11/10} \quad \ldots\ldots\ldots\ (61)$$

This equation for 1 – dimensional dispersive coefficient gives:

$$Dd_2 = 0.20\, x U_1^{11/10} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (62)$$

Where:

U_1 = characteristics wind velocity

Putting x = Lcm

And $U_1 = \omega R$;

Equation (62) combined with equations (53) – (55) gives the dispersion coefficient for the products thus:

PMS: $Dd_2 = [\omega R]^{11/10} \left[1.781 + 0.0666 v_p\right] t^{0.87}$

AGO: $Dd_2 = [\omega R]^{11/10} \left[1.701 + 0.0661 V_p\right] t^{0.87}$

DPK: $Dd_2 = [\omega R]^{11/10} \left[1.733 + 0.0661 V_p\right] t^{0.87}$ …. (63)

Simulated results obtained from the model equations for molecular calm, one – dimensional and two – dimensional dispersion coefficients are present in figures 3.4(a – k). These show credibly that dispersion coefficient on water surface largely depends on the exposure time, discharge rate, quantity of product spill, product physical properties and wind velocity.

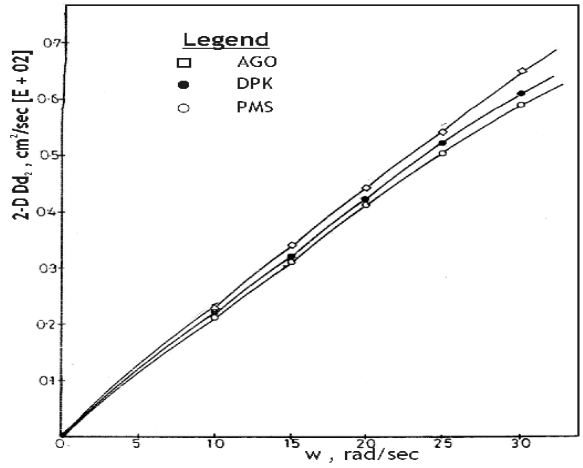


Figure 3.4a: Simulated 2-D Dispersion Coefficient (Dd_2) – Angular Velocity of Product Spills in Turbulent (High tidal) Lagoon water

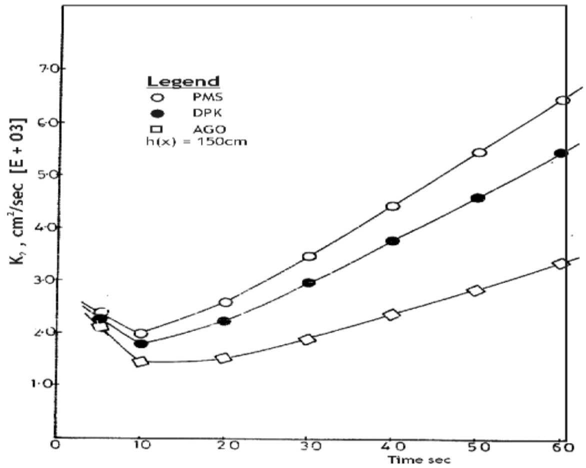


Figure 3.4b Simulated Molecular dispersion Coefficient (K_2) Time Profiles of Product Spills in Calm (Low tidal) Lagoon water

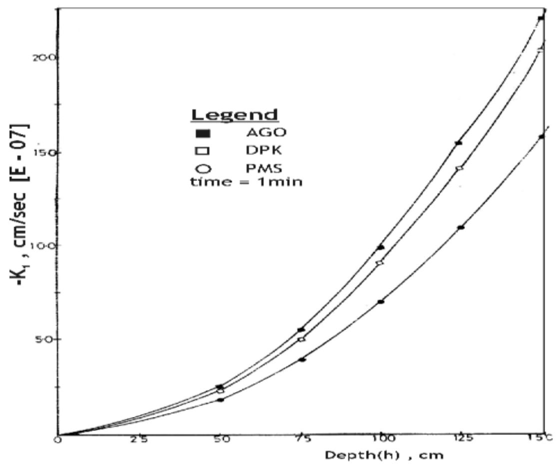


Figure 3.4c: Simulated Molecular Convective Coefficient (k_1) –Depth (h) Profiles of Product Spills in Calm (Low tidal) Lagoon water

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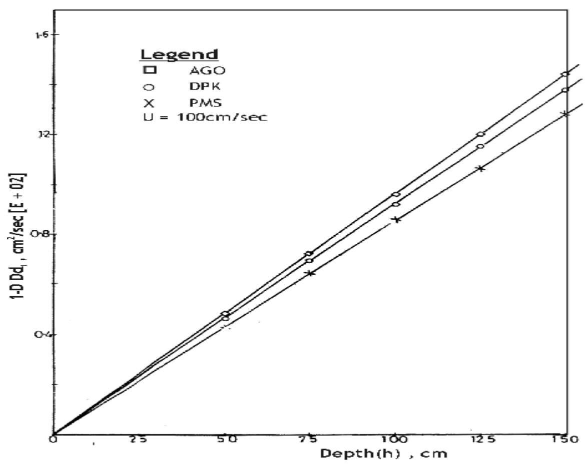

Figure 3.4d: Simulated 1-D Dispersion Coefficient (Dd_1) – Depth (h) Profiles of Product Spills in Turbulent (High tidal) Lagoon water

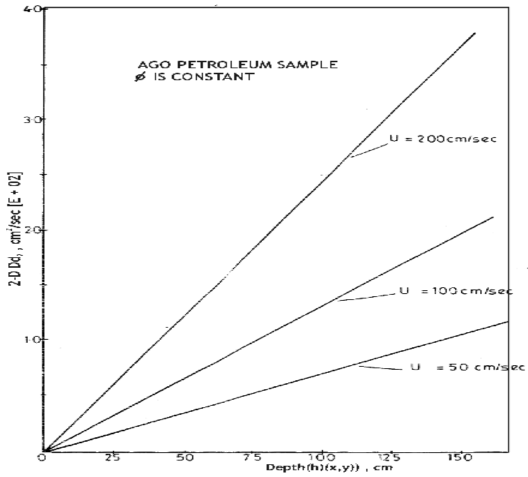

Figure 3.4g: Simulated 2-D Dispersion Coefficient (Dd_2) – Depth (h) Profiles at Various Velocities of Product Spills in Turbulent (High tidal) Lagoon water

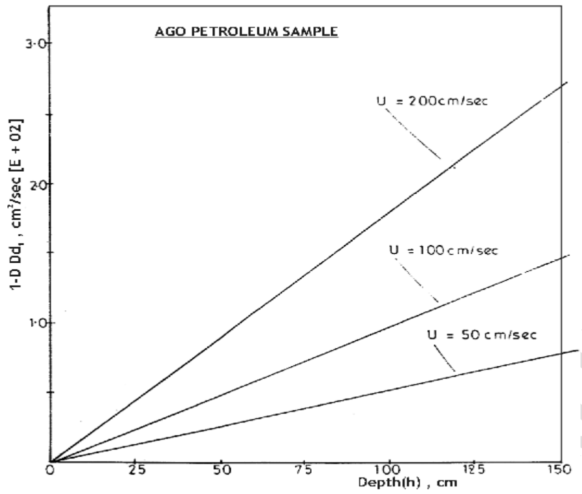

Figure 3.4e: Simulated 2-D Dispersion Coefficient (Dd_1)-Depth (h) Profiles at Various Velocities of Product Spills in Turbulent (High tidal) Lagoon water

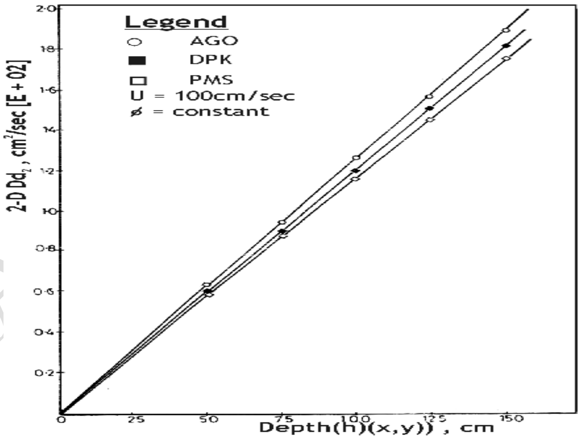

Figure 3.4h: Simulated 2-D Dispersion Coefficient (Dd_2) Depth Profiles of Product Spills in Turbulent (High tidal) Lagoon water

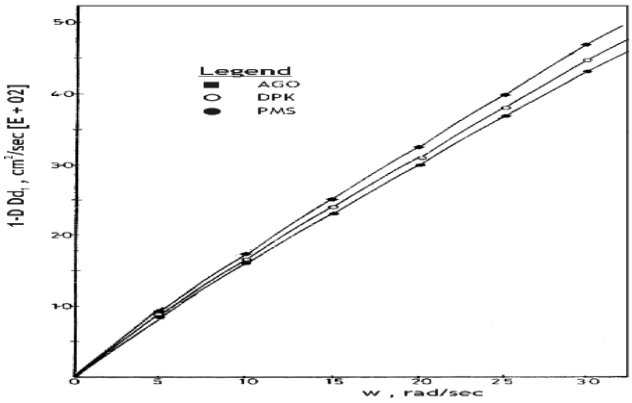

Figure 3.4f: Simulated 1-D Dispersion Coefficient (Dd) Angular Velocity (w) Profiles of Product Spills in Turbulent (High tidal) Lagoon water

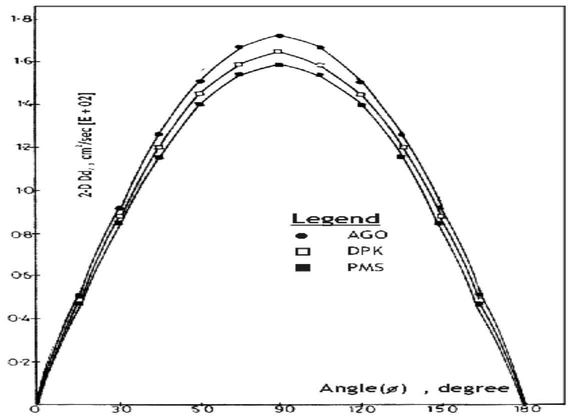

Figure 3.4i: Simulated 2-D Dispersion Coefficient (Dd_2)-Angle (ϕ) Profile of Product Spills in Turbulent (High tidal) Lagoon water

Interestingly, concentration dispersive rate is a function of dispersion coefficient for all water flow regimes as evident in equation (32). Substituting the model expression in equation (63) into (32) provides the expected model equations for the prediction of concentration – dispersive rate for all water flow regimes for each product as:

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PMS

$$C_{(\max)} = \frac{\rho_p\ V_p}{[WR]^{11/10}\ 4\pi A^{1/2}\ t\left[1.78 + 0.0666\, V_p\right] t^{0.87}}$$

DPK:

$$C_{(\max)} = \frac{\rho_p\ V_p}{[WR]^{11/10}\ 4\pi A^{1/2}\ t\left[1.701 + 0.0666\, V_p\right] t^{1.87}}$$

AGO:

$$C_{(\max)} = \frac{\rho_p\ V_p}{[WR]^{11/10}\ 4\pi A^{1/2}\ t\left[1.701 + 0.0666\, V_p\right] t^{1.87}} \qquad (64)$$

Simulation was made using the predictive model equations for each product as reflected in equations (64) – for the obvious computation of concentration – dispersive rate. The results of the simulation are well presented in figures 3.5(a – i).

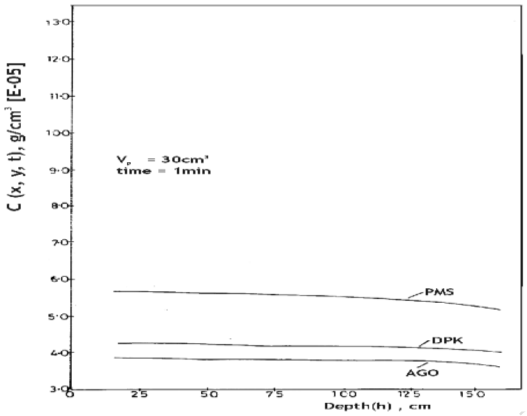

Figure 3.5a: Simulated Concentration (C_{mar}) – Depth (h) Profiles of Product Spills Dispersion Rate in Calm (Low tidal) Lagoon water

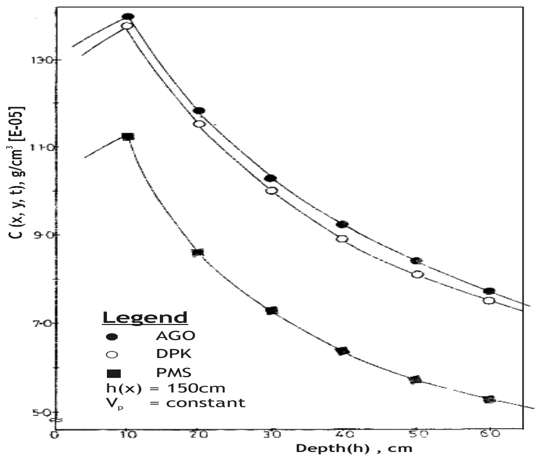

Figure 3.5b: Simulated Concentration (C_{mar}) – Time profiles of Product Spills Dispersion Rate in Calm (Low tidal) Lagoon water

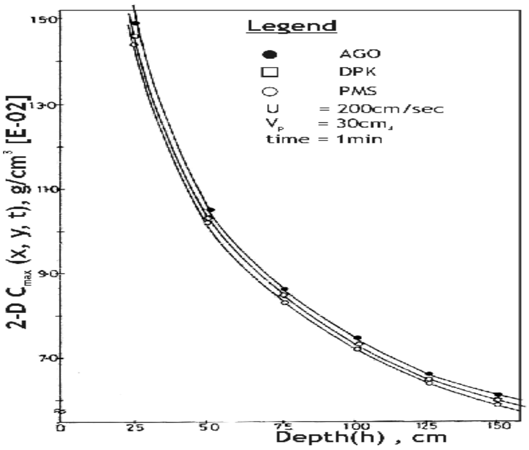

Figure 3.5c: Simulated 1-D Concentration (C_{mar}) – Depth (h) Profiles of Product Spills Dispersion Rate in Turbulent (High tidal) Lagoon water

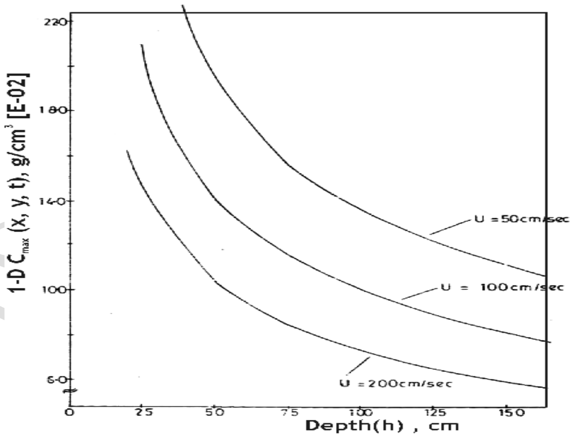

Figure 3.5d: Simulated 1-D Concentration (C_{max}) –Depth (h) Profiles at Various Velocity of Product Spills Dispersion Rate in Turbulent (High tidal) Lagoon water

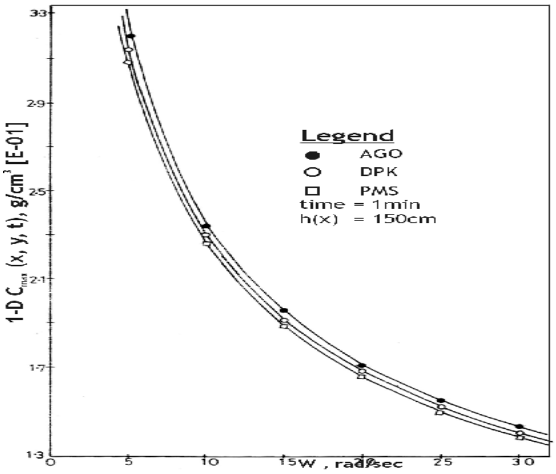

Figure 3.5e: Simulated 1-D Concentration (C_{max}) Angular Velocity (w) Profiles of Product Spills Dispersion Rate in Turbulent (High tidal) Lagoon water

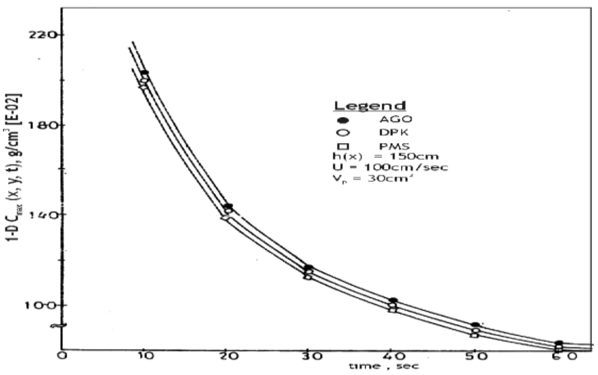

Figure 3.5f: Simulated 1-D Concentration (C_{max})- Time profiles of Product Spills Dispersion Rate in Turbulent (High tidal) Lagoon water

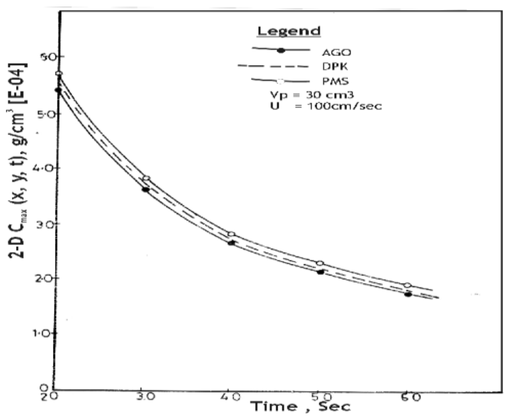

Figure 3.5i: Simulated 2-D Concentration (C_{max}) Time profiles of Product Spills Dispersion Rate in Turbulent (High tidal) Lagoon water

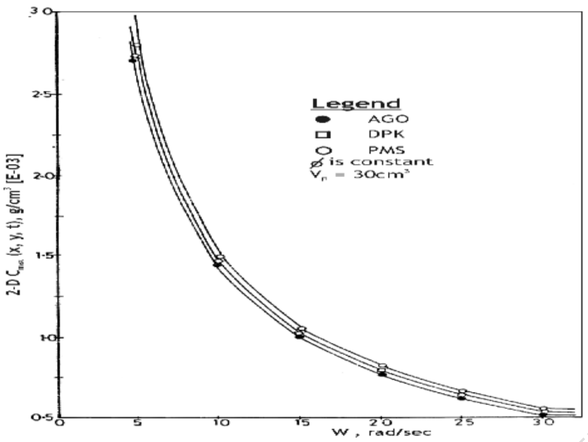

Figure 3.5g: Simulated 2-D Concentration (C_{max})- Angle Velocity (w) Profiles of Product Spills in Turbulent (High tidal) Lagoon water

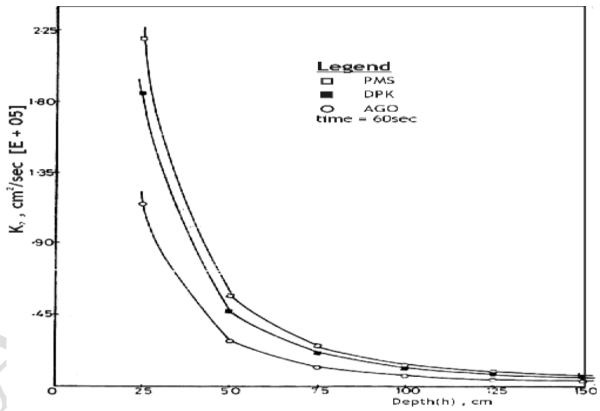

Figure 3.5j: Simulated Molecular dispersion Coefficient (K_2) – Depth (h) Profiles of Product Spills in Calm (Low tidal) Lagoon water

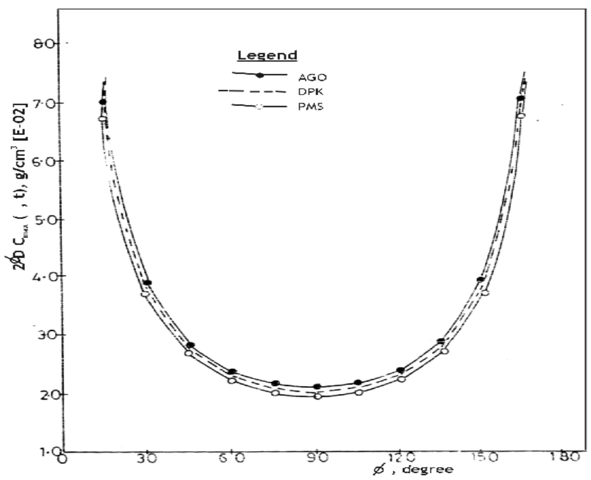

Figure 3.5h: Simulated 2-D Concentration (C_{max})- Angle (ϕ) Profiles of Product Spills Dispersion Rate in Turbulent (High tidal) Lagoon water

The results obtained are very palatable because the effect of physical properties of the product type, the characteristic wind velocity, the quantity of spill, exposure time and the area imparted influenced the over all concentration – dispersive rate.

B. CONTROL AND CONTINGENCY REMEDIAL PLAN

The model equations derived in section 2.2 and 3.1 – 3.2 for the prediction of weathering processes of product spills as it relates to dispersion rates in water and soil medium are very relevant for the prediction of oil spill behavior once discharged.

The characteristics behavior of product sample spill in water and soil environments are influenced by the specified flow require. Reynolds's no is a measure of these regimes, which for wind induced environment such as Lagos lagoon can be represented as a turbulent condition. This flow regime analysis is most relevant for the strategic control of the resulting spill in case of occurrence.

For example, if the flow regime of the aquatic environment is laminar ($Re \leq 272$) and tranquil ($fr < 1.0$); the conditions upstream of the spill are affected by the downstream conditions and therefore the product spills are controlled by down stream conditions.

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Similarly for turbulent flow aquatic regime $\left(R_{e_{1-1}} > R_{e_{c,1-2}} > \frac{\rho_p}{\mu_p}\left(R_{e_{1-2}}\right)^{\frac{3}{2}} g^{\frac{1}{2}}\right)$ and rapid $\left(Fr_{1-2} > Fr_{c_{1-2}} > 100\right)$; the conditions downstream are affected by the conditions upstream. Therefore the product spills will be controlled by upstream conditions.

IV. CONCLUSION

Deterministic and stochastic predictive models have been developed for the simulation of spread-dispersive, concentration-dispersive rate in water and soil environment where Oando's 14km product pipeline network distribution project is situated. Various computational flow chart Algorithms were also developed to facilitate easy simulation of the model equations. The results obtained depicts great dependency of spread – dispersive and concentration - dispersive rates and their associated coefficients as a function of product spill physical properties and wind velocity for water medium.

Conversely, concentration – dispersive rate and their coefficients were found to be sensitive to the prosily of soil and the physical properties of the product sample. The models were very reproducible to the study objectives and scope.

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