COMPUTATIONAL PREDICTION OF PETROLEUM SPILL VELOCITY DISTRIBUTION ON CALM SEA SURFACE

Ikezue, E. N., Ebenighe, D. O. and Amie-Ogan, T. G.
Department of Chemical Engineering, Chukwemeka Odumegwu Ojukwu University, Uli.
Email: eddikezue@yahoo.com.

ABSTRACT

The movement of spilled oil on water or sea surface depend mostly on the effects of wind and the surface currents close to the site of the spillage and of less importance is the internal spread of the slick itself and when the tidal waves are absent. When spillage occur at shoreline areas, the slick movement predictions could be used to determine the probable location of potential shoreline contamination and thereafter direct the prevention of its spread to sensitive spots or area. The parameters of importance in predicting oil-spill movement on water surface include surface current, speed and direction, wind speed and direction, oil spreading characteristics. The spreading behavior depends mostly on the physical properties of the spilled oil i.e., evaporation rate, specific gravity or density, boiling range, viscosity, pour point, emulsification ability, dissolution/water solubility. The forces that contribute to oil spill movement on calm sea (water surface) are gravity force, viscous force, surface tension and inertia force and by making a force balance around a spilled oil molecule, an empirical model is obtained for predicting spill movement and to determine the critical diameter of spilled oil molecule. This helps in the assessment of spill-volume required for determining clean-up equipment and man power requirements for the entire operation. Some of the techniques used in preventing oil-spills include: Proper automation of oil/gas well; Running of pressure element on a wire line; Permanent installation of pressure elements; The use of high resolution aerial photographs; Monitoring oil facilities regularly; The use of oil drainage collection platform. The simulation model was developed from first principles and used to obtain the velocity distribution and validated with MATLAB software implemented on a digital micro-computing device HP model X590 Series.

Keywords: Numerical Model, Spilled Oil, Emulsification, Chocolate-Mouse, Tidal Waves, Simulation Approach, Submarine Seepage.

1.0 INTRODUCTION

Oil spillage is a global phenomenon which has occurred since the discovery of petroleum, which incidentally is a component of industrial revolution. The total volume of oil spilled into the oceans, high seas, rivers, lagoons and estuaries is estimated to range between 0.7 to 1.7 millions tons per year. (www.science.irank.org). Oil spills have been a major threat to mankind and the environment of oil producing communities in Nigeria in particular and other parts of the world where oil/gas is produced in commercial quantities. Human activities coupled with oil exploration and exploitation activity had rendered oil producing communities of Nigeria almost inhabitable and therefore had raised a number of issues such as depletion of the biodiversity, coastal and river banks erosion, flooding, oil-spillage, gas flaring, noise pollution, sewage and wastewater pollution, land degradation, soil fertility loss and deforestation.

Geographically, Nigeria has a coastline of approximately 85km towards the Atlantic Ocean lying between latitude 4°15’ to 4°50’ and longitude of 5°25’ to 7°37’ with a wetland mass of about 28000km^2 area in the coastal area. The surface area of the continental shelf is 463km^2. The coastal areas consist of freshwater swamp, mangrove swamp, beach ridges, sand bars, lagoons, marshes and tidal channels. Nigeria has a total land mass of 923,766km^2 and 918768km^2 being terrestrial and 13000km^2 being aquatic. The coastal area is humid with a mean average temperature of 24-32°C and average annual rainfall between 1500-4000m. The country has two large rivers, the river Benue and river Niger with channels running to the Atlantic Ocean directly.

2.0 BEHAVIOURAL CHARACTERISTICS OF PETROLEUM SPILLS IN MARINE ENVIRONMENT

The characteristics tendency for oil-spill include:

a. Spreading: This is the first phenomenon that follow a spillage and this spreading tendency is affected by wind, tidal waves and water currents. Under the influence of hydrostatic and surface forces, the spill oil spreads rapidly attaining no average thickness less than 0.03mm within 24 hours.
b. Evaporation: This tendency helps to degrade the spilled crude oil on water surface or on land. Wind velocity, intensity of solar radiation help to increase the evaporation rates of the spilled oil.

Evaporation alone can remove 50% of hydrocarbon on ocean's surface and loss of volatile matter increases the density and kinematic viscosity of the oil.

c. Dissolution: This is the process in which the low molecular weight hydrocarbons and the polar non hydrocarbons are partially lost from the spilled oil into the water column.
d. Photo-oxidation: Natural sunlight in the presence of oxygen can transform several mass of spilled oil into hydroxyl compounds such as aldehydes and acetones and then to carboxylic acids.
e. Dispersion: This is a case of oil-in-water emulsification which results from the incorporation of small molecules of oil into water column when the oil starts to disperse on contact with water and this occur in the first ten hours or more.
f. Degradation: Bio-derivative process influence the fate of spilled petroleum and the process include microbial degradation, ingestion by zoo plankton, uptake by aquatic invertebrates and vertebrates and also bio-turbation.

2.1 Sources of Petroleum Spills

Most of oil-spills have originated from sources some of which are not limited to equipment failure, accidents, natural effect (age) human error and sabotage, bunkering operations, submarine seeks, leaking pipeline flanges, vandalism, corrosion and erosion of piping and fittings and blow out from wells and flowlines, sea-going vessel accidents and tanker lorry accidents on the roads. Also tank cleaning processes produce large amount of oil with high chemical oxygen demand (COD) but small amount of biochemical oxygen demand (BOD).

2.2 Oil Spill Prevention and Control Method

The prevention and control of petroleum spill is the subject to highest priority in the oil/gas industry as 45gallons of oil spill can pollute one square mile of water body in few seconds with high speed pumps transfer operations.

i. Proper automation of oil well can help prevent spills from wells, pipelines and pumps.

ii. Booms which are floating barriers can be used to clean oil from the surface of water and prevent spills from spreading. A boom can be placed around a tanker that is spilling oil. It can also be placed around a habitat with many aquatic animals living there. The booms absorb the oil that flows around it.

iii. Boat like skimmers can be used to remove oil from water surface. The skimmers use pumps or vacuums to remove the oil floating on water surface. It uses sorbents or sponge-like materials to collect and absorb the oil when spills occur.

iv. Dispersants or chemicals dropping from an airplane can be used to breakdown the oil and remove it from the water surface
v. Controlled burning with fiber proof booms could be used to remove the spilled oil on top of water surface. Also scooping, scarping and vacuum trucks driven on land could be used to effectively remove the spilled oil.
vi. Bioremediation means could be used to remove the oil-slick by the introduction oil eating microorganisms to the oil column which are capable of breaking up the complex hydrocarbon molecules for energy. A bacterium such as alcanivorax borkomersis can provide a base for this bioremediation strategy.

2.3 Oil Spill Movement Prediction.

The movements of oil spill on water(sea) surface depends primarily on the effects of wind and surface current near the spill site; of less importance is the internal spread of the slick itself when the current and wind are no longer present, hence the slick spreading will dictate the probable location of beach or shoreline contact. When spills affect the shoreline areas, slick movement can be used to determine the true location of potential shorelines contamination and to direct the prevention of pollution of sensitive areas. The following data are helpful in prediction of oil spill movement and they include
a. Surface current speed and direction
b. Wind speed and direction
c. oil spreading characteristics

An area of importance for planning oil spill response actions is the determination of clean up equipment and manpower requirements for the entire cleaning operation.

3.0 DEVELOPMENT OF NUMERICAL MODELS FOR OIL SPILL MOVEMENT

The expression of momentum transfer in the x-direction for an oil-slick is

$$\rho \frac{DVx}{Dt} = -\left(\frac{\partial Rxx}{\partial x} + \frac{\partial Ryx}{\partial y} + \frac{\partial Rzx}{\partial z} \right) - \frac{\partial P}{\partial x} + \rho g_x \qquad (1)$$

Where Rxx, Ryx, Rzx are floxes of x-compnent of movement due to molecular transfer through faces perpendicular to x,y,z directions respectively. For oil-slick (an incompressible sluid of constant viscosity) it can be shown that:

$$\rho \frac{Dvx}{Dt} = \mu \left(\frac{\partial^2 Vx}{\partial x^2} + \frac{\partial^2 Vx}{\partial y^2} + \frac{\partial^2 Vx}{\partial z^2} \right) - \frac{\partial p}{\partial x} + \rho g_x \qquad (2)$$

Equation (2) can be written in an expanded form as:

$$\rho \left(\frac{\partial Vx}{\partial t} + Vx \frac{\partial Vx}{\partial x} + Vy \frac{\partial Vx}{\partial y} + Vz \frac{\partial Vx}{\partial z} \right) = -\frac{\partial P}{\partial x} + \mu \left(\frac{\partial^2 Vx}{\partial x^2} + \frac{\partial^2 Vx}{\partial y^2} + \frac{\partial^2 Vx}{\partial z^2} \right) + \rho g_x \qquad (3)$$

Or $$\rho \frac{Dv}{Dt} = \mu \nabla^2 V - \nabla p + \rho g \qquad (4)$$

If there is no flow in the y and z direction ie upwards and perpendicular directions we have $Vx = V_x(z)$, $V_y = 0$, $V_z=0$
$g_y = 0$, $g_x = 0$, $g_z = -g$
Also if the oil-slick movement is approximately steady we have

$\frac{\partial Vx}{\partial t} = 0, \frac{\partial Vx}{\partial x} == 0, \frac{\partial Vx}{\partial z} = 0$ and for pressure gradient $\frac{\partial P}{\partial y} = 0$

Utilizing these conditions the expanded modified Navier stokes equation (3),

(NSE) become $\frac{-\partial p}{\partial x} + \mu \frac{\partial^2 Vx}{\partial Z^2} = 0$ (5)

Equation (5) could be directly integrated to obtain,

$$\frac{dVx}{dz} = \frac{1}{\mu}\left(\frac{dP}{dx}\right)z + G \quad (6)$$

Integrating equation (6) once more we obtain,

$$\text{Vx} = \frac{1}{\mu}\left(\frac{\partial P}{\partial x}\right)\frac{Z^2}{2} + G + C_2 \quad (7)$$

Now Vx = 0 at Z = 0 and Vx = 0 at Z = b using these boundary conditions we have,

$$\text{Vx} = \frac{1}{\mu}\left(\frac{\partial P}{\partial x}\right)\left(\frac{Z^2}{2} - \frac{bZ}{2}\right) = \frac{Z}{2\mu}\left(\frac{dp}{dx}\right)(z-b) \quad (8)$$

The mean linear oil-slick velocity in the horizontal x-direction is;

$$\text{U} = \frac{1}{b}\int_0^b Vxdz \quad (9)$$

If the equation (8) is substituted into (9) then oil-slick velocity in the presence of tidal waves is obtained as;

$$\text{U} = \frac{-b^2}{12\mu}\left(\frac{dP}{dx}\right) \quad (10)$$

Where μ is the oil-slick viscosity now the velocity gradient $\frac{dP}{dx}$ is negative hence the mean linear velocity of oil-slick on water surface is positive

3.1 Estimates of oil-slick spreading rate

In order to obtain the approximate value of the oil-spill spreading rate we determine the area of coverage of the oil-slick movement designated as A and then multiply this by the mean linear velocity obtained from equation (10) to get the spreading rate.

3.2 Materials and Methods

The numerical equations derived in this work was used to develop the necessary softwares and programs that enables the prediction of spill spreading rate on water surface or in an estruary. Also it enabled the computation of oil-slick volumes that have travelled through the rupture area so that emergency bioremediation or scooping measures could be introduced at the spill sites. The velocity profile for a spillage were obtained from the equation (9) and (10) and the floats shows that at greater distances the oil slick movement retards and a terminal velocity is attained when advective forces, emulsification, evaporation (due to sunshine), mouse or chocolate formation and sinking into the water colomn dominate.

4.0 RESULTS AND CONCLUSION

Figures 1, 2, 3 and 4 are plots of the velocity distribution as a function of distance of oil-slick movement on sea/estuary surface in a riverine town of Niger Delta area of Nigeria. The plots show that the spill velocity declines positively for the pressure gradients induced by the water/wave currents.

The spill movements are predictable using the numerical expression (eqn 10) obtained from first principles by considering the momentum balance around an oil-slick molecule whose motion is induced by the pressure forces at the rupture site or point spillage and also wind direction, tidal waves and advection forces.

The development of the simulation model took into consideration the combined effect of gravitational forces, inertia viscous and surface tension force. The total effect of the forces was to retard the motion of the slick until a terminal velocity is attained to which Vx=0 (see plots).

At a point in the flow direction the surface tension force equals the inertia and viscous forces which retards the slick motion hence we could determine the critical diameter of the spilled oil slick beyond which the oil-spreading rate is dominated by surface tension force.

Symbols and their units

Vx = Velocity of oil-slick, m/s
μ = oil-slicj viscosity, cp or Ns/m^2
Z = direction of motion, Lm
b = thickness of boundary layer, m
P = pressure force, N/m^2
X = perpendicular direction to motion, cm
ρ = oil-slick density, kg/m^s
Y = perpendicular direction to motion, cm
g = gravitational acceleration constant, N/kg
Rx = Surface tension on water surface

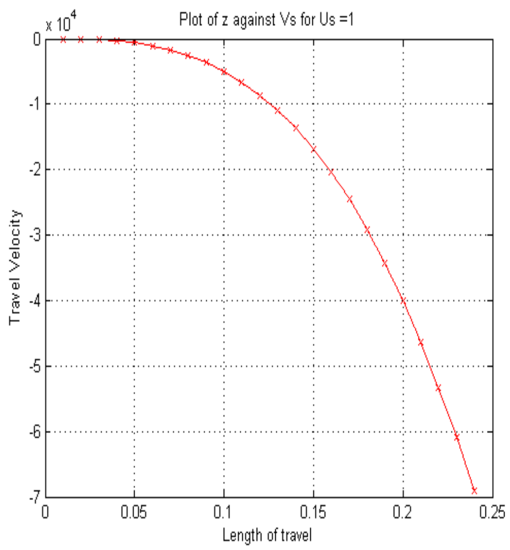
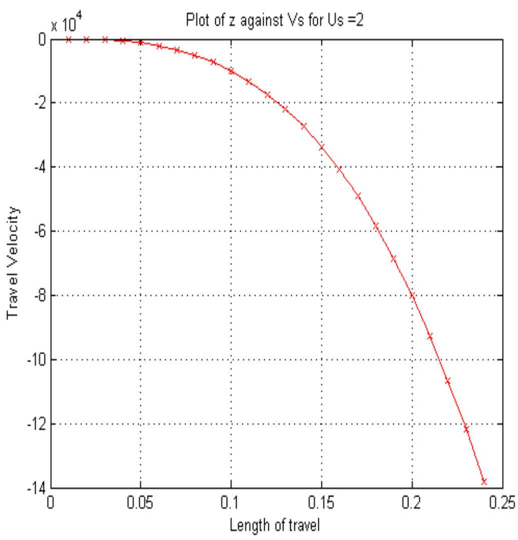


Figure 1:



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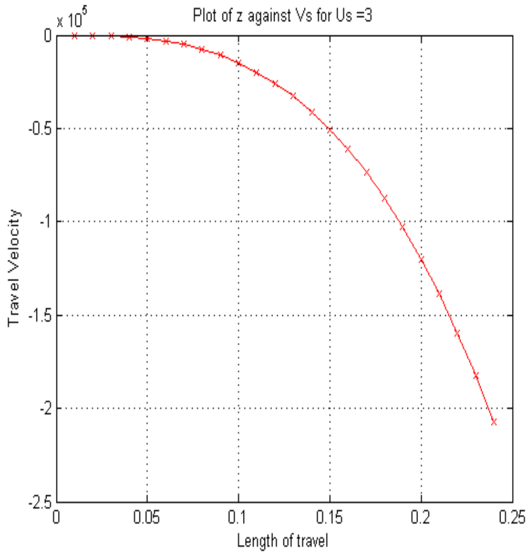

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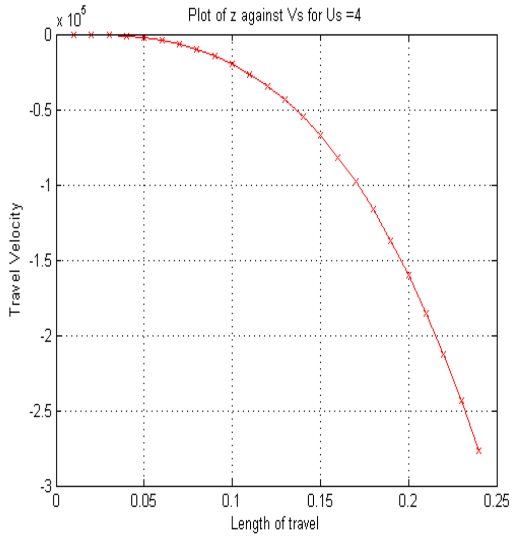

Figure 4:

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