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Development of Predictive Equation for Evaporation in Crude Oil Spill on Non – Navigable River

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Abstract: *Oil spill into rivers and reservoirs is of great concern as the contamination of water bodies has a devastating and obnoxious effect on marine ecology and local water supply systems. Evaporation causes a very significant mass loss in many kinds of oil and is significant for attempts at resource recovery. The objective of this study is to develop predictive equation for the evaporation of crude oil spill on non-navigable rivers. The equation was developed using dimension analysis. The spilled oil parameters used in the analysis were: oil molecular weight and oil vapour pressure. The coefficient used in the analysis is: evaporation mass transfer coefficient. These parameters were obtained from standards published in journal papers in the field of oil spill modeling. Other parameters used were: the universal gas constant, ambient temperature (oil surface temperature), the volume of oil spilled and time elapsed. The developed equation was validated against a reference mass loss equation for evaporation using the coefficient of determination R^2 and percentage deviation. The equation predicted an evaporation loss of 47 percent of initial spill mass 24 hours after a spill. The developed predictive equation had R^2 value of 0.99, which indicates a good fit of the equation. In addition, percentage deviation values of -1.702 between the predictive equation and reference equation indicate a good agreement between the two equations. The predictive equation will be useful in contingency planning, training, spill response and long – term damage assessment of oil spills in non-navigable rivers.*

Keywords: Evaporation, Crude Oil Spill, Non-Navigable River

1. INTRODUCTION

An oil spill is the release of a liquid petroleum hydrocarbon into the environment as a result of uncontrolled well blow-out, pipeline rupture or tank failure. The term also refers to marine oil spills where oil is released into the river, sea, and ocean, coastal or inland waters. Oil may be a variety of materials including crude oil, refined petroleum products (such as gasoline or diesel fuel) or by – products, oily refuse or oil mixed in water [1].

According to [2], the persistence of spilled oil in water bodies are determined by physical, chemical and biological processes which are dependent on oil properties, hydrodynamics, meteorological and environmental conditions. These processes are: advection, turbulent diffusion, surface spreading, evaporation, dissolution, dispersion, emulsification, hydrolysis, photo-oxidation, biodegradation and particulation.

When liquid oil is spilled on the water surface it spreads to form a thin oil film – an oil slick. The composition/character of the oil changes extensively from the initial time of the spill, as light (low – molecular weight) fractions evaporate, water – soluble components dissolve in the water column, the immiscible compounds become emulsified and dispersed in the water column as small droplets [3].

The effects of weathering are generally rapid (1 to 2 days) for hydrocarbons with lower molecular weights as a result of evaporation. Degradation of the higher weight reactions is slower and occurs primarily through microbial degradation and chemical oxidation [3]. Components of spilled oil evaporate at varying rates and are transported and diluted by atmospheric processes. Evaporation accounts for the largest loss in oil volume during the early stages of the slick transformation.

A modification of the work of [4] was carried out by [5]. This model proposed that the fraction of the evaporated petroleum is a function of experimental constants (k_1, k_2, k_e), environmental temperature T_0, slick thickness, C_1 and C_2 are the experimental data obtained by oil distillation.

In the work of [6], the mass loss from oil to environment (evaporation) is calculated for each component. This loss is a function of the transfer coefficient, vapor pressure, the slick area the remainder fraction for each component, the molecular weight for each component, the universal gas constant and the temperature of the water surface.

An improved expression to evaluate the evaporation loss was used by [7]. It is a function of an evaporation constant, exponent of evaporation, wind speed at 10 m above water surface, spill area, molar volume, petroleum molecular weight, density, universal gas constant, surface temperature, initial vapor pressure of oil, molar volume, initial spill volume.

2. MATERIALS AND METHODS

2.1 Description of Non – navigable River

This research was carried out for small non-navigable rivers of the scale typical of a tributary to a navigable river, [8]. According to them, the river is assumed to exhibit a fair degree of meandering and is sheltered from wind by the river banks and vegetation. There may be areas of quiet water or eddies at the inside of river bends and other pools where flow velocities differ from that of the main current.

The cross channel profiles are irregular, with rapids at one extreme and quiet bay at the other. Turbulence results from shear in currents along the banks and river bottom. Increased velocity of flow and bed roughness has direct bearing on turbulence. The river currents and water level are usually increased by seasonal or episodic changes in runoff and rainfall.

2.2 Determination of spilled oil parameters

The spilled oil parameters required for the development of the predictive equation were obtained from standards in papers published by researchers in the field of oil spill modeling. This is because at the initial period of real-life spills, more attention is usually paid to oil combating operations rather than to rigorous measurements. Besides a direct measurement of vast areas, typically affected by such a dynamic event as an oil spill, is an extremely difficult task, [2].

Bonny light crude oil was considered as the specimen for this study as it is the most common crude blend exported from Nigeria, [9].

The spilled oil parameters obtained are as follows:

- Molecular weight (Kg/mol): The value for molecular weight was provided by [8].
- Vapor pressure (Kg/ms^2): The value of vapor pressure in this study is calculated using equations provided by [7]:

$$lnP_0 = 10.6\left(1 - \frac{T_0}{T_E}\right) \quad (1)$$

$$T_0 = 542.6 - 30.275API + (1.565API^2) - (0.03439API^3) + (0.0002604API^4) \quad (2)$$

$$API = \frac{141.5}{S.G} - 131.5 \quad (3)$$

where
P_0 = the vapor pressure (atm)
T_E = the absolute temperature of the interface (^{0}K)
T_0 = reference temperature
API = API gravity

- Mass transfer co-efficient (m/s): The values of standard mass transfer coefficient were provided by [8]. These parameters (variables) will be used in the determination of mass loss due to evaporation in an oil spill.

2.3 Other relevant data

- Universal gas constant R (Kgm^2 K^{-1}mol^{-1}s^{-2}): The value for the universal gas constant was obtained from [10]. This parameter will be used in the determination of mass loss due to evaporation in an oil spill.
- Ambient temperature (oil surface temperature) (K): The value for ambient temperature was obtained from [11]. This parameter will be used in the determination of mass loss due to evaporation in an oil spill.
- Volume of Spill (m^3): A spill volume of was assumed for this study, according to [12]. This parameter (variable) will be used in the determination of mass loss due to evaporation.

2.4 Reference Equation

According to [7], the fraction of mass loss due to evaporation from an oil slick can be calculated as follows:

$$F = \left(\frac{1}{C}\right)\left[lnP_0 + ln\left(CK_E t + \frac{1}{P_0}\right)\right] \quad (4)$$

$$C = 1158.9API^{-1.1435} \quad (5)$$

$$K_E = \frac{0.0025U^{0.7}AV_m}{RTV_0} \quad (6)$$

$$A = \left(K_{lv}\left(\frac{\Delta g.V^2 t^{1.5}}{v^{0.5}}\right)^{0.25}\right) \times W \quad (7)$$

$$V_m = \frac{PM}{\rho \times 10^{-6}} \quad (8)$$

$$lnP_0 = 10.6\left(1 - \frac{T_0}{T_E}\right) \quad (9)$$

$$T_0 = 542.6 - 30.275API + (1.565API^2) - (0.03439API^3) + (0.0002604API^4) \quad (10)$$

$$API = \frac{141.5}{S.G} - 131.5 \quad (11)$$

Where
F = fraction of mass loss
K_E = the exponent of evaporation
P_M = the molecular weight (molar mass)
U = Wind speed (m/s)
P^0 = the vapor pressure (atm)
R = the universal gas constant (atm-$m^3$$mol^-$K)
t = time (s)
T_E = the absolute temperature of the interface (^{0}K)
A = area of the petroleum spill (m^2)
W = the width of the slick
V_m= molar volume in $m^3$$mol^-$
ρ= density of petroleum in gcm^{-3}
V_o= Initial spill volume m^3
T_0 = reference temperature
API= API gravity
S.G. = specific gravity
k_{1v} = the spreading law coefficient for viscous spreading (k_{1v} = 1.5)
υ = the kinematic viscosity of water
Δ = the ratio of density difference between water and oil to density of water, (Δ = 0.14)
g = acceleration due to gravity
t = time
V = the volume of slick per unit length normal to the direction of spreading (per unit width of the river).

2.5 Theory

The governing equations required to evaluate the weathering processes for spilled oil in a river system was established using dimension analysis. With the help of dimensional analysis the equation of physical phenomenon were developed in terms of dimensionless groups or parameters. The methods of dimensional analysis are based on the Fourier principle of homogeneity, [13].

- Buckingham's π-theorem: The Buckingham's π-theorem states as follows: If there are n-parameters (governed and governing parameters) in a dimensionally homogenous equation and if these contain m – fundamental dimensions (such as M, L, T, θ and mol), then the parameters are arranged into (n-m) dimensionless terms, called π – terms.

  Mathematically, if any parameter K_1, depends on governing parameter, K_2, K_3, K_4…K_n; the functional equation may be written as:

  $$K_1 = f(K_2, K_3, K_4 \ldots K_n) = 0 \quad (12)$$

  Equation (12) may be written as:

  $$f(K_1, K_2, K_3, K_4 \ldots K_n) = 0 \quad (13)$$

  It is a dimensionally homogenous equation and contains n parameters. If there are m fundamental dimensions, then according to Buckingham's π- theorem (13) can be written in terms of a number of π-terms (dimensionless groups) in which number of π-terms is equal to (n-m). Hence (13) becomes

  $$f_1(\pi_1, \pi_2, \pi_3 \ldots \pi_{n-m}) = 0 \quad (14)$$

  Each dimensionless π-term is formed by combining *m* parameters with one of the remaining (*n-m*) parameter i.e. each π-term contains (*m*+1) parameter. These *m* parameters which appear repeatedly in each of π-terms are consequently called repeating parameters and are chosen from among the parameters such that they together involve all the fundamental dimensions and they themselves do not form a dimensionless parameter.

  The final general equation for the phenomenon may be obtained by expressing anyone of the π-terms as a function of the other as:

  $$\pi_1 = \Phi(\pi_2, \pi_3, \pi_4 \ldots \pi_{n-m}) \quad (15)$$

  $$\pi_2 = \Phi(\pi_1, \pi_2, \pi_3 \ldots \pi_{n-m}) \quad (16)$$

- Transformation of π–terms: To ensure simplicity in the experimentation process, the present π-terms (π_2, π_3, and π_4,) were adjusted to generate new π-terms by multiplying or dividing with each other [14], while maintaining the independency condition.
- Functional relationship between dimensionless terms (π-terms): The experimental/calculated values of the governed parameter and other governing parameters are substituted into the dimensionless groups. A plot is made of the π-terms containing the governed parameter against the other π-terms. The functional relationship is determined by analyzing the nature of the plot, [15].

3. DEVELOPMENT OF PREDICTIVE EQUATIONS

3.1 DETERMINATION OF Π - TERMS

The evaporation loss from an oil slick in a non – navigable river depends on the following factors. They include:

- Initial vapor pressure, P (kg/ms^2)
- Mass transfer coefficient, K (m/s)
- Molar gas constant, R ($kgm^2K^{-}mol^{-}s^{-2}$)
- Ambient temperature (oil surface) T (K)
- Initial spill volume, V (m^3)
- Molecular weight (g/mol)
- Time elapsed (s)

The evaporation loss E (kg) is a function of:

P, K, R, V, T, m, t

Mathematically,

$E = f(P, K, R, V, T, m, t)$ or $f(E, P, K, R, V, T, m, t) = 0$ (17)

Total number of variables, n = 8

Table 1 show variables expressed in terms of fundamental dimensions:

Table 1: Variables expressed in terms of fundamental dimensions

E	P	K	R	V	T	m	t
M	$ML^{-1}T^{-2}$	LT^{-1}	$ML^2\theta^{-1}mol^{-1}T^{-2}$	L^3	$L^{-1/3}T$	$Mmol^{-1}$	T

The fundamental dimensions are:

- Mass (m)
- Length (L)
- Time (T)
- Temperature (θ)
- Mole (mol)

Thus, number of fundamental dimensions, m = 5

Number of π – terms

$n - m = 8 - 5 = 3$

From (17):

$f\ (\pi_1, \pi_2, \pi_3)\ =\ 0$ (18)

Selecting repeating variables as: K, T, m, P, t

$\pi_1\ =\ K.T.m.P.t.E$ (19)

$\pi_2\ = K.T.m.P.t.R$ (20)

$\pi_3\ = K.T.M.P.t.V$ (21)

π_1 – term:

$\pi_1 = K^{a_1}.T^{b_1}.m^{c_1}.P^{d_1}.t^{e_1}.E$ (22)

$M^0L^0T^0mol^0\theta^0 = (LT^-)^{a_1}.(\theta)^{b_1}.(Mmol^-)^{c_1}.(ML^-T^{-2})^{d_1}(t)^{e_1}.(M)$ (23)

Equating indices

$M: 0 = c_1 + d_1 + 1$

$L: 0 = a_1 - d_1$

$T: 0 = -a_1 + (-2d_1) + e_1$

$\theta: 0 = c_1$

$Mol: 0 = c_1$

Solving the above equations;

$a_1 = -1, b_1 = 0, c_1 = 0, d_1 = -1, e_1 = -3$

$\pi_1 = K^{-1}.T^0.m^0.P^{-1}.t^{-3}.E$ (24)

$\pi_1 = \frac{E}{KPt^3}$ (25)

π_2 – term

$\pi_2 = K^{a_2}.T^{b_2}.m^{c_2}.P^{d_2}.t^{e_2}.R$ (26)

$M^0L^0T^0mol^0\theta^0 = (LT^-)^{a_2}.(\theta)^{b_2}.(Mmol^-)^{c_2}.(ML^-T^{-2})^{d_2}.(t)^{e_2}.(ML^2\theta^-mol^-T^{-2})$ (27)

Equating indices

$M: 0 = c_2 + d_2 + 1$

$L: 0 = a_2 - d_2 + 2$

$T: 0 = -a_2 - 2d_2 + e_2 - 1$

$\theta: 0 = b_2 - 1$

$Mol: 0 = -c_2 - 1$

Solving the above equations;

$a_2 = -2, b_2 = 1, c_2 = -1, d_2 = 0, e_2 = 0$

$\pi_2 = K^{-2}.T^1.m^{-1}.P^0.t^0.R$ (28)

$\pi_2 = \frac{RT}{K^2m}$ (29)

π_3 – term:

$\pi_3 = K^{a_3}.T^{b_3}.m^{c_3}.P^{d_3}.t^{d_3}.V$ (30)

$M^0L^0T^0mol^0\theta^0 = (LT^-)^{a_3}.(\theta)^{b_3}.(Mmol^-)^{c_3}.(ML^-T^{-2})^{d_3}.(t)^{e_3}.(L^3)$ (31)

Equating indices:

$M: 0 = c_3 + d_3$

$L: 0 = a_3 - d_3 + 3$

$T: 0 = -a_3 - 2d_3 + e_3$

$Mol: 0 = -c_3$

$\theta: 0 = b_3$

Solving the above equations;

$a_3 = -3, b_3 = 0, c_3 = 0, d_3 = 0, e_3 = -3$

$\pi_3 = K^{-3}.T^0.m^0.P^0.t^{-3}.V$ (32)

$\pi_3 = \frac{V}{K^3t^3}$ (33)

From the above calculations, the determined π – terms are:

$$\pi_1 = \frac{E}{KPt^3}; \qquad \pi_2 = \frac{RT}{K^2m}; \qquad \pi_3 = \frac{V}{K^3t^3}$$

3.2 Transformation of π – terms

The π_2 term (29) is divided by the π_3 term (33) as follows:

$$\frac{RT}{K^2m} \div \frac{V}{K^3t^3}$$

$\pi_2^! = \frac{RTKt^3}{mV}$ (34)

According to the π-theorem,

$\pi_1 = \Phi(\pi_2')$ (35)

$\frac{E}{KPt^3} = \emptyset\left(\frac{RTKt^3}{mV}\right)$ (36)

3.3 Determination of functional relationship

Table 2 shows the values of the π – terms after the calculated and pre-determined values of the governing and governed parameters have been substituted:

Table 2: Values of π – terms

$\boldsymbol{\pi_2^! = \frac{RTKt^3}{mV}}$	$\boldsymbol{\pi_1 = \frac{E}{KPt^3}}$
8.4634 x 10^{12}	1.9077 x 10^{-11}
67.707 x 10^{12}	3.4322 x 10^{-12}
228.51 x 10^{12}	1.2279 x 10^{-12}
541.66 x 10^{12}	5.8213 x 10^{-13}
1057.9 x 10^{12}	3.2269 x 10^{-13}

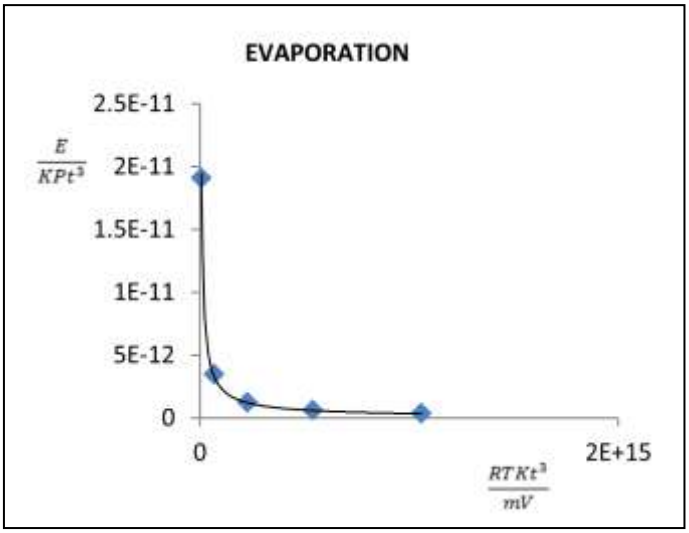

Fig. 1 shows the plot of π_1 (y – axis) against π_2' (x – axis). The functional relationship between the π terms may now be established from the plot.

As can be seen from the plot, the curve is that of a power function which is represented by the expression:

$$y = ax^b \tag{37}$$

The values of the constants a and b were determined by the method of averages using the procedure suggested by [16]. For clarity the procedure is stated as follows:

- The variables in the plot are related by the expression:

  $$y = ax^b \tag{38}$$

  The logarithmic form of which is:

  $$\log y = \log a + b\log x \tag{39}$$

- Substitute the values of *x* and *y* into (39). This will yield a number of equations based on the number of data sets available.
- Divide the number of equations into two to give two different sets of equations. Add each to give two different equations in *a* and *b*.
- The solution of the two different equations in a and b gives the following results:

  $$a = 1.5705 \; and \; b = -0.8438$$

- Substituting the values of the constants into equation (38)

  $$y = 1.5705x^{-0.8438} \tag{40}$$

The relationship between the π – terms can now be written as:

$$\frac{E}{KPt^3} = 1.5705\left(\frac{RTKt^3}{mV}\right)^{-0.8438} \tag{41}$$

From the above expression, the Evaporation loss (kg) can now be calculated as follows:

$$E = KPt^3\left(1.5705\left(\frac{RTKt^3}{mV}\right)^{-0.8438}\right) \tag{42}$$

3.4 Validation

The predictive equations were validated by comparison of computed results from developed and reference equations using coefficient of determination R^2. According to [17], the coefficient of determination R^2 is used in the context of equations whose main purpose is the prediction of future outcomes on the basis of other related information. It provides a measure of how well future outcomes are likely to be predicted by the equation. It is a statistic that gives information about the 'goodness of fit' of an equation. An R^2 value of 1.0 indicates a perfect fit of the equation. Percent deviation formula is very useful in determining how accurate the data collected by research really is. The data is usually compared to reference data. If the percent deviation is a negative number that means the student data is lower than the standard value.

Using the equation for coefficient of determination provided by the above mentioned author and percentage deviation formula, the predictive equations were validated against the reference equations for evaporation.

- Coefficient of determination

$$R^2 = \frac{a\sum Y + b\sum XY - n\bar{Y}^2}{\sum Y^2 - n\bar{Y}^2} \quad (43)$$

Where,

R^2 = coefficient of correlation.

$\bar{Y}$ = mean value of Y

X = independent variable (calculated values).

Y = dependent variable (predicted values).

n = number of measurements / calculations.

- Percentage deviation

$$\%\ deviation = \frac{Predicted\ value - Standard\ value}{Predicted\ value} \quad (44)$$

4. Results and Discussion

4.1 Spilled oil parameters and other relevant data

The spilled oil parameters (variables) in addition to other relevant data which determine the rate of mass loss due to evaporation, in an oil spill on a river system were identified. Table 3 shows the values of the parameters (variables) that determine the rate of mass loss due to evaporation in an oil spill on a non – navigable river.

- Molecular weight (g/mol): Molecular weight is the mass of one molecule of that substance, relative to the unified atomic mass unit (equal to ½ the mass of one isotope of carbon -12). Many chemists use molecular mass as a synonym of molar mass, differing only in units. A stricter interpretation does not equate the two, as the mass of a single molecule is not the same as the average of an ensemble, [18].
- Vapor pressure (Kg/ms^2): The vapor pressure of a liquid is the equilibrium pressure of a vapor above its liquid (or solid); that is, the pressure of the vapor resulting from evaporation of a liquid (or solid) above a sample of the liquid (or solid) in a closed container. The vapor pressure of a liquid varies with its temperature. As the temperature of a liquid or solid increase its vapor pressure also increases. Conversely, vapor pressure decreases as the temperature decreases [19].
- Mass transfer co-efficient (m/s): In engineering, the mass transfer coefficient is a diffusion rate constant that relates the mass transfer rate, mass transfer area and concentration gradient as driving force. This can be used to quantify the mass transfer between phases, immiscible and partially miscible fluid mixtures. Quantifying mass transfer allows for design and manufacture of separation process equipment and estimate what will happen in real life situations e.g. chemical spills etc., [20].
- Universal gas constant R ($Kgm^2\ K^{-1}mol^{-1}s^{-2}$): The gas constant (also known as the molar, universal, or ideal gas constant, denoted by the symbol R) is a physical constant which is featured in a large number of fundamental equations in the physical sciences, such as the ideal gas law and Nermst equation [10].
- Ambient temperature (oil surface temperature) (K): Ambient temperature (also referred to as room temperature) is a common term to denote a certain temperature at which humans are accustomed. Ambient temperature is thus often indicated by general human comfort, with the common range of 27^0C to 32^0C though climate may acclimatize people to higher or lower temperatures [11].

- Volume of Spill (m^3): A major spill is defined as a discharge of oil in excess of 2500 barrels in inland water ways, land or coastal waters, [12].

Table 3: Values of the parameters (variables) that determine the rate of mass loss due to evaporation, in an oil spill on a non – navigable river

S/no.	Parameters (variables)	Value
1	Oil molecular weight	126 g/mol
2	Oil vapour pressure	44.9 g/cm3
3	Evaporation mass transfer coefficient	5.27 x 10-4 m/s
4	Universal gas constant	8.3144 Kgm2K-1mol-1s-2
5	Oil surface temperature	270C (300K)
6	Volume of oil spilled	5,000 barrels = 794.5m3

4.2 Predictive Evaporation Equation

Predictive evaporation equation was developed from the previously described parameters (variables), using dimension analysis. These equations were used to evaluate the percentage mass loss due to evaporation within a period of 24 hours.

The rate of evaporation causes a very significant mass loss in many kinds of oil [21]. It claims approximately 47% of the slick mass in 24 hrs. This figure is significant for attempts at resource recovery. It also has a profound effect on the density, viscosity and other properties of the oil. With the light (low-molecular weight) fractions rapidly leaving the slick, the average molecular weight and viscosity of the slick increases. This creates room for the formation of oil globules which are easily dispersed in the water column or sink to the bottom [22].

Table 4 shows the developed predictive equations and the percentage mass loss due to evaporation, after a period of 24 hours.

Table 4: Developed predictive equation and the percentage mass loss due to evaporation after a period of 24 hours

Weathering Process	Predictive Equation	Mass loss (%) (after 24 hours)
Evaporation	$E = KPt^3\left(1.5705\left(\frac{RTKt^3}{mV}\right)^{-0.8438}\right)$	47

4.3 Validation of Predictive Evaporation Equation

Table 5 shows the comparison between the results of the evaporation equation of [7] and the predictive evaporation equation. The results of the predictive equation showed a cumulative mass loss of 679,821 kg after a period of five (5) days.

The developed predictive equation for evaporation shows a good fit with the reference equation of [7]. The predictive equation has a coefficient of determination R^2 value of 0.99 and an average percentage deviation of -1.702, indicating a reasonable agreement between the two equations. A graph showing percentage mass loss due to evaporation with respect to time elapsed was plotted for both equations.

Table 5: Comparison between the results of the evaporation equation of [7] and the predictive evaporation equation

Time Elapsed (days)	1	2	3	4	5
	Cumulative Evaporation loss (kg)				
Shen and Yapa evaporation equation. $F = \left(\frac{1}{C}\right)\left[lnP_0 + ln\left(CK_E t + \frac{1}{P_0}\right)\right]$	314,502	452,640	546,573	614,205	664,929
Predictive evaporation equation $E = KPt^3\left(1.5705\left(\frac{RTKt^3}{mV}\right)^{-0.8438}\right)$	321,699	445,342	535,120	612,369	679,821
Coefficient of determination R^2	0.99				
Average percentage (%) deviation	-1.702				

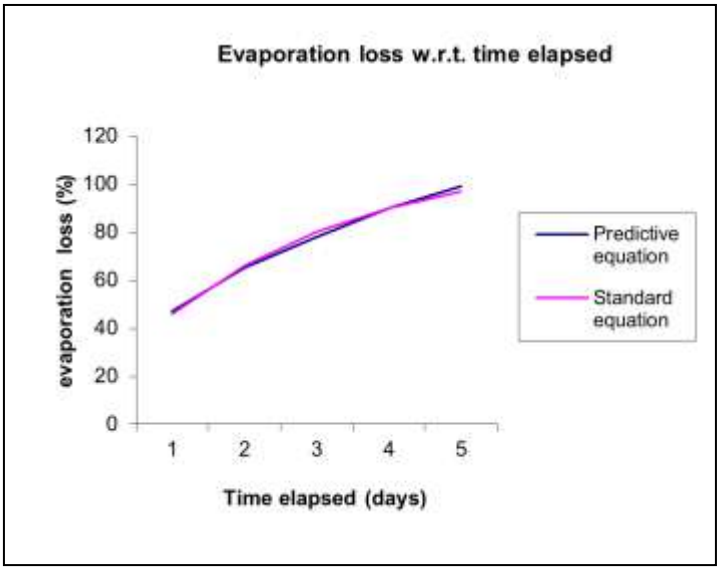

Figure 2: *Percentage mass loss due to evaporation from slick with respect to time*

4.4. Conclusion

This study explored the development of predictive equation for evaporation of spilled oil in non-navigable Rivers. Evaporation is one among the physico – chemical processes that occurs in an oil spill on a water body. This process results in loss of mass and changes in physical characteristics of the spilled oil. A predictive equation has been developed to evaluate the mass loss due to evaporation process in an oil spill on non-navigable river. Parameters considered in the development of the predictive equation are: spilled oil properties, rate coefficients, river and environmental parameters. The predictive equation was developed from first principles using dimension analysis. The developed predictive equation is as follows:

Mass loss due to evaporation: $E = KPt^3\left(1.5705\left(\frac{RTKt^3}{mV}\right)^{-0.8438}\right)$

The result of the predictive equation showed a mass loss of 47% for evaporation, after a period of 24 hours. The result of the predictive equation for evaporation was validated using coefficient of determination. The result obtained was compared with the evaporation equation of [7]. The developed predictive equation had R^2 value of 0.99, which indicates a good fit of the equation. In addition percentage deviation values of -1.702 between the predictive equation and reference equation indicate a good agreement between the two equations.

5. ACKNOWLEDGMENT

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