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A NOVEL APPROACH TO ESTIMATION OF LEAK VOLUME IN AN OIL PIPELINE

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Abstract

A newly different model for the estimation of leak volume in an event of oil spill is presented. The model utilizes the concept of flow through an orifice and liquid relief through a valve to evolve a criterion for elapsed leak time in an event of a leak as well as the orifice area through which the leak is occurring. Orifice area was determined through a liquid relieving scenario and back-pressure at the point of leak assumed to be at atmospheric pressure. A set of mathematical equations were developed and integral solution of the form function of a function was used to solve the resulting differential equation describing the depressurizing process. The model was however validated using a pipeline profile data of a pipeline X which has suffered spill in time past at Niger Delta region where it performed well. Inputs to the model are parameters describing the configuration and characteristics of a pipeline system, the fluid it contains, and the leak or break from which the discharge occurs. Key outputs are the evolution of the release rate over time and the total mass of oil released.

Keywords: *Oil Pipeline*; *Leaks*; *Detection*; *Niger Delta*; *Oil Spill*; *Mathcad; ORIFLO Model; Orifice*.

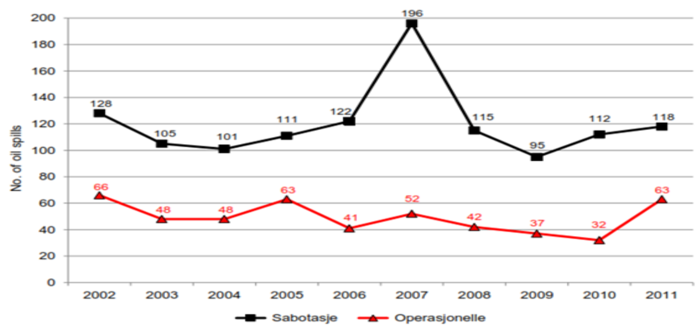
1. Introduction

Due to environmental, economic and social cost of hydrocarbon leaks, the oil and gas industry places great importance to the need to minimize ugly events of oil spill or pollution from occurring. The causes of pipeline leaks could be categorized into four main classes: Operational, structural, unintended or intended damages [1].

Operational include equipment failure, human error *etc*. Equipment Failures can result in environmental hazards due to the release of petroleum and natural gas products. Releases from Equipment Failures rarely result in injuries to the public. An equipment failure may involve a pipeline component or device other than pipe. Sometimes a part on the piece of equipment fails resulting in a release, and sometimes the piece of equipment itself fails to perform its function properly resulting in a release. The concept of human error, whether intentional or unintentional, is defined as any human action or lack thereof that exceeds or fails to achieve some limit of acceptability, where limits of human performance are defined by the system[2]. Human error plays a significant and sometimes overriding role in accident causation. Statistics that attribute accidents or losses to human error are varied and are reported to be as high as 85 % [3].

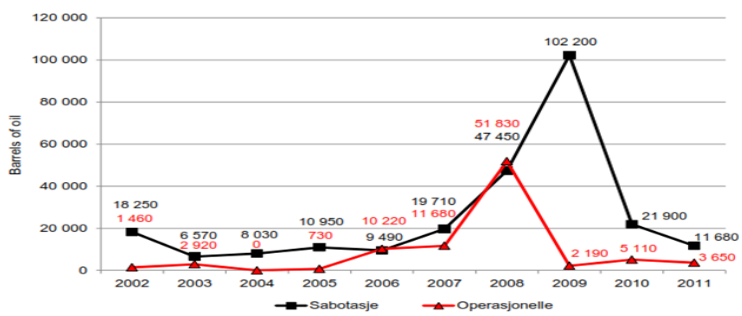
Structural problems include the failure of pipeline in burst, collapse, fatigue, fracture, buckling, corrosion (wall thickness loss), and internal loadings *etc*. The unintended damages are those that are often caused by construction workers working in the vicinity of the pipeline.

The intended damages come in the form of terrorist attack, sabotage/theft/vandalization. Oil pipeline vandalization is a criminal act of destroying oil pipelines in an attempt to illegally tap oil and other petroleum products.



Sabotage Operational failure

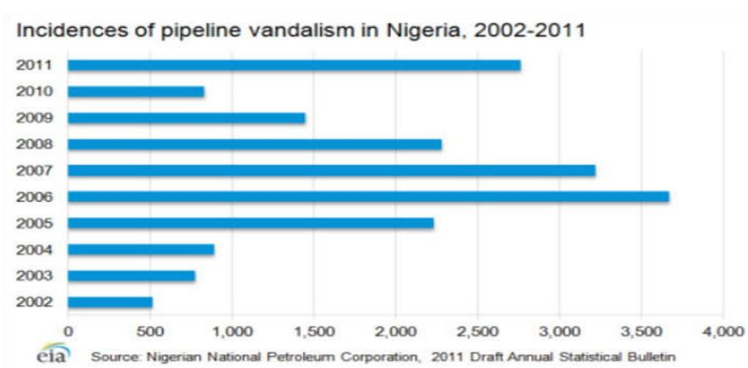
Source: Shell's website, www.shell.com



Sabotage Operational failure

Source: Shell's website, www.shell.com

Pipeline vandalization is a big issue, which has extended into explosion at site where villages in oil communities converge to scoop fuel from burst pipes. Figure by the special committees on fuel distribution show an alarming increase over the past years. Ninety-three cases of rupture and vandalization were recorded by the pipeline and products marketing company in 1993. It increased to 49 in 1996, 45 in 1997, soared to 81 in 1998, 524 in 1999, and spelled to 800 for the half of 2000. Death toll hits 310 on pipeline victims in Adeje, near Warri, Delta state, and the additional victim, earlier rushed to herbal homes for treatment have been reported dead; about twenty, other bodies were recovered in nearby bushes. No fewer than 250 persons were said to have been consumed in the inferno which occurred while the villagers were scooping fuel from the 12-inch pipeline conveying fuel from Warri to the Northern part of the country allegedly vandalized. News of the death of the 40 additional victims came as more bodies of victims were recovered and given instant mass burial at various spots in Oviri court and Adeje communities. Investigation revealed that no fewer than 20 bodies of victims who ran into the bust in an attempt to stay alive were recovered (NATIOA-NAL CONCORD, 2000).



From the above discussion one can see that despite the leak detection technologies present today in the Niger Delta region that oil spills resulting from pipeline vandalism have continued to be a challenge, with most incidents along major pipelines and manifolds [4].

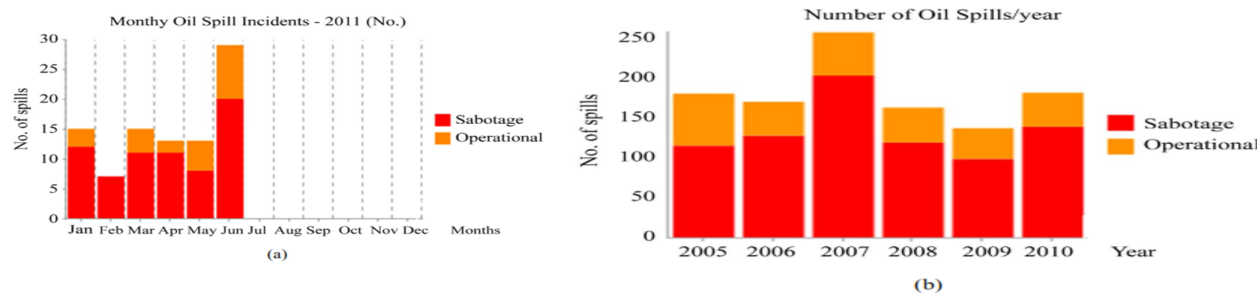


Fig. 1. (a): Showing the 2011 Oil spill monthly statistics from pipelines of Shell Nigeria; (b): Showing some yearly oil spill statistics from pipelines of Shell Nigeria. (Source: SHELL Oil Spill 2011 data. http://www.shell.com.ng/home/content/nga/environment_society/respecting_the_environment/oil_spills/)

Also it has been reported in New York times that a leak occurred in an oil pipeline undetected for 17 hours despite leak detection and alarm systems. This was confirmed by a report issued in July by the National Transportation Safety Board on an Enbridge Energy accident in 2010 near Marshall, Mich., found problems with that company's leak detection system.

The safety board however concluded that Enbridge workers had not been sufficiently trained to recognize the alarms being generated by the system, which contributed to the spill's going undetected for 17 hours. The Enbridge spill dumped more than 840,000 gallons of oil and led to extensive environmental damage that required closing a stretch of the Kalamazoo River for about 2 years.

The dynamic model is more complicated. This model attempts to mathematically model fluid flow within a pipeline. It uses hydraulic equation with actual pipeline data to develop expected hydraulic profile. A leak is suspected when there exist discrepancy patterns between measured and calculated flow; a leak is then declared once a discrepancy pattern specific to a leak is recognized [6-9]. This model fallout because of its mathematical complexity, its inherent thresholds, its dependability on the accuracy and availability of wide range of instrumentation and its extensive data requirement [10]. Hence, this form of leak detection is exposed to a high number of potential false alarms.

For the mean time planning and execution to oil spills from oil pipelines remains inevitable following the previous discussions. This led to the development of a newly different mathematical model (ORIFLO 1) for the estimation of the eventual volume of oil which may be released during the incident. The model utilizes the concept of flow through an orifice and liquid relief through a valve to evolve a criterion for elapsed leak time in an event of a leak as well as the orifice area through which the leak is occurring. Orifice area was determined through a liquid relieving scenario and back-pressure at the point of leak assumed to be at atmospheric pressure. This set of mathematical equations developed where integrated into a computer based MATHCAD software to ease calculation. Inputs to the model are parameters describing the configuration and characteristics of a pipeline system, the fluid it contains, and the leak or break from which the discharge occurs. Key outputs are the evolution of the release rate over time and the total mass of oil released.

2. Model development and simulations for liquid pipeline flow systems

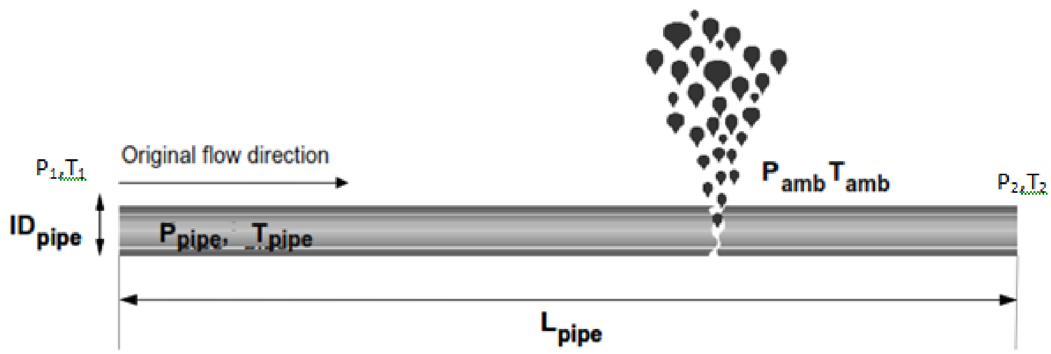
2.1 Derivation of basic equation for the estimation of pipeline oil spill volumes

First is to determine the velocity (V_{amb}) at which the liquid is leaving the pipeline at P_{amb}, T_{amb}.

Assumption:

- ✓ The pipeline is horizontal, no elevation.
- ✓ Pipeline carrying liquid (oil and water) only.

- ✓ Steady state flow.
- ✓ Pressure and temperature at the point of leak is atmospheric.
- ✓ Fluid is incompressible (i.e. density of liquid does not change as pressure decreases from initial pressure P_1 to the total back pressure, atmospheric pressure P_{atm}).
- ✓ Flow is turbulent.
- ✓ Leak occurring through a rupture, C_d = 0.62.



Considering point 1 and point amb. in fig. above, assuming steady state flow and applying Bernoulli theorem we have;

$$\frac{P_1}{\rho_1} + \frac{V_1^2}{2g} + Z_1 = \frac{P_{amb}}{\rho_{amb}} + \frac{V_{amb}^2}{2g} + Z_{amb} \quad (1)$$

Where: V = velocity of flow; P = pressure; ρ_1 = specific weight or density of oil at 60 deg. Centigrade; g = acceleration due to gravity. (9.8m/s^2 or 32.2lb/ft^2).

No elevation between 1 and amb. Eqn. 1 reduces to:

$$\frac{P_1}{\rho_1} + \frac{V_1^2}{2g} += \frac{P_{amb}}{\rho_{amb}} + \frac{V_{amb}^2}{2g} \quad (2)$$

In the event of a leak the pipe is been shut in at a time t and velocity V_1 = 0 equation 2 above further reduces to;

$$\frac{P_1}{\rho_1} = \frac{P_{amb}}{\rho_{amb}} + \frac{V_{amb}^2}{2g} \quad (3)$$

Let $\frac{P_1}{\rho_1}$ and $\frac{P_{amb}}{\rho_{amb}}$ be H_1 and H_{amb} respectively, substitute this in equation 3 above to get;

$$H_1 = H_{amb} + \frac{V_{amb}^2}{2g} \quad (4)$$

Re-arranging equation 4 and making V_{amb} the subject of the formula gives;

$$V_{amb} = \sqrt{2 * g(H_1 - H_{amb})} \quad (5)$$

Calculating the coefficient of discharge and the orifice area

$$C_d = \frac{Actual\ discharge}{Theoretical\ discharge} = \frac{Q_{act.}}{a*\sqrt{2*g*h}} \quad (6)$$

Substitute eqn. 5 in eqn. 6 it becomes

$$C_d = \frac{Actual\ discharge}{Theoretical\ discharge} = \frac{Q_{act.}}{a*V_{atm}} \quad (7)$$

Note 1: C_d ranges from 0.62 – 0.65 depending on the size and shape of the orifice. From API 520 0.65 is used when a PRV is installed on the pipeline with or without rupture disk combination. 0.62 is used when a PRV is not installed and sizing is for a rupture disk.

Actual discharge, $Q_{act} = Q_2 - Q_1$ (8)

Governing Equation:

$$A_r = \frac{Q_{act}}{38K_dK_wK_cK_v}\sqrt{\frac{\gamma_l}{P_1 - P_2}} \quad (9)$$

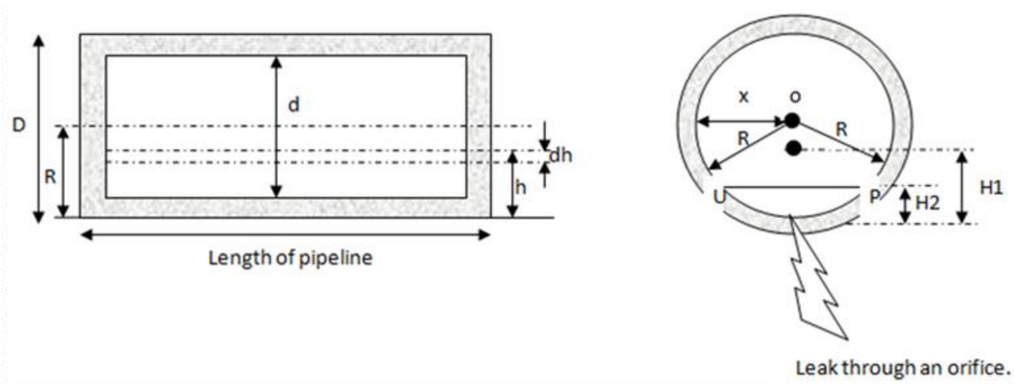
where: A_r =required effective discharge area, in^2; Q_{act} = actual discharge flow rate, gal/min; K_d = Coefficient of discharge (0.62-0.65); K_w = Correction factor due to back pressure. If the back pressure is atmospheric use K_w = 1.0; K_c = combination correction factor. Use 1.0 for rupture scenario; K_v = correction factor due to viscosity. K_v =1 when sizing for non-viscous/turbulent flow regime.

$$K_v = \left[0.9935 + \frac{2.878}{Re^{0.5}} + \frac{342.75}{Re^{1.5}}\right]^{-1.0} \quad (10)$$

γ_l = specific gravity of liquid at flowing temperature referred to water at standard conditions.
P_1 = upstream of leak pressure (i.e initial pressure), Psig.
P_2 = Total back pressure (i.e atmospheric pressure), Psig.
Re = Reynolds Number, dimensionless

$$Re = \frac{2800 * Q_{act} * \gamma_l}{\mu\sqrt{A}} \quad (11)$$

where: μ = viscosity in centipoises, cp; A = effective discharge area from API 520 standard orifice sizes, in^2.



Volume of liquid leaving the pipe in time dT

dT= A * dh (12)

Expanding the R.H.S of equation 12 gives

dT=A*dh=UP*L*dh = 2*x*L*dh (13)

Where A = surface area and UP = 2x

Volume of liquid flowing through the orifice in time dT

$$dT = C_d * a * \sqrt{2 * g * h} * dT \quad (14)$$

Applying volume balance equation 13 and 14 becomes

$$2*x*L* dh = C_d * a * \sqrt{2 * g * h} * dT \quad (15)$$

Note2: Calculation of dT has been discussed extensively in part 1 of this research work under elapsed leak time estimation and thus summarized as follows;

$$= T = \frac{4*L}{3*C_d*a*\sqrt{2*g}} * \left[(2R - H_{atm})^{\frac{3}{2}} - (2R - H_1)^{\frac{3}{2}}\right] \quad (16)$$

Where: C_d = coefficient of discharge anda = area of orifice.

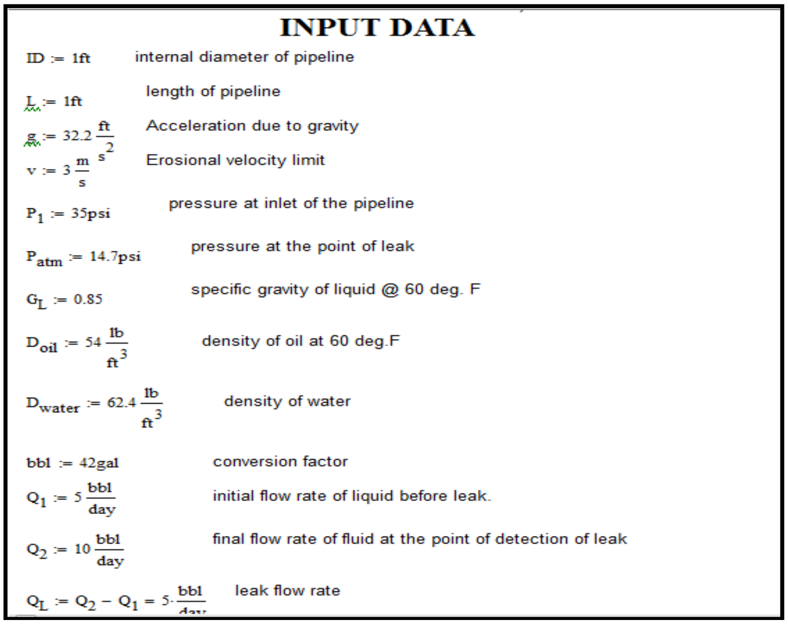
Thus the amount of oil spilled through an orifice in the pipeline can be estimated using the following equation;

$$V_{oil-spill} = C_d * a * \sqrt{2 * g * (H_1 - H_{amb})} * T \quad (17)$$

2.2 Computer model development using MathCAD software

Mathcad is computer software primarily intended for the verification, validation, documentation and re-use of engineering calculations [5]. Mathcad is generally accepted as the first computer application to automatically compute and check consistency of engineering units such as the International System of Units (SI), throughout the entire set of calculations.

An input data section allows the user to define the configuration and characteristics of a pipeline system, the fluid it contains, and the leak or break from which the discharge occurs.



INPUT DATA

$ID := 1ft$ internal diameter of pipeline

$L := 1ft$ length of pipeline

$g := 32.2 \frac{ft}{s^2}$ Acceleration due to gravity

$v := 3 \frac{m}{s}$ Erosional velocity limit

$P_1 := 35psi$ pressure at inlet of the pipeline

$P_{atm} := 14.7psi$ pressure at the point of leak

$G_L := 0.85$ specific gravity of liquid @ 60 deg. F

$D_{oil} := 54 \frac{lb}{ft^3}$ density of oil at 60 deg.F

$D_{water} := 62.4 \frac{lb}{ft^3}$ density of water

$bbl := 42gal$ conversion factor

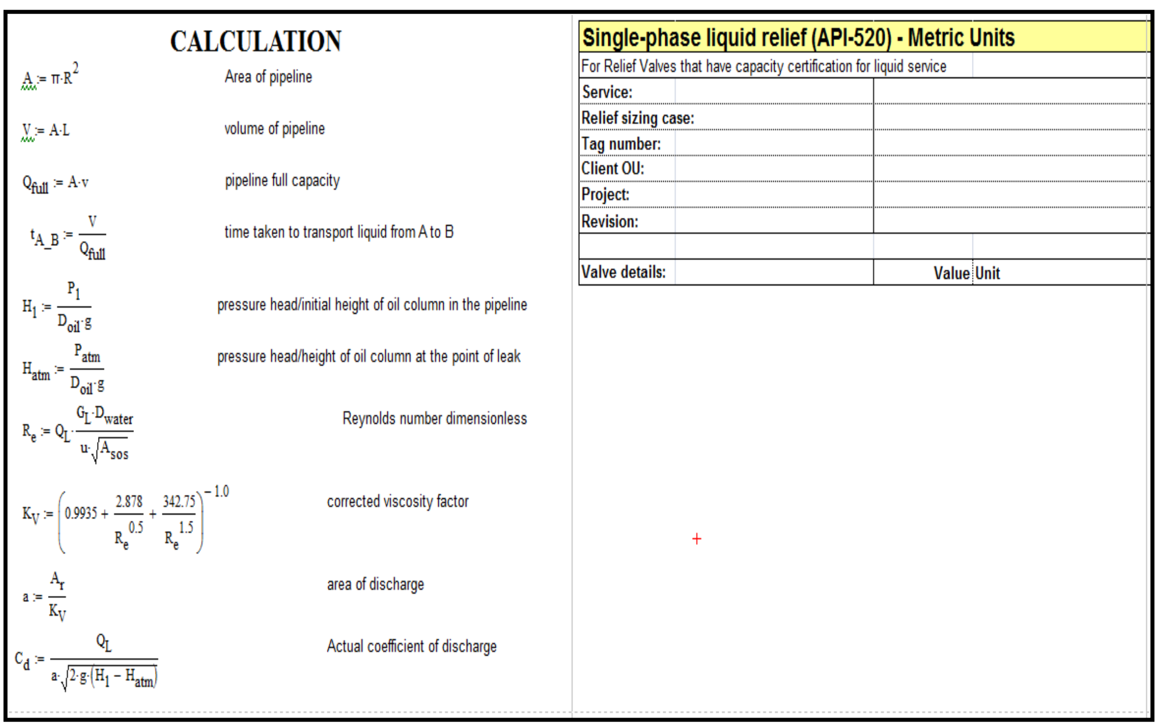
$Q_1 := 5 \frac{bbl}{day}$ initial flow rate of liquid before leak.

$Q_2 := 10 \frac{bbl}{day}$ final flow rate of fluid at the point of detection of leak

$Q_L := Q_2 - Q_1 = 5 \cdot \frac{bbl}{day}$ leak flow rate

Figure 1 Snapshot showing input data section.

An output data section uses the model developed to perform operations using pre-defined computer algorithms and brings out result as output. An interface of the calculation/output section is shown below;



CALCULATION

$A := \pi \cdot R^2$ Area of pipeline

$V := A \cdot L$ volume of pipeline

$Q_{full} := A \cdot v$ pipeline full capacity

$t_{A\_B} := \frac{V}{Q_{full}}$ time taken to transport liquid from A to B

$H_1 := \frac{P_1}{D_{oil} \cdot g}$ pressure head/initial height of oil column in the pipeline

$H_{atm} := \frac{P_{atm}}{D_{oil} \cdot g}$ pressure head/height of oil column at the point of leak

$R_e := Q_L \cdot \frac{G_L \cdot D_{water}}{u \cdot \sqrt{A_{sos}}}$ Reynolds number dimensionless

$K_V := \left(0.9935 + \frac{2.878}{R_e^{0.5}} + \frac{342.75}{R_e^{1.5}}\right)^{-1.0}$ corrected viscosity factor

$a := \frac{A_r}{K_V}$ area of discharge

$C_d := \frac{Q_L}{a \cdot \sqrt{2 \cdot g \cdot (H_1 - H_{atm})}}$ Actual coefficient of discharge

Single-phase liquid relief (API-520) - Metric Units		
For Relief Valves that have capacity certification for liquid service		
Service:		
Relief sizing case:		
Tag number:		
Client OU:		
Project:		
Revision:		
Valve details:	**Value**	**Unit**

Figure 2 Snapshot showing a Mathcad output data section.

3. Case study – Model validation

3.1. Pipeline overview

Pipeline X is a 25 km long, 24" diameter L'Ecole Oil pipeline (original names omitted for confidential reasons), located in OML-17, about 16 Km North of Port-Harcourt in Rivers State. It conveys processed crude oil from L'Ecole oil production system to the storage terminal. Operating at an approximate capacity of 30 MBPD, with a design capacity of 60 MBPD so other lines can tie to it. Lately, an oil spill has occurred along this pipeline with real data measured from leak location. However this measured data will serve as a reference point to the validation of the models so developed.

3.2 Aim of simulation

Primarily the aim of this simulation is to validate the models (Pipesim and Pipeline model) so developed and also populate the MathCad sheet with output data from simulation results to estimate the volume of leak.

3.3 Setting up simulation

Data gathering: Data used for the simulation study was sourced from the following key documents: L'Ecole Flow station As-Built Drawing (2012), L'Ecole Flow station Equipment Data sheet, L'Ecole Flow Stations IPSC for July 2013.

Further data and information were obtained from various sources including PVT reports, PipeSim simulation results, Production Chemistry laboratory data, DEPs and surveillance data from site visit.

Data Validation: A QA/QC was done on the PVT data gathered using mole balance plot. Figure 4 below shows the degree of accuracy of the data obtained.

Table 1 Pipeline X profile data used for simulation

parameter	symbol	SI	US
Pipeline capacity	Q	0.074 m^3/s	1167 gpm
Length of pipeline	L	80,470 m	264,000 ft
Diameter	D	16"	1.33 ft
thickness	d	0.311"	0.026 ft
Mass density	ρ	885.7 kg/m^3	55.292 lb/ft^3
Velocity range	v	3-5 m/s	9.84-16.4 ft/s

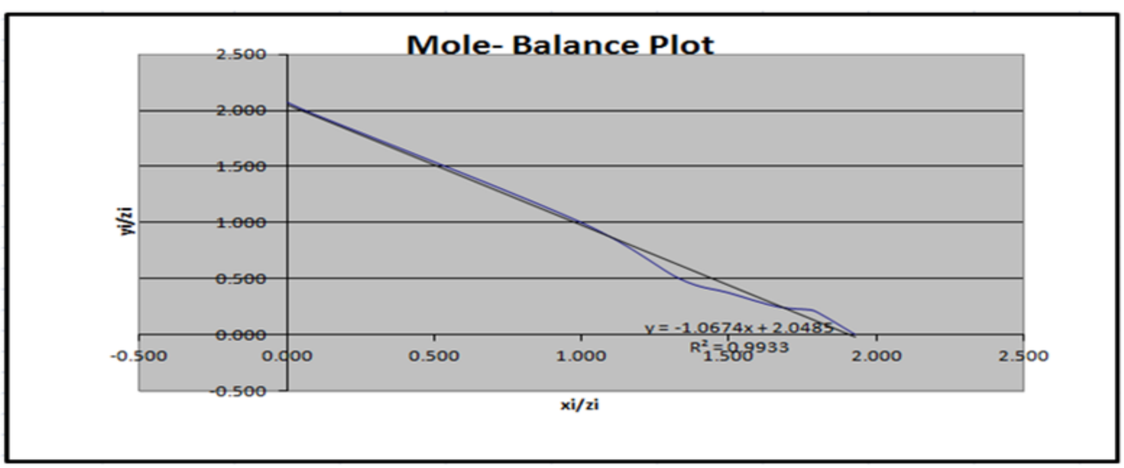


Figure 3 Plot showing Pipeline X fluid composition data validation

Other data were also validated using different data validation techniques. Figure 5 shows a flowchart of the trend followed by the data validation technique.

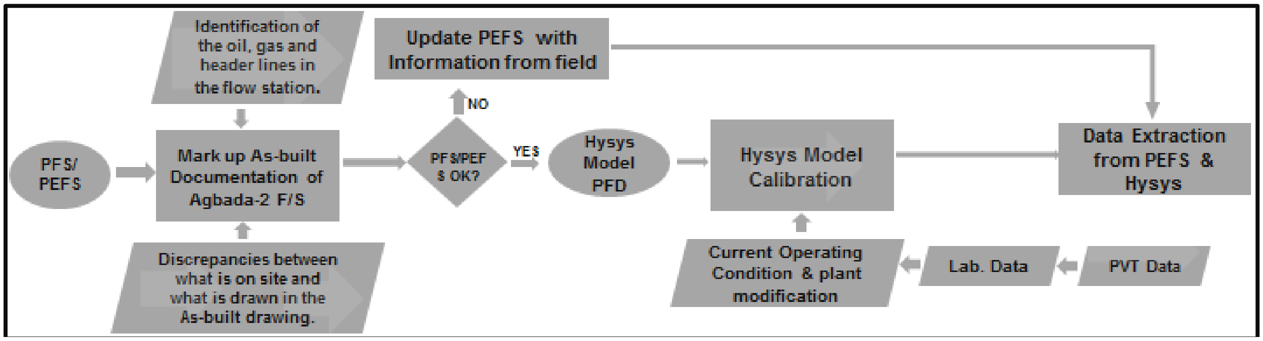


Figure 4 Basic process chart showing data validation from Pipesim and PEFS.

Building Model: Updated Pipeline X model was unavailable as no study has been done on this pipeline recently, so the old existing model was calibrated with current operating data gotten from pipeline X operators. However this model served as an input to the MathCAD sheet as further data were extracted from this model to populate the sheet for calculation. Basic steps taken to calibrate model include;

Step 1-Selecting units: The built in units system allows you the flexibility to select any variable and define the unit of measurement to be used. For this study the oil field unit has been chosen as a default.

Step 2-Set Fluid Data: Compositional type fluid data was used in this study for more accuracy. Basic Sediments and water content of 30% was used. Also performed in the compositional analysis is the C_7^+ characterization. In order to employ an EOS, one must characterize the C_7^+ fraction of the reservoir fluid. In this context, characterization is defined as the determination of the critical temperatures, critical pressure, acentric factor and interaction parameters. In this study, C_7^+ was characterized in the petroleum fraction sub-section using the boiling point, molecular weight and specific gravity as input parameter. The composition is then added to the main composition and an amount entered before calculating the critical properties and acentric factor. A snapshot of this characterization is shown below;

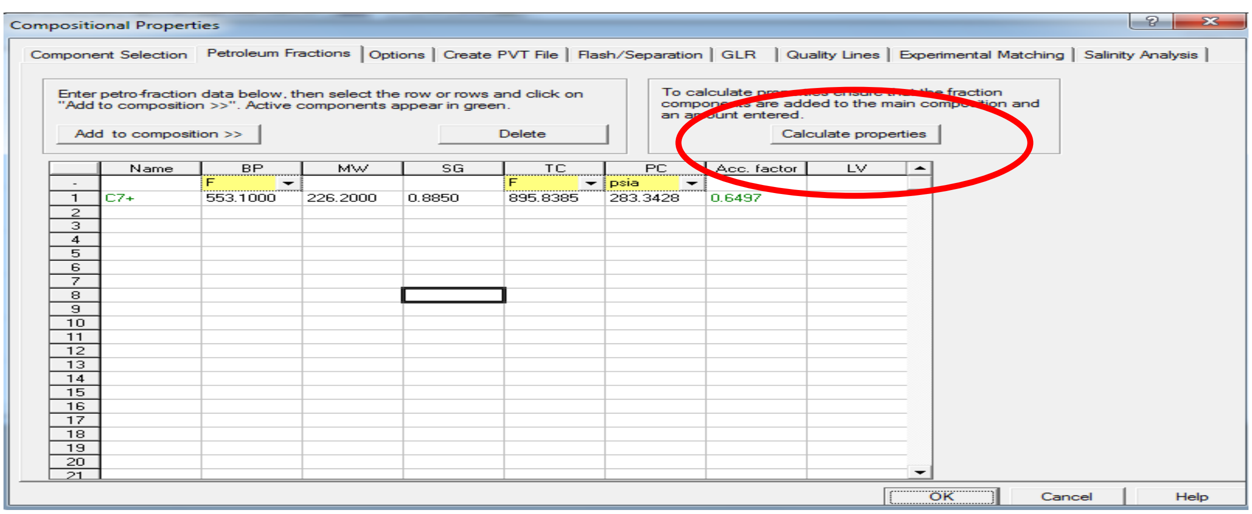


Figure 5 An Interface of the C7+ characterization Section.

Step 3: Adding flow line/equipment: A single branch flowline of diameter 24" and length 25 Km was added to the simulation package. A simple view schematic as the pipeline was assumed to be horizontal. Other data needed for the convergence of flowline calculation can be found in the process engineering flow scheme (PEFS).

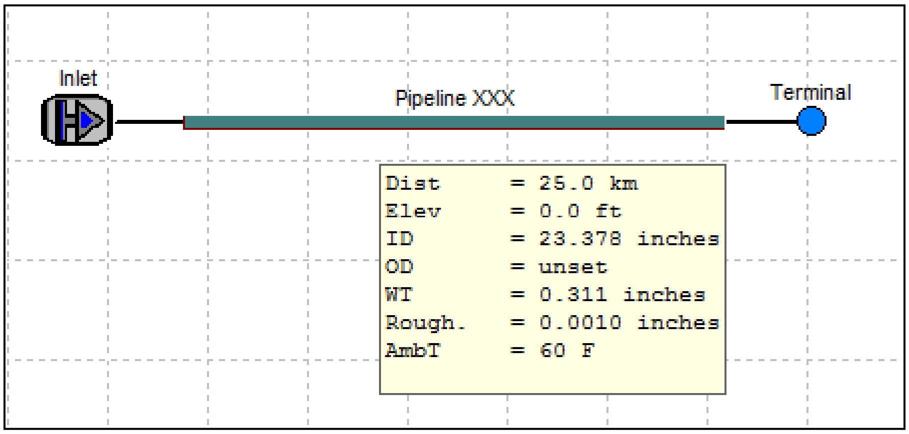


Figure 6 A snapshot of the pipeline X solved model.

3.4 Running simulations

Simulation 1: Simulation 1 was run to ascertain the accuracy of the pipeline model built using pipesim. Accuracy was checked against the conventional pressure drop profile of a liquid pipeline. Trendline of the plot showed that the model built was a representative model. However this was used as a means of validating the data obtained and also as an input to the MathCAD calculation sheet. Sensitivities were also run for different pressure drops and results showed a good match. Sensitivity plots can be seen in the appendix figure 16, 17 and 18. The figure below shows an interface of the simulation setup before run;

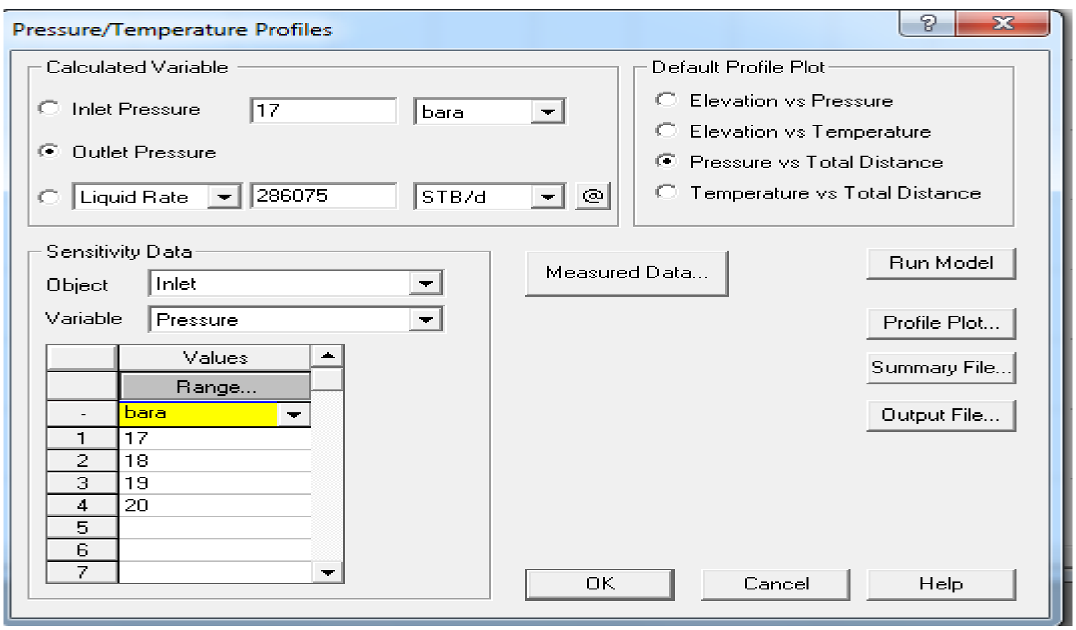


Figure 7 A snapshot of the pressure drop simulation interface.

Simulation 2: Here the Mathcad sheet is used to generate time taken for leak to occur at different flowrates. Dimensionless flowrates were used as ranges of flowrates were expressed in terms of percentage of the initial volume. For clarity on how to generate this plot, refer to the steps listed below;

Step 1: populate the Mathcad sheet with the available data as shown below;

INPUT DATA

$ID := 23.378in$	internal diameter of pipeline
$L := 25km$	length of pipeline
$g := 32.2\frac{ft}{2}$	Acceleration due to gravity
$v := 1.9\frac{m}{s}$	Erosional velocity limit
$P_1 := 250psi$	pressure at inlet of the pipeline
$P_{atm} := 14.7psi$	pressure at the point of leak
$G_L := 0.8857$	specific gravity of liquid @ 60 deg. F
$D_{oil} := 885.7\frac{kg}{m^3}$	density of oil at 60 deg.F
$D_{water} := 62.4\frac{lb}{ft^3}$	density of water
$bbl := 42gal$	conversion factor
$Q_1 := 286075\frac{bbl}{day}$	initial flow rate of liquid before leak.
$Q_2 := 0\frac{bbl}{day}$	final flow rate of fluid at the point of detection of leak
$Q_L := Q_1 - Q_2 = 2.861\times10^5\cdot\frac{bbl}{day}$	leak flow rate

Figure 8 Input data section

Step 2: Calculate the area through which the discharge occurs, a using the single – phase liquid relief sizing/rating spreadsheet on the right hand side of the input section. Note: Assume full discharge i.e. Q_2 = 0 BPD. Further guide on how to use the single phase liquid relief sizing/rating spreadsheet can be found in section 3.3.1.

Single-phase liquid relief (API-520) - Metric Units			
For Relief Valves that have capacity certification for liquid service			
Service:			
Relief sizing case:			
Tag number:			
Client OU:			
Project:			
Revision:			
Valve details:		**Value**	**Unit**
Set pressure, Ps		16.8	barg
Overpressure		10.0	%
Upstream relief pressure, P1 (gauge)		18.5	barg
Back pressure, P2 (gauge)		8.0	barg
Liquid relief:		**Value**	**Unit**
Mass flowrate		500,000	kg/h
Liquid density		835.0	kg/m³
Discharge coefficient, Kd		0.65	
Back pressure factor, Kw		1.00	
Rupture Disk combination factor, Kc		1.00	
Viscosity factor, Kv		1.00	
Volume flowrate		9,980	l/min
Specific gravity		0.8	
Calculated orifice area, A		51.076	cm²
	Standard orifices (DEP)	**Area**	**Unit**
	1D2	0.71	cm²
	1E2	1.26	cm²
	1.5F2	1.98	cm²
	2H3	5.06	cm²
	3K4	11.86	cm²
	4L6	18.41	cm²
	4P6	41.16	cm²
	6Q8	71.23	cm²
	6R10	103.23	cm²

Figure 9 Excel spreadsheet for the calculation of discharge area.

Step 3: Calculate the percentage flowrates/volume of liquid in the pipeline (measured leak volume was used in this study) and their corresponding height in the pipeline by using the Excel spreadsheet on the right hand side of the output section. Note3: pipeline volume was used as the initial volume.

Leak time taken (	%	% vol. of Leak	Height (H11)
17.54	1	435.5	0.1948
	2	871	0.275488802
	3	1306.5	0.337403497
	4	1742	0.3896
	5	2177.5	0.435586042
	6	2613	0.477160602
	7	3048.5	0.515392355
	8	3484	0.550977604
50.58	9	3919.5	0.5844
52.2	10	4355	0.616011688
72.3	20	8710	0.871172084
85.7	30	13065	1.066963542
95.4	40	17420	1.232023376
103.6	50	21775	1.37744401
109.8	60	26130	1.508914312
114.8	70	30485	1.629813732
118.6	80	34840	1.742344168
121.5	90	39195	1.848035065
122.93	100	43550	1.948

Figure 10 Leak volume expressed in percentage of the pipeline volume.

Step 4: calculate the time taken for leak to occur at different flowrates. This is done by inputting the H11 value and tabulating the leak time value as shown above. A plot of % volume of leak against time taken is shown in the result section. However this time gotten is utilized in simulation 3 and 4 to calculate the volume and location of leak respectively.

Simulation 3: Simulation 3 aims at calculating/predicting the measured volume of leak. Here Mathcad automatically reads the value of leak time into the leak volume equation and thus calculates/predicts the volume of leak or oil spilled. Note4: The leak volume equation must always be below the leak time equation. Figure below shows a cross-section of the calculation interface.

$$H_{11} := 0.22\text{ft}$$

$$H_{22} := 0\text{ft}$$

$$C_d := \frac{Q_L}{a\cdot\sqrt{2\cdot g\cdot(H_{11}-H_{22})}} = 36.569$$

$$T_L := \left[4\cdot\frac{L\cdot\left[(2R-H_{22})^{\frac{3}{2}}-(2R-H_{11})^{\frac{3}{2}}\right]}{3\cdot K_d\cdot a\cdot\sqrt{2\cdot g}}\right] = 20.223\cdot\text{hr} \qquad \text{Time of leak}$$

$$V_L := K_d\cdot a\cdot T_L\cdot\sqrt{\left[2\cdot g\cdot(H_{11}-H_{22})\right]} = 4.087\times10^{3}\cdot\text{bbl} \qquad \text{Leak Volume}$$

Figure 11 Leak volume calculation Interface.

4. Results and discussion

4.1 Simulation 1 results

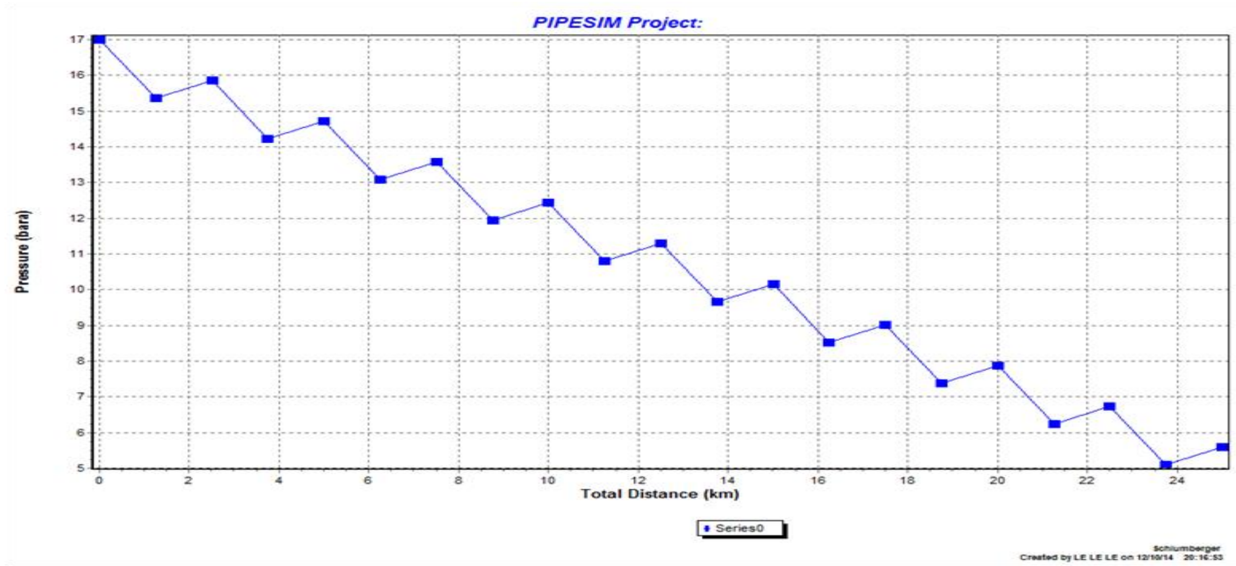


Figure 12 Pressure drop profile at 17 bar inlet pressure.

Simulation 1 shows the pressure drop profile of the liquid along the pipeline. Fluid was flowed at 17 bar (inlet pressure) through a 24 Km pipeline with an arrival pressure of 5.5 bar, pressure drop along the pipeline is 0.5bar/Km. This result however showed a good match with the conventional pressure drop plots/trend line as pressure decreases with an increase in pipeline length.

4.2 Simulation 2 results

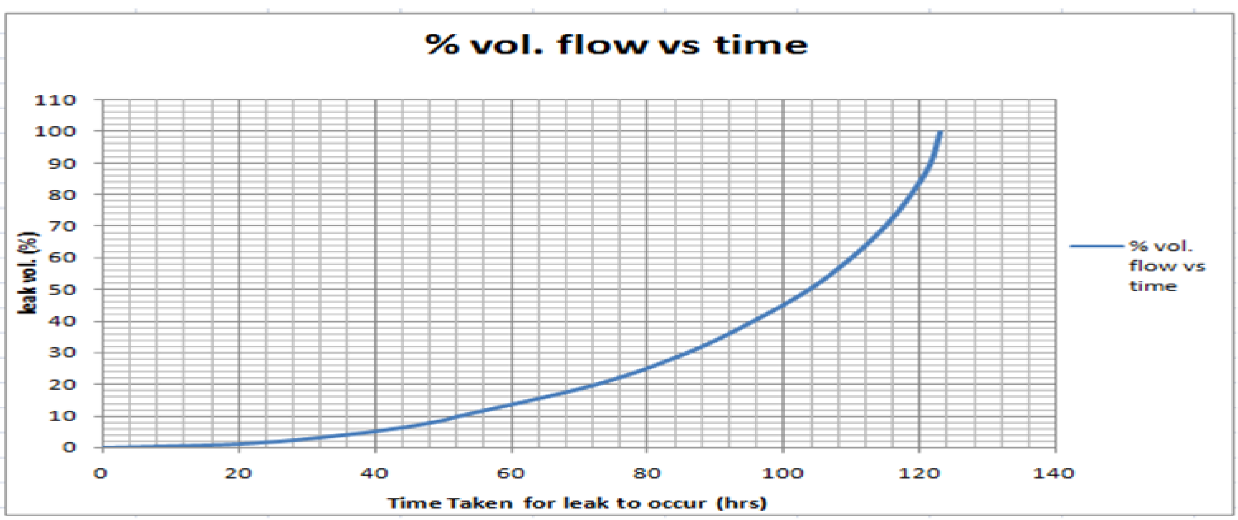


Figure 13 Diagram showing evolution of flow against time.

The area through which discharge occurs was calculated to be 0.135ft^2 from the single-phase liquid relief sizing/rating spreadsheet and Mathcad sheet. Calculated percentage for the measured volume of leak was 1.23 % and this was used to calculate the time taken for the leak to occur, hence 20.223 hrs. Note: The model is been validated as measured volume of leak was used to calculate the % volume of leak thus iterative.

4.3 Simulation 3 results

$$T_L := \left[4 \cdot \frac{L \cdot \left[(2R - H_{22})^{\frac{3}{2}} - (2R - H_{11})^{\frac{3}{2}} \right]}{3 \cdot K_d \cdot a \cdot \sqrt{2 \cdot g}} \right] = 20.223 \cdot hr$$ Time of leak

$$V_L := K_d \cdot a \cdot T_L \cdot \sqrt{\left[2 \cdot g \cdot (H_{11} - H_{22}) \right]} = 4.087 \times 10^3 \cdot bbl$$ Leak Volume

$$t_s := 8hr$$

$$V_T := Q_{full} \cdot 1day = 2.859 \times 10^5 \, bbl$$ Total vol. of liquid transported in a day.

$$V_f := \frac{V_T}{V} = 6.566$$ fraction of pipeline volume transported in a day

$$t_T := t_{A\_B} \cdot V_f = 24\,hr$$ total time for full liquid transport in a day

$$t_G := \frac{t_T}{L} = 1.053 \frac{s}{ft}$$ time gradient

$$t_{LD} := t_s + (24hr - T_L) = 11.777\,hr$$ actual leak time

Figure 14 Leak volume result interface.

Calculated/Predicted leak volume from the Mathcad sheet as seen above is 4087 bbls as against measured value of 4000 bbls. Error analysis include;

$$\%\, \boldsymbol{Error} = \left| \frac{\boldsymbol{measured\ value - predicted\ value}}{\boldsymbol{measured\ value}} \right| * \mathbf{100}$$

An error percent of -2 was gotten from the calculation using the formula above. However, this value is acceptable as over 2% of the actual leak volume was post -accounted for by the model.

5. Conclusion

In conclusion, a new different pipeline model (ORIFLO 1) has been developed to estimate the leak volume in the event of an oil spill. This model utilizes the concept of flow through an orifice and line depressurization.

Discussion from results showed that time taken for leak to occur, T_L are more sensitive parameter to leak volume estimation. Discussion from sensitivity results showed that the time taken for leak to occur increases exponentially with % volume of flow through the orifice which in turn is a function of orifice size and area. This also is a sensitive parameter for leak volume estimation.

Inputs to the model are parameters describing the configuration and characteristics of a pipeline system, the fluid it contains, and the leak or break from which the discharge occurs. Key outputs are the evolution of the release rate in percentage over time and pressure drop along the pipeline. Test applications of the software are described.

The model has been tested against several actual accidental pipeline breaks. The results are good, in that the model estimates tend to lie between minimum and maximum field estimates.

The results of this study make clear the need for more structured reporting of actual events, such that the model can be better calibrated and verified in the future. Important information such as pipeline pressures and shut-in time are often missing from the incident reports, making ORIFLO model difficult and less reliable than necessary.

Finally, depending on the robustness and efficiency of the flow meters installed at the inlet and outlet of the pipeline, Leak volume less than 1% of the initial volume can be accurately modeled using the ORIFLO 1 equation thus accurately estimating the leak volume.

References

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Appendix-sensitivity data

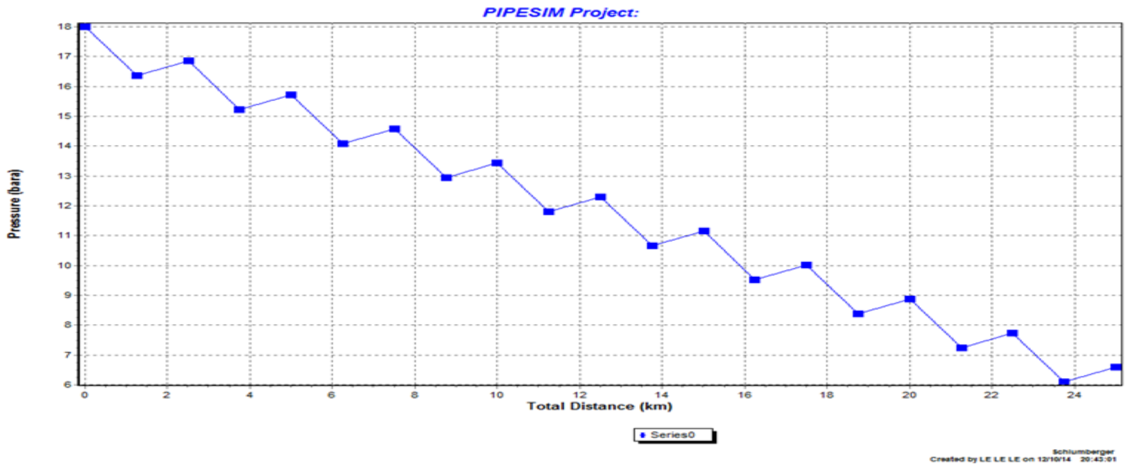

Figure 15 Pressure drop profile at 18 bar inlet pressure

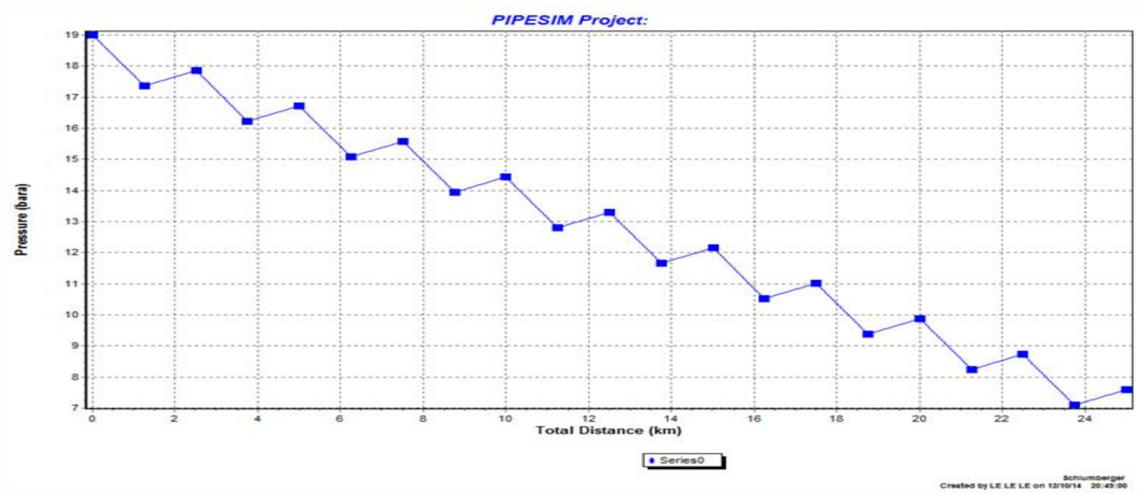

Figure 16 Pressure drop profile at 19 bar inlet pressure

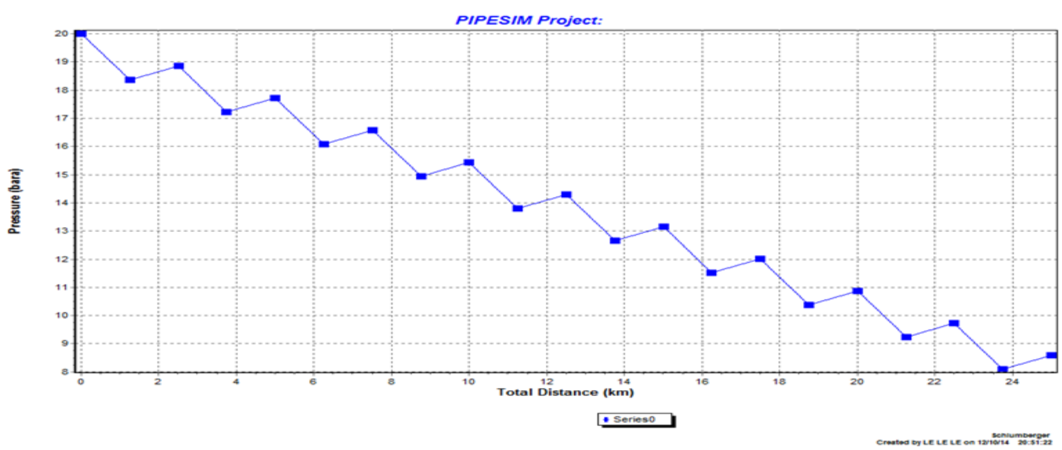

Figure 18 Pressure drop profile at 20 bar inlet pressure