A Novel Approach To Estimation Of Leak Location In An Oil Pipeline

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***Abstract*—This paper presents various approaches to the location of leak in an oil pipeline. However these approaches are based on the available input data for the leak location study. The first approach is the hydraulic gradient intersection approach using Pipesim and Excel worksheet. This method relies on the expectation that a leak disturbance settles out eventually to a new Steady-state position. The second approach utilizes a new 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 actual leak time to determine leak location. 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. The two approaches vary in their input data requirements as mentioned before. Key inputs to the former are the input and output flow conditions of temperature, pressure and flow rate while the latter requires the time (shut-in time and time of leak). Key outputs are the rate variation of flow rates against leak location.**

Keywords—Oil Pipeline, Leaks, Location, Hydraulic gradient, Mathcad, ORIFLO Model.

I. INTRODUCTION

Occurrence of leak in an oil pipeline when undetected and located on time will eventually turn out to become a spill causing more harm than good to the environment. However recent pipeline leak incidents have shown that the cost is much more than the associated downtime and clean-up expenses [1]. It is therefore often necessary to install leak detection (and locating) systems (LDS), especially due to legal regulations like the "Code for Federal Regulations (CFR) Title 49 Part 195"[2], API 1130 2nd Ed.[3], both for the USA, or the "Technische Regeln für Fernleitungen" (TRFL) (Technical Rules for Pipelines) in Germany [4].

A number of models exist in the literature for leak location. This was generally grouped into the External and the Internal based system by API 1130 2nd Ed.[3].

Externally based systems use local sensors, generating a leak alarm. System costs and complexity of installation usually are high; applications therefore are limited to special high-risk areas, e.g. near rivers or nature protection areas. Examples for such a type of LDS are acoustic emission detectors monitoring noise levels and location and vapor sensing cables, sensing gas or hydrocarbon vapor near a leak.

Internally based systems utilize field sensors (e.g. for flow, pressure and fluid temperature) to monitor internal pipeline parameters. These field signals are used for inferring a leak. The classical line balance method balancing inlet and outlet volume flow is an example. From a statistical point of view, leak detection is a detection problem, whereas leak location (and rate determination) is an estimation problem: Given the field data, the location (and the rate) of the leak has to be established.

There are many possibilities to classify externally and internally based systems; we want follow the API classification scheme [5]. Further analyses on the internal based method include;

The least square fit of pressure profile can be used in the manner described. Once a leak is indicated either by an identifiable pattern of flow discrepancies or deviations above mass balance thresholds, then a leak location search is initiated, where a leak is imposed to the location search procedure and the resulting pressure profile is checked against SCADA

(Supervisory Control and Data Acquisition) measurements. See figure below

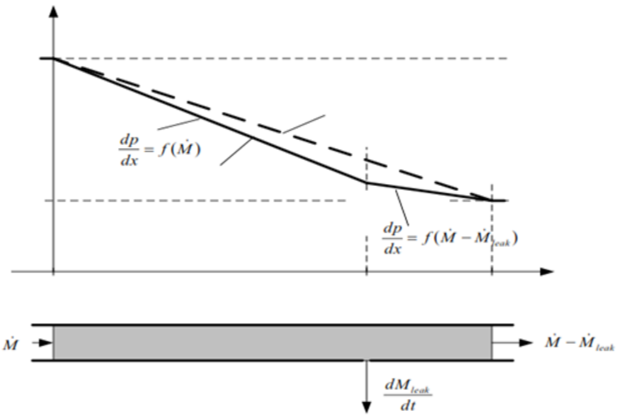


Figure 1 - leak locating with gradient intersection method.

Wave propagation analysis. If a sudden leak M_{leak} & occurs at time t_{leak}, a negative pressure wave with wave front amplitude Δp can be observed propagating with wave speed *a* through the pipeline with cross-sectional area *A*, downstream and upstream with respect to the leak location *x*. Leak location frequently utilizes the negative pressure wave method. This method has its limitation as it can only be used during pumping operations. Further analysis on the wave propagation analysis and leak location in general can be seen in texts [6] and [7]. See figure below

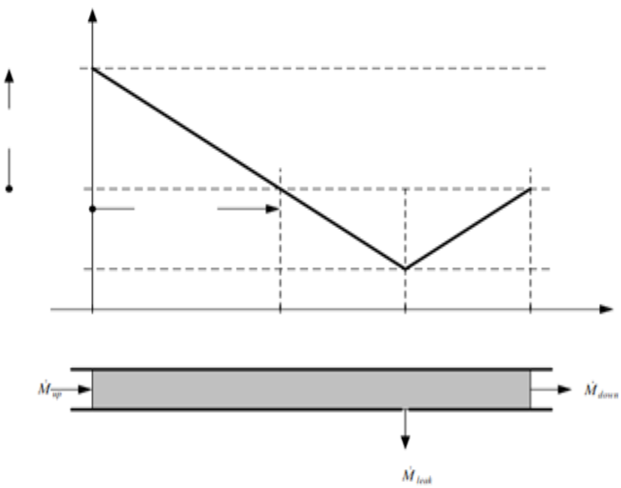


Figure 2 - leak locating with wave propagation analysis.

Presented here are two approaches to the leak location estimation in oil pipelines. One is based on the hydraulic gradient analysis and the other utilizes the concept of flow through an orifice and liquid relief through a valve to evolve a criterion for elapsed leak time as well as location in an event of a leak. Orifice area was determined through a liquid relieving scenario and back-pressure at the point of leak assumed to be at atmospheric pressure. The gradient method uses robust software, Pipesim to generate gradient lines at a defined inlet flow rate for different outlet flow conditions during a leak. Analysis of these gradient lines is done using Excel worksheet. This works best when there is a considerable discrepancy between the inlet and outlet flow rates, therefore it is limited in application to small leaks.

The newly different mathematical model (ORIFLO 2) 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 actual leak time to determine leak location. 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. Key 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 volume over time. Sensitivities were also run at different shut-in time to determine its effect on leak location.

2. METHODOLOGY

When a leak occurs, the resulting leak wave travel at sonic velocity of the fluid [8]. The time lag between the instance when a leak is detected (shut-in time) and when there is no leak is a measure of the time it takes the leak to occur. The distance traveled is evaluated by multiplying this time lag with the upstream velocity v. The leak size can be estimated from the magnitude of flow discrepancies. The leak location can also be determined by two possible methods. They are:

The PIP-XCEL Linear intersection method and
The Orifice Flow (ORIFLO 2) model approach.

2.1 PIP-XCEL Linear Intersection Method

This method uses a steady-state software package, Pipesim to establish the expected pressure drop along the entire length of the pipeline for a particular flow rate. The method as earlier introduced works well when there is a considerable discrepancy between the inlet and outlet flow rate.

Governing Equation for pressure drop in liquid flow;

$$d^5 = 11.5 * 10^{-6} \frac{f L Q_L^2 \gamma_L}{\Delta P} \quad (1)$$

Where
d = pipe inside diameter, in
f = moody friction factor, dimensionless (calculated from Cole-brook white eqn.).
L = length of pipe, ft
Q_L = liquid flow rate, bbl/day
r_L = specific gravity of liquid relative to water
dP = pressure drop, psi

2.2 Derivation of Basic Equation for the Estimation of Location of Leak (X_l) based on the ORIFLO Method

The ORIFLO concept for the determination of the leak location is based on accurate calculation of time of leak. Idea behind this concept also extends to the fact that oil transportation process in pipeline is a continuous process, this fact further emphasizes on the need for accurate measure of time of leak.

Necessary parameters for the derivation of the location of leak can be seen in Fig.3;

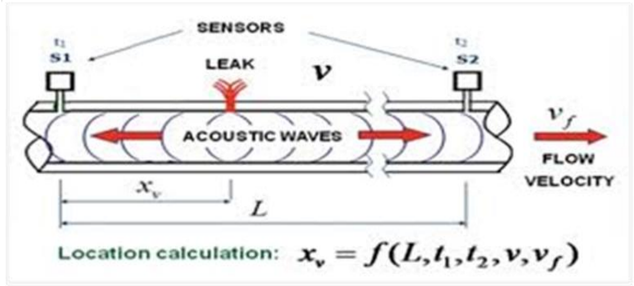


Figure 3 - leak locating dependent parameters.

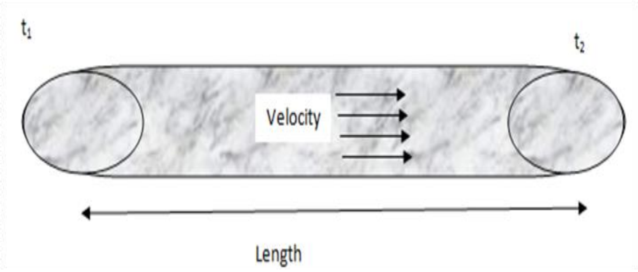
From the diagram above leak location strongly depends on

1. The length of the pipeline.
2. The time interval t_1 and t_2 required to transport liquid along the pipeline.
3. The volumetric flow rate of the liquid been transported.
4. Velocity of the liquid flow.

Assumptions:

1. Time interval between point 1 and 2 has been left in days (0-1day) to minimize error in distance calculated (since oil transport is a continuous process).
2. Time at reference point 1(t_1) = 0, day and time at point 2 (t_2) = 1day.

Consider a pipeline A transporting crude oil from point 1 to point 2 without a leak event as shown below;



- Let the time interval from t_1 to t_2 be t.

$$Q = A * v \quad (2)$$

Where
Q = volumetric flow rate (given).
A = Area of the pipeline (calculated using the diameter of the pipeline).
v = velocity of flow (calculated by making V the subject of formula in the equation above).

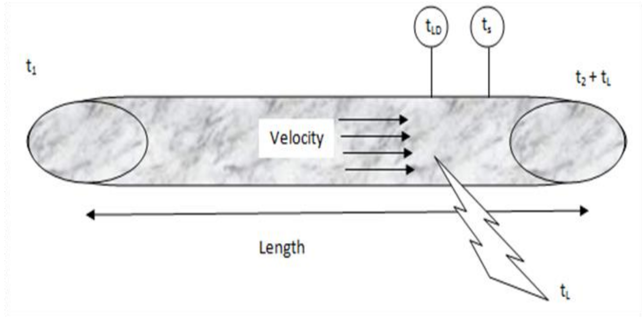
$$Q = \frac{V}{t} \quad (2a)$$

Where
Q = volumetric flow rate (given).
V = volume of the pipeline (Area * length).
t = time required for transportation of liquid from point 1 to 2 in days.

- Time gradient is thus calculated using the equation below

$$t_G = \frac{t}{length} \quad (3)$$

Consider the same pipeline transporting crude oil from point 1 to point 2 with a leak event as shown below;



In the event of a leak just like connecting another pipe to an existing pipeline to share gas or oil transmission, the flow rate increases thereby the time required to deliver the oil to point 2 will also increase. This increase is characterized by the time taken for the leak to occur, t_L therefore time at point 2 as can be seen in the diagram above becomes $t_2 + t_L$.

2.2.1 Relationship between time of leak, t_L, shut-in time, t_s, and time of leak distance, t_{LD}.

When a leak is detected (Q_1 not equal to Q_2) the pipeline is shut in. This time at which the pipeline is shut in is referred to as shut-in time of the pipeline denoted t_s. This simply tells you that before the pipeline was shut-in a leak has occurred and the time taken for this leak to occur is known as time of leak denoted t_L. Therefore the actual time at which the leak started often referred to as the time of leak distance, t_{LD} is calculated by subtracting the time of leak from the shut in time all in days thus stated below;

$$t_{LD} = t_s + (24hr - t_L) \quad (4)$$

NOTE1: If $t_s < t_L$

$$t_{LD} = t_s - t_L) \quad (5)$$

NOTE2: Calculation of dT has been summarized as follows;

$$t_l = \frac{4*L}{3*C_d*a*\sqrt{2*g}} * \left[(2R - H_{atm})^{\frac{3}{2}} - (2R - H_1)^{\frac{3}{2}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where
C_d = coefficient of discharge and
a = area of orifice.
Knowing the actual time at which the leak occurred t_{LD}, the location of leak can be evaluated with low boundary of uncertainty from the equation stated below;
Location of leak,

$$X_L = t_{LD} / t_G \quad (7)$$

Where
Time gradient is calculated from eqn. 3 and t_{LD} from equation 4 or 5.

2.3 Computer Analysis

A computer program was written using Mathcad software to simulate the flow and locate leak of fluid in a pipeline system. Depending on the kind of data available any of the two approaches discussed above can be effectively used to estimate the location of leak within a reasonable bound of uncertainty.

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

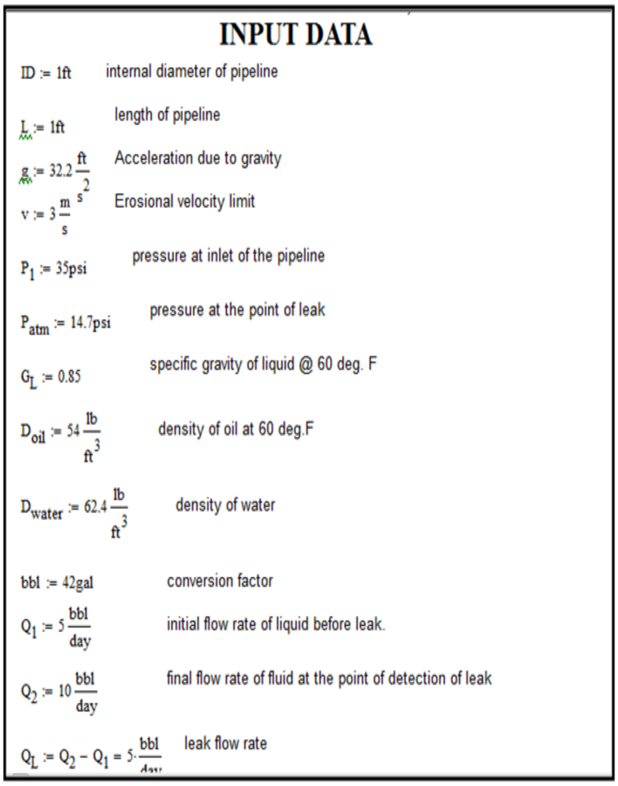


Figure 4 - Snapshot showing input data section.

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;

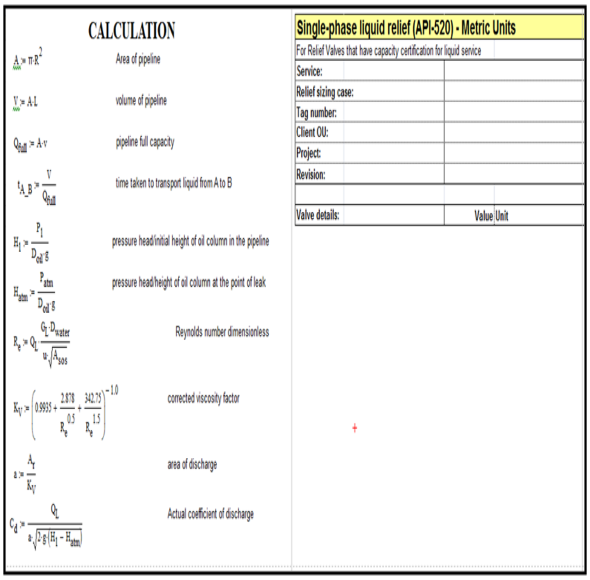


Figure 5 - snapshot showing a Mathcad output data section.

3.0 CASE STUDY – MODEL VALIDATION

3.1 The PIP-XCEL method was validated using the data supplied by pipeline operators was used to simulate the flow pressure and velocity within some specified pipeline segment. The leak and flow behavior of a crude petroleum horizontal pipeline (50miles) segment, of an operating pipeline network of an oil producing company in the Niger Delta was studied. Detailed information about the pipeline is given on Table. 1.0. A flow diagram of the pipeline network was validated using Pipesim as shown in Fig. 6. Below

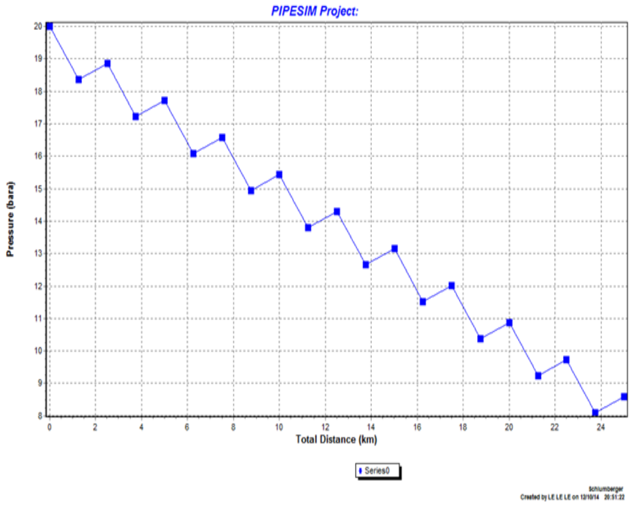


Figure 6 – pressure profile for the 50miles pipeline.

Simulation 1 and 2 were run for the same inlet flow rate and different outlet flow rate as envisaged in a leak scenario.

Simulation results from pipesim are exported into Excel. The Excel work sheet is used to generate correlations and linearly join the resulting outlet flow rate as a result of leak to the pressure drop line when there is no leak thereby locating the leak distance and additionally pressure drop upstream and downstream of the leak location. Pressure drop upstream the leak is calculated from the initial flow rate pressure gradient line while pressure drop downstream is calculated from the final flow rate pressure gradient line.

Discussion on the PIP-XCEL method simulation results can be seen in result section 4.1 and 4.2.

3.2 ORIFLO 2 Model Validation – 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.

3.3 Aim of Simulation

Primarily the aims of this simulation are to validate the models (Pipesim and Pipeline model) so developed and populate the Mathcad sheet with output data from simulation results to estimate the location of leak.

3.4 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 7 below shows the degree of accuracy of the data obtained.

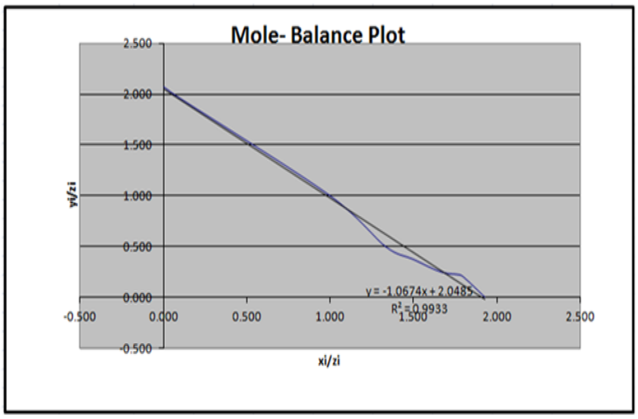


Figure 7 - plot showing Pipeline X fluid composition data validation.

Other data were also validated using different data validation techniques. Figure 8 shows a flowchart of the trend followed by the data validation technique.

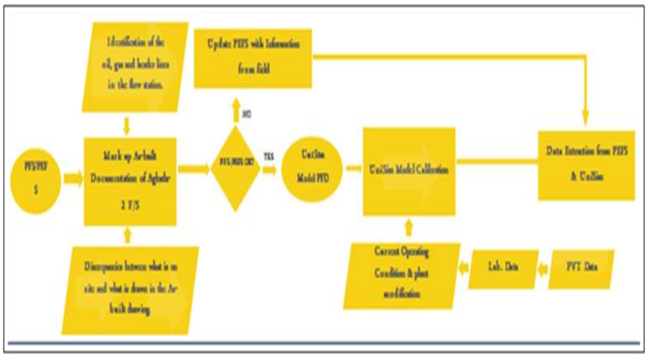


Figure 8 - Basic process chart showing data validation from Pipesim and PEFS.

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;

Step1-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.

Step2-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;

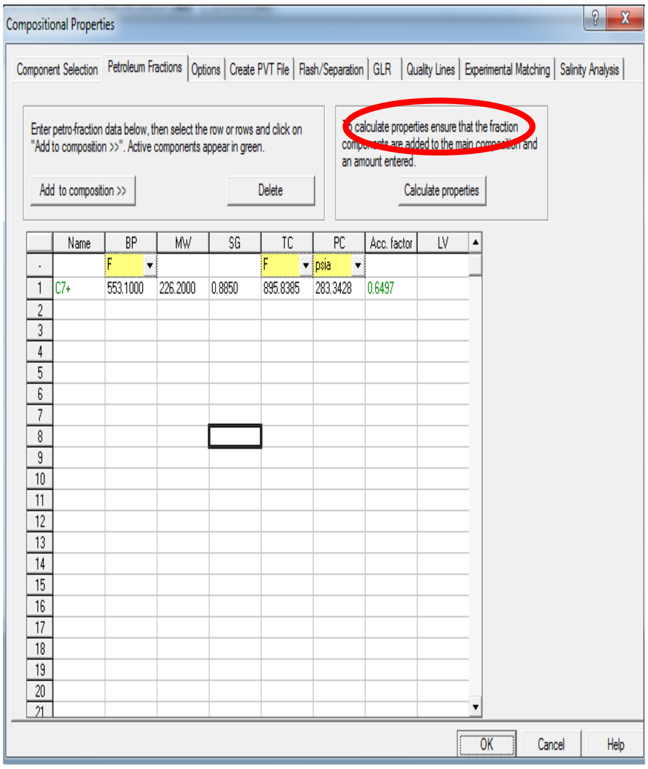


Figure 9 - An Interface of the C7+ characterization Section.

Step3-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).

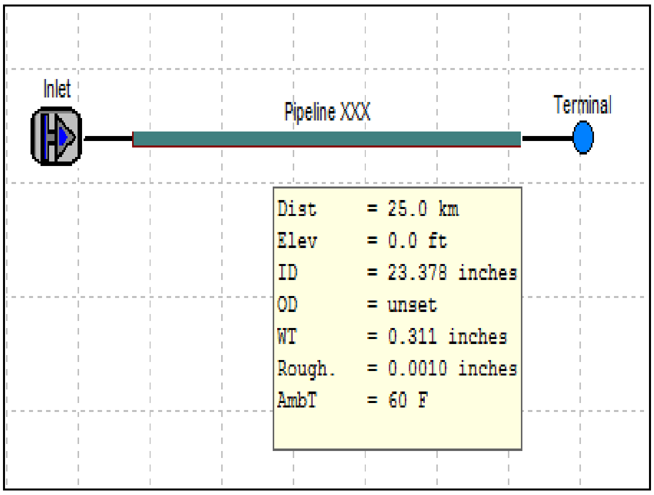


Figure 10 - A snapshot of the pipeline X solved model.

3.5 Running Simulations:

Simulation 3: 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 22 and 23. The figure below shows an interface of the simulation setup before run;

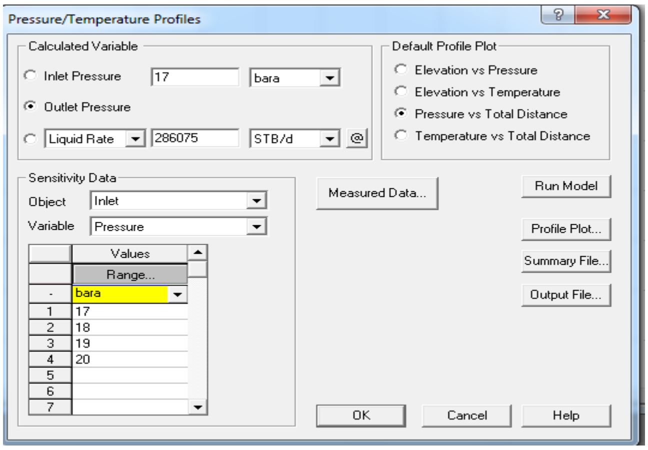


Figure 11 - A snapshot of the pressure drop simulation interface.

Simulation 4: 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

$g := 32.2\frac{ft}{s^2}$ 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

$Q_L := Q_1 - Q_2 = 2.861 \times 10^5 \cdot \frac{bbl}{day}$ leak flow rate

Figure 12 – Snapshot showing the 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. For further guide on how to use the single phase liquid relief sizing/rating spreadsheet, see ref xxx.

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 13 - 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. **NOTE:** 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 14 – A snapshot showing 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 5: In running simulation 4, additional data of shut-in time is used to calculate the actual time at which the leak occurred and then the location. **NOTE**: The pipeline was assumed to be under 24 hrs continuous operation (00.00hrs – 24.00 hrs). The following steps guide the user on how to calculate the leak location using the Mathcad sheet.

Step1: calculate total volume of liquid transported in a day.

Step2: calculate fraction of pipeline volume transported in a day.

Step3: calculate the total time for full liquid transport in a day.

Step4: calculate the time gradient.

Step5: calculate the actual time of leak t_{LD} for different shut in times.

step6: Finally, Mathcad automatically calculates leak location using the data provided above. Sensitivities were run for different shut in times within the range of operation and results shown in the appendix figure 24. Below is a snapshot of the leak location calculation interface;

$$T_L := \left[4\cdot\frac{L\cdot\left[(2R-H_{22})^{\frac{3}{2}}-(2R-H_{11})^{\frac{3}{2}}\right]}{3\cdot K_d\cdot a\cdot\sqrt{2\cdot g}}\right] = 20.223\cdot hr$$ 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 15 - leak location calculation interface.

4.0 Results and Discussion

Simulations were run for different outlet flow rates in the event of a leak. Inlet pressure was kept constant as the flow rate at the inlet was conserved by the pump capacity and also no leak scenario at the inlet.

4.1 Simulation 1 Results

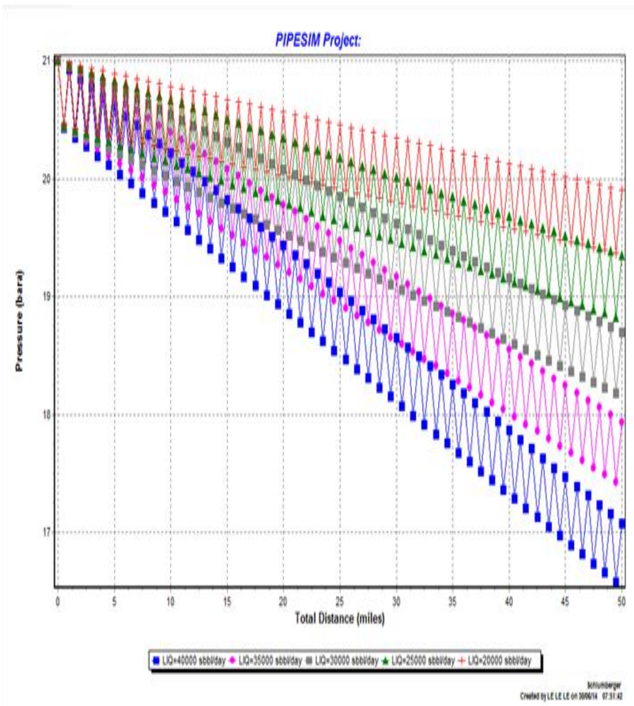


Figure 16 - simulation results of pressure profiles at different flow rates.

Fig. 16 above shows the pressure profile plot of a pipeline x. pipeline data profile used for this simulation is presented in table 1. Depicted in the plots are the expected pressure drops at different outlet flow rates within the same distance.

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

4.2 Simulation 2 Results

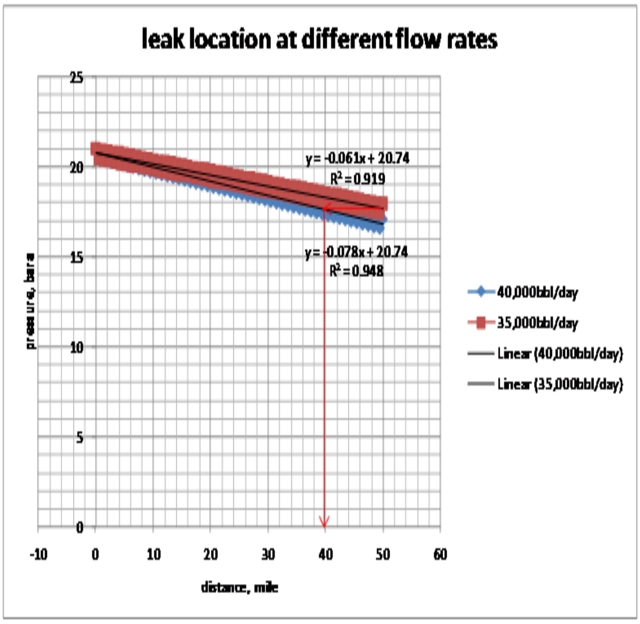


Figure 17 - Result of Leak locating analysis in Excel.

Simulation result data when exported to excel were use to generate plots for inlet and outlet flow rates. Trend line option in Excel was used to identify the line of best fit as flow is turbulent. Linear intersection method was applied and leak location identified. See fig. 17 above. Trend line option was used as a means of validation of the PIP-XCEL linear intersection method which showed a good match as can be seen in Fig. 18. Thus in fig. 18 below the thick lines represents the pressure gradient line at no leak while the dotted lines represents leak at 12.5% decrease in flow rate.

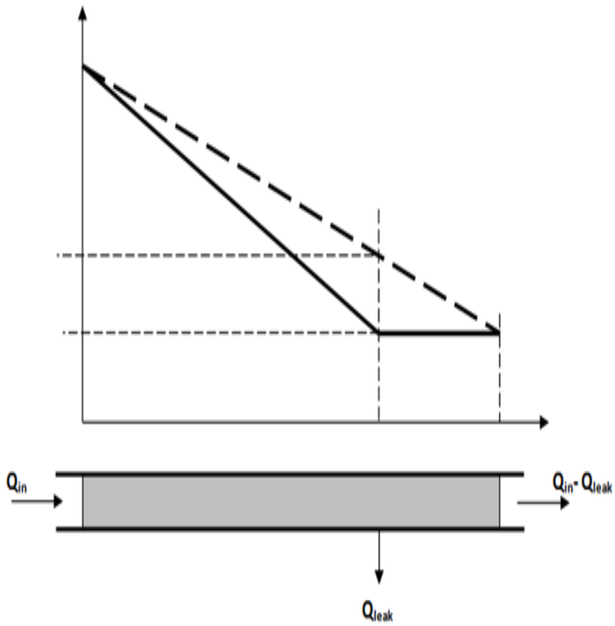


Figure 18 - Leak locating with PIP-XCEL linear intersection method.

4.3 Simulation 3 Results:

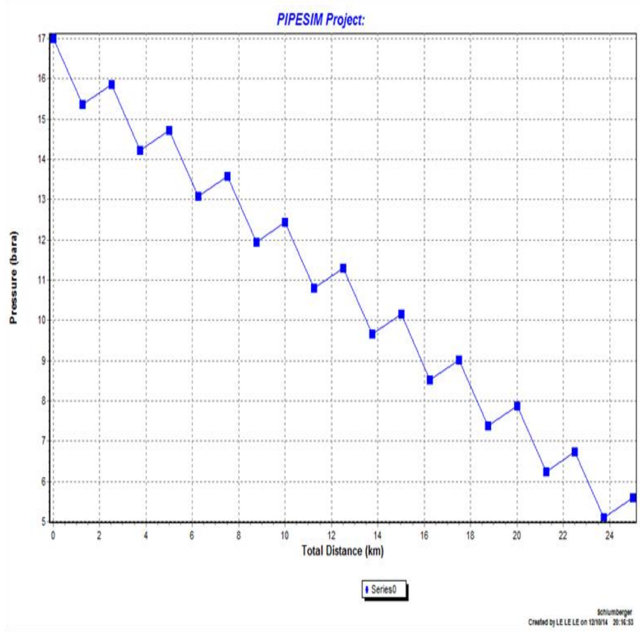


Figure 19 - pressure drop profile at 17 bar inlet pressure.

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.

4.4 Simulation 4 Results:

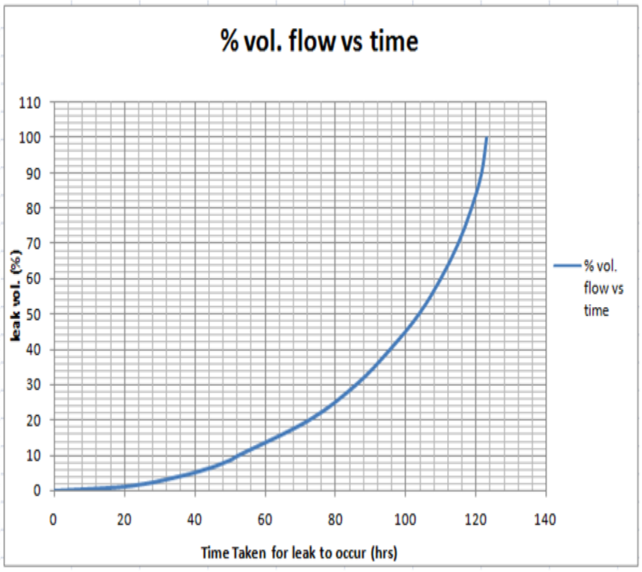


Figure 20 - Diagram showing evolution of flow against time.

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.

4.5 Simulation 5 Results:

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

$$t_s := 4hr$$ shut-in time

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

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

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

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

$$t_{LD} := \begin{cases} t_s + (24hr - T_L) & \text{if } t_s < T_L \\ ((t_s - T_L)) & \text{otherwise} \end{cases} = 7.777hr$$ actual leak time

$$X_L := \frac{t_{LD}}{t_G} = 8.101 \, km$$ Leak Location

Figure 21 - leak Location Result Interface.

Simulation 4 results shows that at a shut-in time of 04:00 HRS as supplied by the pipeline operator, the actual time when the leak started was 07:78 HRS owing to the fact that the leak has lasted for 20.22 HRS as calculated from simulation 2 results. However a leak location of approximately 8 Km was predicted against a measured location of 7.8 Km. Percentage error of 4% was calculated from the error percent formula. NOTE: Accuracy of this model depends on the ability of the operator to record the shut-in time immediately a discrepancy in flowrate or volume is detected. Results of sensitivities can be seen in Figures 22 to 24.

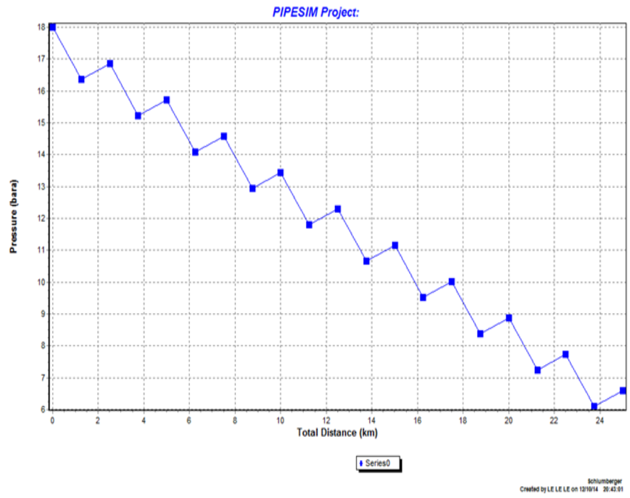


Figure 22 - pressure drop profile at 18 bar inlet pressure.

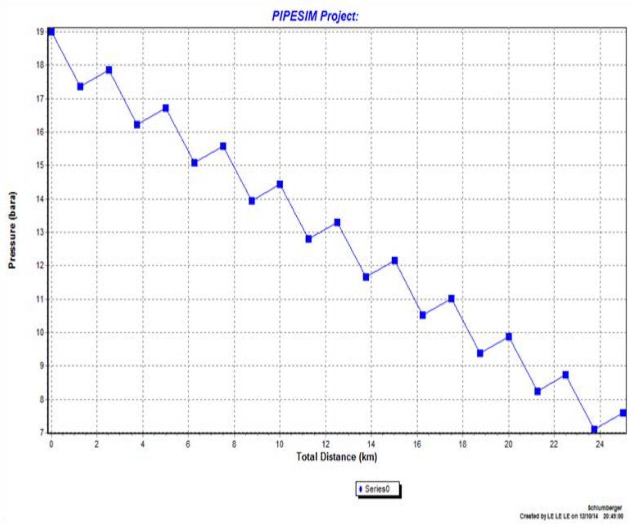


Figure 23 - pressure drop profile at 19 bar inlet pressure.

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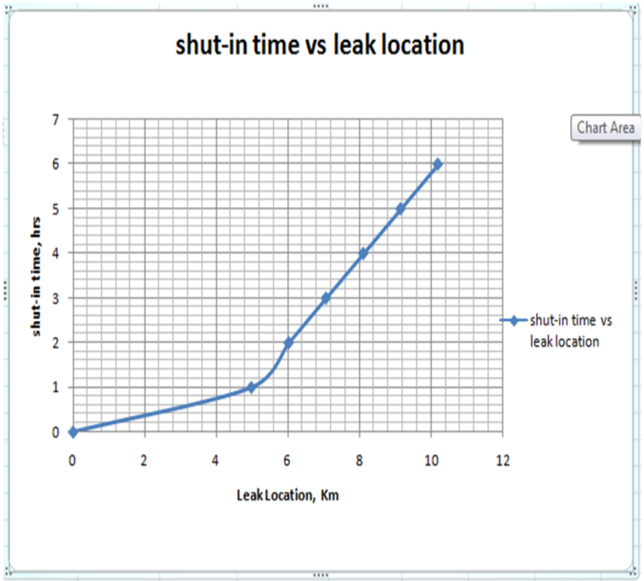

Figure 24 - Leak location at different shut-in times.

5.0 Conclusion

In conclusion two leak locating methods have been presented namely; the PIP-XCEL Linear Interpolation method and the ORIFLO based model approach. The former has been successfully validated using available pipeline data and accuracy compared with already existing method of wave propagation and best fit linear regression, thus it performed well. Results and discussions show that accuracy of this method is highly dependent on pressure and flow rate measurement at the inlet and outlet condition. Limitations to this method can be found in its inability to locate smaller leaks.

The latter ORIFLO based model has also been successfully validated. Discussion from results showed that the time elapsed from the actual time of leak to the shut-in time, t_s are more sensitive parameters to leak location.

Discussion from sensitivity results showed that the shut - time taken for leak to occur increases exponentially with leak location. This also is a sensitive parameter.

Test applications of the model/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. One exception occurs where the field operators are not able to record the shut-in-time and volume/flowrate at this time, for example a leak occurred at 08:00hrs and rate dropped from 10MBPD to 9.5MBPD in 09:00hrs when the operator noticed/shut in at 09:30hrs and recorded 9.5MBPD.

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 2 equation thus accurately estimating the leak location.

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