

# Oil and Gas Offshore Pipeline Leak Detection System: A Feasibility Study

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**Abstract.** Pipelines leaks normally begin at poor joints, corrosions and cracks, and slowly progress to a major leakage. Accidents, terror, sabotage, or theft are some of human factor of pipeline leak. The primary purpose of Pipeline leak detection systems (PLDS) is to assist pipeline operators in detecting and locating leaks earlier. PLDS systems provide an alarm and display other related data to the pipeline operators for their decision-making. It is also beneficial because PLDS can enhance their productivity by reduced downtime and inspection time. PLDS can be divided into internally base or computational modeling PLDS Systems and external hardware base PLDS. The purpose of this paper is to study the various types of leak detection systems based on internally system to define a set of key criteria for evaluating the characteristics of this system and provide an evaluation method of leak detection technology as a guideline of choosing the appropriate system.

## Introduction

Most of the fluids transported by pipelines are hazardous. This will impact on the human safety, pollution on the environment and production lost. Recent pipeline leak incidents have shown that the cost is much more than the associated downtime and clean-up expenses led to increasing awareness and concern for the environment. An effective and proper implementation of pipeline leak detection system will reduced spill volume and increased public confidence [1]. There are a numbers of oil spills issue that cause significant damage to the environment ecosystems, to property, to human life and very high financial loses. Leaks may occur because of many reasons; fatigue cracks, stress corrosion, hydrogen induction and ruptures [2].

Pipeline leak detection technologies can be categorized based on a variety of criteria. They vary from human visual inspections to hardware based sensors to the control systems based, real-time monitoring. Each approach has its strengths and weaknesses. The operational principle, data and equipment requirements, strengths, weaknesses, and the realistic performance limits (size, response time, location, false alarm, etc.) for the leak detection methods are addressed in this paper. Pipeline leak detection systems are varied and uniquely designed for each pipeline application. However, for discussion purposes, leak detection technologies can be classified according to the physical principles involved in the leak detection. Using this type of classification, general categories of leak detection technologies can be divided into the following two groups: Internally Based System and Externally Based System based on [3,4]. Computational Pipeline Monitoring (CPM) has categorized the groups of PLDS methods according to their inherent principle of leak detection as below.

## Internally Base System

Computational pipeline monitoring (CPM) is a term that refers to algorithmic monitoring tools that are used to enhance the abilities of a pipeline controller to recognize anomalies which may be indicative of a release (leak). This Computational method system uses pipeline operation data to calculate prediction operational parameters under normal mode. The predictions are compared to measured parameters to identify changes that maybe indicate a leak [5, 6]. CPM totally relies on the data collected from the field instruments, which are continuously input into a computer program that mathematically or statistically analyses the information. Analysis results are produced in the form of parameter estimates, which in turn are subjected to some decision criteria to determine if a leak is present (API, 1130). The classes of (CPM) are differentiated by the types of instruments and programs (or algorithms) used.

Based on [7], the Mass Balance Method is based on equation of conservation of mass. This technique identifies an imbalance between the incoming (receipt) and outgoing (delivery) volumes of mass. The volumes of product entering and leaving a pipeline are measured over a specified time period. The measurement results are expressed in terms of standardized volumes. The outgoing mass is subtracted from the incoming mass over the time period. A leak is suspected if the difference exceeds a threshold value. According to [8], the Pressure Point-Analysis (PPA) leak detection method is part of the pressure/flow monitoring method, which is based upon the statistical properties of a series of pressure or velocity pipeline measurements at one point being different before and after a leak occurs. The PPA method detects leaks by monitoring pipeline pressure at a single point along the line and comparing it against a running statistical trend constructed from previous pressure measurements contains evidence of a leak.

A sudden leak causes pipeline damage due to carelessly use of equipment, leads to negative pressure wave propagating at the speed of sound to both direction trough the pipeline. Such a wave can be recognised using installed high-sensitivity pressure transmitter, giving a leak alarm. It is also possible to calculate the leak location by timing interval of the pressure wave at two or more points on the pipeline. The technique called Wave Propagation method as reported in [9]. The leak position can be located if the moment T Downstream and T Upstream , when this negative wave passes the transmitter is measured.

In [10], an optimum sequential analysis technique (Sequential Probability Ratio Test) is applied to detect changes in the overall behavior of the inlet and outlet flow and pressure. It works based on the observation that although the control and operation may vary from one pipeline to another, the relationship between the pipeline pressure and flow will always change after a leak develops in a pipeline.

### Externally Base System

The authors in [11, 12] were introduced distributed fibre optic sensing technique. Fibre optic is one of the promising leak detection technologies. Fibre optic sensors can be installed as distributed sensor. The cables will be attached and clamped to the pipeline, and utilize Distributed Temperature Sensor (DTS) method to detect the leaks. In [13],the leak detection in pipelines using acoustic emissions technology is based on the principle that escaping liquid creates an acoustic signal as it passes through a perforation in the pipe. Acoustic sensors affixed to the outside of the pipe monitor internal pipeline noise levels and locations. These data are used to create a baseline “acoustic map” of the line. When a leak occurs, the resulting low frequency acoustic signal is detected and analyzed by system processors. Deviations from the baseline acoustic profile would signal an alarm. The received signal is stronger near the leak site thus enabling leak location.

### Key Consideration of PLDS Evaluation

Table 1: Primary and Secondary considerations

<i>Primary Considerations</i>	<i>Secondary Considerations</i>
<ul style="list-style-type: none"> <li>• Sensitivity (Time of Detection)</li> <li>• Accuracy of Overall PLDS System</li> <li>• Reliability (False Declaration or False Alarm)</li> <li>• Robustness (Loss of Signal)</li> <li>• Leak Location Capability</li> <li>• Cost</li> </ul>	<ul style="list-style-type: none"> <li>• Leak Size</li> <li>• Response Time</li> <li>• Operational Ease of Use /Complexity</li> <li>• Maintainability</li> <li>• Maintenance Support</li> </ul>

A leak detection system is unique and depends on the pipeline locations, condition, types of fluids, pipeline size, length, operating parameters and instrumentation design. Key considerations criteria can be divided into two categories which is Primary and Secondary Considerations as shown in Table 1.

Data and information for each the technology can be quantifiable by translated to rating as shown in Table 3 below. Through the concept scoring a more detailed analyses and finer quantitative evaluation of the remaining concepts using the scoring matrix as a guide. Rating for each criteria will be marked as

5-Very High , 4-High, 3-Moderate, 2-Low, 1-Very Low and 0-None. For better evaluation result, each criterion is weighted to different point base on priority and key criteria. This precise, measurable and quantifiable detail will determine the best technology. The best technology shall score highest rating in this technology evaluation.

## Evaluation Result and Discussion

Table 2 represents the data and rating base on key considerations internally based (CPM) System leak detection methods in oil and gas industries while Table 3 shows the evaluation result.

Table 2: Internally Base System Comparison and Ratings [5,6,7,8]

Criteria	Compensated Volume Balance	Pressure/Flow Monitoring- Pressure Point Analysis + Mass Balance	RTTM	Acoustic/Negative Wave Pressure	Statistical Analysis
<b>Sensitivity</b>	1% of nominal flow rate	5% of nominal flow rate	1% of nominal flow	1% of nominal flow rate	1% of nominal flow rate
	Rating : 5 (Very High)	Rating : 3 (Average)	Rating : 5 (Very High)	Rating : 5 (Very High)	Rating : 5 (Very High)
<b>Reliability (False Alarm declaration)</b>	Free of nuisance alarm (compensated Volume balance) - depending on total accuracy.	Free of nuisance alarm with mass balance method for compensation.	Possible false alarm	Free of nuisance alarm- with filtering technique to remove noise	less frequent- depending on total accuracy
	Rating : 5 (Very High)	Rating : 4 (High)	Rating : 3 (Average)	Rating : 5 (Very High)	Rating : 4 (High)
<b>Accuracy</b>	±2%-3% of flow rate (based on FE=±0.15% and PT=±0.007%)	±2-4% of flow rate	±2%-3% of flow rate (Based on FE=±0.15% and PT=±0.007%)	±1-4% of flow rate	±2%-5% of flow rate (Based on FE=±0.15% and PT=±0.007%)
	Rating : 5 (Very High)	Rating : 4 (High)	Rating : 5 (Very High)	Rating : 4 (High)	Rating : 3 (Average)
<b>Leak Location Estimate/Accuracy</b>	No	Yes	Yes / 1% - 2% of Pipeline Length	Yes / Within 100meters	Yes / 1% - 2% of Pipeline Length
	Rating : 0 (None)	Rating : 3 (Average)	Rating : 5 (Very High)	Rating : 3 (Average)	Rating : 5 (Very High)
<b>Robustness (Loss of Signal)</b>	Depending on the Flow meter robustness and accuracy	Yes, not depending on the flow meter.	Depending on the Flow meter , temperature and pressure robustness and accuracy	Yes, not depending on the flow meter	Depending on the Flow meter, temperature and pressure robustness and accuracy
	Rating : 4 (High)	Rating : 5 (Very High)	Rating : 3 (Average)	Rating : 5 (Very High)	Rating : 3 (Average)
<b>Cost (CAPEX and OPEX)</b>	Approximately USD200K (Cost only on the hardware and software. Field instruments, engineering and installation are not included)	Approximately USD 440K (Price includes the hardware, software, 4 units of PT, 4 units of Flow meters, installation cost is excluded)	Approximately USD 250K (Cost only on the software and hardware. Field instruments, engineering and installation are not included)	Approximately USD 280K (price includes hardware, software and engineering)	Approximately USD340K (Cost only on the software and hardware. Field instruments, installation and engineering are not included)
	Rating : 4 (High)	Rating : 1 (Very Low)	Rating : 4 (High)	Rating : 3 (Average)	Rating : 2 (Low)
<b>Estimate Leak Size/Accuracy</b>	Yes	Yes	Yes/Less than 1 Litre loss	Yes/ 5 Litre loss	Yes
	Rating : 3 (Average)	Rating : 3 (Average)	Rating : 5 (Very High)	Rating : 4(High)	Rating : 3 (Average)
<b>Ease of use/complexity</b>	Software is complicated, require training  Instrument Required: Flow meter, Pressure, Temperature transmitter	Software is complicated, require training  Instrument Required: • Pressure Transmitter	Software is complicated, require training  Instrument Required: Flow meter, Pressure, Temperature transmitter	Software is complicated, require training  Instrument Required: Pressure Transmitter	Software is complicated, require training  Instrument Required: Flow meter, Pressure, Temperature transmitter
	Rating : 3 (Average)	Rating : 4 (High)	Rating : 3 (Average)	Rating : 4 (High)	Rating : 3 (Average)
<b>Response Time</b>	within 60 minutes	From 5 minutes	Within 9 minutes	Within 60 minutes	Within 60 minutes
	Rating : 3 (Average))	Rating : 5 (Very High)	Rating : 5 (Very High)	Rating : 3 (Average)	Rating : 3 (Average)
<b>Maintainability</b>	Yearly calibration on the field instruments.	Yearly calibration on the field instruments.	Yearly calibration on the field instruments.	Yearly calibration on the field instruments	Yearly calibration on the field instruments
	Rating : 4 (High)	Rating : 3 (Average)	Rating : 4 (High)	Rating : 4 (High)	Rating : 4 (High)

Maintenance Support	Yes	Yes	Yes	Yes	Yes
	Rating : 5 (Very High)	Rating : 5 (Very High)	Rating : 5 (Very High)	Rating : 5 (Very High)	Rating : 5 (Very High)

Table 3: Evaluation result of Internally Base.

Selection Criteria	weight	(CPM) Technology/Method									
		Volume Balance		Pressure Point Analysis		RTTM		Negative Pressure Wave		Statistical Analysis	
		Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
Sensitivity	10	5	50	3	30	5	50	5	50	5	50
Accuracy	9	5	45	4	36	5	45	4	36	3	27
Reliability	8	5	40	4	32	3	24	5	40	4	32
Robustness	9	4	36	5	45	3	27	5	45	3	27
Leak location Detection	9	0	0	3	27	5	45	3	27	5	45
Cost	8	4	32	1	8	4	32	3	24	2	16
Leak Size Detection	7	3	21	3	21	5	35	4	28	3	21
Response Time	6	3	18	5	30	5	30	3	18	3	18
Complexity	5	3	15	4	20	3	15	4	20	3	15
Maintainability	5	4	20	3	15	4	20	4	20	4	20
Maintenance Support	4	5	20	5	20	5	20	5	20	5	20
Total Score		297		284		343		328		291	
Rank		3		5		1		2		4	

According to the evaluation process, the best rated PLDS method is RTTM (Real Time Transient Model) Method. This method is widely accepted, provide sensitivity to detect small leaks, detect estimate location and low false alarm (if tuning and calibration is done properly). However, the sensitivity and accuracy of the flow meter device depends on the characteristics of the fluid to be measured. Thus, this higher value of flow meter's accuracy will decrease the PLDS overall system accuracy.

### Recommended design

The architecture for the basic PLDS generally consist of three major elements: field instrumentation, a SCADA or RTU or PLC with associated software and telecommunications links. The sensors required for RTTM technique can be categorized as flow, pressure, and temperature. Flow meters are required at all inlets and outlets of the pipeline. Custody metering, i.e., the metering of flow necessary as the fluid passes from one operator's domain to another, thus serves a dual purpose. Pressure and temperature sensors are required. Ideally these sensors should be distributed along the length of the pipe. The effectiveness of most of the PLDS software methods are depend on the sensitivity and accuracy of the field instrumentation especially the flow meter, thus it is critical to select the best performing flow meter. There appears a growing trend to utilize ultrasonic meter and coriolis mass meter for the crude oil metering application within oil and gas and Petrochemical Plants.

Field instrumentation needs control system interface as a medium of data transfer such as PLC or RTU system. This is because RTTM pipeline leak detection system is software base computer station system which extracts and analyzes the field data (flow, pressure and temperature) from control system. The main PLDS system software usually is proposed to be sitting in a dedicated computer, located in Control Room. In order to transfer field data from a site to another site, for example, Platform Alpha to Platform Beta, telecommunication system is required. There are two types of telecommunication system commonly use for offshore upstream oil and gas industry, which are Microwave/Radio Telecommunication system- Microwave and Fibre Optic Cable- Fibre-optic communication. Through the technology evaluation above, the conceptual design for pipeline leak detection system has been

finalized. Fig. 1 shows the conceptual architecture design for offshore upstream pipeline leak detection system.

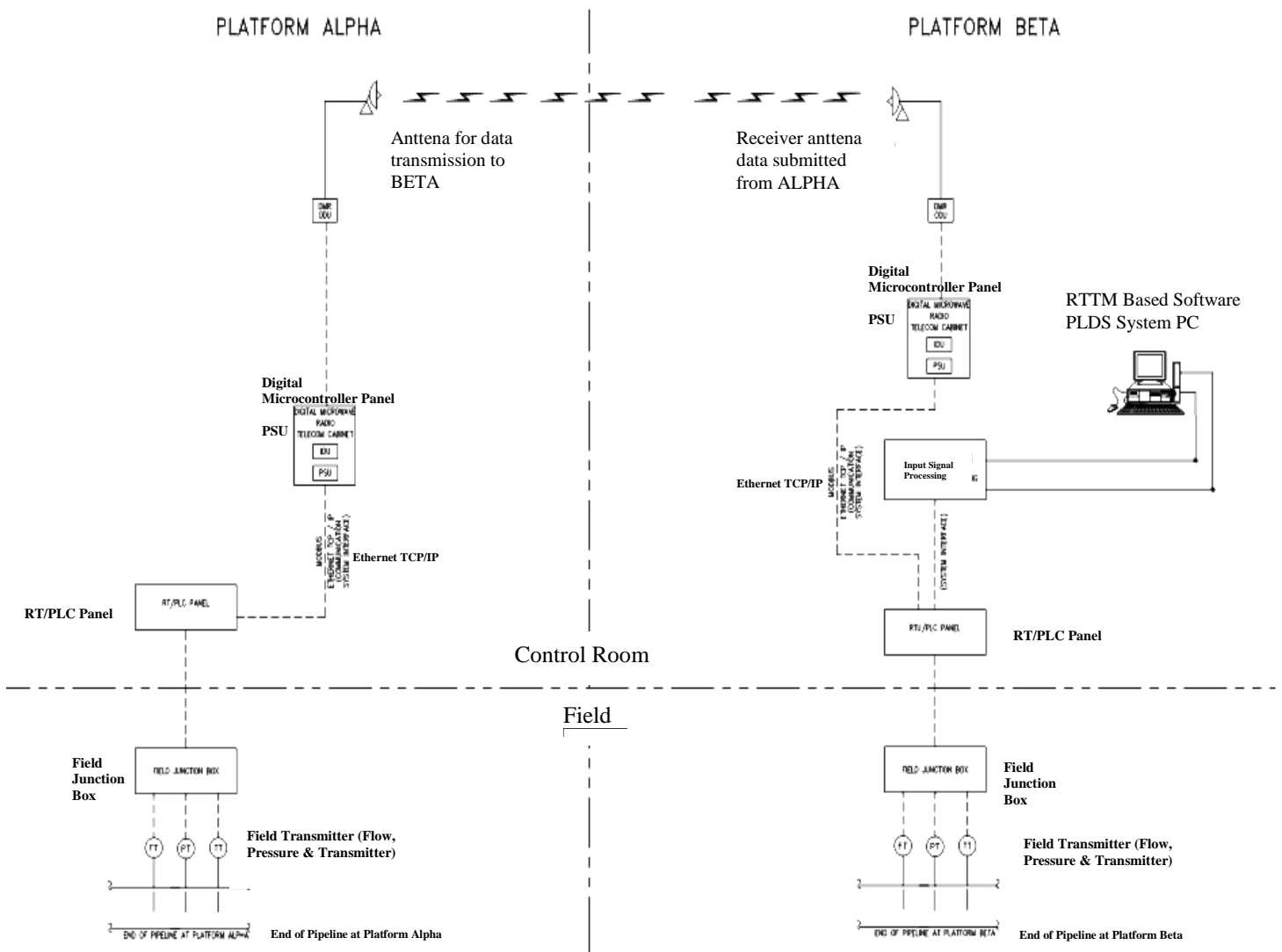


Fig. 1: Final Recommended Design for upstream PLDS

## Summary

Internally based systems appear to offer future advantages. RTTM method is the best technology which scores the highest rating. The result and recommendation of this study result is focused on offshore upstream pipeline only. Future development and enhancement efforts on pipeline leak detection system method for oil and gas industry should be made. Major technology vendors shall play their role to develop new method or enhancement of existing method of pipeline leak detection systems. A low-cost, sensitivity, accuracy, and reliability should be improved in developing new technology of PLDS. Combination of existing modeling with intelligent algorithm such as neural networks may offer better characteristics and advantages. For future work, this project can be improved by using simulation and detail calculation for each technology to prove the data given by each manufacturer of the technology.

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