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Pipeline leak Detection

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بسم الله الرحمن الرحيم

قال تعالى:

{فَتَعَالَى اللَّهُ الْمَلِكُ الْحَقُّ وَلَا تَعْجَلْ بِالْقُرْآنِ مِنْ قَبْلِ أَنْ يُقْضَى إِلَيْكَ وَحْيُهُ وَقُلْ رَبِّ زِدْنِي عِلْمًا}

صدق الله العظيم

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Abstract

Pipelines are widely used for the transportation of hydrocarbon fluids over millions of miles all over the world. The structures of the pipelines are designed to withstand several environmental loading conditions to ensure safe and reliable distribution from point of production to the shore or distribution depot. However, leaks in pipeline networks are one of the major causes of innumerable losses in pipeline operators and nature. Incidents of pipeline failure can result in serious ecological disasters, human casualties and financial loss. In order to avoid such menace and maintain safe and reliable pipeline infrastructure, substantial research efforts have been devoted to implementing pipeline leak detection and localization using different approaches.

Keywords:

Leakage; leak detection; leak characterization; leak localization

List of contents:

List of figure:

List of table:

List of abbreviation:

LDS	Leak detection system
CCTV	Closed Circuit Television
NPW	Negative Pressure Wave
CPM	Computational Pipeline Monitoring
RTTM	Real Time Transient Modeling
MFL	Magnetic Flux Leakage
GPR	Ground Penetrating Radar
SCADA	supervisory controls and acquisition
RFEC	Remote Field Eddy Current
RFTC	Remote Field Transformer Coupling
BEM	Broadband Electromagnetic
SPSS	Statistical Package for the Social Sciences
SPPC	Sudanese petroleum pipe line company
PAPCO	bashayer pipeline company
PETCO	Petrolines pipeline company
BV	Block valve
MCC	Main control center
ERP	Emergence reasonability plan

CHAPTER ONE

INTRODUCTOIN

1.1. Problem Statement:

The usage of pipeline is considered as a major means of conveying petroleum products such as fossil fuels, gases, chemicals and other essential hydrocarbon fluids that serve as assets to the economy of the nations. It has been shown that oil and gas pipeline networks are the most economical and safest mean of transporting crude oils and they fulfill a high demand for efficiency and reliability. For example, the estimated deaths due to accidents per ton-mile of shipped petroleum products are 87%, 4% and 2.7% higher using truck, ship and rail, respectively, compared to using pipelines. However, as transporting hazardous substances using miles-long pipelines has become popular across the globe in recent decades, the chance of the critical accidents due to pipeline failures increases. The causes of the failures are either intentional (like vandalism) or unintentional (like device/material failure and corrosion) damages, leading to pipeline failure and thus resulting in irreversible damages which include financial losses and extreme environmental pollution, particularly when the leakage is not detected in a timely way.

The average economic loss due to incidents of pipeline leakages is enormous Over the past three decades, pipeline accidents in USA damaged property which coasted nearly $7 billion, killed over 500 people and injured thousands For example, the incident of pipeline explosion in the community of San Bruno, California, USA on September 6, 2010 killed eight people, and injured more. Than fifty in a similar incident of pipeline defect that occurred in Michigan, USA on July 26, 2010, more than 840,000 gallons of crude oil spilled into Kalamazoo River with estimated cost of $800 million.

1.1.1Factors affecting pipeline deterioration:

Pipeline deterioration is caused by static factors, such as soil type, pipe material, size, etc., and dynamic factors, such as changes in pressure zones and climate. Little is known about the breaking modes of buried pipes, and the physical mechanism is not completely understood. The broad aspects of pipeline leak detection encompass physical modeling of the pipe in the soil, understanding the nature of pipe failure, empirical and/or statistical modeling of historical failures, inspecting pipes to identify stress factors, rating the pipe conditions, and modeling the deterioration to forecast future failures and residual life. The length and size of the pipeline, type of product carried, proximity of the pipeline to a high consequence area, swiftness of leak detection, location of nearest response personnel, leak history, and risk assessment results, etc., determine the efficiency of a leak detection system. The parameters for the evaluation of a leak detection system (LDS) are derived based on API1995b and the Alaska Department of Environmental Conservation 1999. Generally, for any good LDS, the most important four criteria are: Reliability, Sensitivity, Accuracy, and Robustness, and these criteria are what we use in this work.

The following are some of the Characteristics of Leak Detection Systems under different environments, which were taken in consideration during this study:

Type of fluids: Pipelines transport a variety of fluids, such as gases, crude oil, petroleum products, steam, carbon dioxide, water, wastewater, etc.

Type of operation: Pipelines may operate in single batch or multi-batch mode. In the single-batch mode of operation, pipelines operate continuously around the clock. In multi-batch mode, the pipelines function is based on a time schedule.

Characteristics of leaks: Leaks can occur suddenly or gradually depending on the causes and circumstances. Sudden leaks occur due to external damage, resulting in a significant change in the temperature, flow, pressure, etc. Gradual leaks may occur due to corrosion. Sudden leaks may be successfully detected using an internally based LDS. In contrast, gradual leaks have very low magnitudes, and dedicated equipment, such as externally based LDSs, may be required to identify such leaks.

Operational phase: Pipeline conditions vary. The pumping condition involves the transport of fluid, whereas in the paused flow condition, the fluid flow is zero. Sometimes, valves will be used to block the fluid flow in a given segment. This special flow phase is known as the shut-in or blocked-line condition.

1.2. Objective:

- Provide general overview of leak detection and localization method that have been used in recant decade in system consisting a pipe.
- Analyses data getting from different working pipeline have history of leakage and try to link or find relationship between normal operation and leakage state.
- Identify leak location mathematically
- Prevention leak occurring and what to do after leak occurring.

1.3. Project layout:

Chapter 2 contain review of various leak detection method focused internal (pressure point analysis), chapter 3 describes the methodology used in this project, Sudanese companies operate pipeline and leak location, chapter 4 result and discussion of analysis data, models of leak in Sudanese pipeline company and ERP team, chapter 5 recommendation and conclusion.

CHAPTER TWO

2.1. Introduction:

This chapter overviews different categories of leak detection techniques. In modern world, pipeline networks are an essential mode of transporting fluid from one place to another. Small percentages of loss can lead to significant economic impact, and potential risks to public health. The leak happens as a result of aging pipelines, deterioration or extreme pressure forced by operational error or valve rapid variation. Removing leakage completely would be virtually impossible and very expensive. Thus, the development and implementation of an organized leakage control policy is one of the possible ways to reduce the leakage rates. In order to prevent further loss and public risk many techniques with different applicability have been proposed in following section.

2.2. State of The Art of Leak Detection Technologies:

The related work on leak detection systems as in [1] and [2] classified leak detection systems into visual, internal, and external based on the physical principles involved in the leak detection process. Monitoring can be continuous or non-continuous. In the classification by [3], non-continuous inspection includes acoustic and non-acoustic methods, whereas continuous monitoring includes measurement and model-based methods. Classified technologies based on the area of inspection, such as internal pipe surface, pipe wall integrity, and pipe bedding/void conditions. References [4] and [5] classified leak detection systems into nontechnical and hardware- and software-based methods. Non-technical methods do not involve any devices and use only natural senses, such as hearing and smelling, to identify a leak, whereas the technical methods use special devices to identify leaks; in the hardware methods, these devices include liquid sensing cables, vapor sampling, etc., and in the software methods, these devices include negative pressure waves, pressure point analysis, etc. Reference [2] divided the leak detection systems into visual, physical, acoustic, ultra-spectrum, and electromagnetic. A similar classification divides LDSs into visual, acoustic, and Electromagnetic-Radio Frequency (EM-RF) techniques. Depicts the LDSs classification. Recent high level abstraction classification for water distributed network leak detection classify LDS into transient, model, and data based approaches.

LDSs can be broadly classified into continuous and non-continuous monitoring systems. In noncontinuous monitoring systems, the inspection is performed at regular intervals. Depending on the mode of inspection, pipeline operations can either continue or need to stop. For example, visual inspection or a helicopter survey does not require pipeline operations to be stopped, whereas an intelligent pigging system may require the operations to be stopped. The remote sensing of liquid hydrocarbons using aircraft mounted gas remote sensing is given in [7]. This system detects evaporative plumes from pools of oil, gasoline, condensate, or pentane. Continuous monitoring systems monitor pipelines around the clock and are based on a physical principle. This approach can further be classified into external and internal systems.

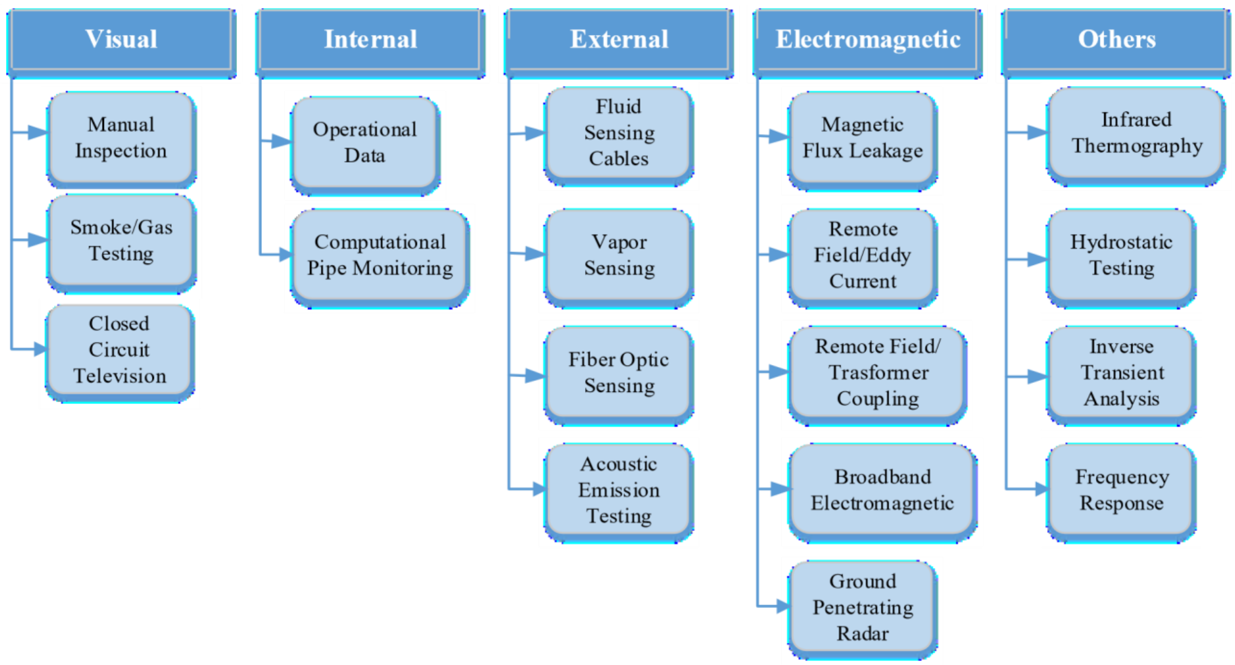

Figure 2.1: classification of LDSs

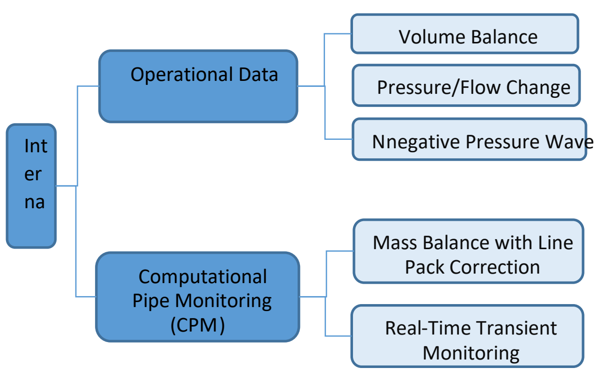

Figure 2.2: internal LDSs

2.2.1 Visual Technologies:

2.2.1.1 Visual Manual Inspection: Visual inspection requires the manual patrolling of the pipeline for leaks. Patrolling can be performed by any means (e.g., walking, in a vehicle, or from a helicopter). The operator examines the area for stains or other evidence of leaks. The leak detection capability depends on the ability of the inspection team, frequency of inspection, and the size of the leak. Limited for reachable pipelines; and not real-time detection, which has a negative effect in terms of loss of oil and gas as well as environmental pollution.

2*.2.1.2. Smoke/gas testing*: A smoke bomb is placed inside a water pipe with a blower to push the smoke. The smoke filters out through any cracks, thus exposing them. Water utilities used Formier10 gas (10% hydrogen and 90% nitrogen) for approximately 20 years. Hydrogen is a very lightweight gas and easily escapes through small cracks. The time taken for the gas to reach the surface depends on the depth of the pipe, soil conditions, and size of the leak. The gas detector is sensitive to small leaks. This method is not usable in large pipe mains due to the larger volume of gas required.

2.2.1.3. Closed Circuit Television (CCTV): CCTV technology typically involves the use of a video camera, lighting source and event recording software. The camera is passed through the pipe and records the interior surface. The operator later looks for defects in the pipe from the recorded images.

2.2.2. Internal System:

Internal systems use field sensors to monitor the operational and hydraulic conditions of the pipeline, e.g., measurements of the flow, pressure and temperature. The normal working parameters of the pipeline are determined either manually by pipeline controllers or based on sophisticated algorithms and hydraulic models, which function with particle swarm optimization AI technique to get accurate detection and localization.

A difference between the measured and predicted operational parameters indicates a leak. Typically, the remote field sensors provide data to a centralized monitoring station, where the data undergoes filtering, signal processing and modules with leak detection algorithms to identify a leak. Internal systems generally do not require the installation of extensive hardware throughout the pipeline.

2.2.3. Regular or Periodic Monitoring OF Operational Data:

2.2.3.1. Volume balance: Volume balance identifies the imbalance between incoming and outgoing volumes. Volume balance can detect catastrophic failures; however, its usage is rare due to its limited performance.

2.2.3.2. Rate of pressure flow change*:* The rate of pressure or flow change is based on the principle that a leak causes a rapid change in pressure. First, a sudden pressure drop can also be due to transient conditions. Filtering techniques need to be used to differentiate operational conditions from leak conditions. Second, pressure waves damp out as they traverse a longer length and thus additional pressure sensors need to be installed along the pipelines. This method is only effective for large leaks, and transient conditions may trigger false alarms.

2.2.3.3. Negative Pressure Wave (NPW): When the pipeline leak occurs, the fluid pressure drops suddenly at the position of the leak and generates negative pressure wave, which propagates with a certain speed towards both upstream and downstream of the pipeline. Two pressure sensors are installed at the beginning station and the end station of the pipeline respectively. The negative pressure wave received by the two sensors can identify pipeline leak and furthermore locate the leak by calculating the time difference between the arrival times of the negative wave at each end.

2.2.3.4. Pressure point analysis pressure: This method detects the occurrence of leaks by comparing the current pressure signal with a running statistical trend taken over a period of time along the pipeline by pressure monitoring and flow monitoring devices. The principle of this method is based on the fact of pressure drop as a result of leak occurrence. Using an appropriate statistical analysis of most recent pressure measurements, a sudden change in statistic properties of pressure measurement such as their mean value is detected. If the mean of newer data is considerably smaller than the mean of older data, then a leak alarm is generated. This method may require sensitive high resolution but not necessarily very precise instrumentation. So, the lower overall installation costs are not very high. Furthermore, this method is able to identify the occurrence of leaks, but not necessarily the presence of them. Since this method use of pressure drop as a leak signature, it can yield false alarms as the pressure drop is not unique to the leak event.

2.2.4. Internally Based Computational Pipeline Monitoring (CPM):

This research project focuses on the widely-employed computational pipeline monitoring approaches to leak detection. These methods use field sensors installed on the pipeline, as part of a SCADA system, to monitor operating conditions such as pressure and flow rate. The data collected by the sensors are transmitted to a central control location (which is geographically-distant from the pipeline) by the SCADA system. This control location may have a computer simulator for the prediction of model outputs and a screen for display of the field and of the estimated data, primarily (ADEC). The data is used by the computer model to produce new values via algorithmic computation. If the calculated new values exceed some predefined thresholds the computational pipeline monitoring system generates an alarm that may indicate the occurrence of a leak. A pipeline controller evaluates the alarm and additional information presented by the computational pipeline monitoring system to support their decision of taking appropriate action [6]. The algorithms used in computational pipeline monitoring system range widely in their level of complexity from balance methods to real-time transient modeling. These are described in the following sections.

2.2.4.1. Mass -Volume balance: Mass balance (and volume balance) are, in effect the same method based on the principle of conservation of mass. The principle states that a fluid enters the pipe section either remains in the pipe section or leaves the pipe section. In standard pipeline networks the flow entering and leaving the pipes can be metered. A leak can be identified if the difference between upstream and downstream flow measurement changes by more than established threshold value.

Pipeline industry. This method is very sensitive to pipeline instrumentation accuracy. The main weakness of the mass balance method is the assumption of steady state. As a result of this assumption, the detection period has to be increased in order to prevent false alarms. Therefore, the response time to the leak will be delayed, which is undesirable. For instance, a 1% leak needs about 60 minutes to be detected. Another significant disadvantage of mass balance method is location of the leak is unknown. Consequently, in real application other methods are required in conjunction with mass balance method after the leak has been detected to identify the location of the leak.

2.2.4.2. Real Time Transient Modeling (RTTM*):*

The parameters derived from a simulation model are compared with actual field data to look for discrepancies. Leaks occurring under all flow conditions can be modeled using this software, and small leaks can be detected in seconds. However, RTTM needs extensive training and skilled workers to operate and maintain.

2.2.3. External System:

External systems are leak detection methods in which sensors are placed outside of the pipeline to directly detect commodity release. These sensors collect data and their associated SCADA monitors raise leak alarms when the values exceed certain limits. There are several types of external leak detection methods.

Acoustic Devices: A leak generates noise signal which can be picked up by acoustic sensors installed outside the pipeline.

Cable Sensors: These sensors use polymer materials that swell in the presence of hydrocarbon thus changing their electrical properties.

Fiber Optic Sensors: Leaks can be identified through the identification of temperature changes in the immediate surroundings using fiber optic cable or through change in the optical property of the cable itself induced by the presence of a leak.

Ultrasonic Flow Meters (USFM): This uses a patented wide beam technology to induce an axial sonic wave in the pipe wall for detection of leaks.

Vapor Monitoring System: If the product inside a pipeline is highly volatile, this system sucks the vapors in a low-density polyethylene (LDPE) sensor tube and run this gas stream past specialized sensors that can detect trace concentrations of specific hydrocarbon compounds [7].

2.2.3.1. Liquid sensing cables: Similar to optical fiber methods, *liquid sensing probes* or cables are laid throughout the pipeline. Leaking fluids come into contact with cables and change their electrical properties, such as impedance, electrical resistance, dielectric constant, etc. A dedicated evaluation unit connected to the cable identifies the changes to the cable and detects a leak. Liquid cables can continuously monitor and accurately locate leaks. As with optical fibers, cable replacement may be required after a leak occurs.

2.2.3.2. Fiber optic sensing cables*:* In this method, a fiber op- tic cable is installed along the entire length of the pipeline. When a liquid comes into contact with the cable, the transmission characteristics of the fiber change. While a pulsed laser propagates through the fiber, any changes to the density or composition of the fiber cause the light to scatter backwards. Spectral analysis reveals the temperature profile, leading to leak detection and localization.

Cable replacement may be required after a leak. Recent advances in fiber optic sensors include quasi-distributed sensing, e.g., integrated Bragg gratings, and distributed sensing, e.g., interferometry and fiber sheath sensors.

When a pipeline leak occurs, the liquid moves from a high-pressure area to a low-pressure area and a turbulent flow is generated. This flow generates a characteristic sound that can be picked up by a specially designed hydrophone. Using sophisticated software, Leak ACO detects this signal, analyzes it, and evaluates the measurement results, thus identifying and providing the location of the leak.

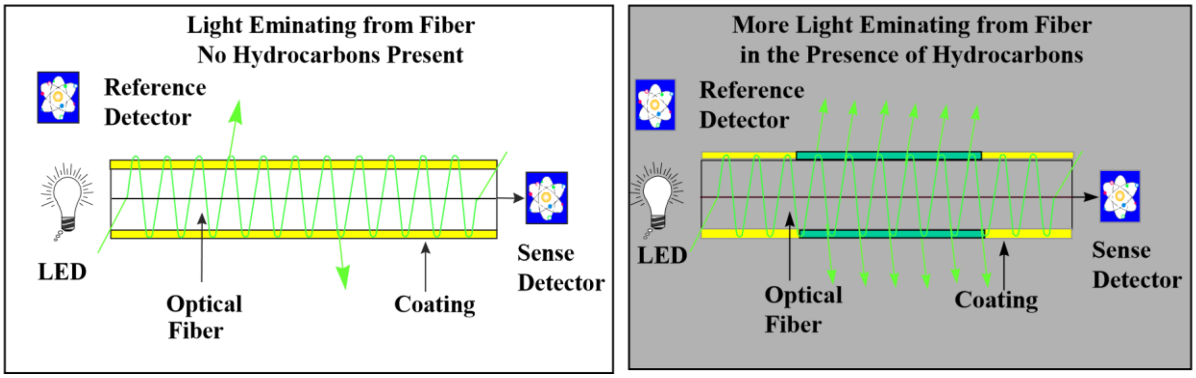

Figure 2.3: leak detection by fiber optical

2.2.3.3. Acoustic Emission (AE) testing: When a pipeline leak occurs, turbulent liquid flow occurs in a high-pressure to a low-pressure area, creating a low frequency sound signal. Acoustic sensors affixed to the outside of the pipe, e.g., accelerometers, hydrophones, piezoelectric transducers, etc., pick up these signals. The deviation of the sound signals from a baseline fingerprint triggers a leak alarm. The received signal is stronger near the leak site, enabling localization of the leak. For pipes, such as PCCP, wire breaks release energy and cause a series of discrete events. AE monitoring of wire breaks is limited only to ongoing wire events and cannot be used to detect already broken wires. Another recent technique using a combination of the ultrasonic sound and flow rate signals in order to detect and localize a small pipeline leak.

2.2.3.4. Vapor or liquid sensing tubes: The vapor or liquid sensing tube based leak detection method involves the installation of a tube along the entire length of the pipeline. If a leak happens, the content of pipe gets in touch of tube. The tube is full of air in atmospheric pressure. Once the leak occurs, the leaking substance penetrates into the tube. First of all, to assess the concentration distribution in the sensor tube, a column of air with constant speed is forced into the tube. There are gas sensors at the end of sensor tube. Every increase in gas concentration leads to a peak in gas concentration which its size is an indication of the size of the leak. The detected line is equipped with an electrolytic cell. This cell diffuses an exact volume of test gas into the tube constantly. This gas along with air passes through the whole length of the sensor tube. When the test gas travels through the detector unit, it produces an end peak. So, the end peak is a sign of the whole length of the sensor tube. Leak localization is carried on by calculating the ratio of end peak arrival to leak peak arrival. Figure 2.4 indicates this technique. As shortcoming of this method, it could be mentioned that its speed of leak detection is very low. In addition, it's not very practical for applying in long pipelines as the cost of its equipment is very high. The other drawback of vapor sensing tubes is the difficulty of their application in pipelines above ground or in deep sites.

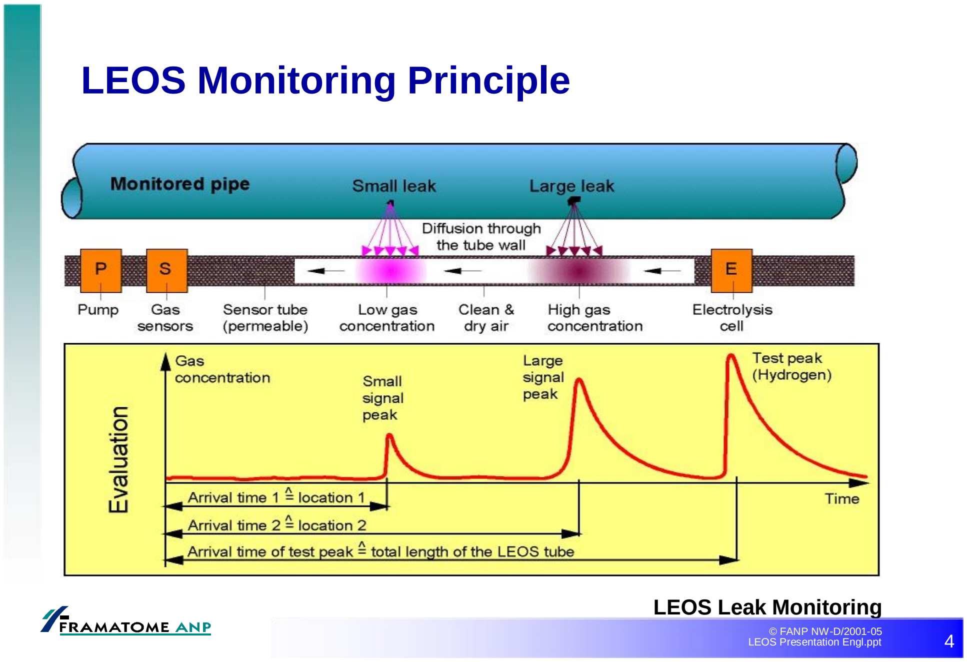

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Figure 2.4: leak detection by vapor monitoring system

2.2.3. Comparison:

External leak detection systems are expensive. To install along pipelines that expand over hundreds of miles is expensive regardless of where the pipe is situated or what elements it runs through. It also adds more equipment that needs service and repairs. The internal systems usually only need flow, pressure and may be temperature measurement sat the inlet and outlet. If the distribution system is very large with many branches, measurement equipment inside the pipe at certain points is necessary, but it will still be cheaper than the hardware based detection methods.

2.2.4. Electromagnetic systems:

2.2.4.1. Magnetic Flux Leakage (MFL): MFL analyzes the flux leakage in a magnetic field when magnetized by strong, powerful magnets. A flawless pipe exhibits a homogeneous magnetic flux distribution, while a damaged pipe causes a flux leakage. The detection system also consists of a smart tool that can reflect the changes in the flux distribution in case of leakage or corrosion; this tool acquires the measurements from a sensor, which is placed between the poles of the magnet. DC inspection of pipes can be performed using Hall Effect devices and magneto resistive materials, while AC inspection can be performed using pick up coils. This testing mode is non-invasive and accurately detects cracks, corrosion, and the thinning of pipe walls. However, MFL is usable only on ferrous pipes and requires access to the surface of the pipe. The analysis of test results requires experienced personnel. Traditional MFL only detects defects perpendicular to the magnetic field and cannot identify defects parallel to it. To overcome this, a new inspection method called Traverse Field Inspection (TFI) is employed in t h e Spiral MFL tool.

2.2.4.2. Remote Field Eddy Current (RFEC*):* In BEM, a solenoid exciter probe generates pulsed eddy currents and magnetic flux lines within the pipe. Anomalies such as cracks or defects disrupt the current flow, which is captured by a receiving probe placed at a distance of 2.5 pipe diameters. The contour maps obtained after intensive post processing reveal the corrosion and thickness of the pipe wall.

2.2.4.3. Remote Field Transformer Coupling (RFTC): RFTC detects any broken wires in pre-stressed concrete cylinder pipes (PCCP) and holes or perforations in the steel used in PCCP.

2.2.4.4. Broadband Electromagnetic (BEM): In BEM, a primary winding or exciter coil generates a short burst of pulsed waves in the broadband frequency range. Eddy currents are induced in the adjacent ferrous conductive material shortly after the excitation pulses have been turned off; these eddy currents create a time varying magnetic field. The varying magnetic field induces a time varying voltage on the secondary winding or the receiver coil, which is correlated to the thickness of the pipe. BEM is similar to RFEC, but the signal transmitted covers a broad frequency spectrum. BEM is immune to electromagnetic interference and differs from other electromagnetic inspection methods because of its frequency independence.

2.2.4.5. Ground Penetrating Radar (GPR*):* GPR transducers radiate a short burst of varying radio frequencies into the ground and identify buried objects based on the scattering of the EM waves. The propagation of EM waves in soils is governed by parameters such as permittivity, magnetic permeability and conductivity. The occurrences of leaks increase the moisture content of the soil nearby and cause dielectric variation. Reflections occur at the interfaces between media with different electrical properties. The time lag between the transmitted and reflected waves determines the depth of the objects. An array of antennae attached to a survey vehicle driven along the transmission main detects the pipe anomalies.

2.2.5. SCADA-based systems:

The supervisory controls and acquisition (SCADA) system monitor the pipeline at every block valve site and collect pipeline data over the entire pipeline length, including metering station at the end.

The data give the operator an instantaneous (or real time) view on pipeline condition. The data can also be utilized for leak detection, usually within a dedicated computer connected to the SCADA computer.

This technique attempts to mathematically model the one dimensional hydraulic behavior of the pipeline. Mathematically this is an initial boundary value problem which is completely defined by boundary condition taken from sampled measurement of pipeline pressure, flow and temperature. Given pressure and flow at the pipeline inlet the equations will solve for the outlet pressure and flow. Leak are determined as discrepancies between predicted and measured values.

The hydraulic equation is based on the conservation laws of mass, momentum and energy plus an equation of state relating fluid density to pressure and temperature.

The conservation laws are described by non-steady partial differential equations in which the hydraulic parameters of pressure, temperature and flow are function of time and distance along pips. These equations are solved by a variety of computational techniques. The alternative methods currently are use in commercial software packages include:

- Finite difference
- Finite element
- Method of characteristics
- Frequency response, spatial discretization

2.2.6 Pig-based leak detection method (inelegant pig):

A pipeline is a free moving position inside the pipeline, sealed against the inside wall using a number of sealing elements. Various pigs are widely used in the oil and gas industry for pipeline commissioning, cleaning, filling, dewaxing, batching, and pipeline monitoring. Pig generally need especially designed apparatus for launching and receiving vessels for recovery. Pig can be located using fixed signalers along the pipe or an electronic tracking system mounted inside the pig. Recently, pipeline pig that carry a wide range of surveillance and monitoring equipment, such as acoustic or ultrasonic instrument, have been used for monitoring in the oil and gas industry. The pig is normally used at regular intervals to check the internal condition of pipelines. By analyzing the data transfer from pigs, not only can leaks be located accurately but also pipe wall corrosion pits and weld characteristic can be assessed regularly.

Although the pig-based leak detection methods are impressive for monitoring the integrity of pipeline, their application is limited to pipes with larger than 200mm. pig-based method are unlikely to be applied in water distribution networks where the presence of valves, elbows, pipes with different diameters and pipe flanges limit the pig movement. Also even in oil and gas pipelines, the pig-based leak detection method need to work with other techniques to insure quick response to pipeline failure since pig based monitoring is still a batch rather a continuous process.

CHAPTER THREE

METHODOLOGY

3.1. Introduction:

This chapter showed the selected software program to analyses data statistically used pressure point analysis (PPA) method as discussed in chapter two and this study focused on companies operating pipeline in Sudan include four company that have history of leaks, factors should be considered while running pipe line, leak location and pipeline Master Control Center / SCADA System.

3.2. SPSS:

SPSS (**Statistical Package for the Social Sciences**) is a widely used program for statistical analysis in social science. It is also used by market researchers, health researchers, survey companies, government, education researchers, marketing organizations, and data miners The original SPSS manual (Nie, Bent & Hull,1970) has been described as one of "sociology's most influential books “for allowing ordinary researchers to do their own statistical analysis. In addition to statistical analysis, data management (case selection, file reshaping, creating derived data) and data documentation (a metadata dictionary is stored in the data file).

3.3. Companies operating pipeline in Sudan:

- **Sudanese petroleum pipe line company (SPPC)**
- **bashayer pipeline company (PAPCO)**
- **Petrolines pipeline company (PETCO)**
- **Petro energy company**

3.3.1. Sudanese pipeline petroleum company (SPPC):

The Sudanese Petroleum Pipelines Company Ltd. is a pioneer of pipelines for transporting petroleum materials, a company affiliated with the Ministry of Oil and Gas, one of the main pillars of the oil industry in Sudan, as it was established in 1976 and established the first pipeline for petroleum products with a diameter of 8 inches and a length of 815 km between Port Sudan and Khartoum. Then, in the year 2005, it added a second line with a diameter of 12 inches and a length of 741 km between Ruwayan "Al-Jili Refinery" and Port Sudan to export surplus gasoline, and it developed the lines to operate in both the export and import directions. Since its inception, the company has pumped more than 20 million tons of petroleum products through pipelines.

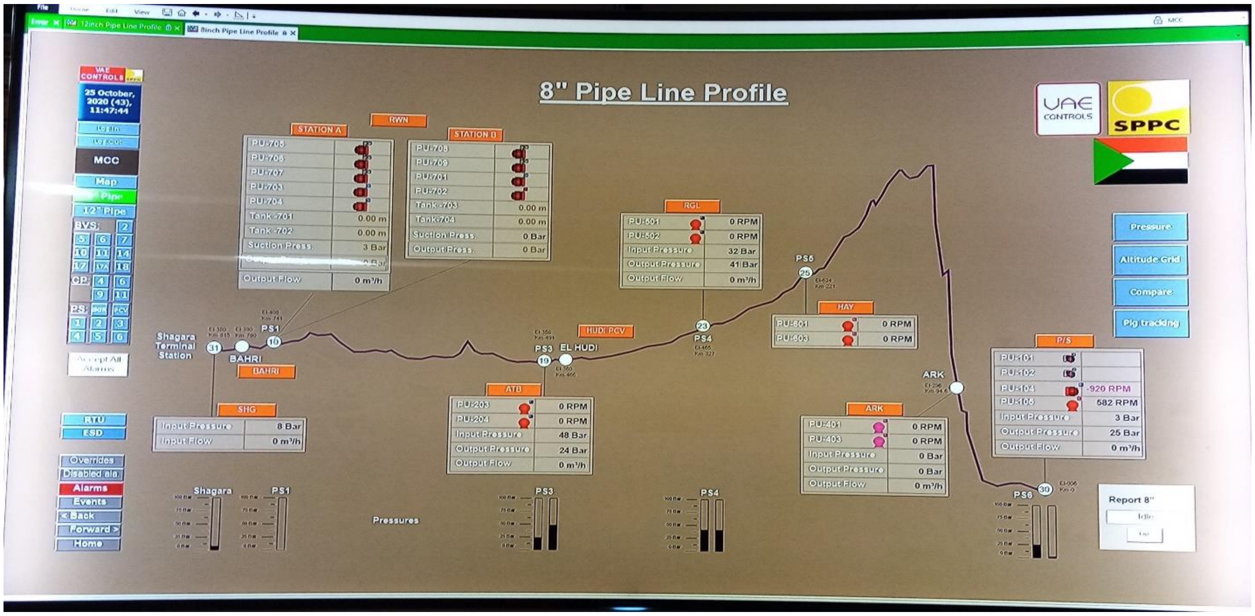

Figure 3.1: 8in pipeline profile

3.3.2. bashayer pipeline company (PAPCO):

bashayer pipeline company Transportation system starts from Al Jabalyn (CPF) intake point at the second Pump station up to MT (Bashayer-2) through 5 Pumping Stations Processing activities are carried out at Al Jabalyn Central Processing Facilities (CPF) which receives Dar Petroleum Operating Company (DPOC) crude oil from (South Sudan) producing oil fields via first Pump Station located in the Republic of South Sudan.

Marine Terminal (MT) (Bashayer-2) is fully operated by BAPCO through Operations and Oil movement for crude oil shipping planning, scheduling and loading to international market.

The pipe line is 32 in diameter, 1337km length contain 19 block valves along pipeline.

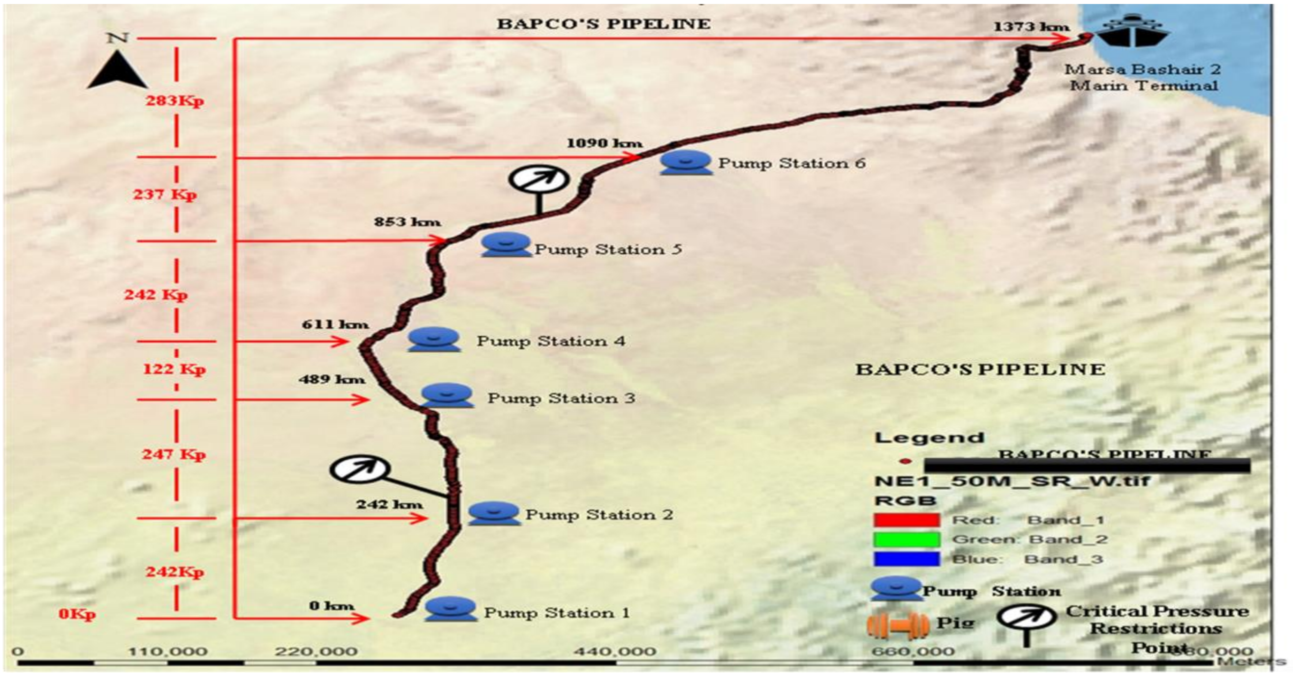

Figure 3.2: PAPCO pipeline 32 in diameter

3.3.3. Petrolines company (PETCO):

Petrolines 28" Pipeline, 1506 KM Length Transport Oil from Heglig to Bashya Marine Terminal. Two delivery points at ElObeid and Khartoum feeding two refineries with light Crude Oil. Marine terminal; which includes 8 crude storage tanks, shipping and boosters pump and subsea line & loading facilities.

The line has 19 block valves extend along pipeline.

3.4. Pressure point analysis using (SPSS):

The pressure point analysis leak detection method is based upon the statistical properties of series of pressure or velocity pipeline measurement at one point being different before and after leak occurs. The PPA method detects leaks by monitoring pipeline pressure at single point along the line and comparing it against a running statistical trend constructed from previous pressure measurement. By using SPSS to determine if the behavior of successive measurements contains evidence of a leak.

The data will be analyzed collected from (PAPCP, SPPC) companies

3.5. Data collected from PAPCO:

Table 3.1: parameters at pump stations before leakage (PAPCO)

Station	Input pressure	Output pressure	Speed rpm	flow
PS3	24.0	23.4	Offline	562
PS4	16.2	49.8	501	561
PS5	33.1	32.7	Offline	562
PS6	13.8	52.7	512	562
MT	76			
Peak Point				

Table 3.2: parameters at pump station after leakage (PAPCO)

station	Press (Bar)		Speed (rpm)	flow
	Input	**Output**		
PS2	**11.0**	**55.5**	**502**	600
PS3	**49.7**	**48.9**	**Offline**	600
PS4	**49.9**	**49.6**	**Offline**	600
PS5	**9.0**	**7.8**	**Offline**	700
PS6	**4.8**	**36.7**	**Offline**	800
MT	**Closed**			
Peak Point	**9.0**			

3.6. Data collected from SPPC:

Table 3.3: parameter at pump stations before leakage (SPPC) data

Standard	Inlet pressure	Outlet pressure	Flow
Ps1	3	48	89
Ps2	13	60	90
Ps3	16	42	89
Ps4	25	52	88
P5	3	-	88

Table 3.3: parameters at pump stations after leakage (SPPC) data

estimation	Inlet pressure	Outlet pressure	flow
Ps1	3	48	89
Ps2	13	60	90
Ps3	16	42	89
Ps4	15	32	120
Ps5	2.5	-	130

3.6. Factors should be considered while running pipeline:

1. Compressibility
2. Amount received and amount rejected
3. Gain and loss

3.7. Pipeline Master Control Center / SCADA System:

Along pipeline and Pump stations to transferring data from site to site and site to MCC, looking for mimic data to workstations connect with SCS.

3.7.1 SCS:

System control has been working at only pump station to keeping at safe condition

3.7.2 Block valve (BV) cross river Nile:

For safe condition can be closing from MCC

3.8. Leak location:

Leak location can be determined approximately by this equation.

$$x = \left(\frac{Q^2}{Q1} * \frac{P21 - P20}{P11 - P10} * L\right) - \left(\frac{Q2^2}{Q1^2 - Q2^2} * L\right)$$

X: leak point from pumping station

L: distance between two stations

Q: flow rate before leak is occurred

Q1: output flow at pumping station after leak is occurred

Q2; input flow at receiving station after leak occurred

P10: pressure at receiving before leak occurred

P11: pressure at pumping station before leak occurred

P20: pressure at receiving station after leak occurred

P21: pressure at pumping station after leak occurred

The correlation was obtained from SPPC Company which intern deducted experimentally.

CHAPTER FOUR

Result and Discussion

5.1. Introduction:

This chapter showed the results of the software program for two data collected from SPPC and PCPCO, and identify leak mathematically
And history of leak for each company.

5.2. Result from SPSS:

Table 4,1 mean values of pressure before and after leak PAPCO

Parameters	Before (Mean±SD)	After (Mean±SD)	*P-value*
Input Pressure C.A	19.30±9.36	24.88±22.85	0.899
Output Pressure C.A	40.08±12.13	39.70±19.09	0.771

Table 4,2: mean values of pressure before and after leak SPPC

Parameters	Before (Mean±SD)	After (Mean±SD)	*P-value*
Input Pressure C.B	12.00±9.32	9.90±6.61	0.037
Output Pressure C.B	50.50±7.54	45.50±11.7	0.468

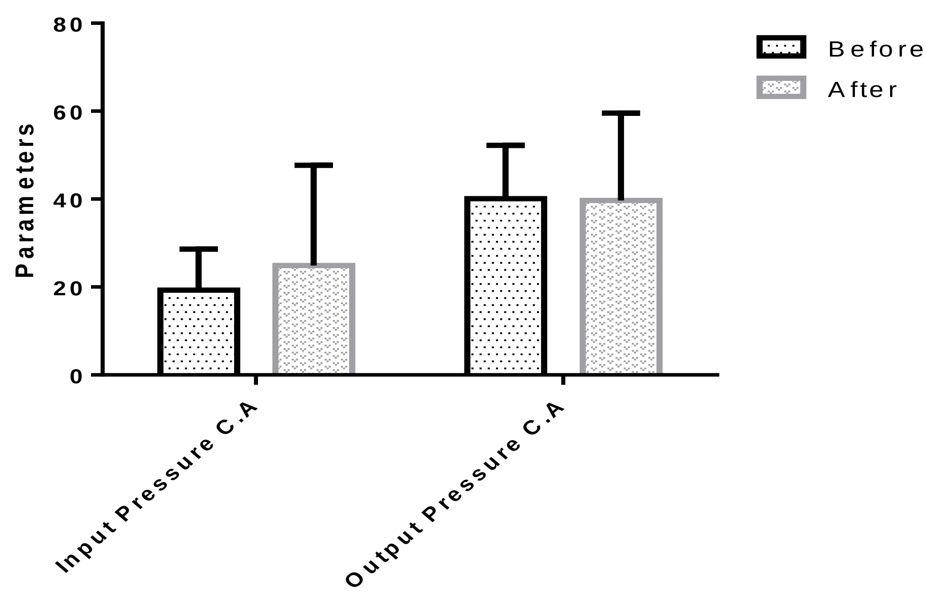

FIGURE 4.1: pressure drop after leak case 1

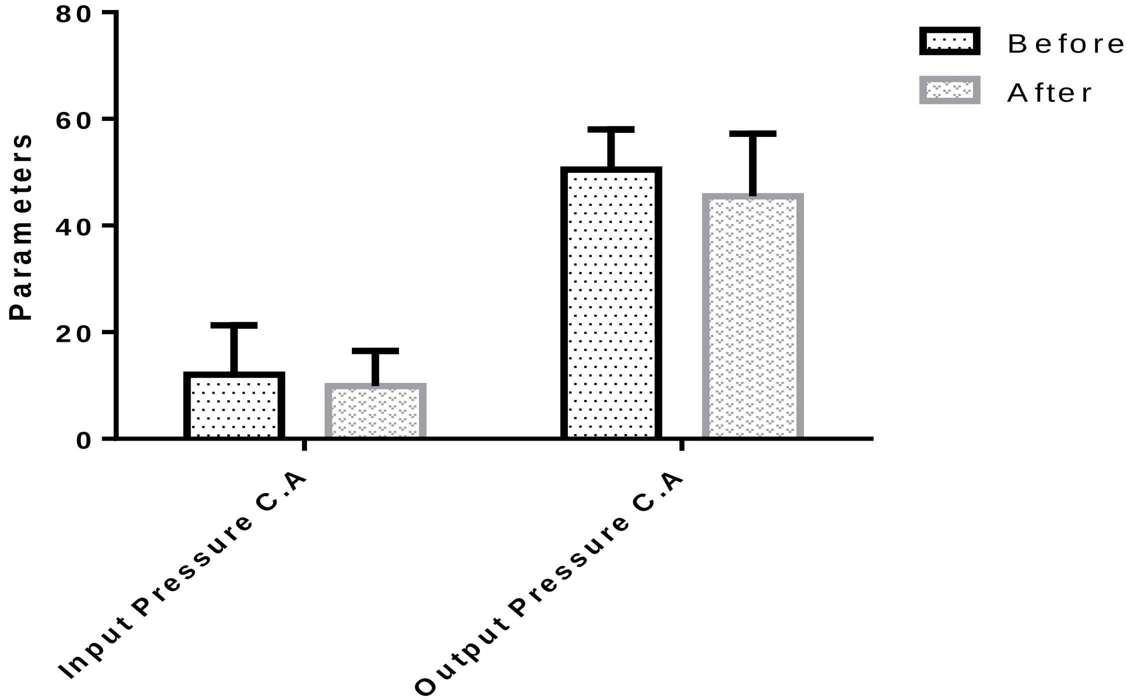

Figure 4.2: pressure drop after leak case 2

4.3. Discussion:

The above charts show that the mean values of pressure data were less than the older mean values which increase the leak probability (generate leak alarm).

On the other hand, if the mean values of pressure data are large or equal the older mean values decrease leak probability.

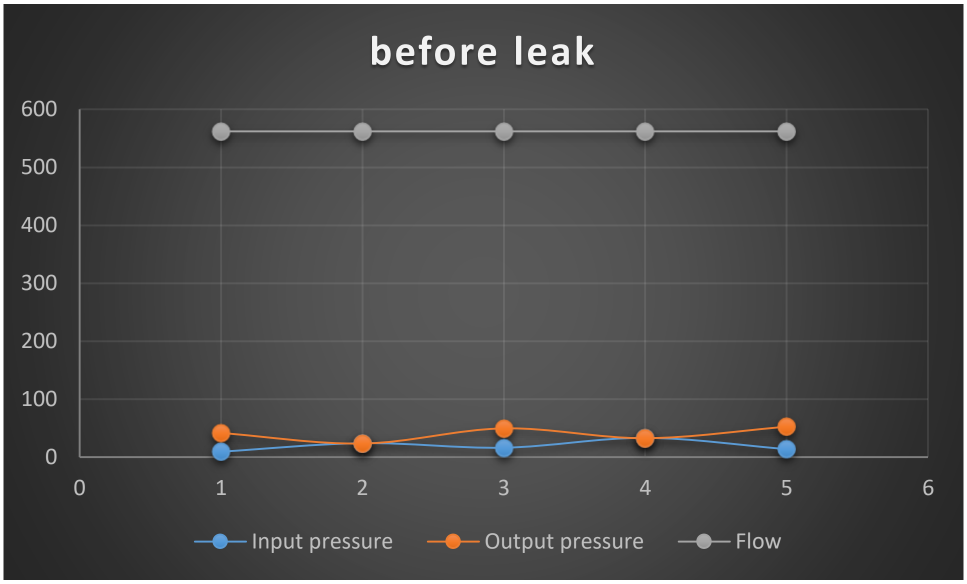

Figure 4.3: pressure point flow before leak case1

Flow rate is stable along pipeline before leak. Case 1

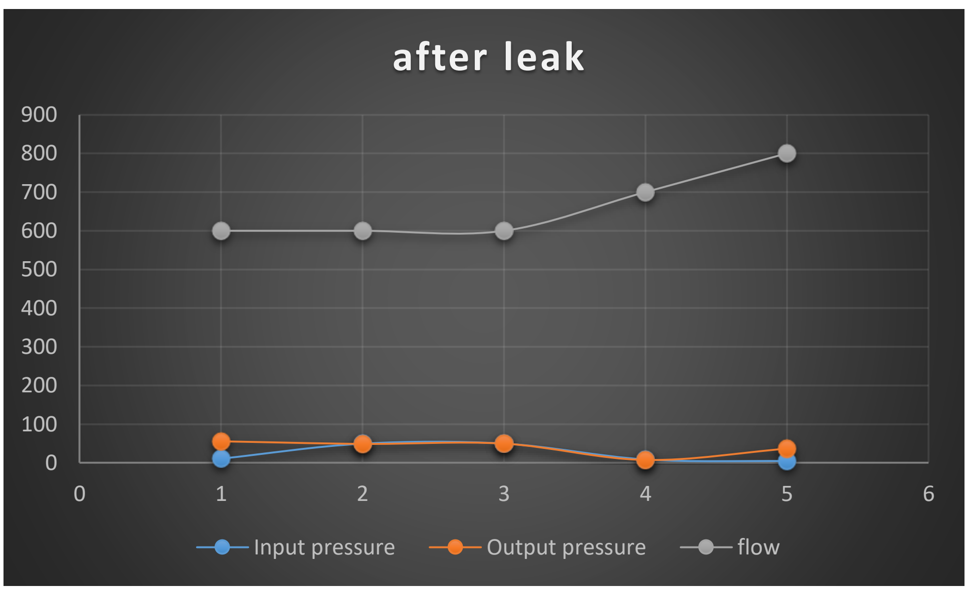

Figure 4.4: pressure point and flow after leak case1

Flow rate increase along pipeline after leak case1

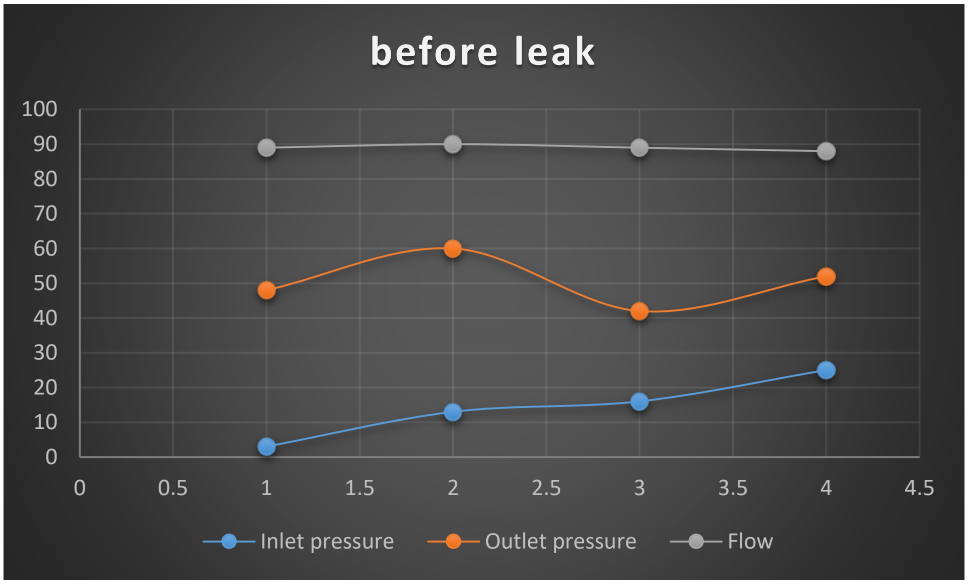

Figure 4.5: pressure point flow before leak case2

Flow rate is stable along pipeline before leak. Case 2

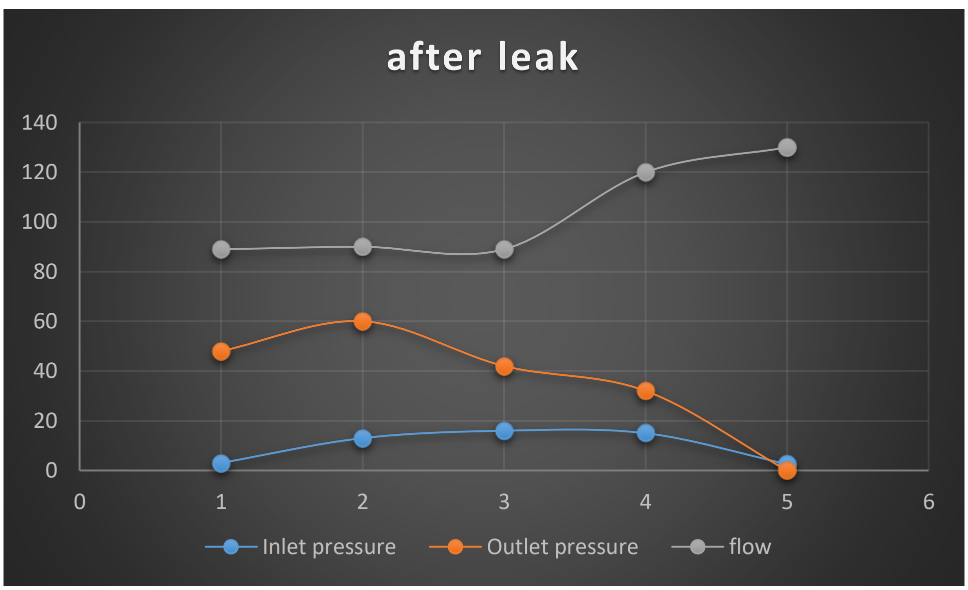

Figure 4.6: pressure point flow after leak case2

Flow rate increase along pipeline after leak case2

4.4. Leak location mathematically:

According to the data collected from PAPCO the leak location was been determined

$\boldsymbol{Q1 = 700m^3/h}$ $\boldsymbol{Q2 = 800m^3/h}$ $\boldsymbol{Q = 562m^3/h}$ **P21=7.8 bar**

P20=4.8bar P11=32.7bar P10=13.8bar L=237km

$$x = \left(\frac{562^2}{700^2 - 800^2} * \frac{7.8 - 4.8}{32.7 - 13.8} * 237\right) - \left(\frac{800^2}{700^2 - 800^2} * 237\right)$$

$\boldsymbol{x = 931km}$

The actual leak location was 925km

Approximate location 931km

4.5. Leak detection in Sudan:

Generally, their no leak detection system in Sudan but leak can be determined by daily monitoring (SCADA) and patrolling along pipeline.

4.5.1. PETCO leaks:

Date	Location of incident	Incident case
July 1999	Kp1435	sabotage
Septembers 1999	Kp1075	sabotage
January 2000	Kp1369	sabotage
May 2000	Kp1369,06	sabotage
November 2004	Kp928	sabotage
March 2010	Kp0,43 downstream ps#1	Leak(ml/crack)
April 2012	Ps#1 launcher	ss.Gov. invasion
July 2013	Kp1189	Leak (corrosion)
June 2014	Kp1199	Leak (corrosion)

Table 4.3: leak in Petco pipeline 28in

Sabotage:

Cause by human: free lions group

Detect: sudden sharp decrease in pressure and highly flow rate clear in mcc

The action tack: isolate the pipeline by block valves to control spillage of oil

And determine leak location

Crack:

Cause: due to closed valve preventing flowing and reflected back caused crack on pipe

Leak due to loss of metal corrosion

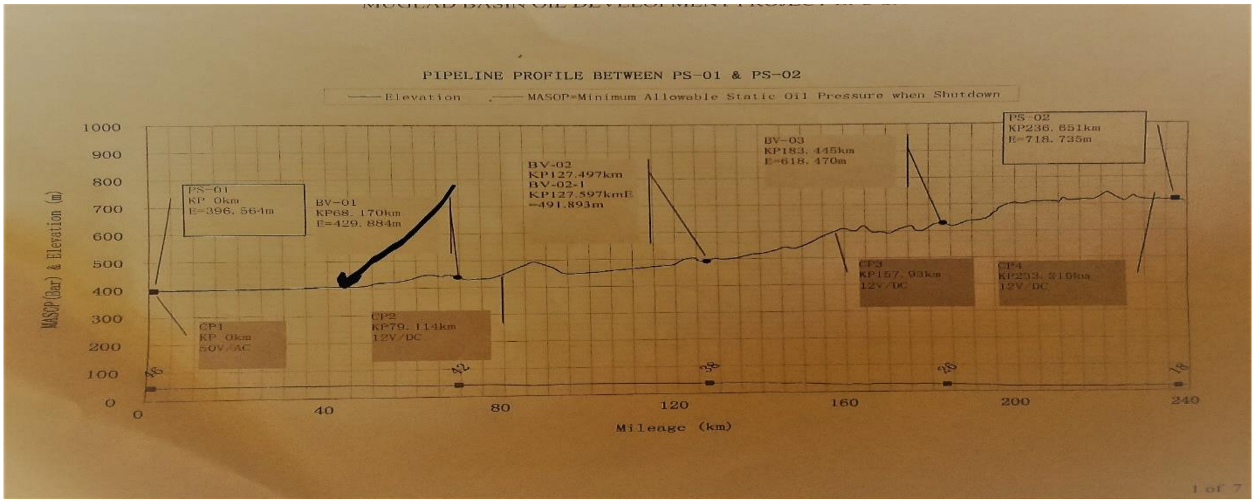

Figure 4.7: pipeline profile 28in between ps1 and ps2

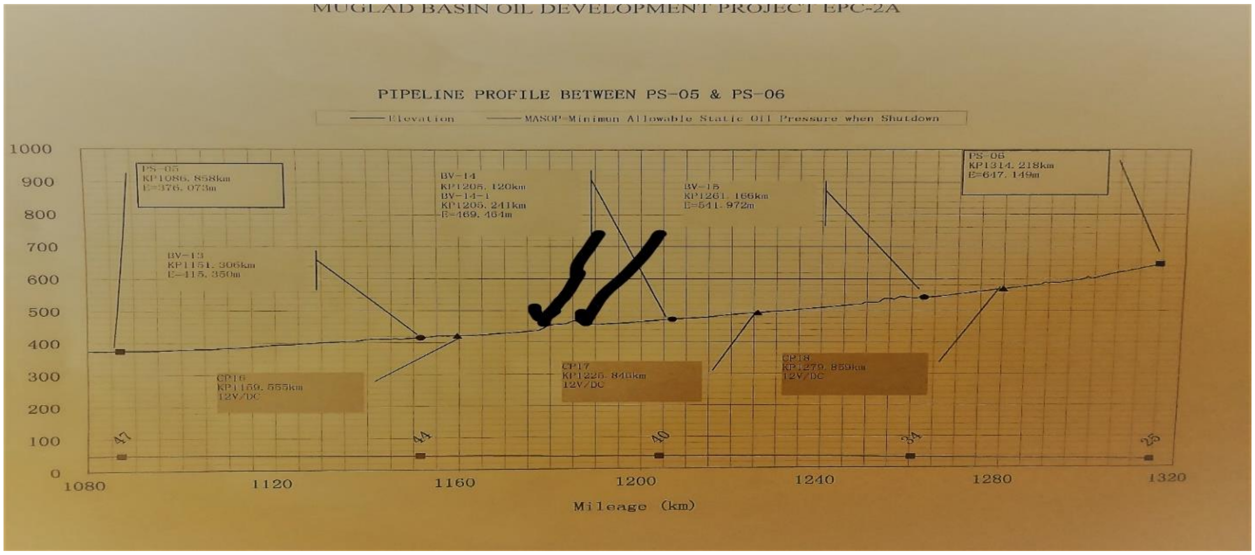

Figure 4.8: pipeline profile 28in between ps5 & ps6

4.5.2. PAPCO leaks:

They have two or three case of leaks due to corrosion in Upstream Atbara River crossing (Kanjari)

Leakage had occurred and spillage observed several meter radius closed to farmer area. At 925km.

Causes of leak: due to loss of metal (corrosion)

Figure 4.9: oil spill in farmer area in Atbara

Action take: closed all block valves and patrolling to determine leak location

Figure 4.10: block valve and it protection

Figure 4.11: heavy equipment for repair leak

Figure 4.12: clamp to repair leak

4.5.3. SPPC leaks:

Have many cases of leaks like in 1986 at kilo zero in portsudan and was difficult to determine location of leak due land topography.

And in 11/2019 at 61km portsudan

Cause: loss of metal (corrosion)

4.5. ERP team:

The team standby for Emergence reasonability plan for any cause happing along Pipeline.

- At general Preparation, inspection, repair (welding + composite).
- Company Top Management assigned an ERP team to supervise, coordinate, and manage the repair of the affected pipeline
- The patrolling security is team movement has been working along pipeline looking for damage and safe condition keep contact with other department.

No	Description	Position
1	Site Commander	Intervention Maintenance Section Head
2	Company rush repair team Leader	Intervention supervisor
3	Technical Specialist	Operation Support Engineer TS
4	Repair work team leader	Intervention Supervisor
5	Earth movement representative	PL Main. Supervisor
6	Civil work team leader	Intervention civil Engineer
7	Senior operation representative	Close PSs or MT Operation superintendent
8	Support Services Site Representative	G.S. coordinator
9	HSE Site Representative	PS or MT safety officer
10	Security Site Representative	PS or MT security coordinator
11	Welders	4 Tech
12	Pipe Fitter	1 Tech
13	Welding inspector	2 Inspector
14	Hot tapping operator	2 operator
15	Supervisor Engineer	3 Engineer
16	Unskilled Labor	1 Labor
17	Foreman	2 Foreman
18	Heavy equipment operator	4 Operator

Table 4.4: ERP members

CHAPTER FIVE

Recommendation and Conclusion

5.1. Recommendations:

(1) Non-routine task looking for smoking, leakage, to checking SCADA daily, communication with main control center (MCC).

(2) The control room to keep close monitoring at any pump station pressure and temperature and looking for any change compare with pipeline parameters.

(3) Immediately report at any cause happened to upper pipeline management (ERP) should be ready for any cases (oil leakage) happened, tools, manpower and spare part as like joint repair, clamps, ECT.

(4) Patrolling security to keeping contact with pump station and MCC when up normal condition like leakage, firing or other (non-routine task).

(5) Daily Lab report and reading for crude oil data per day compare with crude oil parameters.

(6) Natural area for human area along pipeline like farmer, muddy or irrigation, to be keep close monitoring for cathodic protection reading

(7) Nation the public area to be care along pipeline to lead damage can be happening.

(8) Inspection team make survey reading and looking for sickness and compare with parameters.

(9) To use two leak detection systems in redundancy with each other

5.3. Conclusion:

Information's and data were gathered from Sudanese companies working in transporting crude and products via pipeline, Results obtained from SPSS and compared with actual data that calculated using the correlation, and found that the external methods (eg. Fiber optic) are more accurate than internal ones.

5.3. References:

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