CHAPTER ONE

INRTODUCTION

1.1 General

Pipeline networks are the most economic and safest method of transport for mineral oil, gases and other fluid products. Pipelines have to meet high demands for safety, reliability and efficiency. Most pipelines, regardless of what they transport, are designed with a lifespan of around 25 years. When they do begin to fail, they do so slowly beginning with leaks at poor construction joints, corrosion points and small structural material cracks, and gradually progress to a catastrophic ending. But there are also other reasons for leak disasters such as accidents, terrorism, sabotage and theft [1].

The primary purpose of Leak Detection Systems (LDS) is to assist pipeline controllers in detecting and localizing leaks. LDS provide an alarm, and display other related data to the pipeline controllers in order to aid in decision-making. Pipeline leak detection systems are also beneficial because they can enhance productivity and system reliability thanks to reduced downtime and reduced inspection time. LDS is therefore an important aspect of pipeline technology [1].

This thesis presents an overview about the most commonly used principles for leak detection (and leak localization) by showing LDS branches (internal and external methods). The main focus is on internal LDS systems, which utilize field instrumentation (for example flow, pressure and fluid temperature sensors) to monitor internal pipeline parameters [1].

1.2 Problem Statement

Pipelines play great role of transportation of oil and gas for long distances efficiently and economically comparing with traditional transportation methods such as wooding vats, railway and road tanker. Although the progressing of transportations of products, the main problem is the leakage occurrence in pipelines, which is causing negative impact on different aspects such as environmental and economic impacts.

1.3 Objectives

The main objectives of this thesis are listed as:-

- To be familiar with liquid and gas pipelines.
- To understanding of leaking reasons.
- To study LDS requirements.
- To study acquire of leakage monitoring and detection fundamentals.
- To be familiar with leak detection system methods.

1.4 Methodology

- Study the previous works.
- Study the pipelines.
- Study the leak detection system.
- Study SCADA system.
- Evaluate the performance based on simulation results.

1.5 Thesis Layout

This thesis comprises of five chapters:-

Chapter one gives general concepts, problem statement, objectives and methodology. Chapter two is about pipeline types, crude oil types, crude oil pipeline philosophy, crude oil pipelines in Sudan and the operating companies in Sudan and their pipelines components. Chapter three is the core of LDS includes an overview of leakage reasons; the official requirement and performance criteria requirements to build LDS and the LDS classifications have been presented. In Chapter four the simulation has been implemented using Citec SCADA and the readings has been inserted into the table. Chapter five presents conclusion and recommendations for future work are presented.

CHAPTER TWO

PIPELINE

2.1 Introduction

Everything from water to crude oil even solid capsule is being transported through millions of miles of pipelines. The pipelines are vulnerable to losing their functionality by internal and external corrosion, cracking, third party damage and manufacturing flaws. If a small water pipeline bursts a leak, it can be a problem but it usually doesn’t harm our environment. However, if a petroleum or chemical pipeline leaks, it can be an environmental and ecological disaster. Thus, for keeping pipelines operating safely, periodic inspections are performed to find cracks and damage before they become cause for serious concern. Therefore, maintenance of pipelines is essential in order to keep them functional, and moreover the continuation cost for these activities are being increased. Even with the above mentioned problems in pipeline, people still prefer them. The reason being, pipelines are used in transporting substances through a mere pipe. Most of the time liquid and gases are sent through pipes. Pneumatic tubes that transport solid capsules using compressed air are also being used. Like gases and liquids, any chemically stable substance can be sent through a pipeline. Hence sewage, slurry, water, and even beer pipelines exist. With this knowledge we can classify pipelines with respect to the substance that it carries. When a pipeline is built, many inspection methods can be used to evaluate its quality such as visual, X-ray, magnetic particle, and ultrasonic. These inspections are performed as the pipeline is being constructed so gaining access to the inspection area is not problem. Most pipelines are buried. Once the pipeline is buried, it is undesirable to dig it up for any reason. Therefore, manyremote visual inspection equipment to assess the condition of the buried pipe have been developed [2].

2.2 Pipeline Types

There are many different types of pipeline, we willing to take some examples of different types of pipelines, which are currently in widespread use [2].

2.2.1 Oil pipelines

Pipelines are generally the most economical way to transport large quantities of oil or natural gas over land. Compared to railroad, they have lower cost per unit with higher capacity. The material used in manufacturing oil pipes are from steel or plastic tubes with inner diameter typically varying from 4 to 48 inches. Most pipelines are buried underground at a typical depth of about 3 to 6 feet. The oil is kept in motion by pump stations along the pipeline, and usually flows at a speed of about 1 to 6 m/s. Multi-product pipelines are used to transport two or more different products in sequence on the same pipeline. Usually in multi-product pipelines there is no physical separation between the different products. Some mixing of adjacent products occurs, producing interface. This interface is removed from the pipeline at receiving facilities and segregated to prevent contamination. Oil contains varying amounts of wax, or paraffin. In colder climates wax accumulation may occur within a pipeline. Often these pipelines are inspected and cleaned using pipeline inspection [2].

2.2.2 Ethanol pipelines

These pipelines are majorly used in Brazil and United States. There are several ethanol pipeline projects in Brazil and the United States. Main problems related to the shipment of ethanol by pipeline are its high oxygen content, which makes it corrosive, and absorption of water and impurities in pipelines [2].

2.2.3 Hydrogen pipelines

The most cost-effective way to move gaseous hydrogen over a long distance is via pipeline. Hydrogen pipeline is used for transportation of hydrogen through a pipe as part of the hydrogen infrastructure. Hydrogen pipeline is used to connect the point of hydrogen production or delivery of hydrogen with the point of demand, with transport costs similar to Compressed Natural Gas(CNG). Most hydrogen is produced at the place of demand with every 50 to 100 miles and industrial production facility [2].

2.2.4 Water pipelines

This is one of the most used pipelines all around the world and an ancient method as well. The first people to transport water were the Romans to transport large aqueducts water from higher altitudes by building the aqueducts in graduated segments that allowed gravity to simply push the rushing water along until it reached its intended destination. As time passed by hundreds of pipelines were built throughout Europe and elsewhere, and along with flour mills. The ancient Chinese also made use of channels and pipe systems for public works [2]. Pipelines are useful for transporting water for drinking or irrigation over long distances when it needs to move over hills, or where canals or channels are poor choices due to considerations of evaporation, pollution, or environmental impact. Plumbing derived from the Latin plumbum for lead, is the skilled trade of working with pipes, tubing and plumbing fixtures for drinking water systems and the drainage of waste. Plumbing is a piping system constitutes the form of fluid transportation that is used to provide potable water to their homes and business and also remove waste in the form of sewage. The plumbing industry is a basic and substantial part of every ten developed economy, due to the need for clean water and proper collection and transport of wastes. A building's waste-disposal system has two parts: the drainage system and the venting system [2].

The drainage system, also called traps and drains, comprises pipes leading from various plumbing fixtures to the building drain (indoors) and then the building sewer (outdoors). The building sewer is then connected to a municipal sanitary sewage disposal system. Where connection to a municipal sewage system is not possible, a local, private, code-approved septic system is required. Cesspools and outhouses do not meet health codes. Plumbing drainage and venting systems maintain neutral air pressure in the drains, allowing flow of water and sewage down drains and through waste pipes by gravity. As such, it is critical that a downward slope be maintained throughout. In relatively rare situations, a downward slope out of a building to the sewer cannot be created, and a special collection pit and grinding lift ’sewage ejector’ pump are needed. By comparison, potable water supply systems operate under pressure to distribute water up through buildings. Water systems of ancient times relied on gravity for the supply of water, using pipes or channels usually made of clay, lead or stone. Present-day water-supply systems use a network of high-pressure pumps, and pipes are now made of copper, brass, plastic, steel, or other nontoxic material. Present-day drain and vent lines are made of plastic, steel, cast-iron, and lead. Lead is not used in modern water-supply piping due to its toxicity. The straight sections of plumbing systems are of pipe or tube. A pipe is typically formed via casting or welding, where a tube is made through extrusion. Pipe normally has thicker walls and may be threaded or welded, where tubing is thinner-walled and it requires special joining techniques such as compression-fitting, brazing, crimping, or for plastics, solvent welding [2].

2.3 Crude Oil

Crude oil (or petroleum) forms in the earth’s crust by the heating and compression of organic materials over millions of years. It is comprised primarily of hydrocarbons, other organic compounds and small amounts of other components like metals. Crude oil is extracted with wells or strip mines, and refined into petroleum products such as gasoline, diesel, heating oil, solvents and lubricants. Crude oils are classified according to their per unit weight (specific gravity) as follows [3]:

- Light crude oil: has a low density and flows freely at room temperature.
- Heavy crude oil: does not flow easily at room temperature. Heavy crudes must be blended, or mixed, with condensate (liquids often found in the ground with natural gas) to be shipped by pipeline.
- Bitumen: is a highly viscous form of heavy crude found in the Alberta Oilsands. In order to meet pipeline viscosity and density guidelines and make it flow through pipes, it is often blended with additives like Naptha. Naptha is any of various volatile, often flammable, liquid hydrocarbon mixtures used chiefly as solvents and diluents. This blend is called dilbit (diluted bitumen).

Oil can also be divided into sweet and sour crudes. Sweet crudes contain less than 0.5 percent sulphur[3].

2.4 Oil Pipeline Philosophy

Oil pipelines transport liquid petroleum products from one point to another. There are generally three types of oil pipelines [3]:

- Gathering lines: travel short distances, collect unprocessed oil products from wells and deliver them to oil storage tanks. Pipes range from 4 to 12 inches in diameter.
- Feeder lines: move product from oil storage tanks and processing plants to the transmission pipelines. They are generally bigger than gathering lines, but smaller than transmission lines.
- Transmission lines: can be up to 48 inches in diameter and transport oil and associated products from producing to consuming areas, including

across provincial and international boundaries. The oil is piped to refineries where it is refined into petroleum products.

The main features of an oil pipeline are [3]:

- Storage tanks to accumulate oil for injection and to accept deliveries.
- Injection stations: where the product is injected into the pipe.
- Pump stations: located along the line to keep the product moving.
- Intermediate delivery stations: allow product to be delivered to clients along the way.
- Block valve stations: allow a section of the pipeline to be closed for maintenance, or to isolate a leak or spill. These can be operated manually, or remotely.
- Final delivery station: where the remainder of the product is distributed to the client.

2.5 Crude Oil Pipelines

There are three main oil pipelines in Sudan, two of them are for exportation and they are belong to Greater Nile Operating Company (GNPOC) and PetroDar Operating Company (PDOC) and the last one is for domestic consumption which is owned by Petro-Energy Operating Company[3].More details are as follows:

2.5.1 Greater Nile Operating Company pipeline

The pipeline was established in 1999 to transport crude oil product from the blocks No. 1, 2 and 4 from the South Western of Sudan to a location near Port Sudan called Bashayer 1 marine terminal for the purpose of exportation. The length of the pipeline is estimated to be about 1505Km with 28 inch diameter coated with three layers of poly propylene and contains the following [3]:

1) Six Pump stations (PS) for crude pumping, each pump station contains 4 pumps and two fuel tanks.

2) Bashayer 1 Marine Terminal which has eight tanks, capacity of 400 000 barrels per each, pumps for crude shipping, power station with five generators of 3.5MW per each and Single Point Mooring system to link and load the tankers.
3) SCADA system covers all the pipeline and centralized in main control room in Elgaili.
4) 18 insulating valves distributed along the pipeline.
5) Cathodic protection system.
6) Two custody transfer metering stations to measure the crude supplied to Elobied refinery and Khartoum refinery.

The construction cost of the pipeline was about $ 1.2 billion, funded by the companies CNPC, Petronas, Tlemcen and Sudapet. Currently, the pipeline owned by the government of Sudan [3].

2.5.2 Petrodar Operating Company pipeline

The pipeline was established in 2006 to transport South Sudan crude oil in Palogue field. The pipeline starts from Elgabalein to Bashayertwomarine Terminal with length of 1134Km and 32 inches diameter and contains the following [3]:

1. Five Pump stations each pump station contains three pumps, two heat tracing,two fuel tanks, control room and a power plant station with three generators.

2. Bashayertwo marine terminal port which has power station with five power generators, six crude tanks of 500,000 barrels capacity of each tank, three heat tracers, eight loading pumps and control room as a platform to export crude in the Red Sea.

3. Control system covering all the pipeline and main control room centralized in Elailafon and satellite ground station.

4. Cathodic protection system.

5. Insulating valves along the pipeline.

Construction cost was estimated to be about $ 1.7 billion [3].

2.5.3 Petro-Energy Operating Company pipeline

It was established in 2004 to transport the crude oil from block 6 in Southern Kordofan – Balila field. The pipeline is started from Balila till Khartoum refinery with length of 715Km, diameter of 24 inches and currently contains the following [3]:

1. Five Pump stations each pump station is containing pumps for crude pumping, fuel tanks, and power plants in each of the third and the fourth stations and control room.
2. Custody transfer metering skid to measure the crude oil before Khartoum refinery.
3. Control system linking all pipelines by the main control room with last control station.
4. Cathodic protection system.
5. Insulating valves along the pipeline.

Construction cost is about $ 350 million with profit margin of 16.2% [3].

The abovementioned pipelines in Sudan illustrated in Figure2.1.

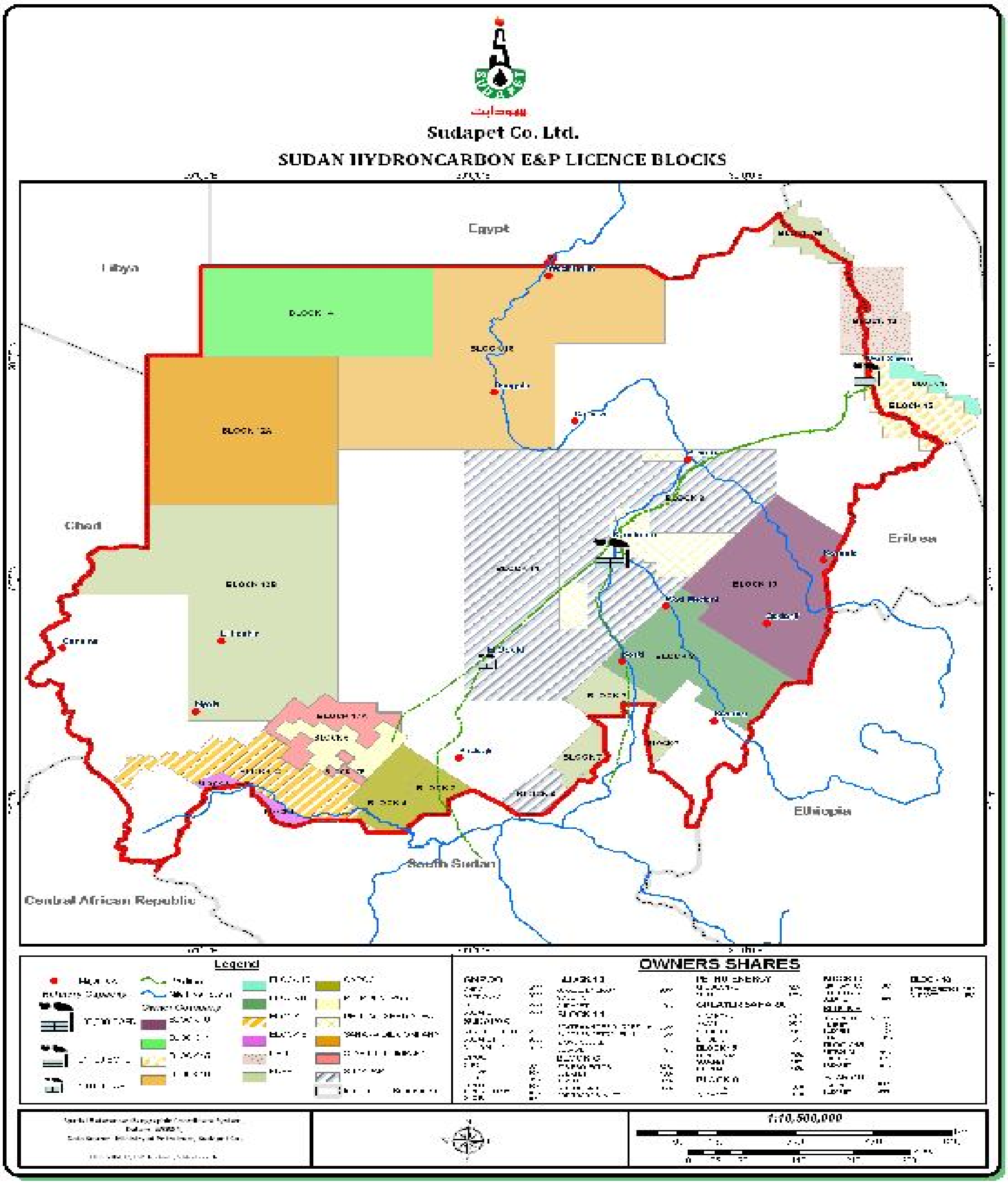


Figure 2.1: Sudan hydrocarbon E&P license blocks and pipelines

CHAPTER THREE

LEAK DETECTION SYSTEM (LDS)

3.1 Introduction

The necessity of leak detection system result of accidents and thefts can be occur with pipelines. In such cases, leak detection systems can help minimize damage to people, the environment, and the companies image as well as the high costs for repair, renovation, indemnity, breakdowns and the lost value of the liquid or gas that has been released [4].

3.2 Causes of Leak

Causes of leakage can be categorized as due to:

1- Fatigue cracks: These occur as the result of material fatigue and are often found on longitudinal welds. Figure 3.1 shows the fatigue cracks [4].

Figure 3.1: Fatigue cracks

2- Stress corrosion: Tensile strength can cause stress tears which can reduce the effectiveness of cathodic corrosion protection systems, resulting in corrosion on the pipeline. The stress corrosion shown in Figure 3.2[4].

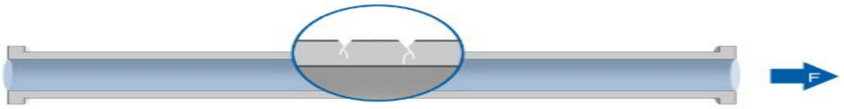


Figure 3.2: Stress corrosion

3- Cracks can also be caused by hydrogen indexing. In this case, atomic hydrogen is diffused into the metal grid, forming molecular hydrogen. This can lead to the pipe material becoming brittle and prone to failure. Figure 3.3shows cracks caused by hydrogen[4].

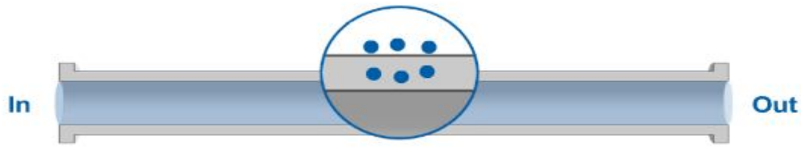


Figure 3.3: Cracks caused by hydrogen

4- Material manufacturing errors: e.g. when cavities are rolled into the material during production of the pipe. Figure 3.4 shows the manufacturing errors [4].

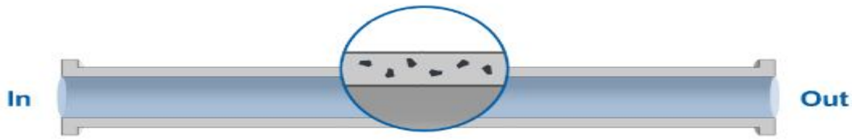


Figure 3.4: Manufacturing errors

5- Leaks can also occur when an external force acts from the outside: This is the case when backhoes dig up a pipeline or seismic ground movements cause shifts in the pipeline. Figure 3.5 shows the external force leakage.[4]

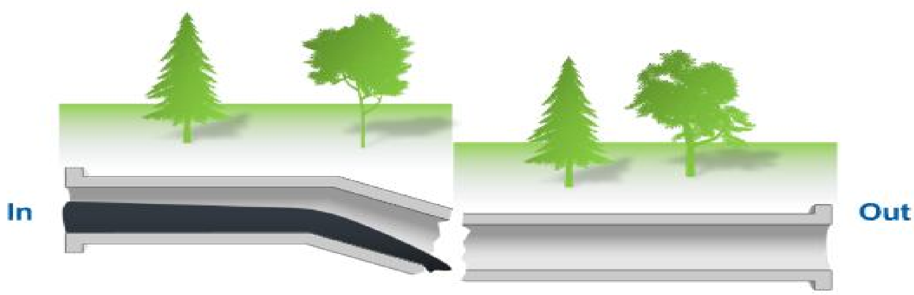


Figure 3.5: External force leakage

3.3 Leak Detection System Requirements

LDS according to regulations divided into two requirements as the follows:

3.3.1 Official requirements (regulatory framework)

In many countries it has become necessary to observe official requirements in order to ensure safety of pipelines, particularly for hazardous materials. These requirements include [5]:

1- Technische Regel fürRohrfernleitungen (TRFL - Germany)

TRFL stands for Technische Regel fürRohrfernleitungen, which was published in 2003 in Germany and applies to all pipelines that transport flammable and/or dangerous liquids or gases. The TRFL requires for leak detection systems all such pipelines [5]:

a) Two autonomous, continuously operating systems that can detect leaks in steady state conditions.
b) One of these systems, or a third one, able to detect leaks in transient conditions.
c) One system to detect leaks in shut-in conditions.
d) One system to detect gradual leaks.
e) One system to detect the leak position.

- Installations according to TRFL (a and b)

TRFL requires two autonomous, continuously operating systems that can detect leaks in the steady state. Either of these systems, or both, or a third one, must be able to detect leaks in transient conditions. Special attention should be paid to the difference between the steady state and the transient state. Steady state conditions exist when all relevant physical variables such as flow, pressure, temperature and density are sufficiently constant along the pipeline to ensure that no wave effects can be observed. Transient conditions exist when the physical variables change significantly with time, so wave effects are present. Redundant instrumentation is required in principle, but in practice the requirement for redundant equipment is frequently relaxed. This may happen either because the risk of damage to life and property is relatively low, or because instruments at substations effectively provide back-ups for each other. Redundant signal paths and communication are always required.However,the leak detection system itself must always be redundant, for example using multiple techniques including [5]:

- Pressure and Flow monitoring.
- Acoustic/negative pressure wave.
- Line balance methods.
- Statistical LDS.

- Installations according to TRFL c)

TRFL requires that each pipeline has one system to detect leaks in shut-in conditions.In shut-in conditions, valves will lock a pressure into one or more sections of the pipeline. It is possible for considerable pressure changes to occur in this case as a result of thermal effects, but any rapid or unexpected fall in pressure indicates that a leak has occurred [5].

- Installations according to TRFL d)

Typically these systems utilize a sensor cable installed along the pipeline. Leak detection is either by change in temperature (fiber optics) or change in gas concentration (semi permeable sensor cable). The following should be taken into account [5]:

- The operating pressure and temperature must be suitable

- Not all fluids can be monitored.

- Installations according to TRFL e)

The TRFL requires the LDS to locate the position of a leak as fast as possible. This function can be integrated into one of the systems installed to comply with section a) [5].

2- American Petroleum Institute Standard 1130 (API 1130 - USA)

The second edition of American Petroleum Institute (API) standard 1130 “Computational Pipeline Monitoring (CPM) for liquid pipelines was released in 2002 [API 1130]. API 1130 does not directly impose legal requirements on pipeline operators in the same way as TRFL, but it provides the necessary technical information for conscientious operators to operate their pipelines safely [2].API 1130 covers liquid pipelines only. It describes design, implementation, test and operation of CPM systems, based on an algorithmic approach to leak detection. It also gives recommendations for (self) test and operator training [6].

3- API 1155 (USA)

The API 1155 evaluation methodology for software based leak detection systems was first published in 1995, and defines methods of comparing LDSs from different manufacturers [7].

4- The former API 1155: contains performance criteria for leak detection systems, which has since been replaced by API 1130 [5]
5- The American 49 CFR 195: Which is regulates the transport of hazardous liquids via pipeline [5].
6- The Canadian CSA Z662: regarding oil and gas pipelines [5].

Regardless of the specific national regulations, these rules are observed internationally and often form the basis for the selection of a suitable leak detection system [5].

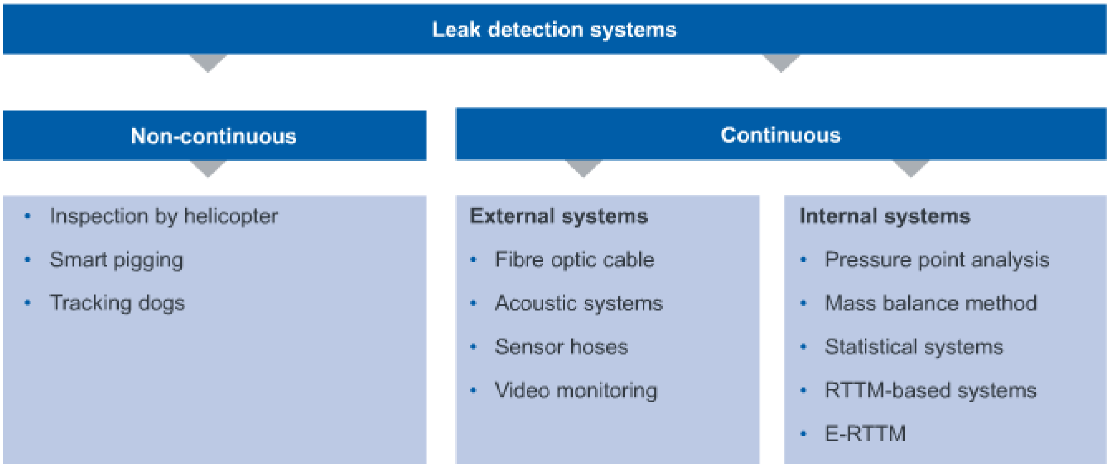
3.3.2 Performance criteria requirements

- Sensitivity: The sensitivity is a composite measure of the size of a leak that a system is capable of detecting, and the time required for the system to issue an alarm in the event that a leak of that size should occur [1].
- Reliability: The reliability is a measure of the ability of a leak detection system to render accurate decisions about the possible existence of a leak on the pipeline, while operating within an envelope established by the leak detection system design. It follows that reliability is directly related to the probability of detecting a leak, given that a leak does in fact exist, and the probability of incorrectly declaring a leak, given that no leak has occurred [1].
- Accuracy: The accuracy covers estimation of leak parameters such as leak flow rate, total volume lost, type of fluid lost and leak location within the pipeline network. The validity of these leak parameter estimates should be as accurate as possible [1].
- Robustness: The robustness is a measure of the leak detection system's ability to continue to function and provide useful information even under changing conditions of pipeline operation, or in conditions where data is lost or suspect. A system is considered to be robust if it continues to function under such non-ideal conditions; this includes things like sensor failure. In this case the leak detection system should be able to detect the failure and at least continue to work albeit with reduced sensitivity. When evaluating individual leak detection systems, you should weigh each of these individual criteria against one another and not decide based on a single specification. It is very important to choice the suitable leak detection system. That means no generation of false alarms, caused by normal operation[1].

3.4 Leak Detection System Classifications

The leak detection system can be classified into two major types shown in Table 3.1 [8]:

Table 3.1: LDS types:



3.4.1 The non-continuous systems

The non-continuous systems comprises of [4]:

1- Inspection by helicopter

The helicopter flies along the pipeline, looking to detect any outflowing gas. Three common methods when detecting leaks by helicopter include Detection using:

a. Laser:When using lasers for leak detection, a laser is set to the absorption wavelength of the medium to be detected. When the laser hits the medium, a part of the laser energy is absorbed. The amount of energy absorbed from the laser is measured to arrive at the amount of leaked medium. The detecting leaks by laser shown in Figure 3.6 [4].

Figure 3.6: Detecting leaks by laser

b. Infrared Cameras:Our eyes are detectors that are designed to detect visible light (or visible radiation). There are other forms of light (or radiation) that we cannot see. The human eye can only see a very small part of the electromagnetic spectrum. At one end of the spectrum we cannot see ultraviolet light, while at the other end our eyes cannot see infrared. Infrared radiation lies between the visible and microwave portions of the electromagnetic spectrum. The primary source of infrared radiation is heat or thermal radiation. Figure 3.7 shows electromagnetic spectrum.

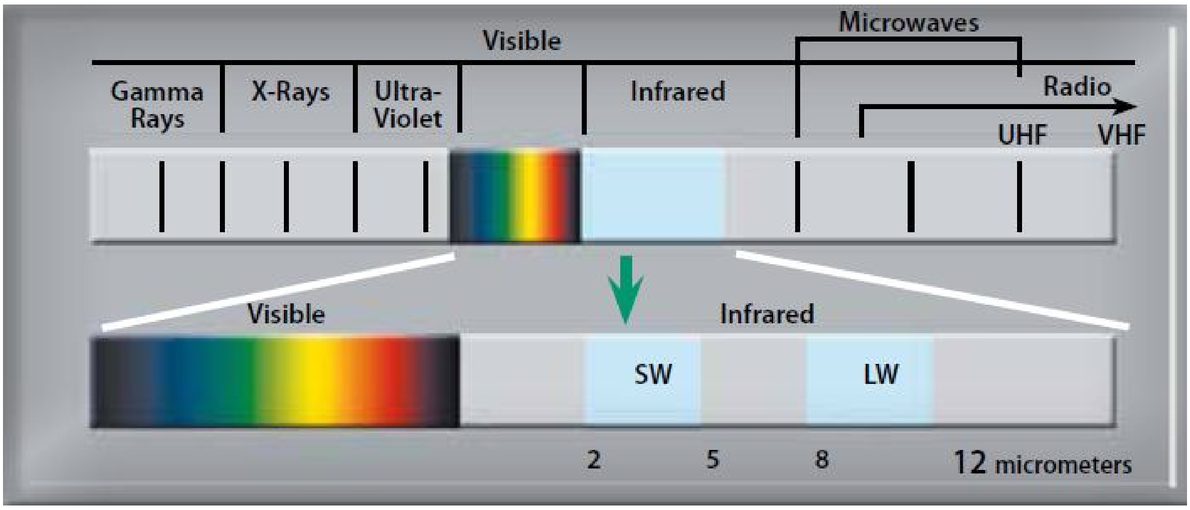


Figure 3.7: Electromagnetic spectrum

Detecting leakage using infrared cameras functions by using video cameras that are fitted with a special filter that highlights a selected spectrum of infrared wavelengths. Infrared camera is a preventative maintenance solution to spot leaks in pipelines. The infrared camera can rapidly scan large areas and pinpoint leaks in real time. It is ideal for monitoring plants that are difficult to reach with contact measurement tools. Literally thousands of components can be scanned per shift without the need to interrupt the process. It reduces repair downtime and provides verification of the process. Above all it is exceptionally safe, allowing potentially dangerous leaks to be monitored from several meters away. Figure 3.8shows infrared camera [4].

Figure 3.8:Infrared camera

Certain hydrocarbons absorb infrared radiation from this spectrum and leakis detected as a visual indication similar to smoke in the video image shown in Figure 3.9 [4].

Figure 3.9: Leakage detected by infrared camera appeared as smoke

c. Leak Sniffers:Leak sniffers draw in air samples to evaluate in an analyzing unit to directly measure the concentration of the leaked medium. Figure 3.10 shows detecting leaks by leak sniffer [4]

Figure 3.10: Detecting leaks by leak sniffer

To do this, the helicopter must fly low enough to pass through the gas cloud made by a leak. The analyzing unit then indicates whether gas is present and in what concentration. Helicopters are a good option to detect small gas leaks when the pipeline route is suitable for accurate flight routes; however the accuracy also depends on the weather conditions. Poor weather conditions mean that the leaking gas can drift and in severe cases the helicopters cannot even fly during extreme weather [4].

2- Pipeline pigs

Pipeline pigs are utilized for a variety of tasks in pipeline integrity management. This includes:

- Cleaning the pipelines.
- Separating product batches.
- Gauging pipeline condition.
- It helps gain valuable information about corrosion, cracks, wall thickness as well as existing leaks in pipelines.

In this case, we use the term smart pigging. To perform pigging, a pig is inserted into the pipeline using a pig launcher. The pig advances through the pipeline, propelled by the medium and gathers data along the way. A receiver is used to guide the pig out of the pipeline in order to subsequently analyze the collected data. Various techniques are used to collect pipeline information using smart pigs; two of these are the magnetic flux leakage method and the ultrasonic principle. With the magnetic flux leakage method, a strong permanent magnet is used to magnetize the pipeline. Any changes to the wall of the pipe, such as corrosion, change the magnetic flux lines which are then recorded by sensing probes attached to the pig as shown in Figure 3.11 [4].

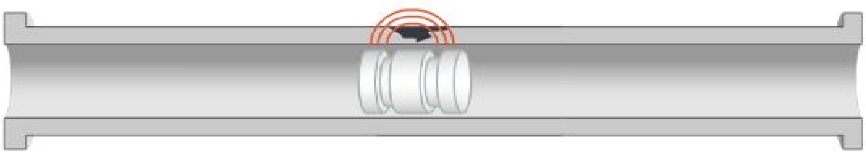


Figure 3.11: Smart pigging

Following pigging, the recorded signals are evaluated based on reference signals to detect any defects or abnormalities in the pipe wall. When it comes to the method based on the ultrasonic principle, the pig transmits ultrasonic pulses into the line and receives their reflected signals. The signals are reflected by the inner and outer pipe wall and based on the running speed of the pig, the thickness of the pipe wall can be derived [4].

By using smart pigs, existing leaks can be detected as well as any damage to the pipeline which could result in leaks. Prior to commissioning pipelines they are often pigged and the results used as the baseline for further inspections, this is called zero or baseline pigging. It’s important to ensure that the pipeline is piggable in the first place. This means that you must be certain that there are no obstacles in the pipeline such as restrictions or fittings making the passage too narrow and that there are pig launchers and receivers to capture the pig. In addition, the speed of the pig must be kept between 3–15 feet per second to obtain accurate results [4].

3- Tracking dogs

Another non-continuous solution for monitoring leaks is the use of tracking dogs. These dogs are specially trained to recognize the odor of a certain compound which is injected into the pipeline to be inspected.

The pipeline is then operated as usual and the dog is led along the path, sniffing for the compound. The use of tracking dogs usually only takes place with short pipelines or segments of pipeline. It is also a good method when it is not possible to accurately localize the leak using other methods and then the dogs can be used to further narrow down the leak site. However, it is difficult to certify a tracking dog as a leak detection system within the framework of API or TRFL, for example [4].

3.4.2 The continuous systems

The continuous system includes the followings:

1- External systems

(1) Fiber optic

The use of fiber optic cables for the continuous external monitoring of leak is based on physical changes that occur at the leak site. One of those physical changes is a typical change in temperature profile. To detect such changes, the fiber optic cable is placed along the pipeline. Figure 3.12shows fiber optic cable[5].

Figure 3.12:Fiber optic cable

A laser then emits pulses that are reflected by molecules. The reflected laser pulse magnitude gives insight as to the temperature at the place where the photon hits the molecule. Figure 3.13show the laser emitted [4].

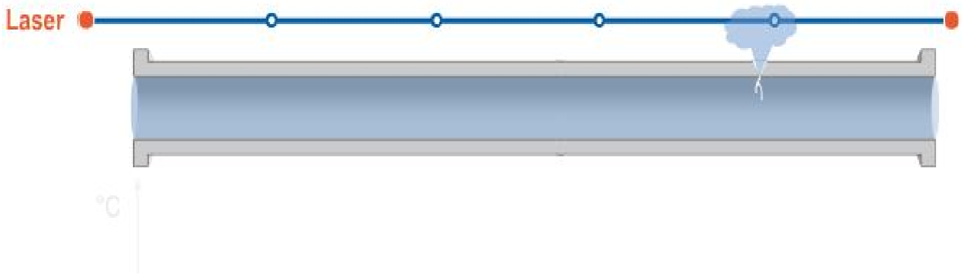


Figure 3.13: Laser emitted

By adding these reflections, a temperature profile can be made and it is then possible to detect the characteristic change in temperature that occurs at the leak site. Figure 3.14 shows that [4].

Figure 3.14: Temperature profile against reflected pules

Monitoring pipelines with fiber optic cables is a good option for accurately localizing leaks. However, use of this method is only possible up to limited lengths of pipeline and many reflections are required to plot a useful temperature profile [4].

When installing the cable it is also necessary to pay attention to the medium to be monitored. If it is a gas to be monitored, the cable should be installed above the pipeline as gas normally rises as shown in Figure 3.15 [4].

Figure 3.15: The cable installed above gas pipeline

When it comes to liquids, it makes sense to install the cable below the pipeline as shown in Figure 3.16 [4].

Figure 3.16:The cable installed below liquid pipeline

(2) Acoustic systems

Acoustic sensors are installed outside of the pipeline to detect leaks by measuring the noise levels at multiple sites along the pipeline. This information is used to create a noise profile of the pipeline as shown in Figure 3.17 [4].

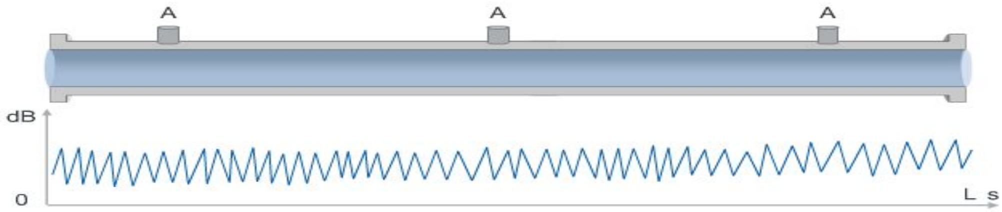


Figure 3.17: Noise profile of pipeline

Detecting leaks using acoustic signals is possible because an acoustic signal is created when gases or liquids flow through a crack or hole in the pipeline. Deviations from the baseline noise profile that are created result in the leak alarm going off as shown in Figure 3.18 [4].

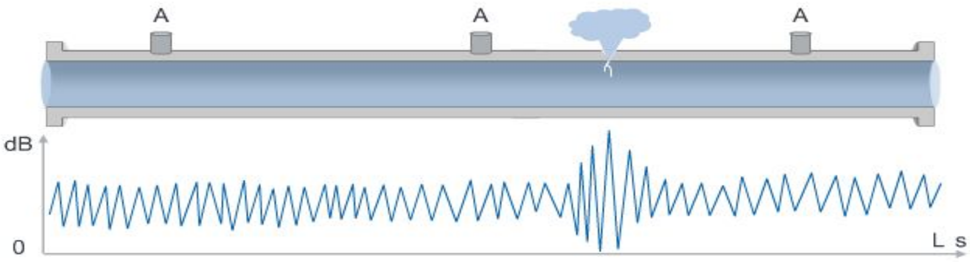


Figure 3.18: Noise profile of pipeline when leakage occured

Acoustic sensors can be mounted directly to the pipeline or coupled to the pipe's wall using steel rods for underground pipelines as shown in Figure 3.19 [4].

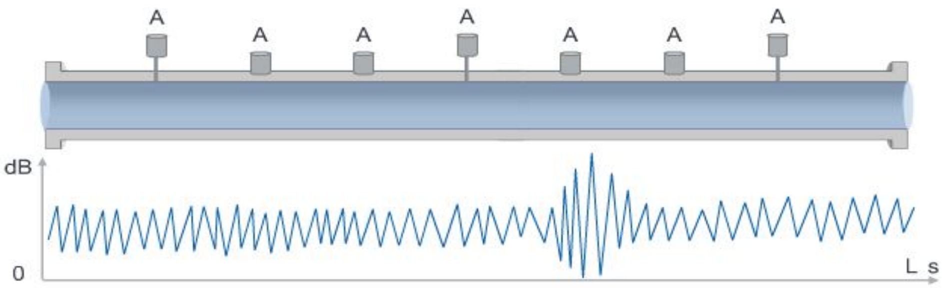


Figure 3.19: Sensor connected with pipeline

To monitor longer pipelines, a large number of acoustic sensors are needed. Small leaks whose acoustic signal is small and only differ slightly from the background noise cannot be detected as otherwise there would be many false alarms [4].

(3) Video monitoring

Detecting gas leaks using infrared is made possible through video cameras, featuring a special filter which is sensitive to a selected spectrum of infrared wavelengths. Infrared camera is a preventative maintenance solution to spot leaks in pipelines. The infrared camera can rapidly scan large areas and pinpoint leaks in real time. It is ideal for monitoring plants that are difficult to reach with contact measurement tools. Literally thousands of components can be scanned per shift without the need to interrupt the process. It reduces repair downtime and provides verification of the process. Above all it is exceptionally safe, allowing potentially dangerous leaks to be monitored from several meters away [4].Figure 3.20 illustrates infrared camera mechanism in detecting gas leaks. Infrared energy (A) coming from an object is focused by the optics (B) onto an infrared detector (C).The detector sends the information to sensor electronics (D) for image processing. The electronics translate the data coming from the detector into an image (E) that can be viewed in the viewfinder or on a standard video monitor or LCD screen.

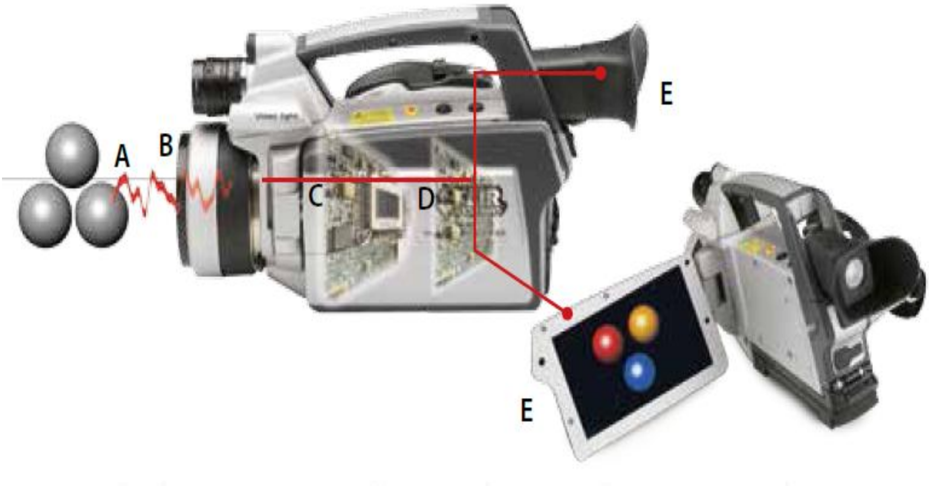


Figure 3.20:Infrared camera mechanism

Certain hydrocarbons absorb infrared radiation from this spectrum. This makes it possible to detect the leaks as an image of smoke on the video display. Figure 3.21 is shown the gas leakage occur in infrared camera [4].

Figure 3.21: Gas leakage occurred in infrared camera as smoke

Liquid leaks can also be detected using infrared cameras as the thermal conductivity in wet ground is different than in dry ground. In this case, you get a different temperature pattern above the leak position as shown in the following Figure 3.22 [4].

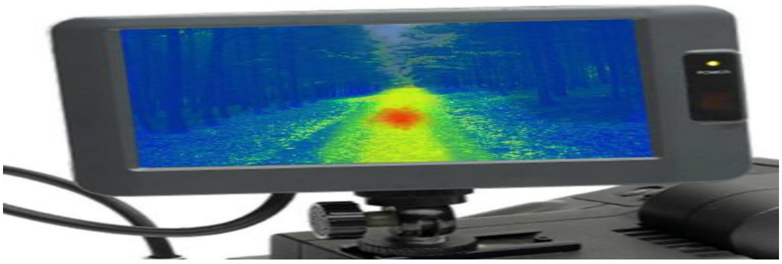


Figure 3.22: Liquid leakage occurredin infrared camera as different temperature pattern

Video monitoring of pipelines is designed for short distances. It is thus an interesting option in critical areas such as on company premises or for high consequence areas [4].

(3) Sensor hoses

When using sensor hoses, a semi-permeable hose is installed along the pipeline as shown in Figure 3.23 [4].

Figure 3.23: Sensor hose

In the event of a leak, the medium comes out of the pipeline and into the hose as shown in Figure 3.24 [4].

Figure 3.24: Leakage detected by sensor hose

In a timed cycle, a test gas is injected into the hose at the beginning of the pipeline. Then the contents of the hose are pumped to the end of the pipeline. There is an analyzing unit at the end which then tests the hose contents for the presence of hydrocarbons. The run time of the test gas indicates the total run time of the pipeline. As the total run time is known, the difference between the arrival of the medium out of the pipeline and that of the test gas can be used to derive the leak site. Figure 3.25 illustrates the leakage localization by using sensor hose[4].

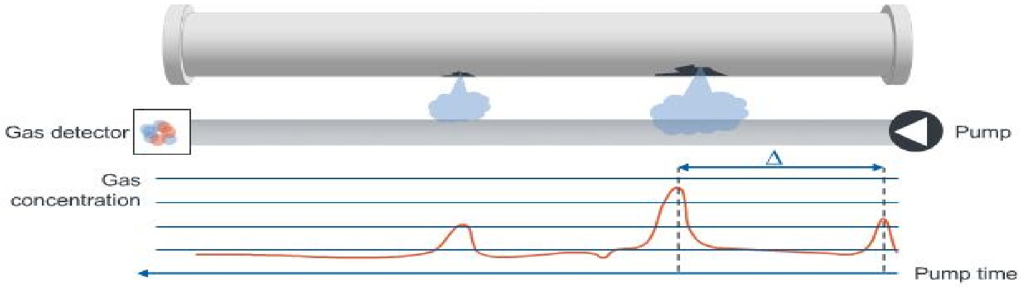


Figure 3.25: Leakage localization by sensor hose

Due to the material-specific properties of the hose, the use of sensor hoses usually only takes place in short pipelines. The analyzing units can detect very small volumes of substances meaning even the smallest of leaks can be detected. Just as with fiber optic cables, when installing the sensor hoses pay attention to the positioning of the hoses above or below the pipeline[4].

2- Internal systems

Before we look at the individual methods of internal continuous leak detection let's first take a look at the basic functioning of these systems. When there is a leak the pressure and flow patterns in the pipeline change. These changes are recorded by the instrumentation and the Supervisory Control And Data Acquisition (SCADA) system transmits them to the control room. The system then calculates whether there is a leak in the pipeline and the operator is informed at the HMI of the current status. The types of internal systems are [1]:

(i) Pressure point analysis

Pressure point analysis is based on the evaluation of pressure drop or the pressure profile measured at individual points. Figure 3.26 shows the pressure point analysis method [4].

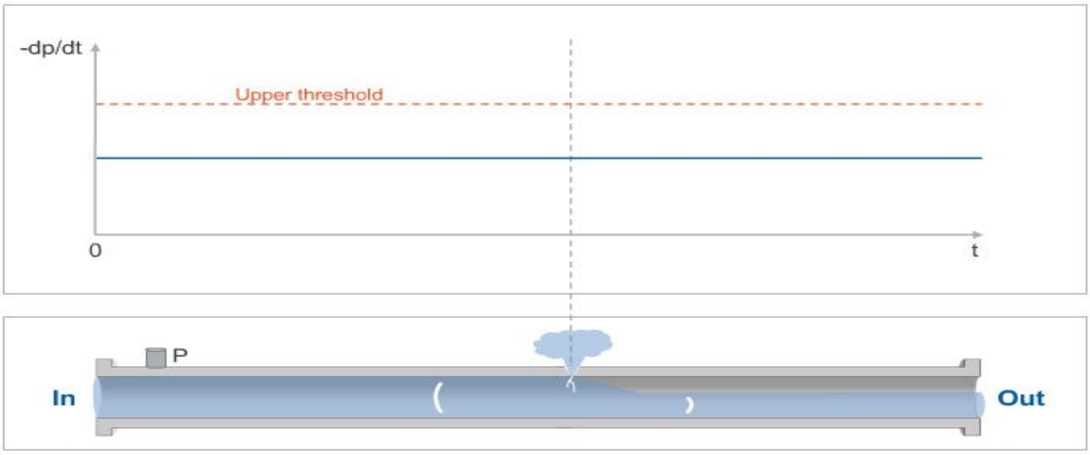


Figure 3.26: Pressure point analysis method

As a spontaneous leak brings up a characteristic negative pressure wave, you can check whether the measured pressure drop (dp) within a time period (dt) exceeds set thresholds. Figure 3.27 illustrates the leakage detection by pressure point analysis method[4].

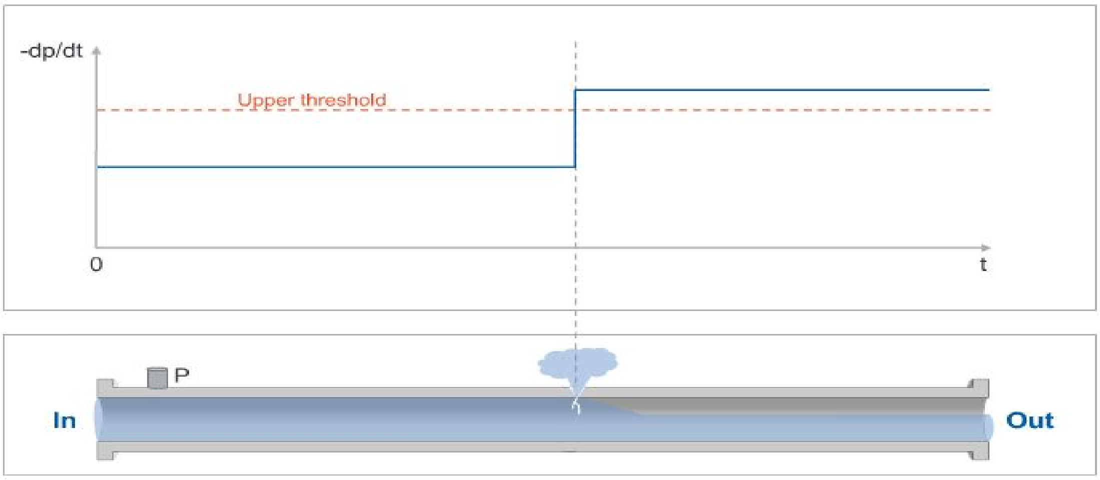


Figure 3.27: Leakage detected by using pressure point analysis method

In addition a lower threshold for the absolute pressure is also determined and if either one of these events occurs; the system triggers an alarm[4].

(ii) Mass balance method

Another type of internal leak detection system is based on Antoine Lavoisier's conservation of mass principle. According to this principle, mass in a closed system remains constant and is not changed by processes within the system. If the pipeline is considered to be a closed system and you compare the mass flow at the inlet and the outlet, the difference in a leak-free case should always equal zero as shown in Figure 3.28[4].

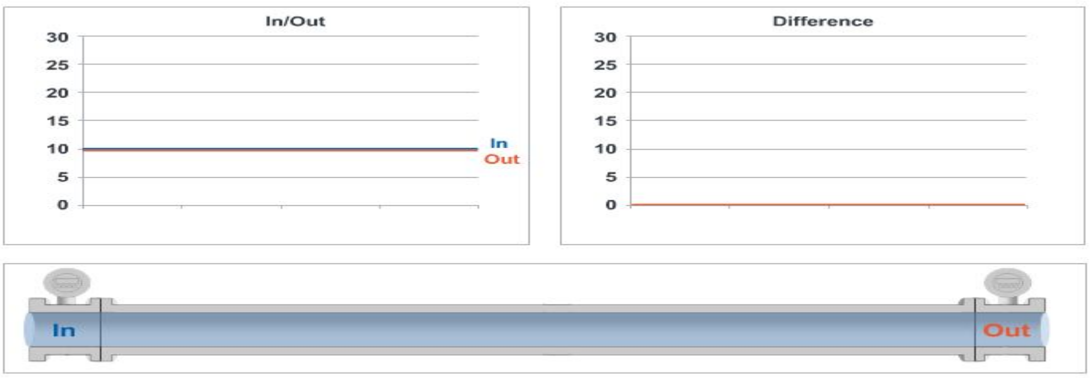


Figure 3.28: Mass balance method in case of no leakage occurred

If, however, a leak occurs, the system has been opened and mass escapes. This results in a decrease in the measured mass flow at the outlet and an increase in the mass flow at the inlet as shown in Figure 3.29 [4].

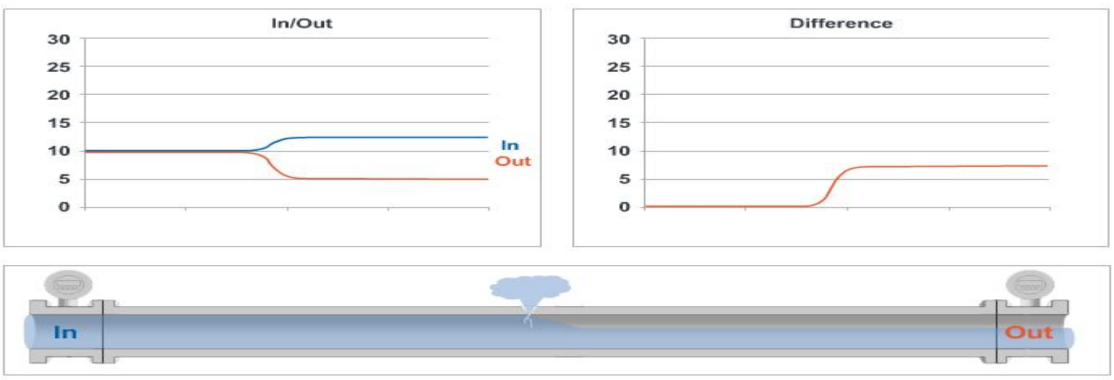


Figure 3.29:Leakage detected by using mass balance method in case of leakage occurred

The problem with this type of leak detection is that it does not take into account dynamic changes in the contents of the pipe, often referred to as line pack. This can happen, for example, when more productsare being produced for a gas pipeline than is currently being consumed and the pipeline packs, serving as a large tank or cache. This type of leak detection is thus also known as uncompensated mass balance [4].

(iii) Statistical leak detection systems

Statistical leak detection systems subject a previously determined variable to a statistical test. Common statistical variables include pressure change over time or the result of a mass balancing[4].

The so-called hypothesis test as shown in Figure 3.30 is widely used here. With this test, two hypotheses are prepared, namely:

- Hypothesis 0: No leak
- Hypothesis 1: Leak.

Figure 3.30 shows the statistical leak detection system.

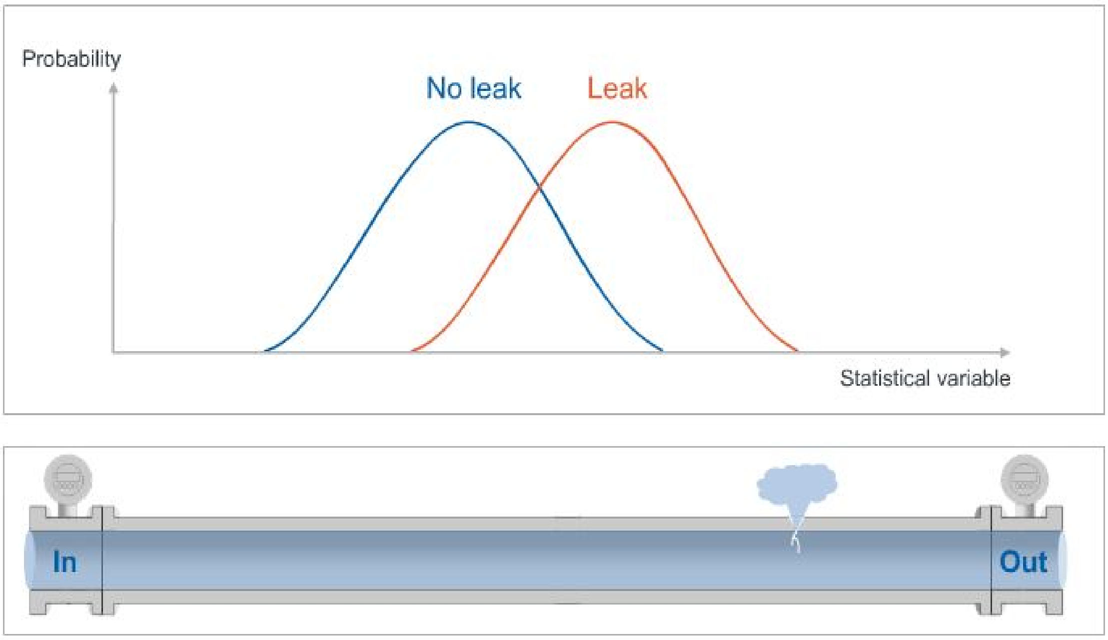


Figure 3.30: Statistical leak detection systems

The system checks whether there is enough data for the statistical variable to be a plausible part of the leak hypothesis and if it is, sends out an alarm as shown in Figure 3.31 [4].

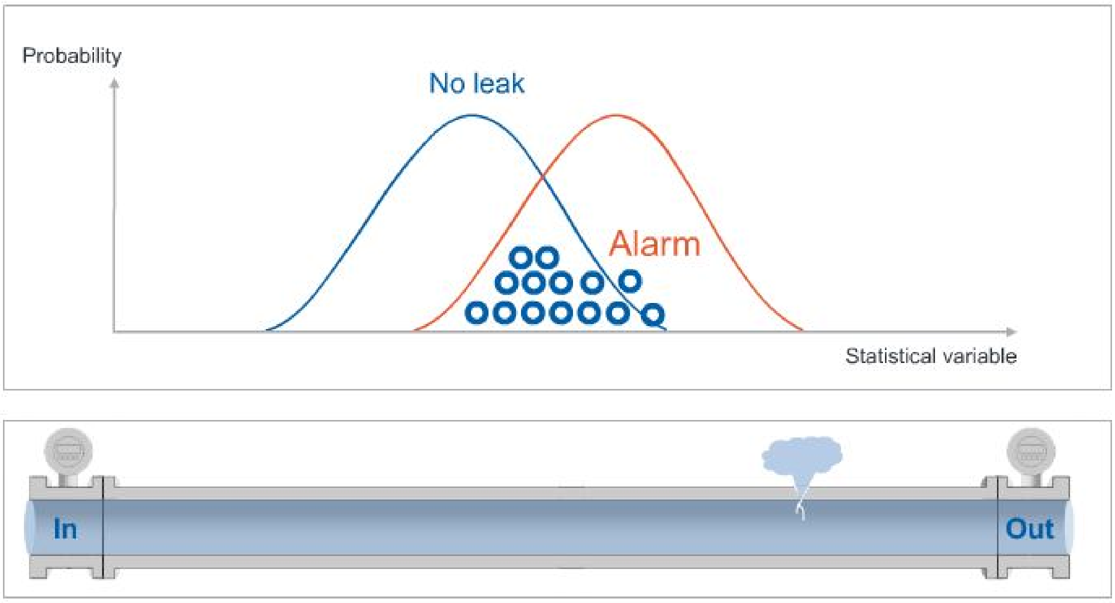


Figure 3.31: Leakage detected by using statistical leak detection system

(iv) Real Time Transient Model Systems (RTTM)

RTTM systems can compensate for dynamic changes. To do this, they make use of basic physical laws which the pipeline must obey. The conservation of mass principle, which includes the density (rho), the time (t), the flow velocity (v) and the pipeline location coordinates (s), the conservation of momentum principle, which includes the flow velocity, the time, the pressure (P), the pipeline location coordinates and the pipeline friction (fs) and the conservation of energy principle, which includes the enthalpy (h), the time, the density, the pressure and the specific loss performance (L). These physical principles precisely describe the stationary and transient behavior of the flow in the pipeline. Using these equations flow, pressure, temperature and density can be calculated and integrated in real time for each point along the pipeline. These trends are also known as hydraulic profiles and accurately predict the true performance along the entire pipeline. But how do we actually detect leaks? To answer that question, let's take a closer look at the individual measurements[4].

At the inlet the pressure (P_0) and the temperature (T_0) are measured and at the outlet the pressure (P_L) and the temperature (T_L) are measured as shown in Figure 3.32[4].

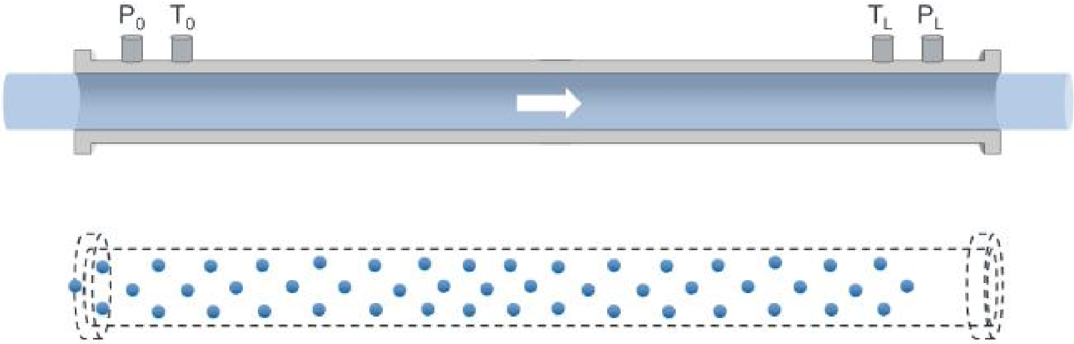


Figure 3.32: RTTM systems

Using these measurements along with detailed knowledge of the pipeline geometry and the properties of the product being transported the leak detection system calculates the actual change in pipe contents or line pack as shown in Figure 3.33[4].

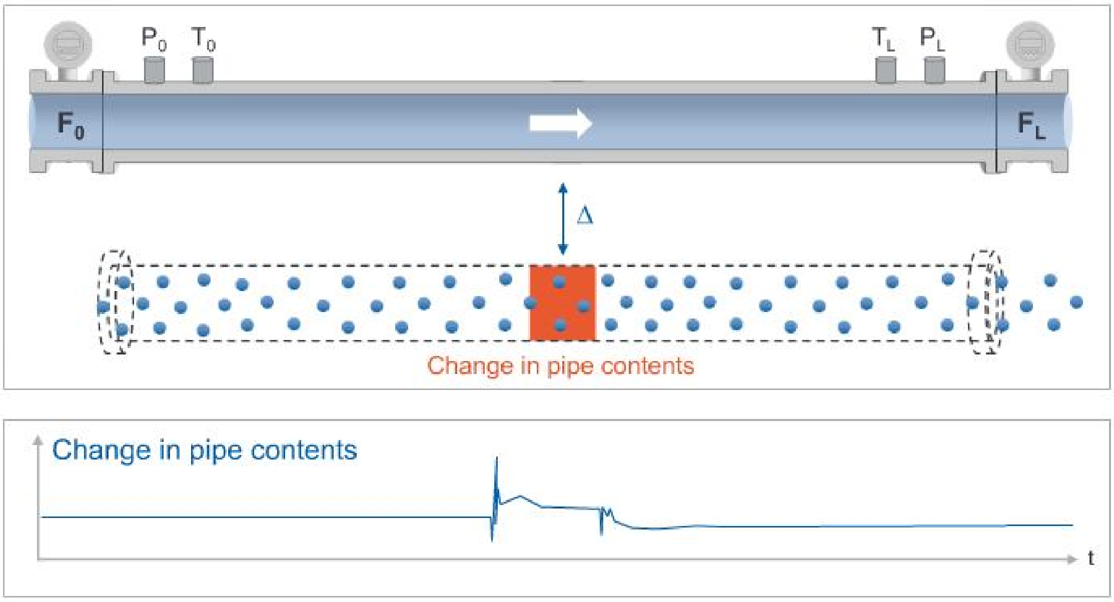


Figure 3.33:Leakagedetection by RTTM systems

This is subtracted from the difference between the measured flow values (F_0) at the inlet and (F_L) at the outlet and results with the current, compensated leak rate of the system. We also talk about RTTM-compensated mass balancing as shown in Figure 3.34 [4].

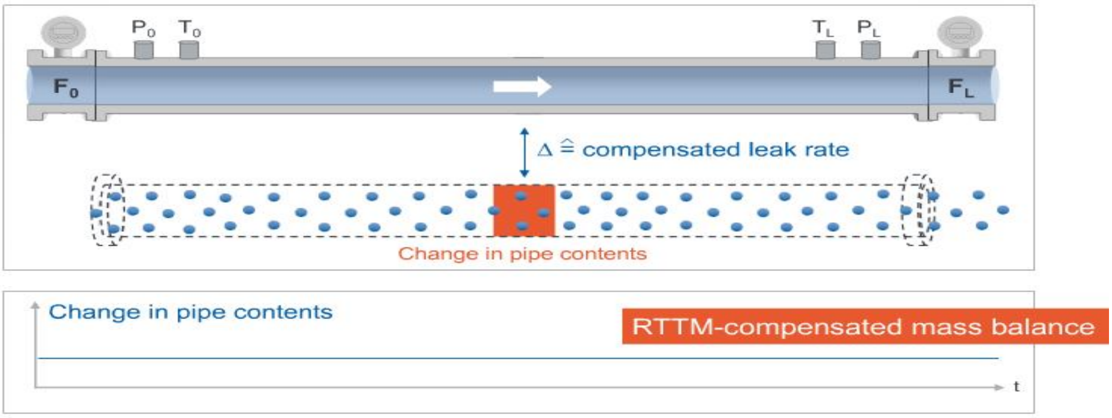


Figure 3.34: RTTM-compensated mass balancing

(5) Extended Real Time Transient Model Systems (E-RTTM)

E-RTTM systems use the same principle as RTTM systems. The pressure (P_0) and the temperature (T_0) are measured at the inlet and the pressure (P_L) and the temperature (T_L) are measured at the outlet.Using these measurements the leak detection system calculates using the laws of physics, expected flow rates at the inlet and outlet. These expected values are then compared to the measured flow values (F_0) at the inlet and (F_L) at the outlet. Two residuals can be obtained as:

x= measured flow at the inlet – calculated flow at the inlet and(3.1)

y= measured flow at the outlet – calculated flow at the outlet(3.2)

- In a leak-free situation both x and y ~ 0 as shown in Figure 3.35[4].

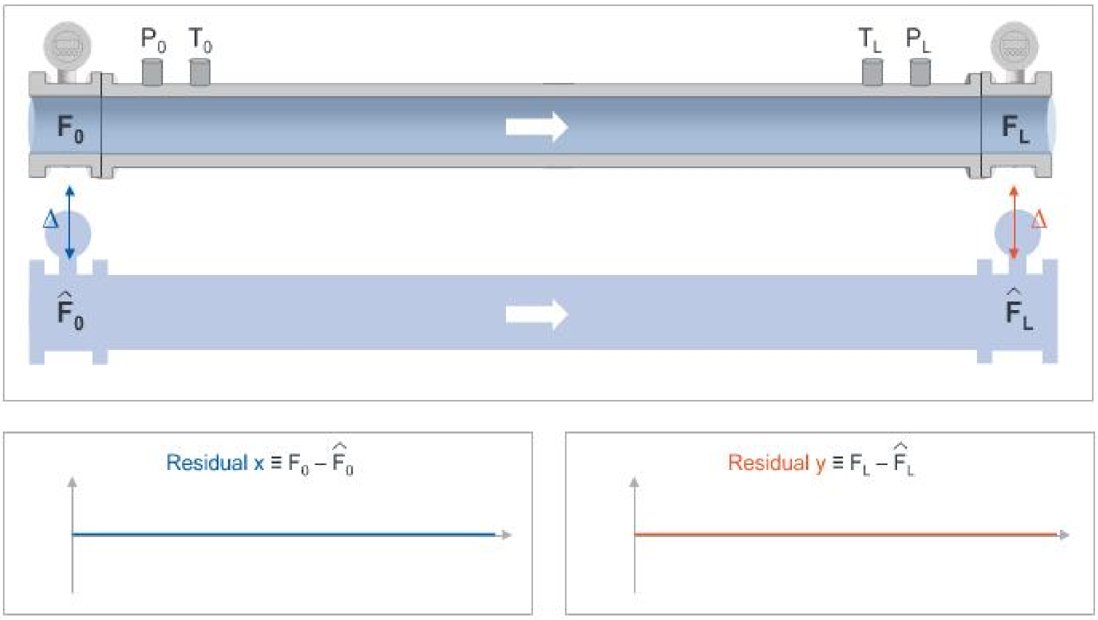


Figure 3.35: E-RTTM systems in case of no- leakage occurred

- In the event of a leakage, we see deviations where residual x > 0 and residual y < 0 as shown in Figure 3.36[4].

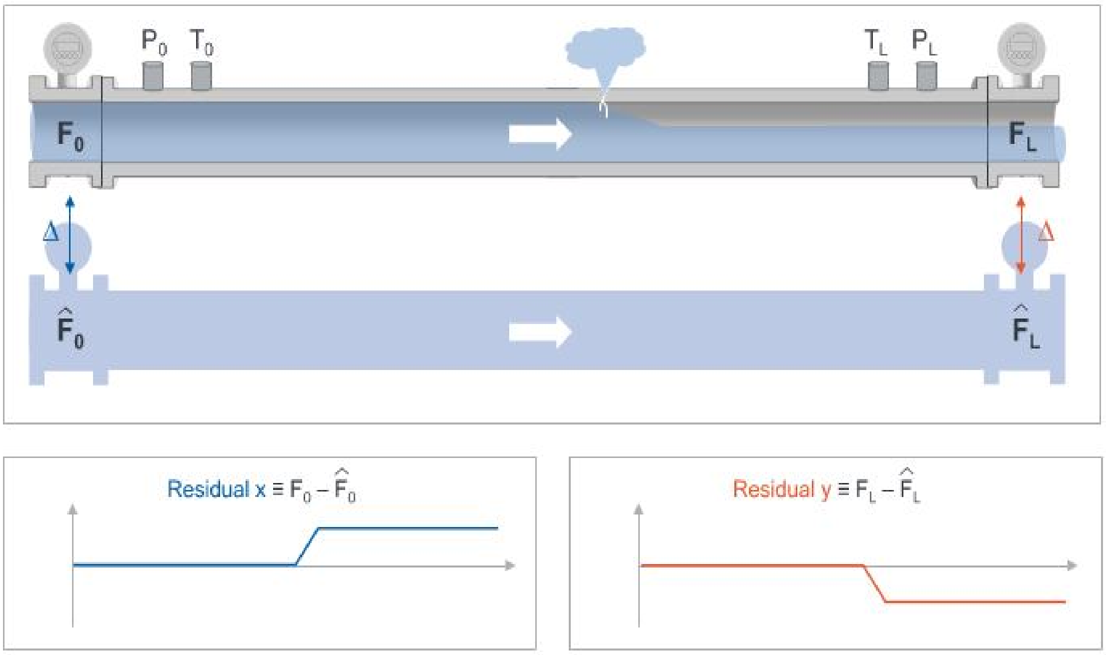


Figure 3.36: Leakage detected by E-RTTM systems

In order to avoid false alarms, E-RTTM systems also use leak pattern recognition. The system uses the residuals x and y as decision values and a leak situation is not the immediate result of a deviation. Figure 3.37 shows the E-RTTM system with leakage pattern recognition[4].

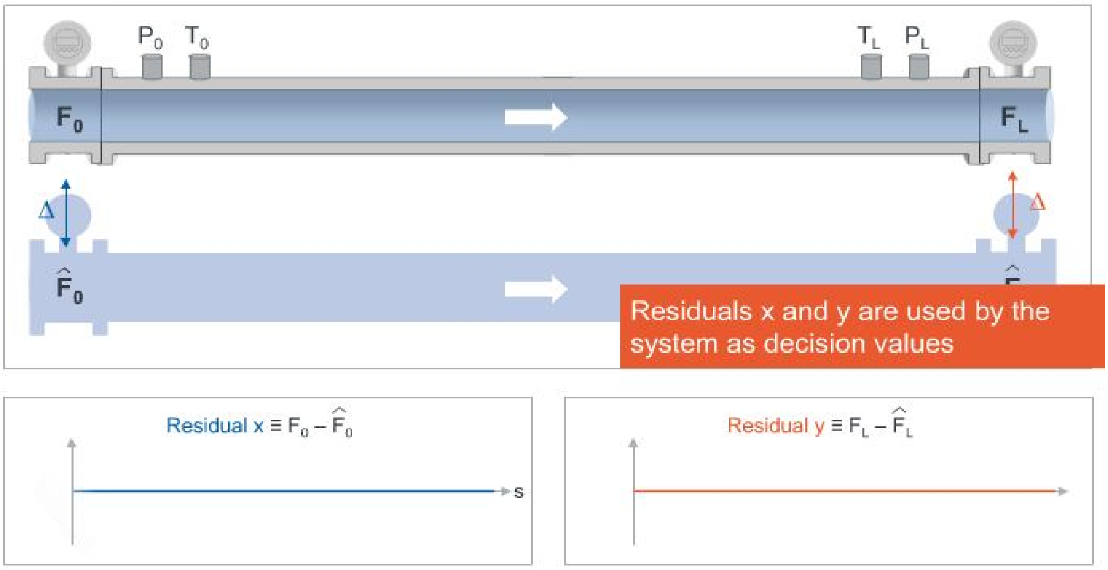


Figure 3.37: E-RTTM systems with leakage pattern recognition

Let's take a look at residual x in the Figures 3.38, 3.39 and 3.40[4].

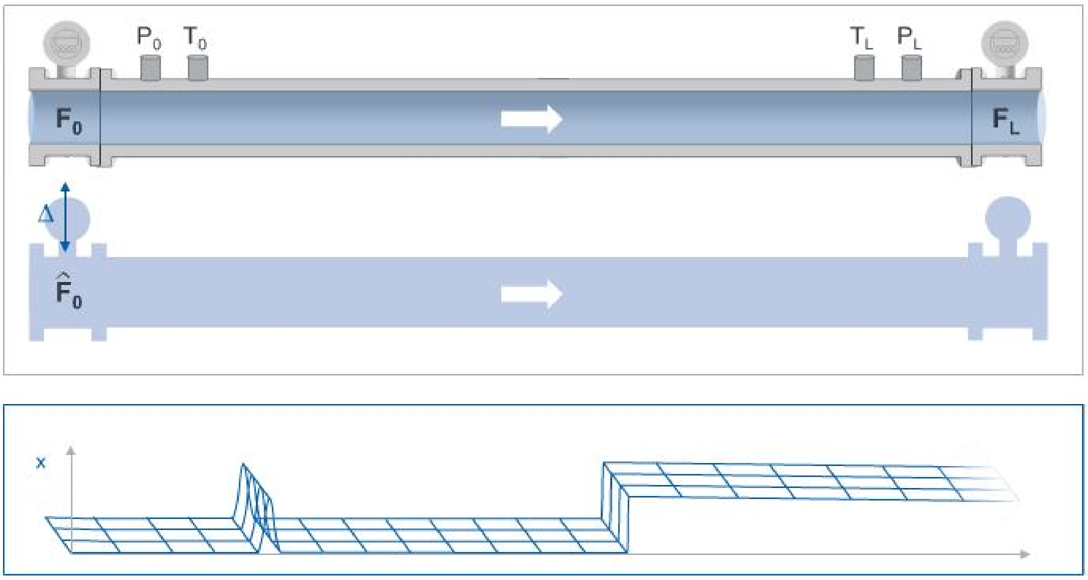


Figure 3.38: E-RTTM systems with leak pattern recognition

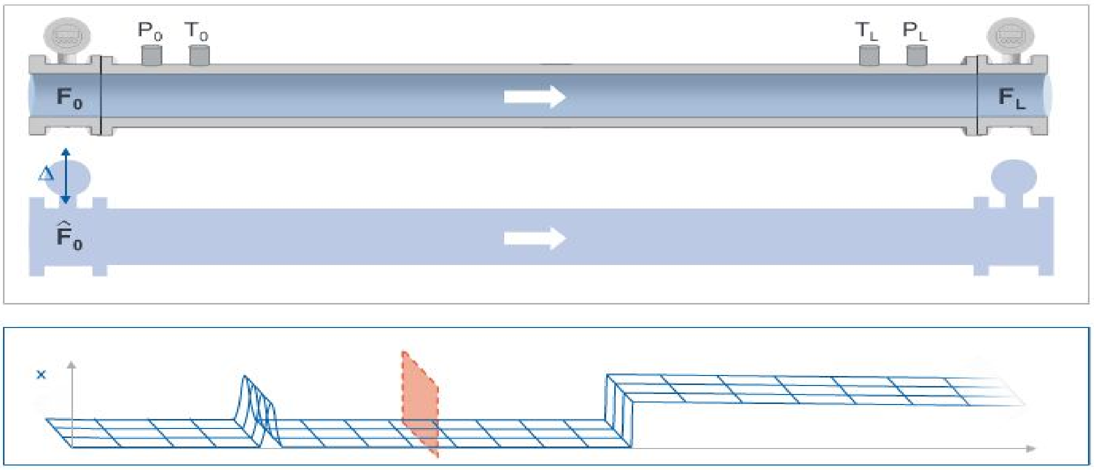


Figure 3.39: E-RTTM systems with leak pattern recognition

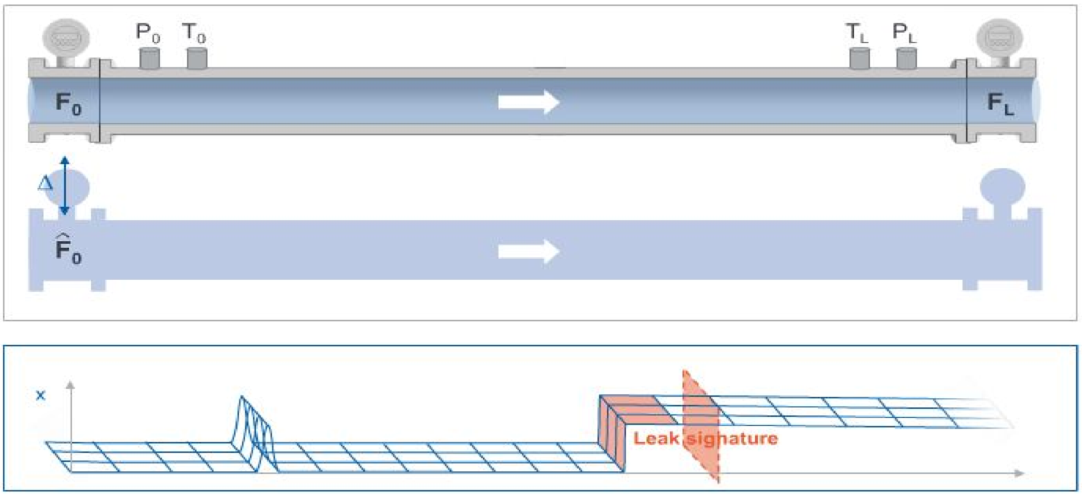


Figure 3.40: E-RTTM systems with leak pattern recognition

Leak pattern detection accesses an expandable database of different leak signatures and can thus differentiate between accidental interference (such as instrument drift) and leaks. Thanks to the special type of signal evaluation, small leaks are reliably detected and false alarms avoided[4].

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 SCADA System

The SCADA system is a computer-based communications system that monitors, processes, transmits, and displays pipeline data for the controller. SCADA systems may be used directly for leak detection, they may provide support for an LDS, or an LDS may operate independently of SCADA. Generally, a pipeline LDS will use the data generated by a SCADA system to aid in assessing the potential for a product release. SCADA systems collect real-time data from field instruments using Remote Terminal Units (RTUs), Programmable Logic Controllers (PLCs), and other electronic measurement devices, which are placed at intervals along the pipeline. Communication with these devices can occur in many ways, including microwave, cellular, satellite, leased line, etc., but the most common media are dedicated phone circuits and terrestrial- and satellite-based radio systems. An emerging trend is to use multiple methods of communicating based on the concept that each method will have a cost or performance advantage for a given installation.

Data from RTUs or PLCs are gathered into a Master Terminal Unit (MTU) which consists of one or more central computers built around a real-time, memory-resident database. The MTU displays the current operating conditions for the controller, who, in turn, can act on these data if necessary. Messaging between the field devices and the MTU is known as the communications protocol. In this chapter the simulation has been implemented by using SCADA system. The virtual pipeline has been assumed including the followings:-

- Two Pump stations.
- Two pressure transmitters per each.

- Pipeline within length 75Km.

The SCADA system used is CitecSCADA product of Schneider Electric. We insisted in two servers in SCADA system considered as an important servers in LDS, which are:-

1- Client server: To provide the operator ability to monitor the LDS.
2- Trend server: To show the leakage deviation when happened.

By the two above servers, the leakage can be notable by operator. In this project the Pressure Point Analysis method has been used to specify the leakage localization.

4.2 Pressure Point Analysis

The rarefaction wave (also called an acoustic, negative pressure, or expansion wave) method of leak detection is based on the analysis of pipeline pressure variation. When product breaches the pipeline wall there is a sudden drop in pressure at the location of the leak followed by rapid line repressurization a few milliseconds later. The resulting low-pressure expansion wave travels at the speed of sound through the liquid away from the leak in both directions. Instruments placed at intervals along the pipeline respond as the wave passes. If a leak occurs in the middle of a line segment with uniform construction, the rarefaction wave should be seen at opposite ends of the line simultaneously. If the leak is closer to one end, it should be seen first at the close end and later at the far end. The time evidence recorded at each end of the monitored line or segment is used to calculate the location of the leak.

A sudden leak caused, for example, by careless use of an excavator, leads to a negative pressure wave propagating at the speed of sound (c) upstream and downstream through the pipeline of given length (L). Such a wave can be recognized using installed pressure transmitters, giving a leak alarm. The leak position can be determined if the moment t_{down}(downstream) and t_{up}(upstream), when this negative wave passes the transmitters is measured. Setting

$$\Delta t = t_{down} - t_{up} \quad (4.1)$$

Where:

t_{down} = The flow time in downstream (sec).

t_{up} = The flow time in upstream (sec).

Δt = The different betwean upstream and down stream (sec).

Then the leak location is:

$$S_{Leak} = \frac{1}{2}.(L - c.\Delta t) \quad (4.2)$$

Where:

S_{Leak} = *The leakage location* (m).

$L \equiv$ *Pipeline length* (m).

c = *The speed of sound* $\left(m^2/_{sec}\right)$.

4.3 Simulation

In the simulation the concentration has been on the graphical side to illustrate the LDS mechanism, Figures 4.1 and 4.2 show that the client server OFF and ON states respectively.

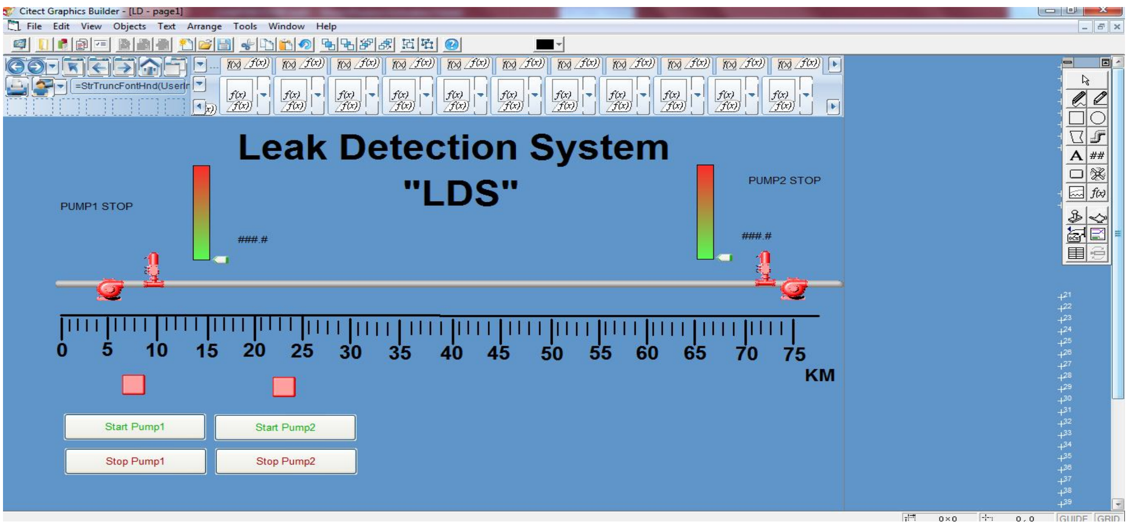


Figure 4.1: Client server OFF state

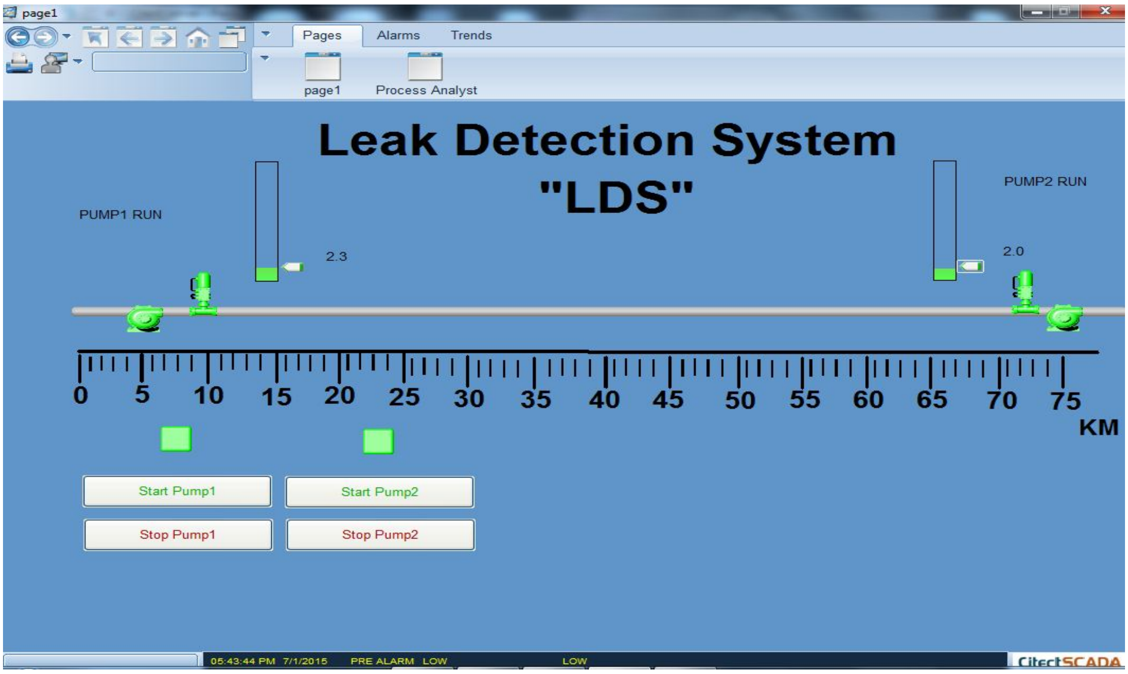


Figure 4.2: Client server ON state

The two pressure transmitters in the upstream and downstream are measuring the pressure values continuously. Herein the pressure range presumed to be within the range low to high. If sudden leak happened, the pressure will be low than the min value, meanwhile the alarm will be appearing in the screen with the message pressure is low low which indicate that the leakage happened. The Table 4.1 shows readings collected from simulation.

Table 4.1: Collected reading from simulation.

No.	PT (Upstream)(bar)	PT (Downstream)(bar)	Alarm signal	Remark
1	5.6	4.9	No alarm	No leak
2	5	4.3	No alarm	No leak
3	4.5	3.8	No alarm	No leak
4	4	3.2	No alarm	No leak
5	3.8	3.2	No alarm	No leak
6	3.5	3.1	No alarm	No leak

7	3	2.9	Low	No leak
8	2.5	2.1	Low	No leak
9	2	1.7	Low Low	Leak detected
10	1.9	1.6	Low Low	Leak detected

The Figures 4.3 and 4.4 show the pressure fluctuation in the client servers respectively.

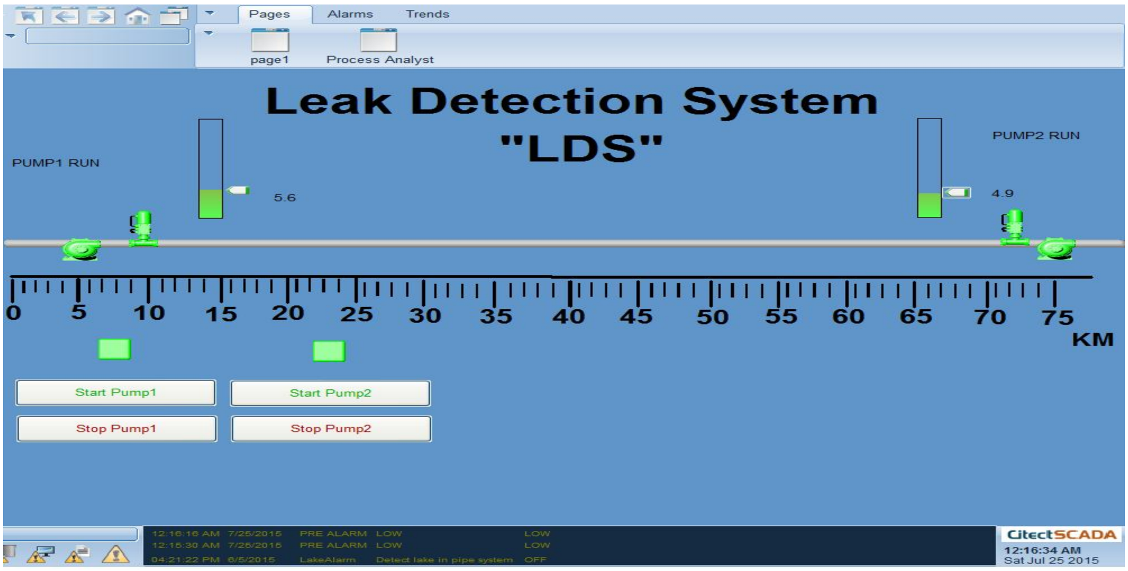


Figure 4.3: Pressure transmitters without leakage appearance

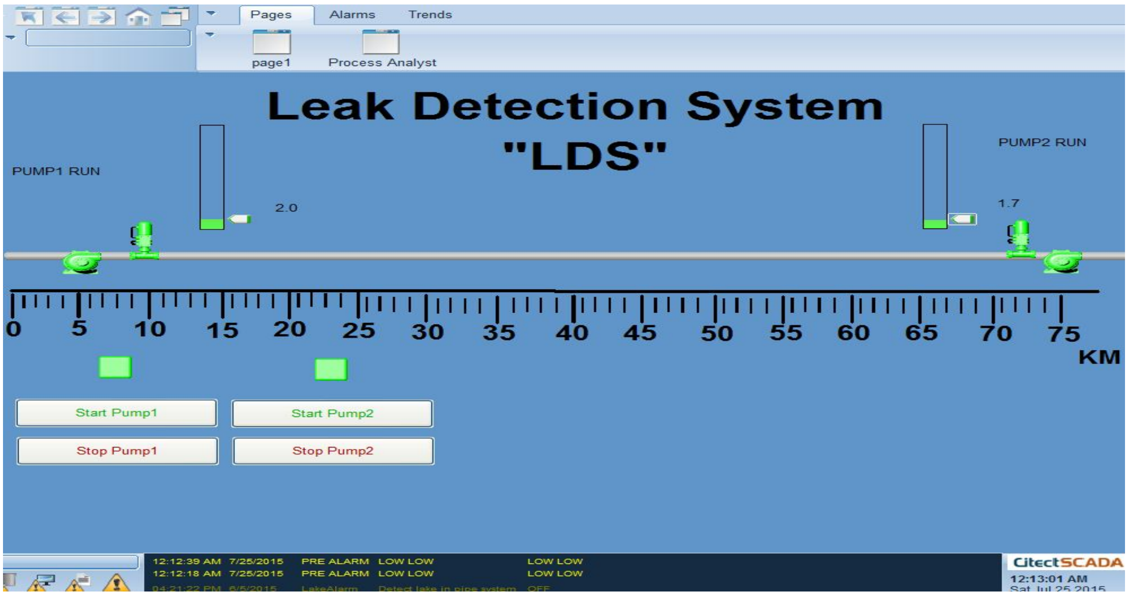


Figure 4.4: Pressure transmitters with leakage appeared

Another server is trend server which is changing according to the pressure changes in the client server. By the trend server we can localize the leakage location by adding kilometers scale. Figures 4.5 and 4.6 illustrate the trend server without and with leakage respectively.

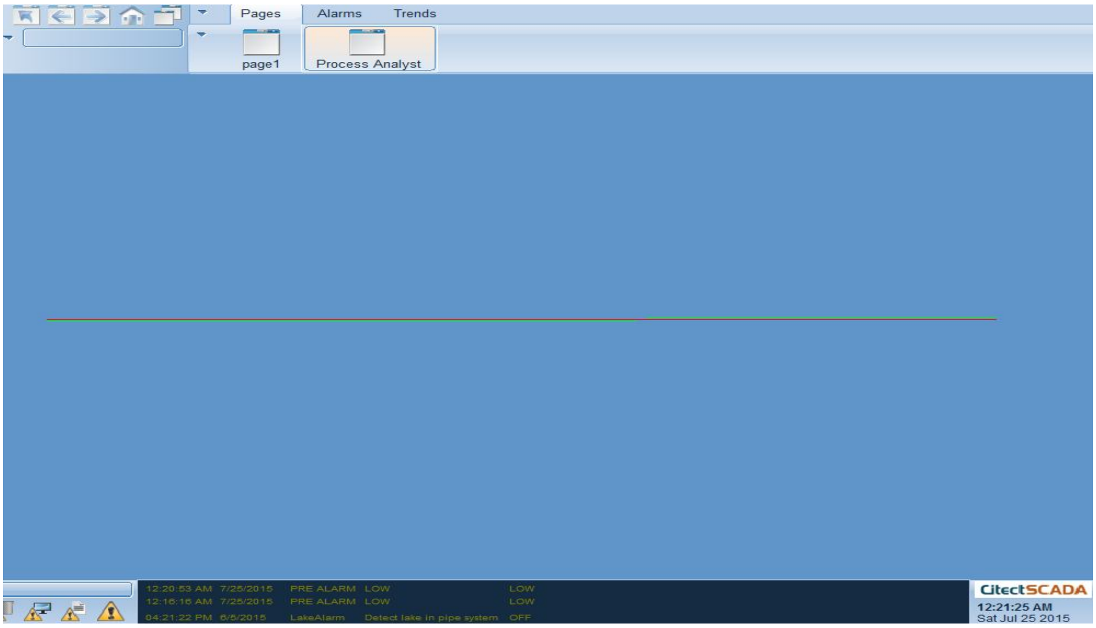


Figure 4.5:The trend in case of no leakage

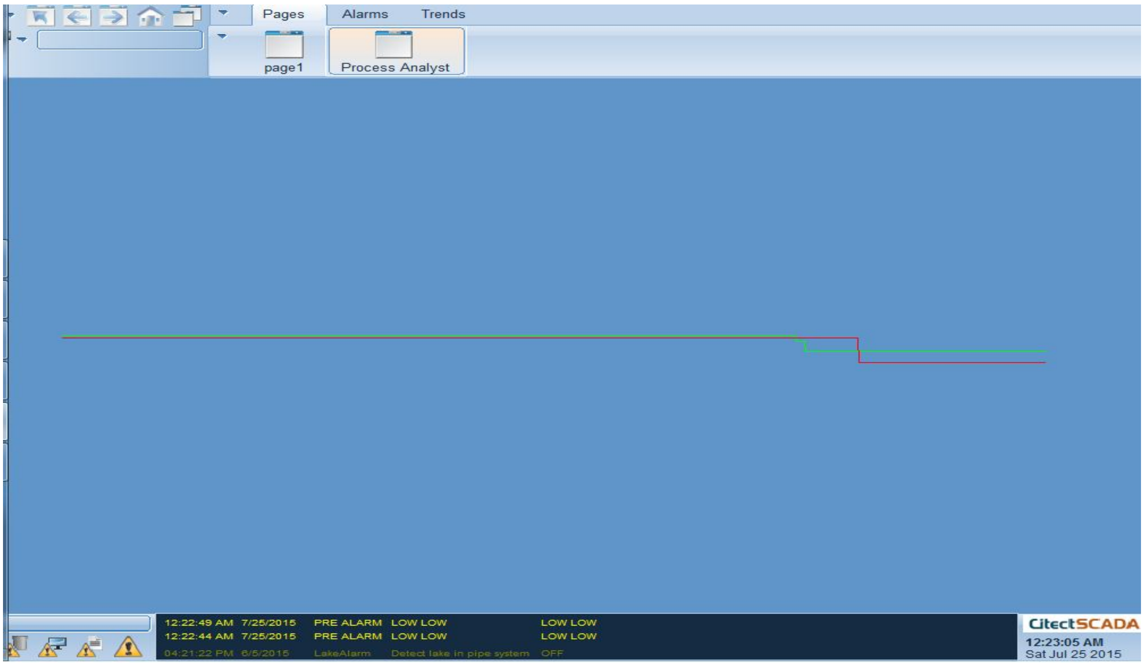


Figure 4.6:The trend in case of leakage appeared

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study provides the proper methodology to facilitate the choice of leak detection system. The study deals with some external methods based on external measurements and internal methods based on flow and pressure measurements in the pipelines.In chapter four the pressure wave detection method simulation has been implemented and the following results/notices have been found:

- Pressure wave detection method is able to very rapidly detect large leaks.
- The pressure transmitters also can be used to detect if the pumping reduced of the normal.
- When the pressure more than 3 bar, no alarm signal will occur.
- When the pressure within 3 to 2.1 bar, the alarm signal Low will be occurred to show there is reduction in pumping.
- When the pressure less than 2 bar, the leak alarm will be active as Low Low.

5.2 RECOMMENDATIONS

- LDS strongly recommended student to be considered for new pipelines to be includedwith control system.
- More PTs distributed along the pipeline, more robust, reliable and accurate readings.
- While the temperature is direct proportional with pressure, we can add temperature transmitters (TT) to grant more reliable readings.
- The LDS is recommended to be installed with the new pipelines. But in case of the old pipelines without LDS, SDH or pilot cable along pipeline is required to transfer the LDS signals to the centralized control. Also it’s required to add LDS function to control system.

- In regards to our simulation in chapter four, we disabled to add distance scale for the trend server, that attributed to some files of the program has been missed. For further studies for LDS we recommended to use new version of Cietec SCADA.
- Usually, PIGs are common use to track and localizing the leakage, but this is old fashion method because it takes more time. Sometimes the pig stuck due to the joint or welding in pipeline found, and that call to shunt the pig or it requires hot tapping which will cause delay in flow time.

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