Gas Pipeline Leak Detection Using Differential Pressure Method and Acoustic Emission Method

By

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FINAL REPORT

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own expect as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MUHAMMAD ZHAFIF BIN ZAMROS)

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ABSTRACT

This report essentially discusses the work on the project entitled Gas Pipeline Leak Detection Using Differential Pressure Method and Acoustic Emission method. The objective of this project is to implement leak detection using differential pressure method and acoustic emission method and also to determine the ability of these methods to estimate size and location of the leak. In order to carry on experiment on these method, a differential pressure flow meters test rig need to be designed and constructed. The theory part explains in details about principle and mechanism of component related to differential pressure, flow measurement and acoustic emission. The methodology explains about the development of the test rig, hardware and software used in this project and experimental procedure to acquire differential pressure, flow rate and acoustic emission signal. Chapter 4 shows results obtained from experiment and analysis part of the results. The analysis part will verify the theory and hypothesis made before doing experiment. Throughout the project, there are some difficulty face such as lack of hardware and instrument needed for the project and also time constrains as a final year students. However, all these difficulties have been overcome in order to complete the project at the time given. The outcome of this project would be very useful in the industry as leak detection is very crucial in a process plant which can save lives and cost for early detection.

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CHAPTER 1

INTRODUCTION

1.1 Background

The needs to transport fluid from the point of production to the area of end use have led to a rapid increase in the number of pipeline being constructed [1]. Many of these pipelines carry toxic and hazardous product which could cause accident and environmental hazard if leak occurs. The statistics suggest that long pipelines network can expect a reportable incident every year [2]. With increasing public awareness and concern for the environment, recent pipeline leak incidents have shown that cost effective and reliable leak detection systems are in demand [3].

To avoid any further pipelines incidents and saving our environment, the most promising solution comes from implementing better pipeline monitoring and leak detection equipment and practices. Early detection of a leak and, if possible, identification of the location using the best available technique allows time for safe shutdown and cleanup works.

The need to have reliable leak detection in oil and gas pipeline also has been a priority in the industry. Uncontrolled release of gas into the atmosphere has both on environmental and economical impact on both pipeline operators and the community. Early detection of leaks can prevent both environmental hazards and financial loss.

1.2 Problem Statement

Pipeline leakages are wasting precious natural resource such as oil, gas or even water. From the leak also, there will be economic loss to company due to damage to the pipe network itself and for the maintenance purpose. Leaking pipes also create a huge risk to a plant, which can leads to explosion.

Leaking pipes could create a public health risk, as the substance escaping from the leak may be hazardous to human. It also can cause environmental hazards if the gas is exposed expose into the atmosphere as any excess gas concentration will create imbalance in the air.

1.2 Objectives

1. To study and research on pipeline leak detection technique. This project is started by reviewing the existing leak detection system so to get the main idea, purpose and technique used in leak detection.
2. To construct a differential pressure flow meters test rig. The test rig which consist of a small pipeline network with capability to measure differential pressure and flow need to be designed and constructed for experimental purpose of this project.
3. To implement leak detection using differential pressure method and acoustic emission method. This project will mainly be focusing on these two leak detection method and the approach used is by experiment on the test rig constructed earlier.
4. To evaluate occurrence of leak in gas pipeline. From experimental results and analysis, condition and characteristic of the differential pressure, flow rate and acoustic emission signal should be able to determine existence of leak.
5. To estimate the size and location of the leak. In leak detection, information of the leak such as the size and location also is very important. So in this project, experiment and analysis will be done thoroughly in order to estimate those factors.

1.4 Scope of Study

1. Leak detection method at gas pipeline. Study on numerous existing leak detection method used at all type of pipeline is needed in order to gain general knowledge of leak detection. The knowledge is important before implementing leak detection using differential pressure method and acoustic emission ,method
2. Differential Pressure and flow measurement instruments. This project will involve usage of measurement instruments such as differential pressure transmitter and orifice plate, so knowledge on these instruments is needed to handle the instruments properly and for constructing the test rig. Knowledge on DCS is also needed to control and monitor the pilot plant
3. Mathematical modeling to calculate pressure and flow rate in the pipeline. The measurement gain from the instrument will be use in the mathematical model to calculate flow rate. The model that will be use is the standard model learned from industrial automation and control system class.
4. Acoustic Emission devices, data acquisition and signal processing. All these components will be use to gain data for the acoustic emission method.
5. Leakage effect on differential pressure, flow rate and acoustic emission signal. After all the data is obtained, detail and trough analysis will be made in order to see leakage effect on the method used.

CHAPTER 2

LITERATURE REVIEW & THEORY

They are numerous existing leak detection technique that had been implemented in the industry and lots of new technique that are still under research and development process in order to provide a perfect solution to the problem. Dr Jun Zhang from REL Instrumentation Limited, Manchester, UK categorizes leak detection method into three which are Hardware Based Methods, Biological Methods and Software Based Methods [3]. Other researcher mostly categorized leak detection technique into internal and external based leak detection. Despite all the different technique in leak detection method, they share seven same important key attributes in order to measure the performance of the leak detection technique which is:

1. Leak sensitivity
2. Location estimate capability
3. Operational change
4. Availability
5. False alarm rate
6. Maintenance requirement
7. Cost

This project will be focusing on internal leak detection technique which use differential pressure method and external leak detection technique which is using acoustic emission method.

2.1 Differential pressure flowmeters principle and mechanism.

Differential pressure flowmeters use Bernoulli's equation to measure the flow of fluid in a pipe. Differential pressure flowmeters introduce a constriction in the pipe by an orifice plate that creates a pressure drop across the flowmeter. The flow velocity increases when it enters the constriction. This results in increasing of dynamic pressure and decreasing of static pressure accordingly with flow rate. The pressure drop produced in this way is known as "differential pressure" (ΔP). Then the upstream and downstream pressure before and after the orifice plate can be measured using a u-tube manometer or differential pressure transmitter.

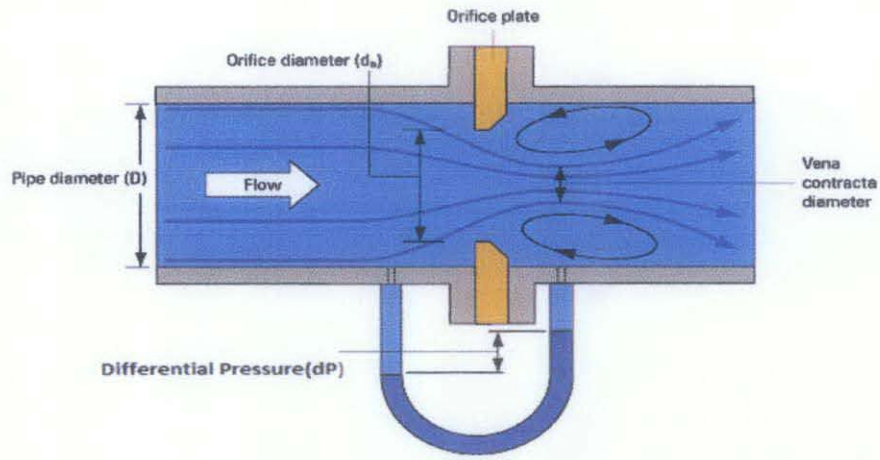


Figure 2.1: Creating a constriction using orifice plate

2.1.1 Orifice plates

An orifice plate consists of a circular plate, containing a hole, which is inserted into a pipeline. The advantage of orifice plates is that they are capable of metering either gas or liquids with high degrees of accuracy. Orifice plate is simple and easy to fabricate, has no moving parts, that a single transmitter can be used without regard to pipe size and flow. Most importantly, orifice plate is the cheapest instrument to measure flow compares to venture tube and flow nozzle. Figure 2.2 below shows most common type of orifice used which is concentric type. This project will also use this orifice type.

Figure 2.2: Orifice plate

However, it still have disadvantage too as orifice plates it does not work well with slurries, and high permanent pressure loss (higher pumping cost). But since this project will be focusing with gas pipeline, the disadvantage will not make difference.

2.1.2 U-tube Manometer

Pressure measuring devices using liquid columns in vertical or inclined tubes are called manometers. One of the most common is the water filled u-tube manometer used to measure pressure difference in orifices located in a pipeline. Using a "U"-Tube manometer enables the pressure of both liquids and gases to be measured with the same instrument. The "U" is filled with a fluid called the manometric fluid. The fluid whose pressure is being measured should have a mass density less than that of the manometric fluid and the two fluids should not be able to mix readily.

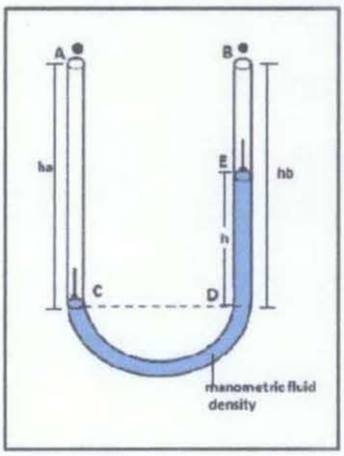


Figure 2.3: U-tube manometer

If the "U"-tube manometer is connected to a pressurized vessel at two points the pressure difference between these two points can be measured.

Pressure at C= Pressure at D

$$P_C = P_D \tag{2.1}$$

$$P_C = P_A + \rho g h_a \tag{2.2}$$

$$P_D = P_B + \rho g(h_b - h_a) + \rho_m g h \tag{2.3}$$

$$P_A - P_B = \Delta P = \rho g(h_b - h_a) + (\rho_m - \rho)\, g h \tag{2.4}$$

If the fluid whose pressure difference is being measured is a gas and $\rho_m \gg \rho$, then the terms involving ρ can be neglected, so

$$\Delta P = \rho_m g h \tag{2.5}$$

Where

P_A, P_B ,P_C , P_D = Pressure at A, B, C and D

ρ = fluid density

g = acceleration of gravity (9.81 m/s^2,)

h_a = height from point A to point C

h_b = height from point B to point D

h = manometric fluid height difference

ρ_m = manometric fluid density

2.1.3 Differential Pressure Transmitter

Figure 2.4: Differential pressure transmitter

In order to get better measurement of differential pressure, Differential pressure transmitter is use to replace the traditional "U"-tube manometer.

Advantages of differential pressure transmitter over u-tube manometer.

- Gives the exact differential pressure value, ΔP rather than the height difference value in the u-tube manometer which involves human error.
- Higher precision and higher accuracy.
- Universally suitable for application involving liquids gas and steam.
- Can be calibrate.
- Can withstand extreme process conditions such as high temperature and high pressure.
- Differential Pressure Transmitter can be replaced during operation without process shutdown.
- Robust primary elements, because entirely mechanical and no moving parts.

A pressure transmitter, or pressure sensor, is a device that is capable of measuring pressure in a liquid, fluid, or gas. A pressure transmitter contains a pressure sensor that can process fluids and calculate an output. This output will be the answer to pressure applied on it by the fluid. A passage will transfer the fluid pressure on each side of the orifice plate to the opposite side of a diaphragm unit in a differential pressure transmitter.

A displacement detector senses any motion resulting from the imbalance of the forces on a force arm (due to pressure difference across the orifice). An amplifier converts this displacement signal into an adjustment of the current input to the force transducer that restores the balanced conditions. Current, proportional to the pressure drop across the orifice plate, is used as the output signal of the differential pressure transmitter.

Pressure transmitters are commonly used for industrial processes and they are used to gauge the pressure and control the operation of industrial equipment. It can warn machine operators of high pressure levels before a disaster takes place. Pressure transmitters can be used in conjunction with other devices to measure depth, altitude, fluid flow, and even pressure loss in order to detect leaks in a system.

2.1.4 Flow rate measurement.

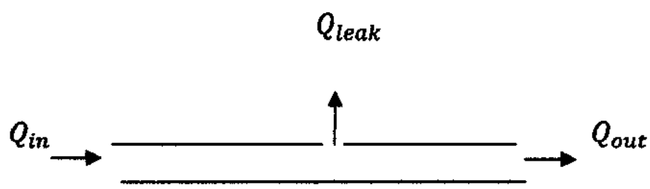


Figure 2.5: Flow rate of a pipeline

The volume balance method of leak detection is based on measuring the difference between the incoming and outgoing product volumes of a particular pipeline segment. During a unit time interval, the volume of product that enters a pipe may not be equal to the measured volume exiting the pipe. It may indicate a leak if the product volume is not equal. In order to see the difference of product volume before and after the leakage, the flow rate needs to be measured.

Form the differential pressure, ΔP value that obtained from the U-tube manometer or the differential pressure transmitter, the value of the inlet, outlet and leak flow rate (if exist) across the pipeline can be obtained using flow rate equation.

The standard equation used for flow rate measurement is:

$$Q = C.\ \frac{1}{\sqrt{1-\beta^4}} \cdot \frac{\pi}{4} \cdot d^2 \cdot \varepsilon . \sqrt{\frac{2.\Delta P}{\rho}} \qquad (2.6)$$

Where;

Q = Mass flow rate, in (mass)/(time) units

C = Discharge coefficient

β = Diameter ratio, d/D

d = Orifice plate diameter

D = Pipeline internal diameter

ε = Expansion factor.

For liquids (uncompressible fluids), is always $\varepsilon = 1$

For steam and gases (compressible fluids) $\varepsilon < 1$

ΔP = Differential pressure upstream and downstream the orifice

ρ = fluid density.

From the incoming flow rate value, Q_{in} and outgoing flow rate value, Q_{out}, the leak flow rate, Q_{leak} can be obtained.

$$Q_{in} = Q_{leak} + Q_{out} \qquad (2.7)$$

$$Q_{leak} = Q_{in} - Q_{out} \qquad (2.8)$$

2.2 Acoustic Emission Principle and mechanism

Leak detection in pipelines using acoustic emissions technology is based on the principle that a leak in pipeline system generates noise, which can be used for leak detection and location. Acoustic sensors such as AE sensor, accelerometer and hydrophones are affixed to the outside or externally of the pipe to monitor internal pipeline noise levels and locations.

When a leak occurs, the resulting low frequency acoustic signal is detected and analyzed by system software or program. The received signal is stronger near the leak site thus enabling leak location. The pipeline distribution system can be systematically checked for leaks by using acoustic equipment, which detects the sound or vibration.

Acoustic Emission is a phenomenon of sound and ultrasound wave radiation in materials undergoes deformation and fracture processes. The sources of acoustic emission are from crack, leak, friction, property changes and fracture.

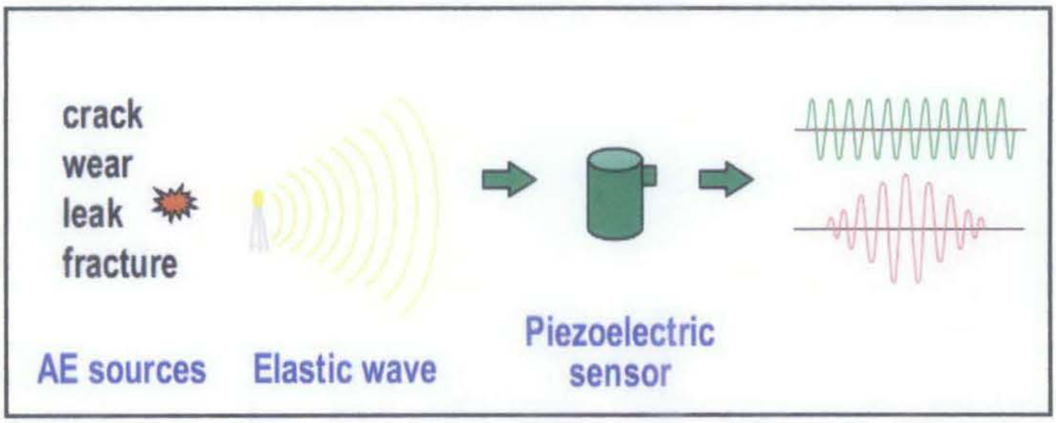


Figure 2.6: Principle of AE detection

2.2.1 Acoustic Emission Sensor

An AE sensor is to detect stress waves motion that cause a local dynamic material displacement and convert this displacement to an electrical signal. AE sensors are typically piezoelectric sensors with elements maid of special ceramic elements like lead zirconate titanate (PZT). Mechanical strain of a piezo element generates an electric signal.

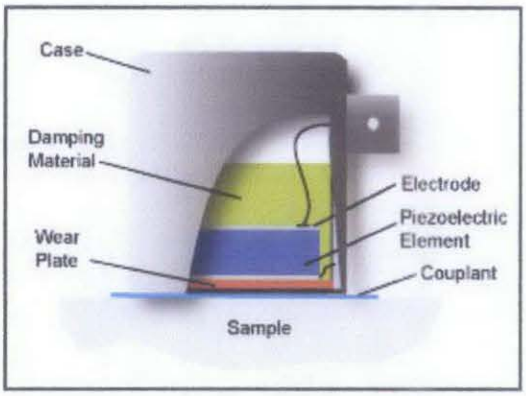


Figure 2.7: Parts of AE sensors

An AE sensor consists of several parts:

- A piezoelectric ceramic element with electrodes on each face.
- One electrode is connected to an electric ground, the other to a signal lead.
- A backing material behind the element is designed to minimize reflections back to the element and to damp the signal around the resonance frequency.
- The case provides an integrated mechanical package and may also serve as a shield to minimize electromagnetic interference.

Acoustic Emission (AE) sensors usually use piezoelectric elements for transduction. The element is coupled to the test item's surface, so that dynamic surface motion propagates into the piezoelectric element. The dynamic strain produced in the element produces a voltage-vs.-time signal as the sensor's output.

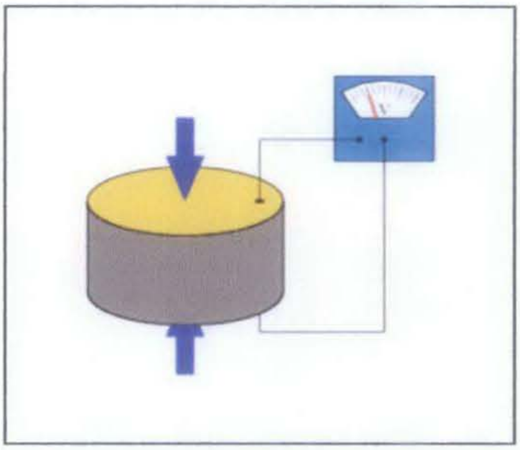


Fig. 2.8: Piezoelectric element under compression/tensile stress.

2.2.2 Preamplifier

By using a differential preamplifier, common mode noise is eliminated, resulting in a lower noise output from the preamplifier, and a higher electrical noise rejection in difficult and noisy environments. Noise improvements in the range of 2dB or higher can be expected using a differential sensor and preamplifier over a single ended general purpose sensor

The function of preamplifiers is to increase the strength of the input signal. Amplifying and frequency filtering are the two components of signal conditioning. The typical AE amplifieir is a linear, voltage amplifier with the property:

Output Voltage= Input Voltage x Gain

$$V_o(t) = G \times V_i(t) \qquad (2.9)$$

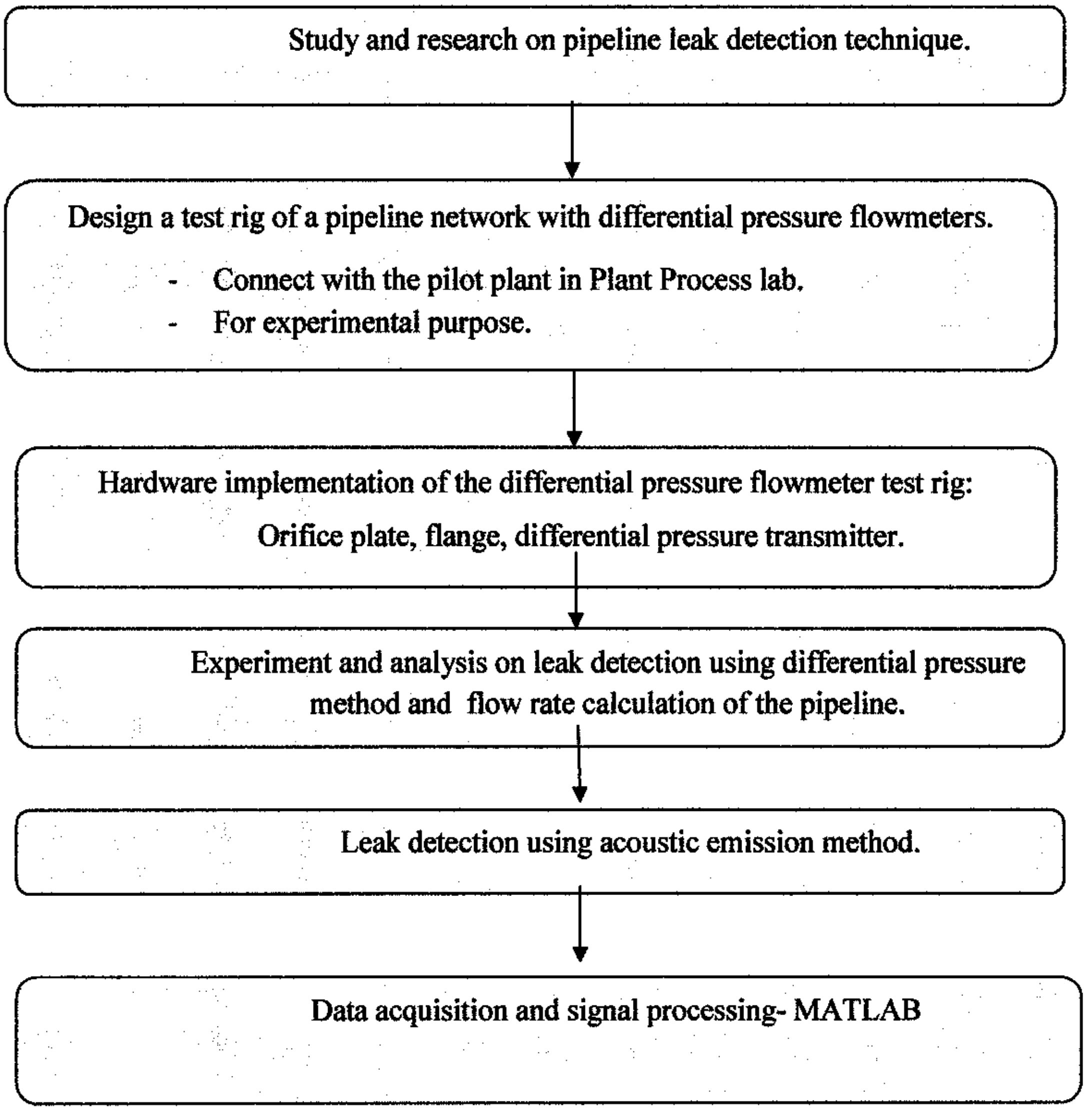
Gain is the ratio of output voltage to input voltage and can also be expressed in decibels, dB. The decibel is a logarithmic unit:

$$dB = 20 \, log \, G \qquad (2.10)$$

CHAPTER 3

METHODOLGY AND PROJECT WORK

3.1 Methodology



3.2 Test Rig Design

In order to carry on experiment on leak detection, a test rig which consist of pipeline network with differential pressure flowmeters need to be design and constructed. The test rig will then be connected to the pilot plant in the Plant Process Lab. So the leak part will be on the test rig and will not damage the pipeline at the pilot plant. The exhaust part in figure below will be connected to the test rig. The pilot plant is equipped with DCS network for controlling and monitoring purpose.

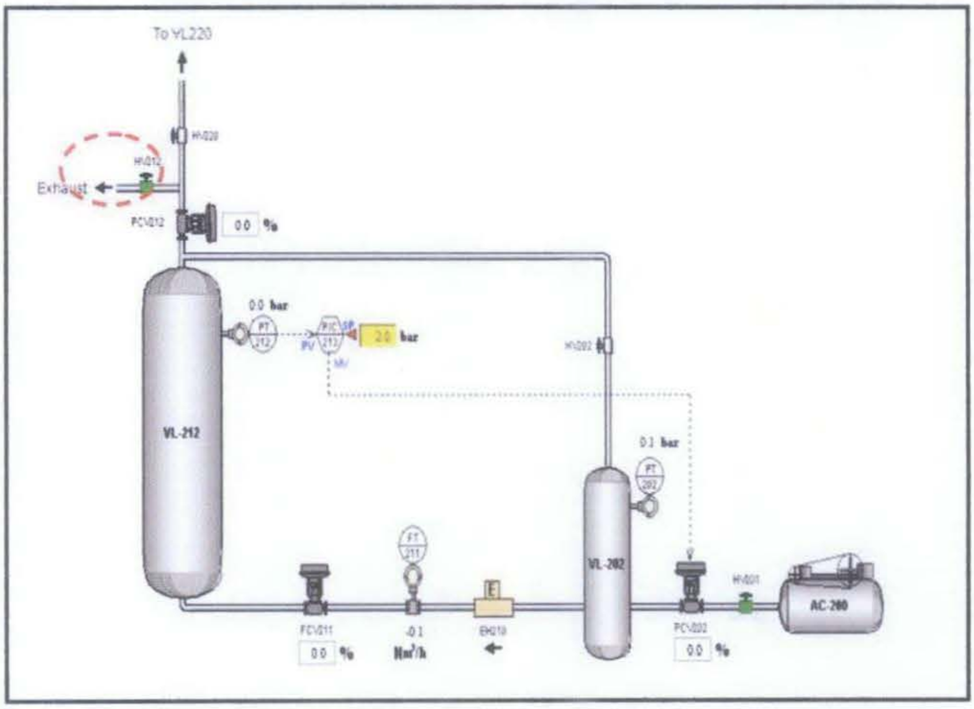


Figure 3.1: Pilot Plant in Plant Process Lab.

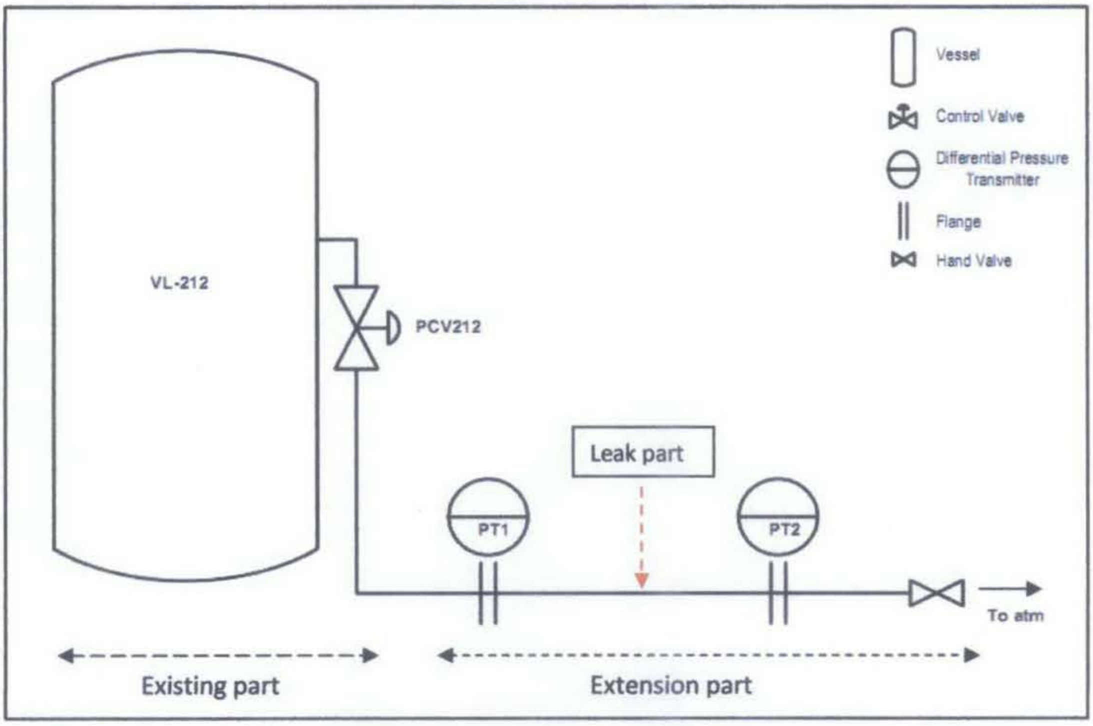


Figure 3.2: P & ID drawing of the test rig

The pipe size that is suitable to connect with the pilot plant is 1.0 inch. The orifice plate hole is design to be 0.5 inch to get a 0.5 ratio.

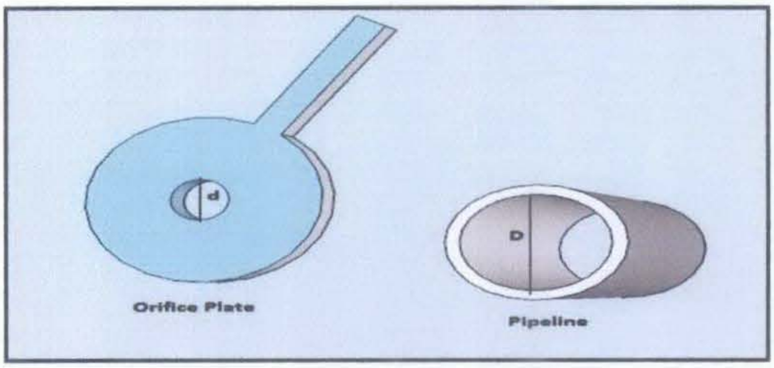


Figure 3.3: orifice plate ratio

d= 0.5 inch , D= 1.0 inch

$\beta = \mathrm{d}/D = 0.5/1.0$

$= 0.5$ ratio

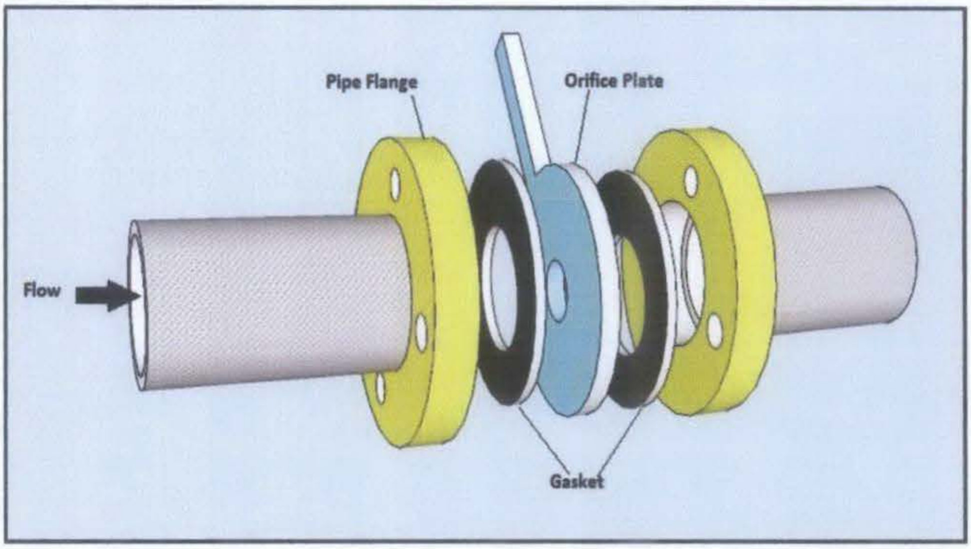


Figure 3.4: Orifice placement

3.3 Complete Test Rig

Figure 3.5: Concentric Orifice Plate

Figure 3.6: Diameter ratio=0.5

Figure 3.7: Completed test rig with U-tube water manometer

Figure 3.8: Completed test rig with differential pressure transmitter

3.4 Transmitter selection

There are number of considerations that should be viewed in selecting a differential pressure transmitter. They include functional specifications, performance specifications, material selection and desirable features. Discussed below are the main criteria that need to be consider before selecting the differential pressure transmitter for this project.

3.4.1 Temperatures

Both the maximum process and ambient temperatures need to be considered. Often the process temperature will exceed the limits of the sensing element. The sensing element of most electronic pressure transmitters will not operate properly above 225 °F (107°C). High ambient temperatures on solid state electronics will affect the component life. High temperatures also tend to cause more electronic failures.

3.4.2 Range and Span

Range is the region between limits within which a quantity is measured. The range of an instrument is usually regarded as the difference between the maximum and minimum reading. Span is the difference between the upper and lower range values. The operating pressure range, minimum and the maximum pressure should be considered beforehand. Then the transmitter can be calibrated to get the desires span and range according to the condition of the plant pressure.

3.4.3 Output

The standard output for two-wire transmitters is 4–20 mA dc or 10–50 mA dc. There are also four wire transmitters that can provide zero-based voltage signals. The most common is 0–5 V dc. The two-wire device, as the name implies, only has two wires to the transmitters. These wires are used for both power and signal. The two-wire unit requires an external dc voltage power supply. The three-wire device also requires an external dc voltage power supply with one lead as common for both signal and power.

3.4.4 Accuracy

As a performance specification, accuracy is the degree of conformity and the accuracy of a measurement system is refers to its ability to indicate a true value exactly. Accuracy includes effect of hysteresis (difference in output according to direction of change in the input), dead zone (the largest change in input that fails to produce any output) and repeatability.

3.4.5 YOKOGAWA EJA110A Differential Pressure Transmitter

In this project, Yokogawa differential pressure transmitter model EJA110A is used for both transmitter. This is because the transmitter satisfies most of the criterion in selecting a transmitter. The high performance differential pressure transmitter can be used to measure liquid, gas, or steam flow as well as liquid level, density and pressure. It is a two wire transmitter with outputs 4 to 20 mA dc signal corre- sponding to the measured differential pressure. It has calibration range of 0-250 kPa. So this transmitter is appropriate enough for this project. Both differential pressure transmitters is calibrated to the range of 0-250 kPa before using it for the experiment. The span and range limit, working pressure and process temperature is included in the appendix.

3.4.6 Experimental procedure to obtain differential pressure.

1. The process of the gas processing pilot plant is turned on.
2. Hand valve, HV 212, HV 220 and HV 202 is turned open.
3. Select the air flow process and select PIC 213 graphic in the workstation.
4. Control valve PCV 202 is set to 100% opening and leaves it under auto mode.
5. Open the PIC 213 controller faceplate.
6. Set the controller set point (SP) at 2 bar and leave it under auto mode.
7. The controller SP is set at 2 bar in order to maintain the pressure in the vessel at 2 bar during the opening of the control valve PCV212 is varied.
8. The PCV 212 is set to manual mode.
9. In this experiment, 2 transmitters are used. The 1st transmitter is to measure differential pressure before leakage and the 2nd transmitter is to measure differential pressure after leakage.
10. The first part of the experiment is to take the differential pressure measurement without any leakage at the pipeline.
11. The PCV 212 is set to 10% opening. The process variable (PV) of the PIC 213 controller must be stable at 2 bar before any measurement are taken.
12. Once the PV is stable at 2 bar, measurement at both transmitter is taken.
13. Step 11and 12 are repeated with 20%, 30%, 40%, 50%, 60%, 70% & 80% PCV 212 opening.
14. Then the experiment is continue with pressure measurement is taken with a leakage hole 3mm diameter at the pipeline.
15. 10 holes of 3mm diameter each, 10 cm apart from each other are drilled on the pipeline to simulate for leak. The holes are then closed tightly.
16. The 1st hole, distance at 6 cm from the flange is open.
17. Then steps 11 to 13 are repeated for the first hole.
18. The 1st hole is closed and the 2nd hole which is 16 cm away from the flange is open.
19. Then the procedure in taking the measurement is repeated for all of the holes at the pipeline.
20. All measurements are recorded accordingly.

3.5 Acquiring acoustic emission signal.

To acquire acoustic emission signal from the pipeline, the AE sensor is mount externally at the pipeline. The AE sensor will be connected to other devices which are preamplifier, amplifier and USB data acquisition before the signal can be view in a computer. Figure 3.9 and 3.10 shows the connection of the AE sensor and its placement at the pipeline.

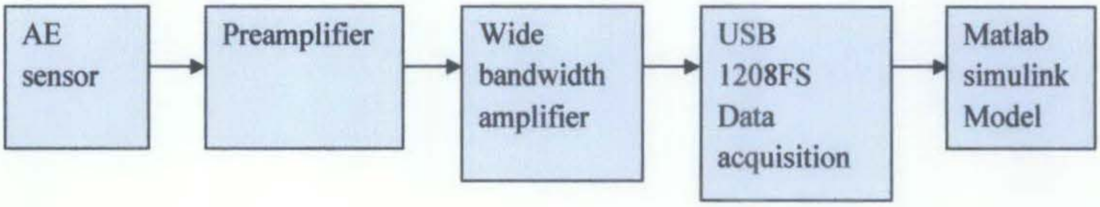


Figure 3.9: Block diagram of AE sensor connection

3.5.1 AE sensor

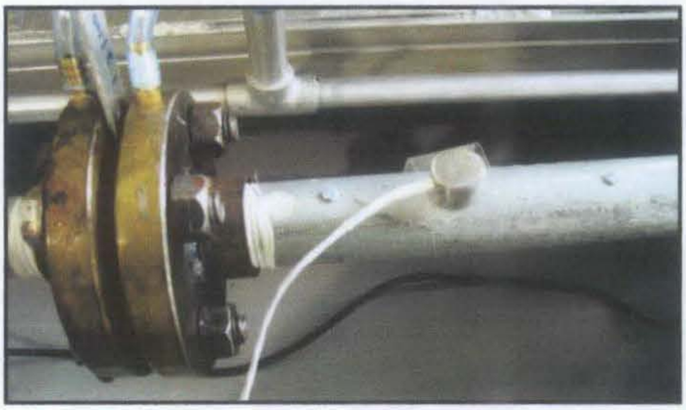


Figure 3.10: Placement of AE sensor at the pipeline

In this project, the Wideband AE sensor with integral Amplifier from Physical Acoustics Corp. (PAC) is used. Wideband sensors are typically used in research applications and other applications where a high fidelity AE response is required. In research applications, wideband AE sensors are useful where frequency analysis of the AE signal is required and to help determine the predominant frequency band of AE sources for noise discrimination.

3.5.2 Preamplifier

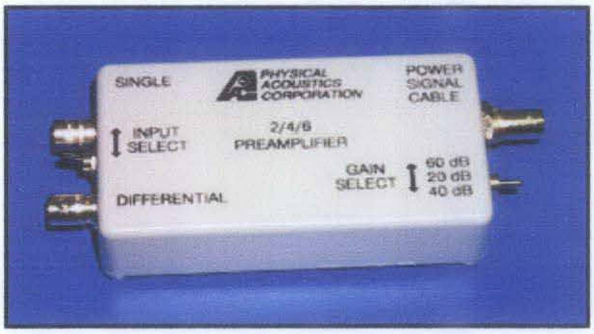


Figure 3.11: 2/4/6 preamplifier

The preamplifier used in this project is the 2/4/6 from PAC (Physical Acoustic Corporation). The Preamplifiers were designed to be used with all available AE systems that have their power supplied via the output signal BNC. Provided with 20/40/60 dB gain respectively, these preamplifiers operate with either a single-ended or differential sensor. Plug-in filters provide the flexibility to optimize sensor selectivity and noise rejection. These filters are supplied in the Low Pass (LP), High Pass (HP) and Band Pass (BP) configurations, and offer constant insertion loss for easy filter swapping without the need for recalibration. The standard Auto Sensor Test (AST) allows the sensor to characterize its own condition, as well as send out a simulated acoustic emission wave that other sensors can detect. Main feature of this preamplifier are:

- Wide dynamic range < 90dB standard
- Low noise <2 microvolts (with standard filter and input shorted)
- Large output signal - 20Vpp into 50 ohms
- Single power/signal BNC or optional separate power/signal BNC
- Plug-in filters
- 20/40/60 selectable gain
- High input impedance
- Standard auto sensor test (AST)

3.5.3 Wide Bandwidth Acoustic Emission Amplifier.

Figure 3.12: Wide Bandwidth Acoustic Emission Amplifier.

The AE Amplifiers used for this project are high-performance acoustic emission (AE) systems that amplify and filter an incoming AE signal either directly from an AE sensor or from an external preamplifier. The resulting high-frequency AE analog signal output can be connected to a variety of external monitoring and data acquisition instruments.. The model AE5A covers the extended AE frequency up to 5 MHz. Featuring variable gains, low noise and an optional variety of high pass, low pass and band pass filters, this device has a plug-in filter to optimize sensor selectivity and noise rejection. Other main features of this amplifier are:

- Pluggable filter modules with the capability of using high pass, bandpass or low pass filter to vary the bandwidth of the detected AE signal.
- Capability of interfacing and powering preamplifiers, 2/4/6,through a single coax cable.

3.5.4 USB 1208FS Data acquisition

Figure 3.13: USB 1208FS

In order to obtain acoustic emission signal from the AE sensor which has been amplify by the preamplifier and amplifier, this data acquisition device is very important as it convert the acoustic emission signal into electrical signal (voltage) which can be view practically and comfortably in the computer. The voltage signal acquired will be analyze using signal processing in Matlab. Some of the main features of the device are:

- Eight analog inputs, two 12-bit analog outputs, 16 digital I/O connections, and one 32-bit external event counter.
- 1.2 kS/s to 1 MS/s sampling
- Powered by the +5 volt USB supply from computer. No external power is required.
- The analog inputs are software configurable for either eight 11-bit single-ended inputs, or four 12-bit differential inputs. Sixteen digital I/O lines are independently selectable as input or output in two 8-bit ports.
- Supported by MATLAB® Data Acquisition Toolbox™

CHAPTER 4

RESULT AND DISCUSSION

4.1 Pipeline Leakage effect to differential Pressure, ΔP.

4.1.1 Measuring differential Pressure, ΔP using U-tube manometer.

Experiment condition:

- Pressure in vessel: 2 bar
- Temperature: ambient temperature (27°C)
- Leak size (diameter): 3mm at same distance.
- Valve opening: 0% - 50 %

The first stage of experiment is carry out using two "U"–tube manometer, one is for measuring differential pressure before leak, and the other one for after leak. The differential pressure value can be obtained from the manometric fluid height difference, *h* as shown in figure below

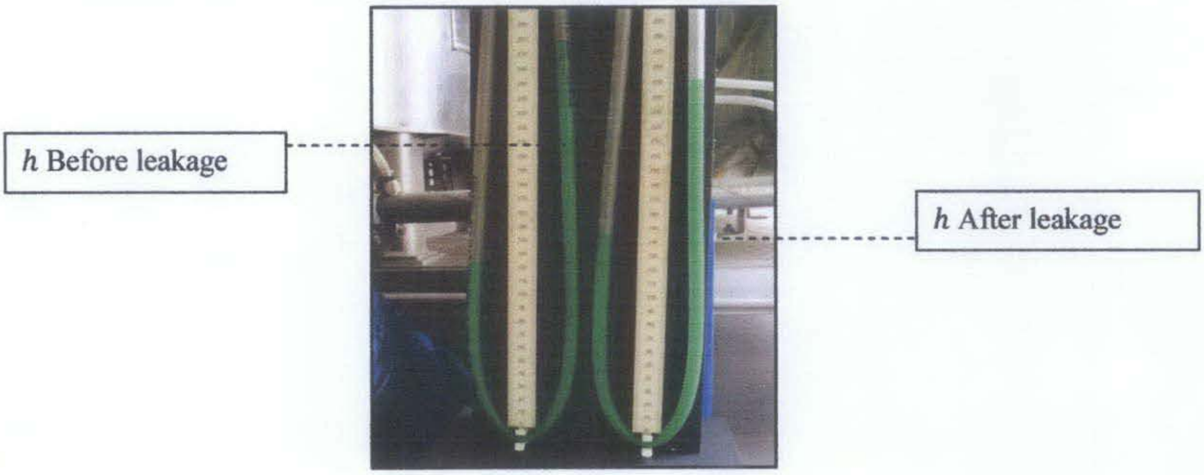


Figure 4.1: Manometric fluid height difference, *h*

Table 4.1: Manometric fluid height difference

Valve Opening	Figure	manometric fluid height difference, *h* before leakage and after leakage
0 %		before leakage, $h = 0$ After leakage , $h= 0$
10 %		before leakage, $h = 10$ mm After leakage , $h= 8$ mm
20 %		before leakage, $h = 15$ mm After leakage , $h= 9$ mm

30%		before leakage, h = 53 mm After leakage , h= 36 mm
40 %		before leakage, h = 153 mm After leakage , h= 106 mm
50 %		before leakage, h = 277 mm After leakage , h= 186 mm

Since the fluid in the pipeline whose pressure difference is being measured is a gas and the fluid inside the manometer is water, so $\rho_m \gg \rho$, then the terms involving ρ can be neglected, so equation (2.5) is used to measure differential pressure before and after leak.

$$\Delta P = \rho_m g h \qquad (2.5)$$

Density of water, $\rho_{water} = \rho_m = 1000$ kg/m^3

g =9.81 m/s^2

Table 4.2: Pressure drop ($\Delta P1$ -$\Delta P2$) after leakage

Valve opening	Differential pressure before leakage , $\Delta P1$ (kPa)	Differential pressure after leakage ,$\Delta P2$ (kPa)	Pressure drop, $\Delta P1$- $\Delta P2$ (kPa)
0 %	0.000	0.000	0.000
10%	0.099	0.079	0.019
20%	0.147	0.088	0.059
30%	0.520	0.350	0.167
40%	1.500	1.000	0.461
50%	2.700	1.800	0.892

Based on table above, there is difference in the value of differential pressure before the leak and after the leak which means there are pressure drop. This shows that leak have cause pressure drop across the pipeline.

The valve opening is tested at 10 % opening to 50 % only opening because the manometer cannot withstand higher pressure at 60% opening and above. Since the manometer cannot withstand high pressure and involve a lot of human error which gives low accuracy, further experiment for relationship with leak distance and leak size is done using the differential pressure transmitter.

4.1.2 Relationship between differential pressure and leak distance

Experiment condition

- Pressure in vessel: 2 bar

- Temperature: ambient temperature (27°C)

- Leak size (diameter): 3mm at different distance

- Valve Opening: 60 %

Table 4.3: Differential pressure, ΔP at different leak location

Distance of leak from flange (cm)	Differential pressure, ΔP(kPa)		
	Tx 1	Tx 2	Pressure drop, Tx1-Tx2
5	7.4	4.5	2.9
15	7.4	4.5	2.9
25	7.4	4.6	2.8
35	7.4	4.8	2.6
45	7.8	4.8	3.0
55	7.8	4.8	3.0
65	7.8	5.0	2.8
75	7.8	5.1	2.7
85	8.7	5.4	3.3
95	8.7	5.4	3.3

4.1.3 Flow rate calculation.

Base on the differential pressure data obtained previously from table 4.3, incoming and outgoing flow rate value can be calculated using equation (2.6):

$$Q = C.\ \frac{1}{\sqrt{1-\beta^4}} . \frac{\pi}{4} . d^2 . \varepsilon . \sqrt{\frac{2.\Delta P}{\rho}} \qquad (2.6)$$

Where;

Q = Mass flow rate, in (mass)/(time) units

C = 0.65

β = 0.5

d = 0.0127 m

D = 0.0254 m

ε = 0.5

ΔP = from table 4.1

ρ = 1.293 kg/m^3(density of air)

From the incoming flow rate value, Q_{in} and outgoing flow rate value, Q_{out}, the leak flow rate, Q_{leak} can be obtained.

$$Q_{in} = Q_{leak} + Q_{out} \qquad (2.7)$$

$$Q_{leak} = Q_{in} - Q_{out} \qquad (2.8)$$

Table 4.4: Flow rate

Distance of leak from flange (cm)	Flow rate, Q (m^2/s)		
	Q_{in}	Q_{out}	Q_{leak}
5	4.78E-03	3.73E-03	1.05E-03
15	4.78E-03	3.73E-03	1.05E-03
25	4.78E-03	3.77E-03	1.01E-03
35	4.78E-03	3.85E-03	9.30E-04
45	4.90E-03	3.85E-03	1.05E-03
55	4.90E-03	3.85E-03	1.05E-03
65	4.90E-03	3.93E-03	9.70E-04
75	4.90E-03	3.97E-03	9.30E-04
85	5.18E-03	4.08E-03	1.10E-03
95	5.18E-03	4.08E-03	1.10E-03

Discussion

All result above is taken at valve opening 60%. This is because during valve opening 60%, the differential pressure, ΔP measurement is optimum to see for difference between before leak and after leak. Measurements for other valve opening are at the appendix. Measurement are taken until 80% valve opening because at above 80%, pressure inside vessel cannot reach the set point set earlier which is at 2 bar. From the results above, there are significant difference in the measurement of the ΔP between transmitter 1 and transmitter 2. This means that the leakage hole have significant effect to the ΔP measurement. The leakage have cause pressure drop across transmitter 1 and transmitter 2.

However, the difference in ΔP is not very big as the leakage hole is small which is 3mm diameter. Results from same leakage size at different distance from flange shows most of the measurement are the same with each other. It shows that ΔP method is not capable in locating leak location for small leak.

From ΔP measurement, flow rate measurement can be calculated. Since there are leak at the pipeline, incoming flow value and outgoing flow value is not the same which means leak flow rate existed and can be calculated using equation 2.8. From table 4.4, it can be seen that leak distance doesn't give much effect to flow rate measurement as most of the values are the same at difference leak location.

4.1.4 Relationship between leak size with differential pressure and flow rate measurement.

Experiment condition:

- Pressure in vessel: 2 bar

- Temperature: ambient temperature (27°C)

- Leak size (diameter): 3mm, 6mm, 8mm & 10mm

- Valve opening: 60 %

Table 4.5: Differential pressure and flow rate at different leak size

Leak size(mm)	Differential Pressure, ΔP (kPa)		Pressure drop, Tx1-Tx2 (kPa)	Flow rate, Q(m^2/s)		
	Tx1	Tx2		Q_{in}	Q_{out}	Q_{leak}
3	7.8	4.8	3.0	0.00467	0.00366	0.00101
6	8.1	4.3	3.8	0.00476	0.00347	0.00129
8	8.1	3.9	4.2	0.00476	0.00330	0.00146
10	8.1	3.4	4.7	0.00476	0.00308	0.00168

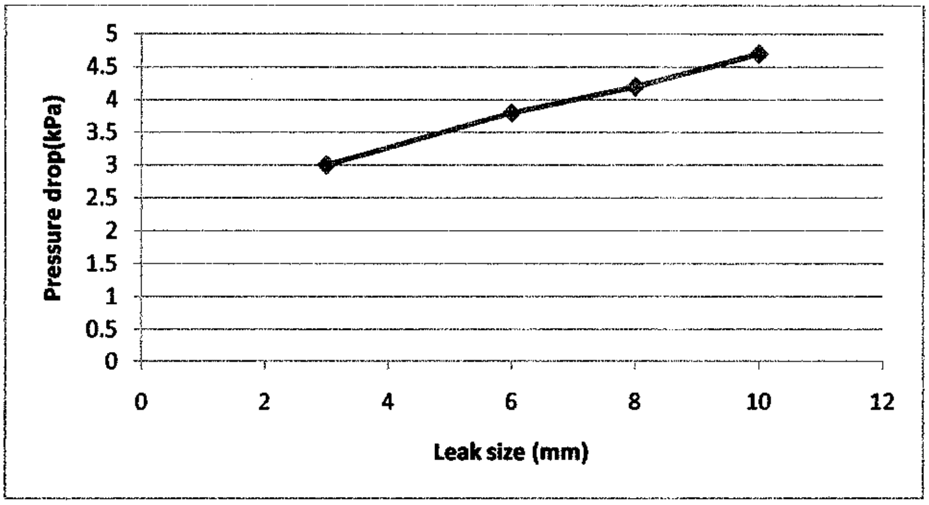


Figure 4.2: Leak size vs Pressure drop

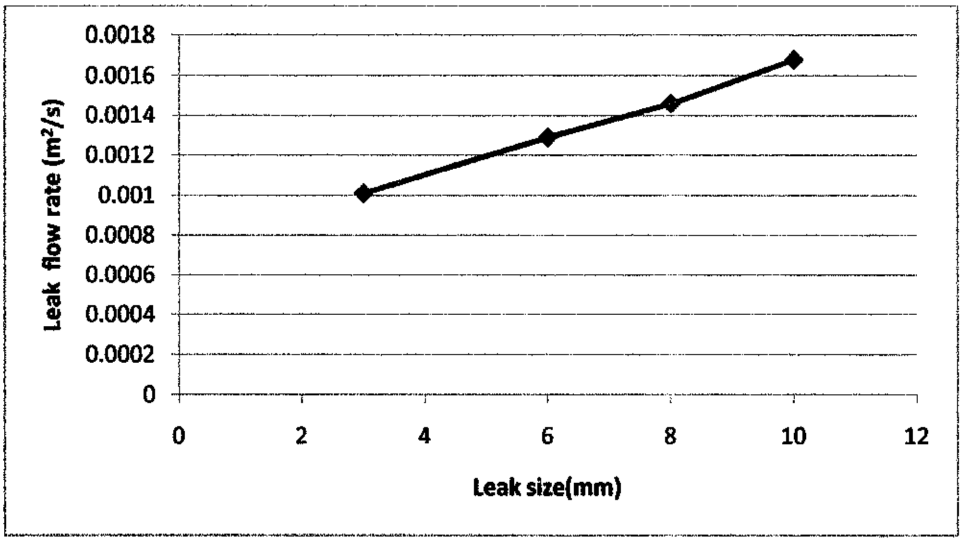


Figure 4.3: Leak size vs leak flow rate

Discussion

Result from table 4.5; figure 4.2 and 4.2 above are obtained by varying the leak size of the leak at 60% valve opening. Result shows that leak size gives significant effect to differential pressure measurement and flow rate measurement. The bigger the leak size, the bigger pressure difference between transmitter 1 and transmitter 2. Differential pressure measurement at transmitter 2 shows that the bigger the leak, the smaller the value becomes. This is because some pressure in the pipeline escape through the leak hole. Bigger leak size means more pressure loss through the leak hole. This is why the leak flow rate value increase proportionally with the leak size. From both figure above, it shows that pressure drop across transmitter 1 & transmitter 2 and the leak flow rate increase proportionally with the leak size. It can be said here that there are strong relationship between leak size and differential pressure.

4.2 Pipeline Leakage effect to acoustic emission signal.

4.2.1 Relationship between PCV212 opening (flow rate) with voltage amplitude during leak and no leak condition in time domain.

Experiment condition:

- Valve opening is varied from 10% to 80%
- Leak size (diameter): 3mm
- Sensor and leak source at stationary position

The signal that acquired from the sensor is viewed using matlab. The signal will be in time domain which is voltage vs. samples graph. Blue color signal is during no leak condition and red color signal is during leak condition. The characteristic of the time domain signal is shown below.

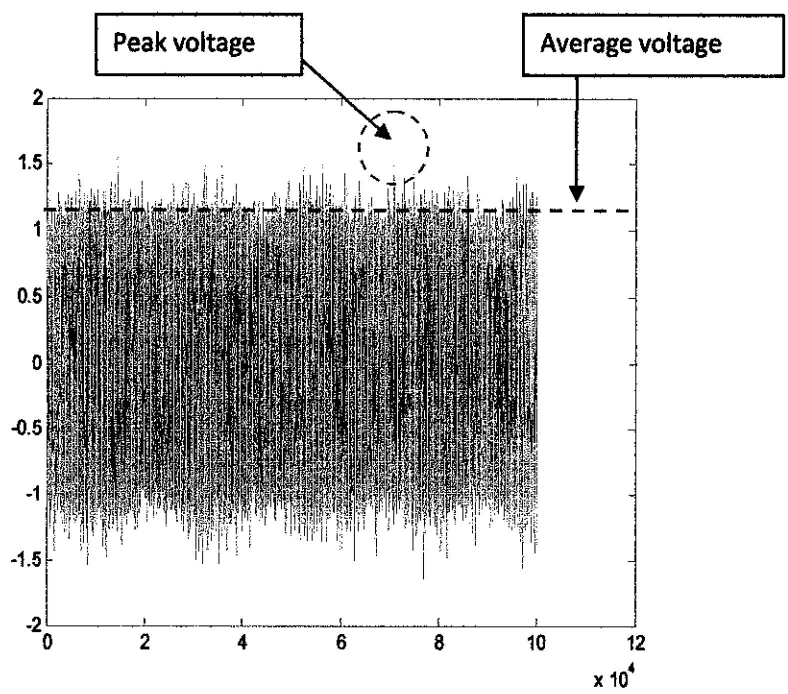
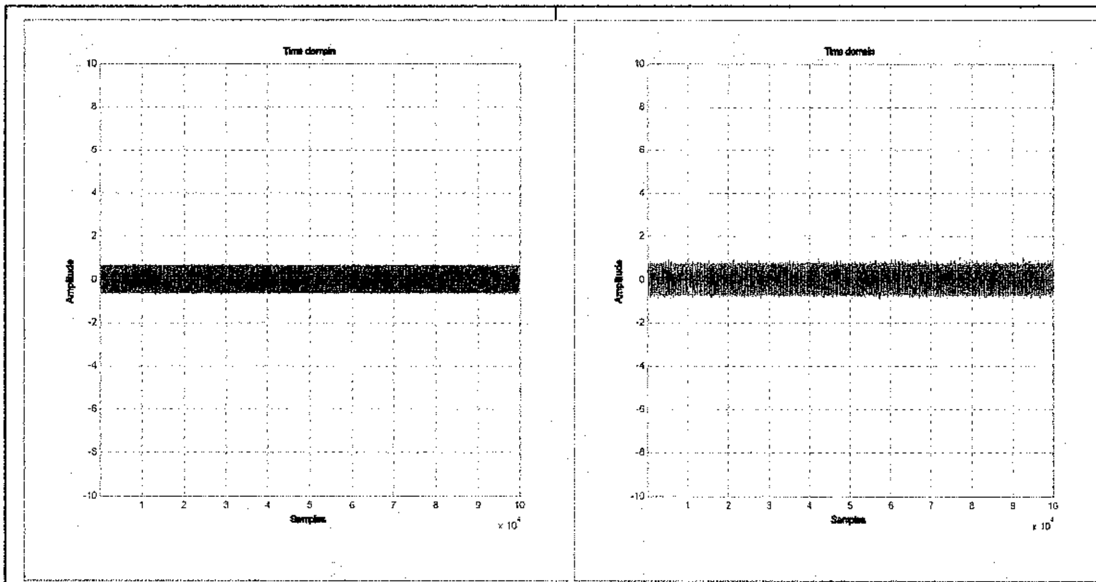


Figure 4.4: Characteristic of time domain signal

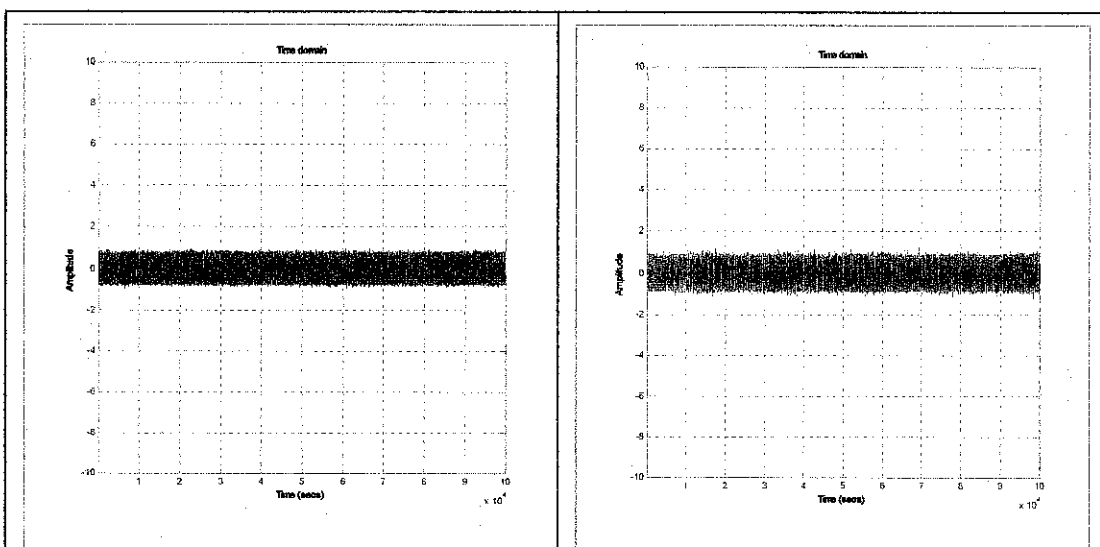


(a) (b)

Figure 4.5: PCV 212 at 10% opening

a) During no leak condition; (Peak voltage = 0.7448, Average voltage = 0.65)

b) During leak condition; (Peak voltage = 1.0574, Average voltage=0.76)



(a) (b)

Figure 4.6: PCV 212 at 50% opening

a) During no leak condition; (Peak voltage = 0.9939, Average voltage=0.81)

b) During leak condition; (Peak voltage = 1.2576, Average voltage=1.00)

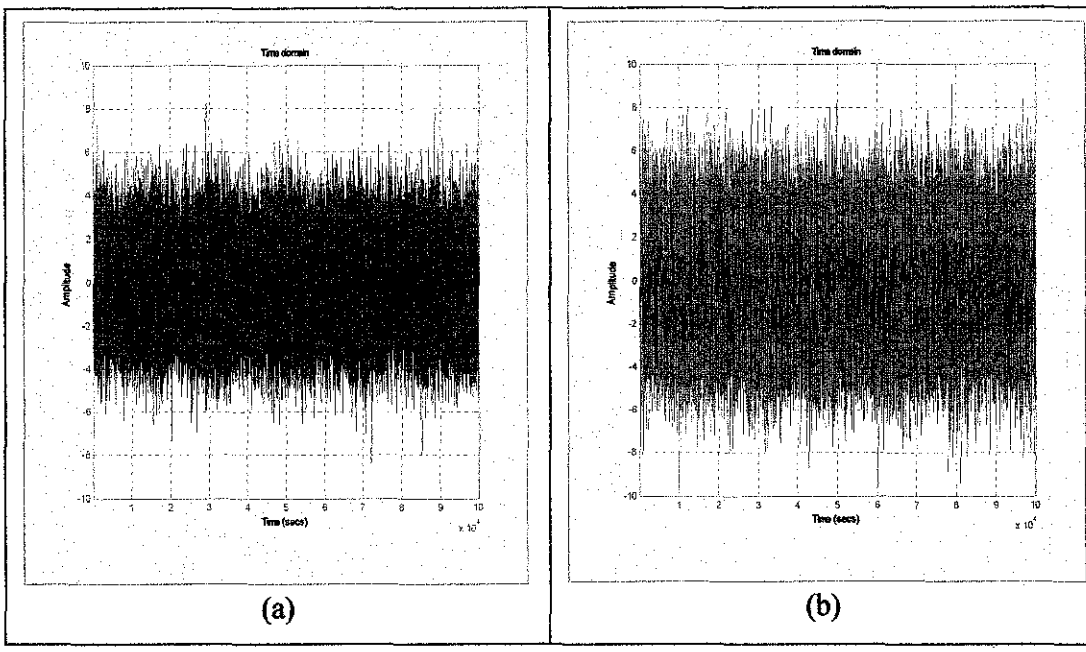


Figure 4.7: PCV 212 at 70% opening

a) During no leak condition; (Peak voltage = 8.2906, Average voltage=4.80)

b) During leak condition; (Peak voltage = 9.0867, Average voltage=5.50)

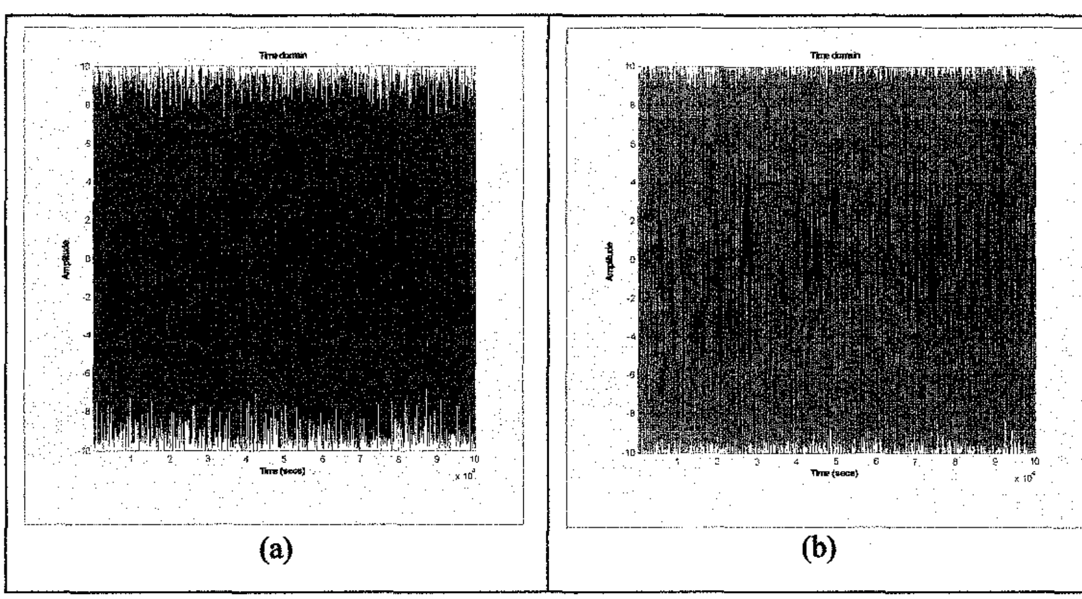


Figure 4.8: PCV 212 at 80% opening

a) During no leak condition; (Peak voltage = 9.58, Average voltage=8.90)

b) During leak condition; (Peak voltage = 10.000, Average voltage=9.70)

Table 4.6: Peak voltage amplitude and average voltage at different flow rate

PCV opening (%)	Flow rate, $Q\ (m^2/s)$	Peak Voltage Amplitude		Average voltage	
		No leak	3mm leak	No leak	3mm leak
10	5.55E-04	0.7448	1.0574	0.65	0.76
20	5.55E-04	0.9646	1.0085	0.66	0.80
30	1.47E-03	0.9696	1.0155	0.75	0.80
40	2.29E-03	0.9890	1.0378	0.79	0.82
50	3.19E-03	0.9939	1.2576	0.81	1.00
60	4.78E-03	1.5653	2.1082	1.20	3.00
70	8.99E-03	8.2906	9.0867	4.80	5.50
80	1.09E-02	9.58	10.000	8.9	9.7

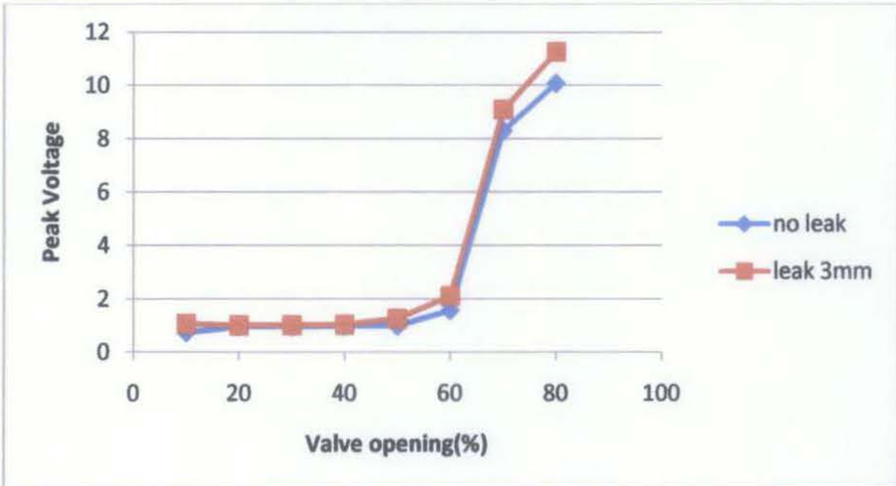


Figure 4.9: Valve Opening vs peak voltage

Discussion

The entire time domain data is acquired in matlab, at 100000 samples. The gain value use is 80 dB for amplifier and preamplifier. In time domain, the voltage amplitude of the acoustic emission signal in the pipeline increase proportionally with the valve opening and inlet flow rate (AE sensor is place at inlet part which is before leak). There are big difference in voltage amplitude between valve opening at 10% opening and 80% opening. It shows that stronger flow inside the pipeline gives stronger acoustic emission signal (higher voltage amplitude).

In time domain, there are differences in voltage amplitude between no leak conditions with during leak condition. From the voltage signal and table, it can be seen that during leak condition, the peak voltage amplitude and average voltage is always higher during leak condition compare without leak condition. It shows that the AE sensor is capable and reliable to check for leak in the pipeline.

However in time domain, the only difference between no leak and leak condition is only at the voltage amplitude. The data in time domain is then analyze in frequency domain to check for better difference between no leak and during leak condition.

4.2.2 Relationship between PCV212 opening (flow rate) with voltage amplitude during leak and no leak condition in frequency domain.

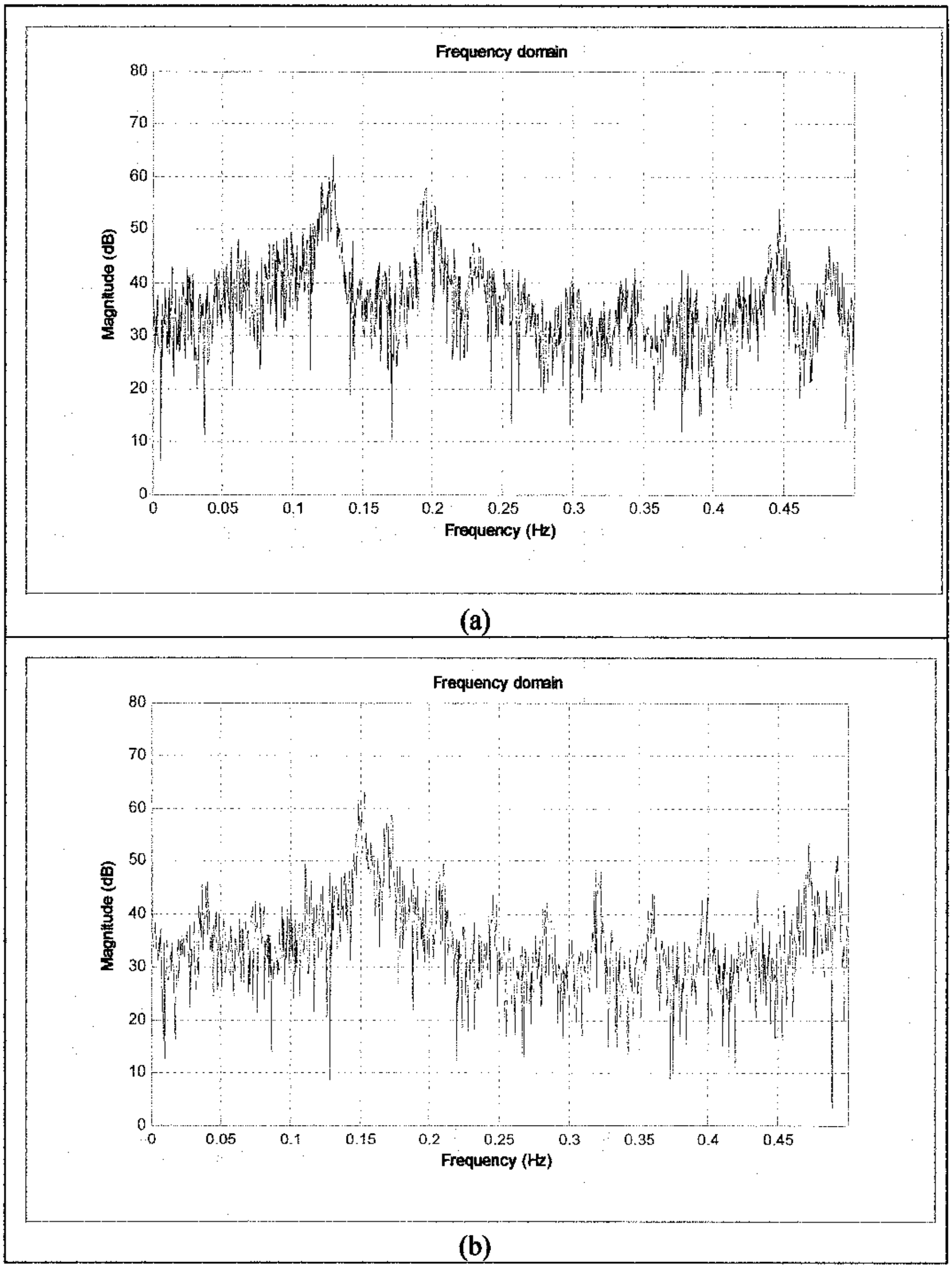
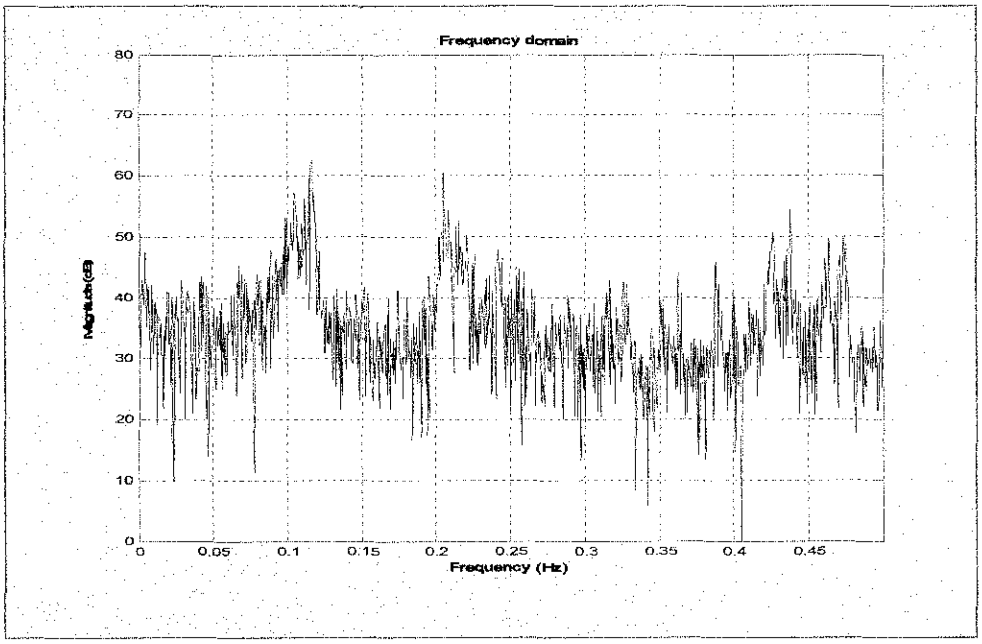
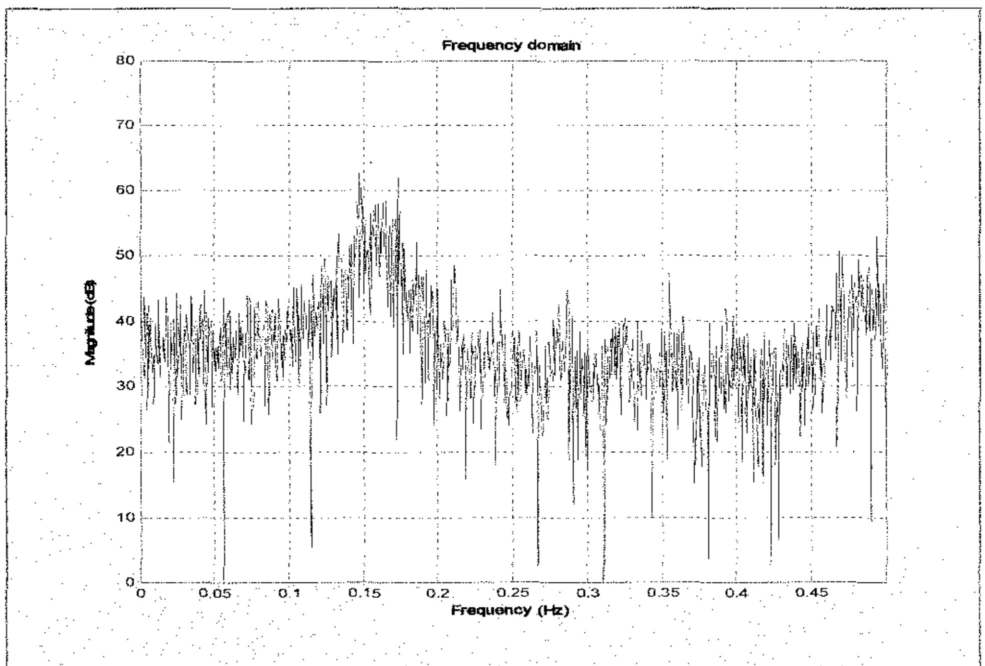


Figure 4.10: PCV 212 at 10% opening in frequency domain;
a) During no leak condition, b) During leak condition



(a)



(b)

Figure 4.11: PCV 212 at 20% opening in frequency domain;
a) During no leak condition, b) During leak condition

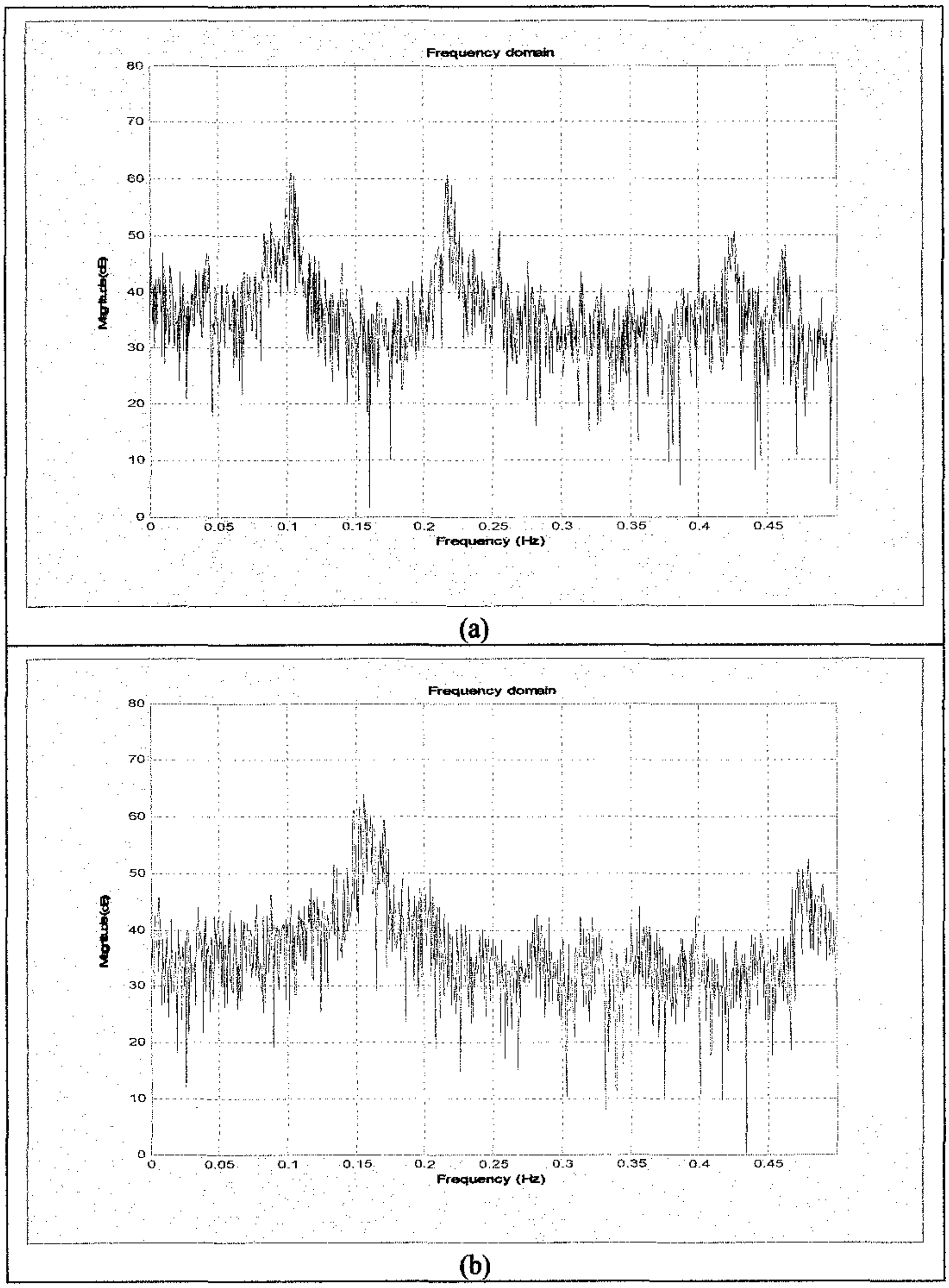


Figure 4.12: PCV 212 at 30% opening in frequency domain;
a) During no leak condition, b) During leak condition

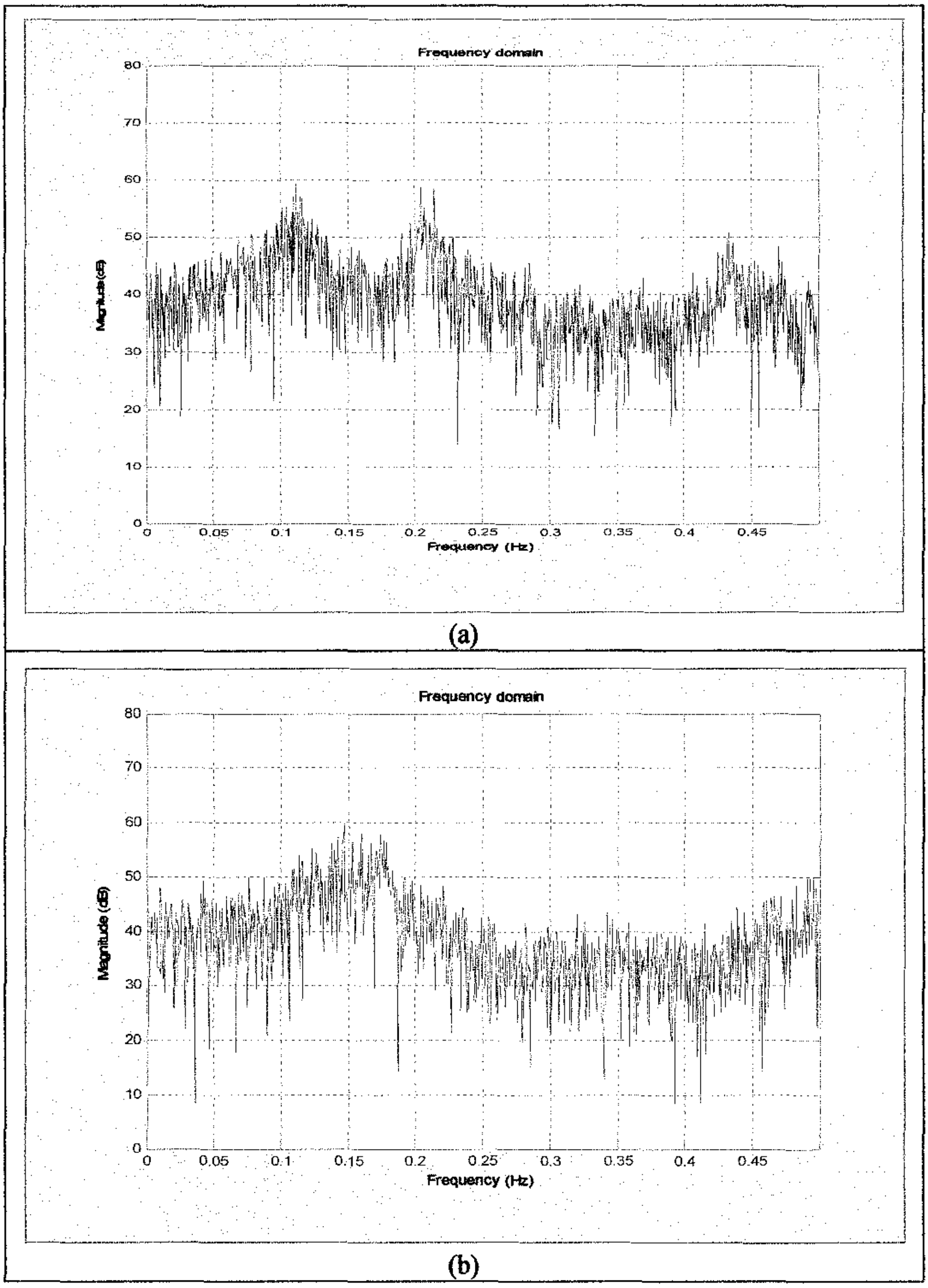
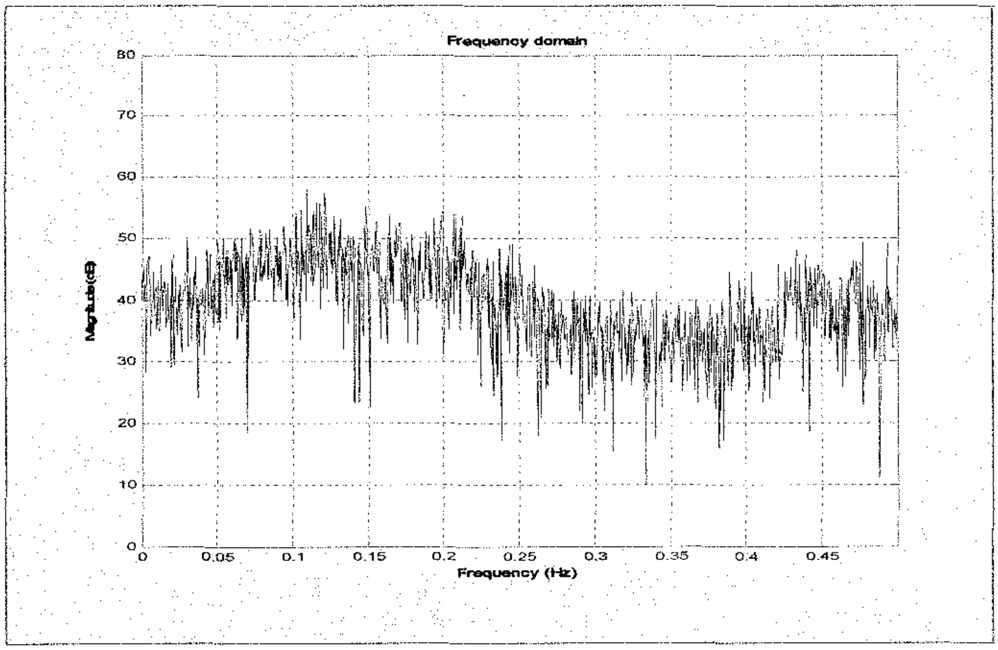
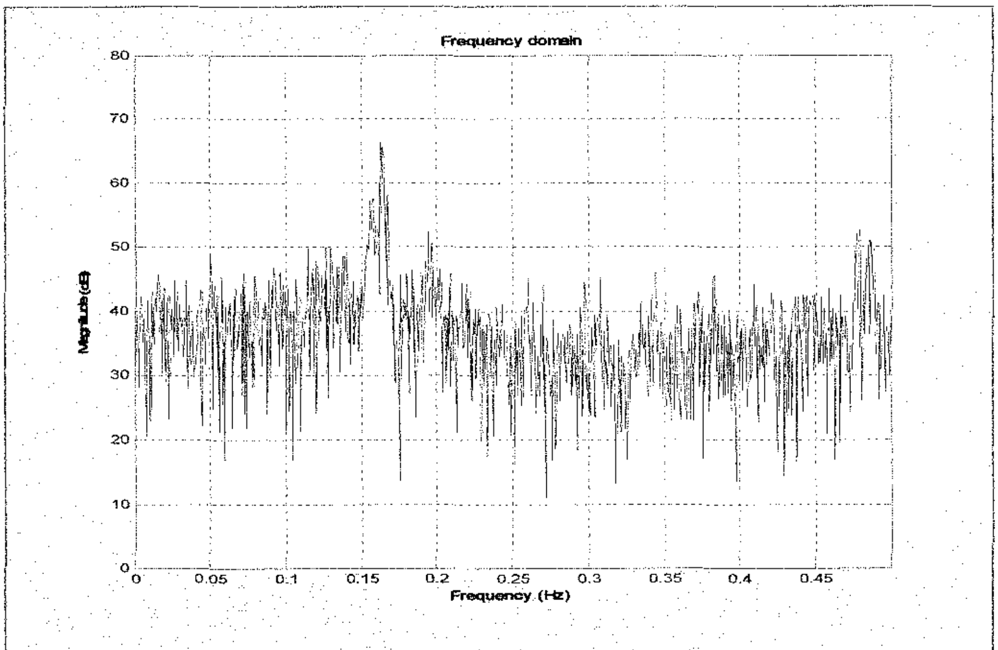


Figure 4.13: PCV 212 at 40% opening in frequency domain;
a) During no leak condition, b) During leak condition



(a)



(b)

Figure 4.14: PCV 212 at 50% opening in frequency domain;
a) During no leak condition, b) During leak condition

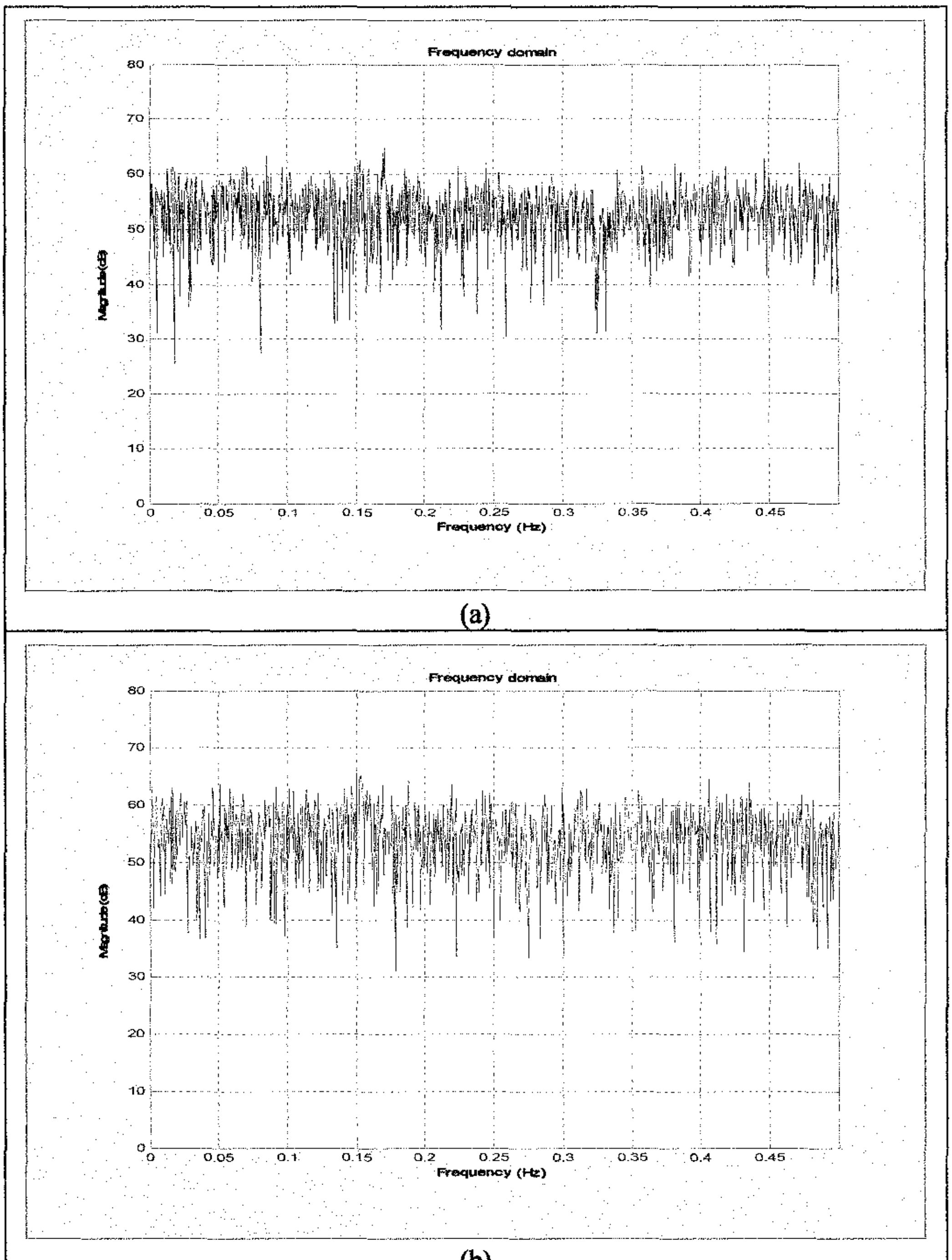
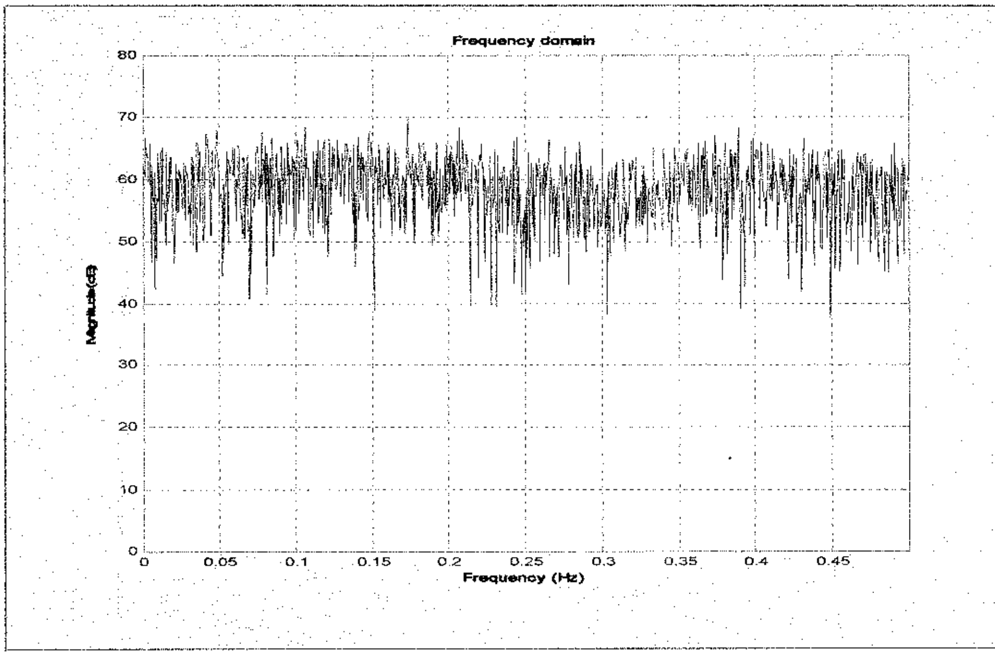
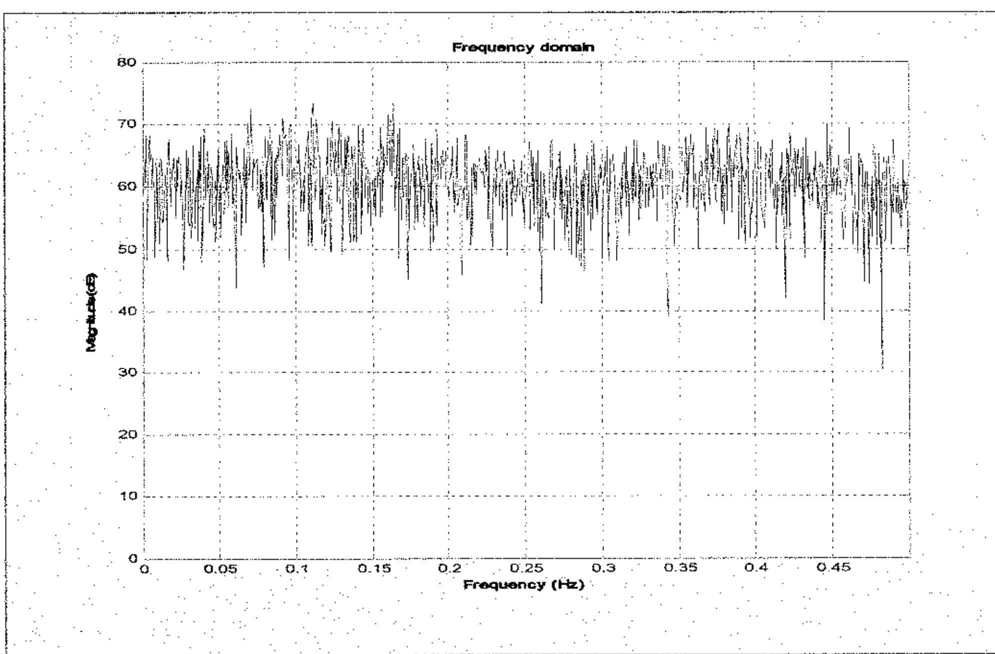


Figure 4.15: PCV 212 at 70% opening in frequency domain;
a) During no leak condition, b) During leak condition



(a)



(b)

Figure 4.16: PCV 212 at 80% opening in frequency domain;
a) During no leak condition, b) During leak condition

Discussion

The same data from time domain is converted to frequency domain using matlab. In frequency domain, the magnitude (dB) of the signal increase proportionally with the PCV 212 opening. At 10 % opening, the magnitude mostly at the range between 30dB to 50dB. At 80% opening, the magnitude mostly at the range between 50dB to 70dB. A better difference between no leak conditions with during leak condition can be seen in frequency domain plots.

Results also shows that there are differences in trend of plots between no leak conditions with during leak condition. During leak condition, we can see that there are peak magnitudes at frequency between 0.15 Hz and 0.17 Hz at all plots. At 50% valve opening, we can see the most significant difference in peak magnitude during leak condition and without leak. It shows that during 50% valve opening, it is the best time to acquire data for acoustic emission signal compare with others opening percentage. So for further experiment on estimation of the leak location, the data should be taken at 50% valve opening in order to get more significant and encouraging results.

4.2.2 Relationship between voltage amplitude with leak distance.

Experiment condition

- Valve opening: 50%
- Leak size (diameter): 3mm
- AE Sensor at stationary position
- Leak location: 250mm, 650 mm and 950 mm away from AE sensor

In order to estimate the location of the leak, experiment is carried out by varying the location of the leak source, with the AE sensor at stationary position. The distance of the leak is shown as figure below.

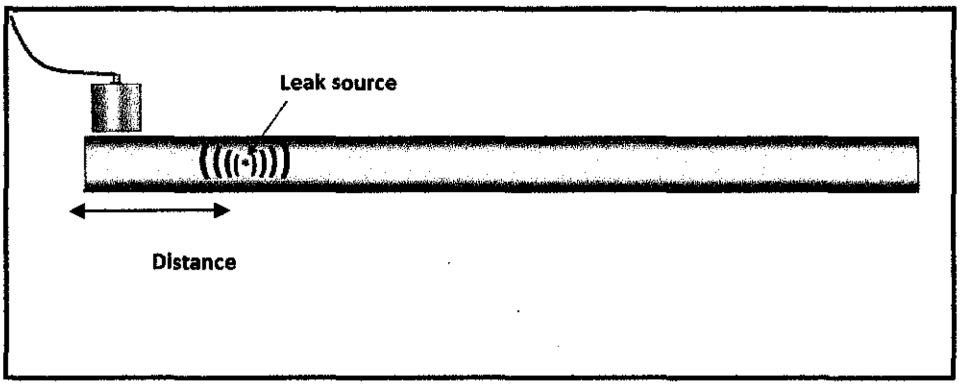


Figure 4.17: Distance of leak source from AE sensor.

In time domain

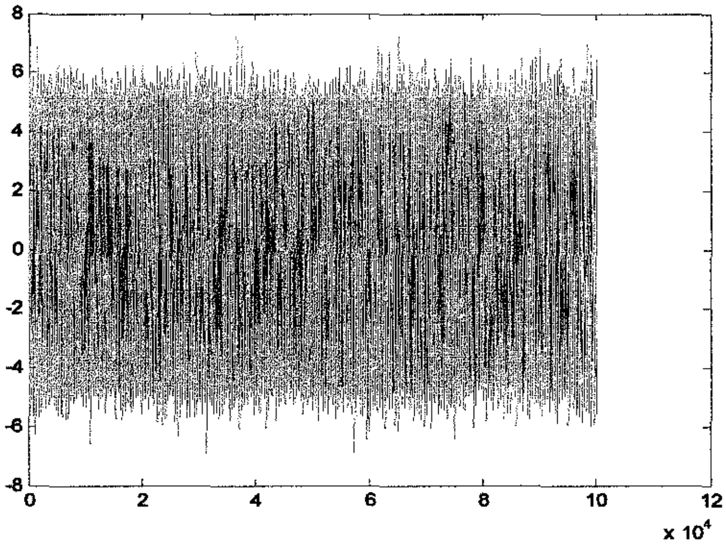


Figure 4.18: Leak 250 mm away from sensor

Peak voltage =7.620 Average voltage = 6.0

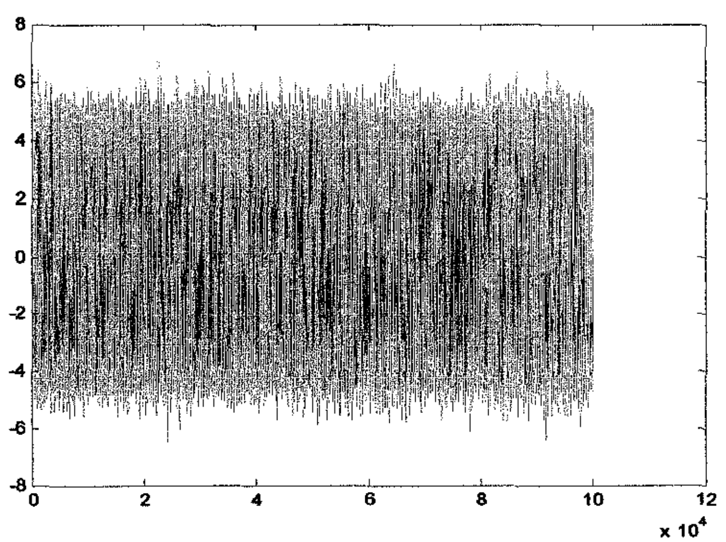


Figure 4.19: Leak 650 mm away from sensor

Peak voltage = 6.7473 Average voltage = 5.5

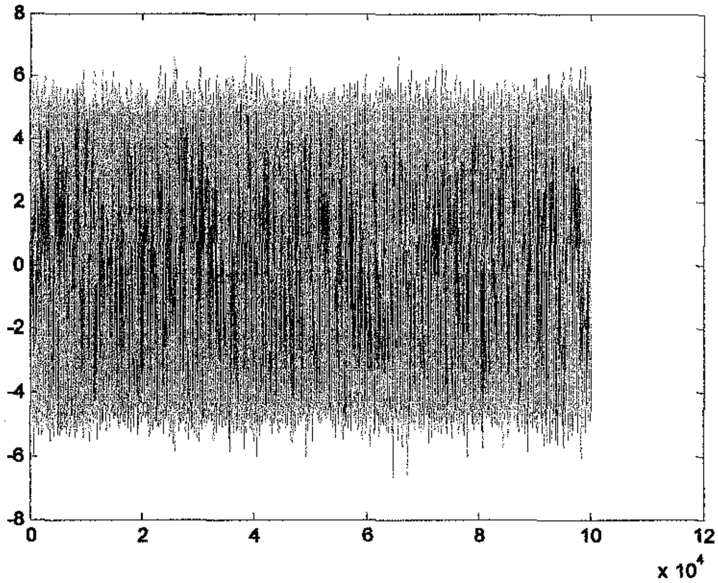


Figure 4.20: Leak 950 mm away from sensor

Peak voltage = 6.7082 Average voltage = 5.1

Discussion

The gain value used for this experiment is 110 dB for amplifier and preamplifier which is maximum gain in order to get the best result. Result shows that in time domain, distance of the leak source gives impact to the voltage signal. The voltage amplitude has highest value at the nearest leak distance and eventually decreasing as the distance is further from the sensor.

However, looking at time domain signal, it is very hard to estimate the location of the leak even though setting amplifier at full gain as in time domain, the difference at voltage amplitude is very small and time domain has very noisy background.

To see a better difference in location of leak and to find the frequency components of a signal buried in a noisy time domain signal, the Fast Fourier Transform (FFT) technique is apply on the time domain signal.

In Fast Fourier Transform (FFT)

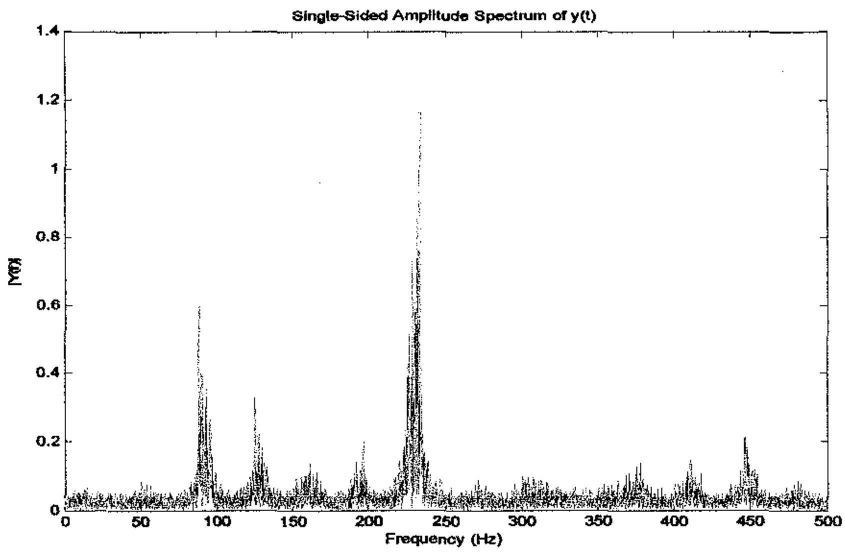


Figure 4.21: Leak 250 mm away from sensor in FFT

Y_{max}=1.19

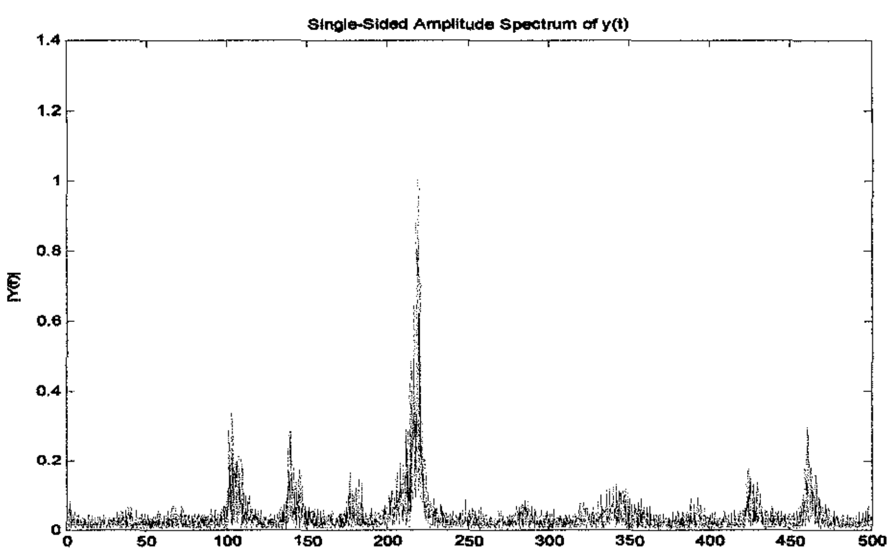


Figure 4.22: Leak 650 mm away from sensor in FFT

Y_{max}= 1.01

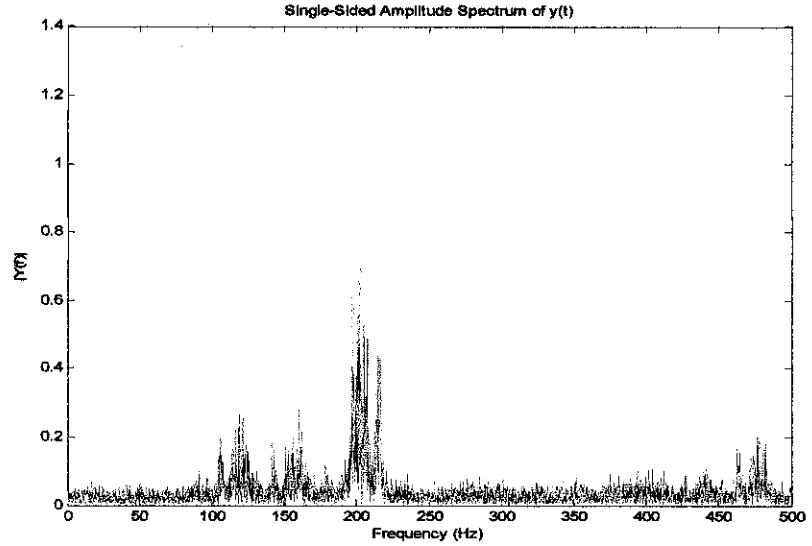


Figure 4.23: Leak 950 mm away from sensor in FFT

$Y_{max} = 0.71$

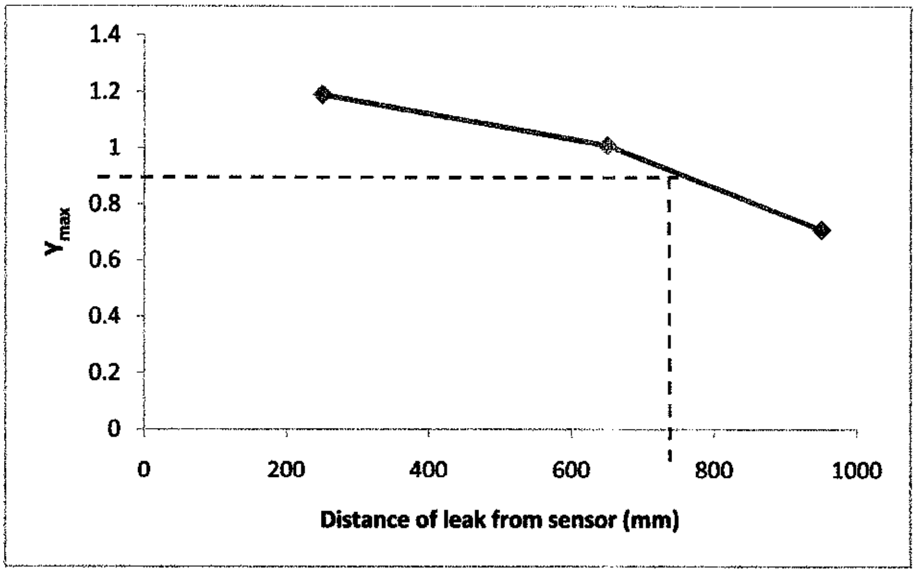


Figure 4.24: Leak Distance vs Y_{max}

Discussion

After transforming the noisy time domain signal using FFT in matlab, the plots obtained are single sided amplitude spectrum of Y(t). From the plots, the frequency components can be known and a better difference can be seen between different locations of the leak. From all plots it can be seen that the significant spike of the signal is at frequency between 200Hz and 250Hz. So the frequency component that needs to be focus on when estimating location of leak is at between 200Hz and 250Hz. The spike is highest at nearest leak location and eventually decreases with the distance of the leak.

As one AE sensor is used in the experiment which is stationary placed on the pipeline, the result satisfy the assumption that the further the distance of the leak from the sensor, the weaker the signal will be.

From the result in FFT, a graph as figure 4.23 is obtained. The graph shows that value of Y_{max} decrease proportionally with the leak distance. From the graph, leak location for other distance can be estimate as well. For example, if we get Y_{max} value is 0.9, we can estimate that the location of the leak is around 720 mm from the sensor.

CHAPTER 5

5.1 CONCLUSION

The differential pressure flow meters test rig has been successfully constructed. The test rig is functioning properly as differential pressure and flow rate can be measured using either the U-tube manometer or the differential pressure transmitter. Throughout the project, improvements have been done to the test rig and experiment method in order to get the best outcome of the project. Initially, the tap location is located on the pipeline, now the tap location is exactly on the flange. This will gives better performance to the whole test rig and better results. Further improvement is rather than using a u-tube manometer for getting ΔP, differential pressure transmitter is used instead.

Experiment of leak detection using differential pressure technique and acoustic emission is carried out successfully. From the result, it is proven that there is a pressure drop in the pipeline after leakage. From the differential pressure data, flow rate of the pipeline before and after leakage can be obtained which the leak flow rate can be calculated later. Results shows that distance of the leak hole have no effect to the ΔP value but leak size have significant effect to ΔP. The pressure drop and leak flow rate increase proportionally with the leak size.

For acoustic emission part, the difference between no leak condition with during leak condition can be identified in time domain plots. During leak condition, the voltage amplitude will have higher value. For estimation of leak location, FFT technique is use and significant different can be seen at the signal produced. The spike is highest at nearest leak location and eventually decreases with the distance of the leak. All these results show that both methods used in this project is reliable and effective in leak detection.

5.2 RECOMMENDATION

Use filter function in matlab in order to eliminate noise and unwanted signal at the signal acquired. Even though external filter such as preamplifier and amplifier have been use in the experiment, there should still be noise and unwanted signal. By using filter function in matlab, maybe a better and more accurate result can be achieved in order to differentiate between no leak condition with leak condition and also for estimation of the leak location.

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APPENDICES

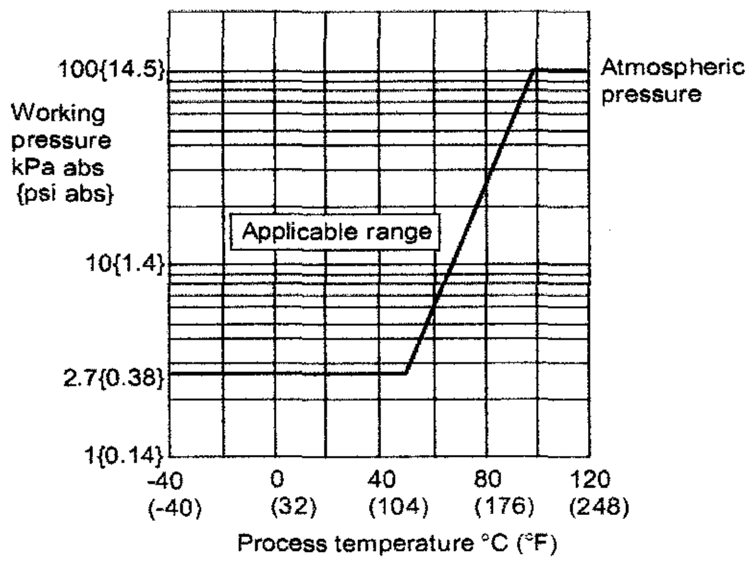
APPENDIX A: Type of orifice

Type	Description
Concentric 	Most commonly used devices for flow measurement of clean liquids, gases and low velocity vapor flows. They are widely used for restricting flows and dropping pressures. A circular hole is machined in the plate so that when the plate is installed the hole will be in the center of the pipe.
Eccentric 	These eccentric orifice are most useful where there are substantial entrained water or air and also if there are suspension in the fluids. It is to minimize measurement inaccuracies that can be caused by solids settling out of the orifice plates.
Segmental 	A segmental orifice plate is used when solids are very heavy.

APPENDIX B: YOKOGAWA EJA110A Differential Pressure Transmitter Specifications.

Span and range limit

Measurement Span/Range		kPa	inH_2O(/D1)	mbar(/D3)	mmH_2O(/D4)
L	Span	0.5 to 10	2 to 40	5 to 100	50 to 1000
	Range	-10 to 10	-40 to 40	-100 to 100	-1000 to 1000
M	Span	1 to 100	4 to 400	10 to 1000	100 to 10000
	Range	-100 to 100	-400 to 400	-1000 to 1000	-10000 to 10000
H	Span	5 to 500	20 to 2000	50 to 5000	0.05 to 5 kgf/cm^2
	Range	-500 to 500	-2000 to 2000	-5000 to 5000	-5 to 5 kgf/cm^2
V*1	Span	0.14 to 14 MPa	20 to 2000 psi	1.4 to 140 bar	1.4 to 140 kgf/cm^2
	Range	-0.5 to 14 MPa	-71 to 2000 psi	-5 to 140 bar	-5 to 140 kgf/cm^2



Working Pressure and Process Temperature

APPENDIX C: Differential pressure at leakage condition: 3mm diameter leakage hole at different distance from flange.

PCV 212 Opening	10%		20%		30%		40%	
	ΔP(kPa)		ΔP(kPa)		ΔP(kPa)		ΔP(kPa)	
Leak Distance(cm)	Tx 1	Tx 2	Tx 1	Tx	Tx 1	Tx 2	Tx 1	Tx 2
6	0.1	0.08	0.1	0.08	0.7	0.4	1.7	1.0
16	0.1	0.08	0.2	0.1	0.7	0.4	1.7	1.0
26	0.1	0.08	0.2	0.1	0.6	0.4	1.7	1.0
36	0.1	0.08	0.2	0.1	0.7	0.3	1.7	1.0
46	0.1	0.08	0.2	0.1	0.6	0.4	1.7	1.0
56	0.1	0.08	0.2	0.1	0.6	0.4	1.7	1.0
66	0.1	0.08	0.2	0.1	0.6	0.4	1.7	1.0
76	0.1	0.08	0.2	0.1	0.7	0.3	1.7	1.0
86	0.1	0.08	0.2	0.1	0.7	0.4	1.7	1.0
96	0.1	0.08	0.2	0.1	0.7	0.4	1.7	1.0

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PCV 212 Opening	50%		60%		70%		80%	
	ΔP(kPa)		ΔP(kPa)		ΔP(kPa)		ΔP(kPa)	
Leak Distance(cm)	Tx 1	Tx 2	Tx 1	Tx 2	Tx 1	Tx 2	Tx 1	Tx 2
5	3.3	2.0	7.4	4.5	26.2	17.5	38.7	27.3
15	3.3	2.0	7.4	4.5	26.3	17.3	38.8	27.3
25	3.3	2.0	7.4	4.6	26.3	17.3	38.7	27.2
35	3.3	1.8	7.4	4.8	26.3	17.5	38.8	27.3
45	2.9	2.0	7.8	4.8	26.3	17.5	38.8	27.2
55	3.3	2.0	7.8	4.8	26.5	17.4	38.6	27.2
65	3.1	2.0	7.8	5.0	26.7	17.5	38.7	27.3
75	3.1	1.8	7.8	5.1	26.7	17.5	38.7	27.3
85	3.1	2.0	8.7	5.4	27.1	17.7	38.8	27.3
95	3.1	2.0	8.7	5.4	27.4	18.5	38.8	27.4

APPENDIX D: Flow rate at leakage condition: 3mm diameter leakage hole at different distance from flange.

PCV 212 Opening	10%		20%		30%	
	Flow rate, Q (m^2/s)		Flow rate, Q (m^2/s)		Flow rate, Q (m^2/s)	
Leak distance(cm)	*Qin*	*Qout*	*Qin*	*Qout*	*Qin*	*Qout*
5	5.55E-04	4.97E-04	5.55E-04	4.97E-04	1.47E-03	1.11E-03
15	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.47E-03	1.11E-03
25	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.36E-03	1.11E-03
35	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.47E-03	9.62E-04
45	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.36E-03	1.11E-03
55	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.36E-03	1.11E-03
65	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.36E-03	1.11E-03
75	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.47E-03	9.62E-04
85	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.47E-03	1.11E-03
95	5.55E-04	4.97E-04	7.85E-04	5.55E-04	1.47E-03	1.11E-03

Cont'd

PCV 212 Opening	40%		50%		60%	
	Flow rate, Q (m^2/s)		Flow rate, Q (m^2/s)		Flow rate, Q (m^2/s)	
Leak distance(cm)	*Qin*	*Qout*	*Qin*	*Qout*	*Qin*	*Qout*
5	2.29E-03	1.76E-03	3.19E-03	2.48E-03	4.78E-03	3.73E-03
15	2.29E-03	1.76E-03	3.19E-03	2.48E-03	4.78E-03	3.73E-03
25	2.29E-03	1.76E-03	3.19E-03	2.48E-03	4.78E-03	3.77E-03
35	2.29E-03	1.76E-03	3.19E-03	2.36E-03	4.78E-03	3.85E-03
45	2.29E-03	1.76E-03	2.99E-03	2.48E-03	4.90E-03	3.85E-03
55	2.29E-03	1.76E-03	3.19E-03	2.48E-03	4.90E-03	3.85E-03
65	2.29E-03	1.76E-03	3.09E-03	2.48E-03	4.90E-03	3.93E-03
75	2.29E-03	1.76E-03	3.09E-03	2.36E-03	4.90E-03	3.97E-03
85	2.29E-03	1.76E-03	3.09E-03	2.48E-03	5.18E-03	4.08E-03
95	2.29E-03	1.76E-03	3.09E-03	2.48E-03	5.18E-03	4.08E-03

Cont'd

PCV 212 Opening	70%		80%	
	Flow rate, Q (m^2/s)		Flow rate, Q (m^2/s)	
Leak distance(cm)	Qin	$Qout$	Qin	$Qout$
5	8.99E-03	7.35E-03	1.09E-02	9.18E-03
15	9.01E-03	7.30E-03	1.09E-02	9.18E-03
25	9.01E-03	7.30E-03	1.09E-02	9.16E-03
35	9.01E-03	7.35E-03	1.09E-02	9.18E-03
45	9.01E-03	7.35E-03	1.09E-02	9.16E-03
55	9.04E-03	7.33E-03	1.09E-02	9.16E-03
65	9.07E-03	7.35E-03	1.09E-02	9.18E-03
75	9.07E-03	7.35E-03	1.09E-02	9.18E-03
85	9.14E-03	7.39E-03	1.09E-02	9.18E-03
95	9.19E-03	7.55E-03	1.09E-02	9.19E-03

APPENDIX E: Matlab simulink model for acoustic emission data acquisition